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# A FULL-SCALE FIRE PROGRAM TO EVALUATE NEW FURNISHINGS AND TEXTILE MATERIALS DEVELOPED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract

A program of experimental fires has been carried out to establish the advantages offered by new space-age materials for the improved fire safety that might be provided. For this purpose four full-scale bedrooms, differing only in the materials used to furnish them, have been built and burned to provide comparative data on the fire hazards produced. Cost and availability differences were not considered.

The visual evidence provided by TV and photographic coverage of the four experimental room fires showed clearly that the rooms responded very differntly to a common ignition condition.

In particular, The Typical Room, furnished from conventional retail sources, ignited easily and burned rapidly so that after 8 minutes the contents of the room were nearly destroyed. The Improved Room, furnished with materials selected as being among the best commercially available, showed substantial improvement over the Typical Room in that there was slower fire spread. However, the relatively complete destruction of the room contents that resulted, and the large amounts of smoke, made it clear that substantial further improvements were needed. This fire was stopped after 29 minutes. The Space-Age Room, furnished completely with new materials that were not yet commercially available, did not ignite under the common ignition condition and so demonstrated the substantial improvement in fire resistance available for those components close to the ignition source. A second and larger ignition arrangement showed that this room can burn, but the difficulty with which this was brought about confirmed the improved fire resistance available with use of these materials. The Mixed Room ensemble, furnished with materials identical to the Typical Room except for the substitution of the bed from the Space-Age Room, illustrated the improvement in control of fire spread available by careful placement of fire resistant materials in the important paths of fire development of an otherwise ordinary room.

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## MANAGEMENT SUMMARY

The plans for the present series of full-scale experimental fires were initiated at the suggestion of NASA following the presentation of a film and discussion illustrating Battelle-Columbus' recent work in fire research. That film showed bedroom-type fires carried out as a part of a program to determine the influence of the cyclic characteristics of real fires under limited ventilation on the burning and pyrolysis properties of the room furnishings. A new series of fires was suggested by NASA designed to show the performance of new fire resistant and fire retardant materials by providing comparative fire and smoldering environmental conditions.

More recently, the goal for the new series of fires was written in a meeting with NASA personnel and others at Battelle on May 3 and 4, 1972. The goal was as follows:

> To establish the need for special materials of improved fire safety in domiciliary settings of public concern, and to assess, in a professionally acceptable manner, the potential of materials arising from the new space-age technology for this purpose.

It was anticipated that some new materials arising from the space-age technology and not yet available through conventional commercial channels might provide significant improvements in fire safety if the best of the commercially available materials showed important shortcomings in this area. It was the intent of this program to assess the benefits that could accrue from the use of these new materials.

Fire safety is a matter requiring the evaluation of a number of factors. For example, fire resistance and fire spread, visibility during the fire, toxicity of evolved gases, and the fire-fighting problem that is created must be evaluated before the relative hazard can be assessed. The plan of the program provided for sampling and instrumentation to evaluate these factors, consistent with the goal of technological utilization that has been specified.

Arrangements were made with the Columbus Fire Department to use an existing six-story concrete building, designed and used as a fire training tower, as the site for the experimental fires.

The visual evidence provided by TV and photographic coverage of the four experimental room fires showed clearly that the rooms responded very differently to a common ignition condition.

In particular:

(1) The Typical room, furnished from conventional retail sources, ignited easily and burned rapidly so that after 8 minutes the contents of the room were nearly destroyed.

(2) The Improved room, furnished with materials selected as being among the best commercially available, showed substantial improvement over the Typical room in that there was slower fire spread. However, the relatively complete destruction of the room contents that resulted, and the large amounts of smoke, made it clear that substantial further improvements were needed. This fire was stopped after 29 minutes.

(3) The Space-age room, furnished completely with new materials that were not yet commercially available, did not ignite under the common ignition condition and soon demonstrated the substantial improvement in fire resistance available for those components close to the ignition source. A second and larger ignition arrangement showed that this room can burn, but the difficulty with which this was brought about confirmed the improved fire resistance available with use of these materials.

(4) The Mixed room ensemble, furnished with materials identical to the Typical room except for the substitution of the bed from the Space-age room, illustrated the improvement in control of fire spread available by careful placement of fire materials in the important paths of fire development of an otherwise ordinary room.

The most significant hazards at early times in each fire were due to the rapid rise in heat flux and the abrupt obscuration of vision by smoke. The most consistent toxicity hazard was due to CO and its importance would depend on the ability of the occupant to survive the initial heat and smoke menace which characterized each fire room. Other gases and vapors were shown to reach hazardous levels in certain fire rooms and, again, their significance to an occupant would relate to the times in which such hazards occurred, and probably to the synergistic nature of the hazard arising from mixtures of such gases.

Fire retardant items in the room are caused to pyrolyze by the heat of burning from other items in the room and so contribute to combustible and toxic vapor accumulations even though they may not have entered into the burning process. This effect of a mixture of combustible materials to produce burning and pyrolyses not characteristic of any one item individually we have chosen to call the "ensemble effect". Further full-scale fire trials may be expected to show the significant changes that control the burning and pyrolytic processes and in that event a programmed fire chamber should be developed to yield realistic laboratory results.

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# A FULL-SCALE FIRE PROGRAM TO EVALUATE NEW FURNISHINGS AND TEXTILE MATERIALS DEVELOPED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

by

L. J. Hillenbrand and J. A. Wray

## INTRODUCTION

Prior research at Battelle-Columbus was based on the recognition that more deaths occurred in residential fires because of anoxia and the inhalation of toxic gases than because of burns. In an approach to this problem a major source of these toxic gases was assumed to be products formed during smoldering and pyrolysis that occur in room-type fires, especially those involving some types of synthetic materials. Experimental examination of means for modifying the pyrolytic decomposition of furnishing materials raised the need for a more exact specification of the temperature and environmental conditions to which materials might be exposed during residential-type fires.

With the cooperation and assistance of the Columbus Fire Department, a program was initiated for development of techniques and procedures that would permit observation of the way furnishing materials respond to the period of fire and smoldering in fires set for this purpose. Using a selection of furniture loadings, several room-type fires were set in residential buildings scheduled for destruction at the Fort Hayes military complex located in Columbus, Ohio. These buildings had been occupied in recent times and were in excellent condition for examination of fires under the limited ventilation conditions that would be typical of residences in this part of the United States in winter months.

The plans for a new series of full-scale experimental fires were initiated at the suggestion of NASA following the presentation of a film and discussion illustrating Battelle-Columbus' recent work in this fire research. That film showed bedroom-type fires carried out as a part of a program to determine the influence of the cyclic characteristics of real fires under limited ventilation on the burning and pyrolysis properties of the room furnishings. This film was shown in connection with a presentation on "Fire Resistant Materials", by Mr. Matthew Radnofsky of NASA-Houston. The obvious advantages of the Columbus set-up, in relation to further experimental study of improved fire safety, led to a meeting of Battelle-NASA and others on November 23, 1971. A new series of fires was suggested by NASA designed to show the performance of new fire resistant and fire retardant materials by providing comparative fire and smoldering environmental conditions.

More recently, the goal for the new series of fires was written in a meeting with NASA personnel and others at Battelle on May 3 and 4, 1972. The goal was as follows:

> To establish the need for special materials of improved fire safety in domiciliary settings of public concern, and to assess, in a professionally acceptable manner, the potential of materials arising from the new space-age technology for this purpose.

It was anticipated that some new materials arising from the space-age technology and not yet available through conventional commercial channels might provide significant improvements in fire safety if the best of the commercially available materials showed important shortcomings in this area. It was the intent of this program to assess the benefits that could accrue from the use of these new materials.

The fires were intended to provide comparative performance data. The settings, while chosen with buildings of public concern in mind, were selected so as to have general significance for fire safety evaluation.

In planning the program it was recognized several situations that must be considered in planning the comparative fires. Thus, the most popular textile and furnishing materials in present-day use might not include those that are among the best commercially available either for reasons of cost, visual appeal, or conventional practice. Further, the new technology that has been stimulated by NASA and the space-age activities has led to the development of a new generation of "space-age" materials not yet commercially available. For these reasons, the plan of investigation was expected to distinguish between those improvements ordinarily available through use of the best of the commercial materials, and those improvements in fire safety that would require substitution by space-age materials.

It was further anticipated that when a material becomes available for use in interior furnishings, it may be expected to go through stages of piecemeal application by gradual substitution into such furnishings. An exception to this would be the construction of new public buildings where optimum material usage can be achieved through regulatory controls. Thus, the program was expected to make a limited demonstration of both the case of the complete substitution of new materials into the chosen room, and the case of partial substitution where only a few materials that should be most effective in improving fire safety were used to replace the best commercially available materials.

Fire safety is a matter requiring the evaluation of a number of factors. Thus, for example, fire resistance and fire spread, visibility during the fire, toxicity of evolved gases, and the fire-fighting problem that is created, are potentially independent factors that must be evaluated before the relative hazard can be assessed. The plan of the program provided for sampling and instrumentation to evaluate these factors consistent with the goal of technological utilization that has been specified.

## OBJECTIVES

To meet the overall goal, the following detailed objectives were set for the investigation.

(1) Obtain comparative performance data for chosen textiles and furnishing materials using fires set in full-scale rooms of identical size and geometry.

(2) Assess fire hazard by evaluation of ignition time, fire spread rate, smoke density, evolution of selected combustibles, toxic gases and combustion products, and heat flux.

(3) Establish baseline data by carrying out a fire in a room equipped with a selection of the popular or typical furnishing materials.

(4) Determine the degree of fire hazard that remains for an improved room when only materials that are among the best commercially available are used under the comparative fire conditions established.

(5) Assess further improvements that can be derived by use of new materials arising from the space-age technology.

(6) Assess the performance of a limited number of new materials selected as most effective in improving fire safety when used for partial substitution in a room otherwise equipped with the typical room furnishings.

## BASIS FOR THE EXPERIMENTAL PROGRAM

The previous work at Battelle-Columbus had demonstrated that the early stages of a room fire exhibited stage-wise development of smoldering, flame flareup, oxygen depletion, combustion product accumulation accumulation, and oxygen-level recovery through air circulation. The particular degree of stage-wise fire development that was obtained clearly would depend on the choice of room characteristics and the arrangement of furnishings. In the present program these choices were fixed to establish comparative fire data under conditions where only the materials used were varied. This room configuration was chosen partly for convenience to the objectives listed and partly for economy of effort. A bedroom arrangement was chosen for the variety of material combinations that are possible and for the circumstances of realistic fire initiation and development that could be simulated.

The fire load for each room can be described in terms of two quantities: one represents the furnishings and the treatments given to walls, ceiling, and floor, while the other represents the uncontrolled and usually combustible items, brought into the room by the occupant, which have served for ignition of the fire.

The choices available for room furnishings and arrangements were manifold and some basis had to be adopted for deciding among these. On one extreme, all metal furniture might be used such that, if the mattress and bed coverings are suitably fire resistant, very little fire risk exists. This is especially true if the igniter load (brought in by the occupant) is also limited to the degree that fatal conditions cannot arise from this part of the furnishing alone. On the other extreme the use of cheap, highly combustible materials could be carried to such an extreme that severe fire risk could be determined by inspection. Neither extreme was suitable for the present research.

Between these two extremes lie a number of choices, suitable for public occupancy, in which metal is used only where its strength and durability are the primary consideration and where the other materials are chosen with cost, comfort, and decor in mind. For the present program, the furnishings and room arrangements have been based primarily on the materials recommended for trial by NASA-Houston and on the configuration needed to demonstrate their values.

The major factors in fire spread are related to the configuration and layout of the room and the type of furnishings involved. The configuration of the room is important since the relative position and distance of each furnishing item from other items will determine the propagation route and intensity. Also, the relative flammability of each item will also determine the route and the intensity.

Some restraint was exercised in equipping the "Typical room" in that some common fire hazards were avoided; prior experience had shown for example, that ignition of a fire in a polyethylene wastebasket filled with scrap paper aided fire spread because the basket melted and spilled the burning contents into the room. The constraints that have been placed on this "Typical" room arose from the consideration of the reproducibility of the spread conditions and the stated intent of evaluating selected material alternatives in the comparative fires.

The "Improved" room furnishings were intended to show how far it was possible to proceed toward the elimination of fire hazard if the materials were among the best commercially available without regard for cost. Again, this demonstration was to be assessed in terms of the chosen comparative conditions. Further, the performance of these "best" materials would determine the degree to which the new, or "special" materials are needed to achieve suitable fire safety in inhabited buildings.

Two concepts for fire study were considered. In one concept each room ensemble would be observed under conditions of gradually-increasing severity of ignition loading until fire spread was sufficient to cause complete room involvement. In this case more than one set of room furnishings of each type might be necessary to complete the set of trials required depending on the accumulation of fire damage from each trial. For the limited series of trials permitted in this program the above approach was not satisfactory.

The concept for study that was finally chosen for the program involved the choice of a standardized ignition load such that it could be expected to reveal differences in inflammability and fire spread character for the ensembles provided. Since the literature provided very little guidance for the choice of that ignition loading, one preliminary room was required that could be used for ignition trials. The ignition loading chosen in this way was kept the same for all rooms so that differences in fire spread and burning character depended largely on the changes in materials combinations employed. Further, in those cases where the ignition did not cause any appreciable degree of fire spread, a second, and larger, ignition could be tried.

The arrangement of the ignition load in the room was chosen so that at least two paths for fire development were provided, In this way, if special materials (used for an item of furnishings) prevented fire development along one path, room involvement might still occur by another route and in that event the response of the fire-retardant item to the pyrolysis conditions might be observed.

For this program it was anticipated that each room ensemble might be examined from at least two points of view, viz

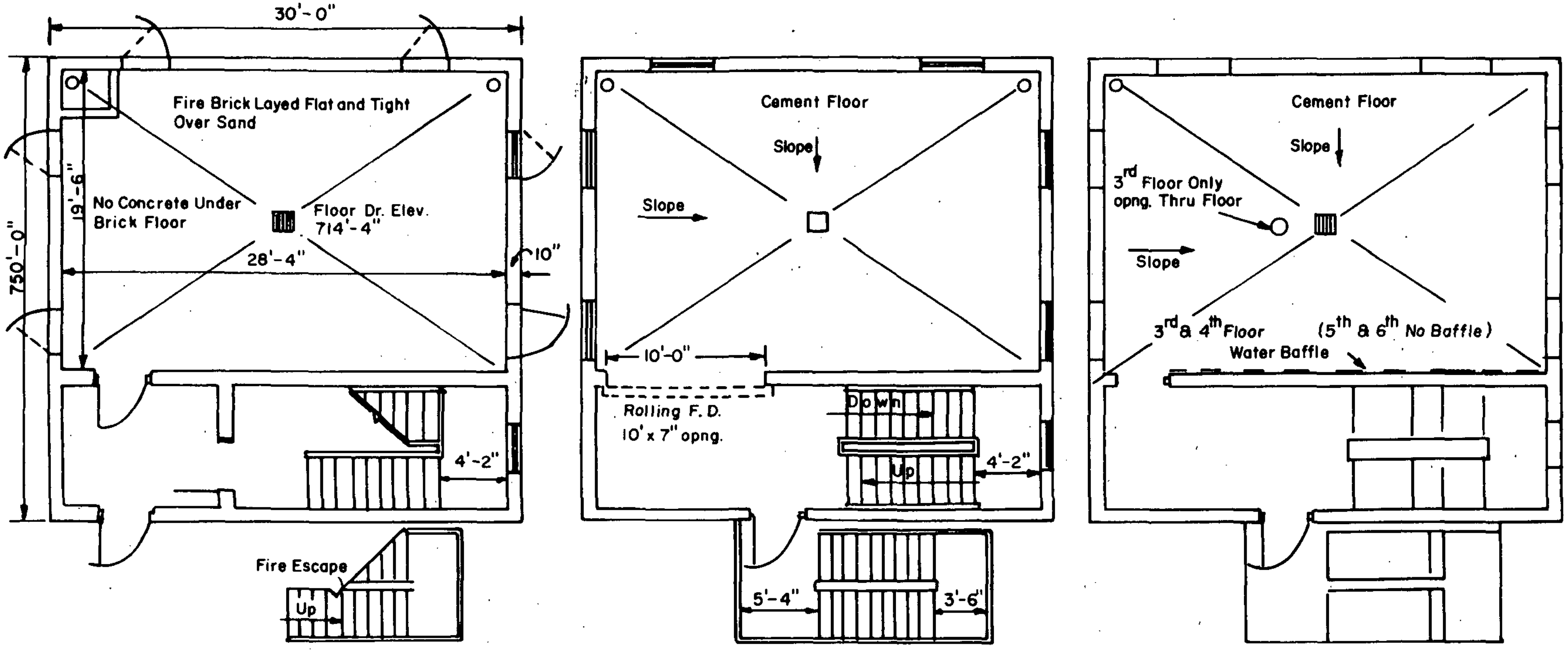
(a) Its effectiveness in controlling fire spread
(b) The development of other hazards, e.g., smoke, toxic gases, under the conditions of fire spread obtained.

To minimize cost, the series of fires were carried out on as rapid a schedule as possible. This required that each fire in the series be carefully planned in advance so that extensive iterative use of the results of one fire to dictate those of subsequent fire was not possible. Further, to maintain a rapid schedule, the fire rooms were prefabricated in sections for storage and then subsequently used by bolting the sections together. Thus, the manpower and instrumentation were committed to this program for an experimental period of about 4 weeks, during which the four experimental fires and a few trial burns using various igniter loads were tried.

## THE EXPERIMENTAL PROGRAM

### The Fire Facility

Arrangements were made with the Columbus Fire Department to use an existing six-story concrete building, designed and used as a fire training tower, as the site for the experimental fires. The training tower is a concrete building with unglazed casement window frames on each of three sides. Figure 1 shows floor plan dimensions for this structure. The layout of the fire room and the required personnel area and instrument room in the fire training tower is illustrated in Figure 2. The figure shows the fire room, about 11 ft by 11 ft inside, with an 8 ft ceiling arranged in a space about 18 ft by 19 ft, 6 in., by 11 ft enclosed by three walls of the fire tower and the barricade. The volume of the fire room, 968 ft$^3$, is about 33 percent of the residual fire tower volume left for circulation of air and gases into and out of the fire room. Communication of such gases between the fire tower volume and the fire room occurred by an open doorway and by a duct opening located in the ceiling of the fire room. All windows were closed during the fire except one, see Figure 2, which was partially opened to provide a continuing supply of air and to relieve pressure fluctuations during the fire. The opening in the window was formed by a wooden panel hinged at the top of the window frame and propped open about 1 foot at the bottom so as to admit air but restrain wind currents that otherwise might affect the fire.



First Floor

Second Floor

Third, Fourth, Fifth and Sixth Floors

FIGURE 1. PLAN VIEWS OF THE TRAINING TOWER OF THE COLUMBUS FIRE DEPARTMENT

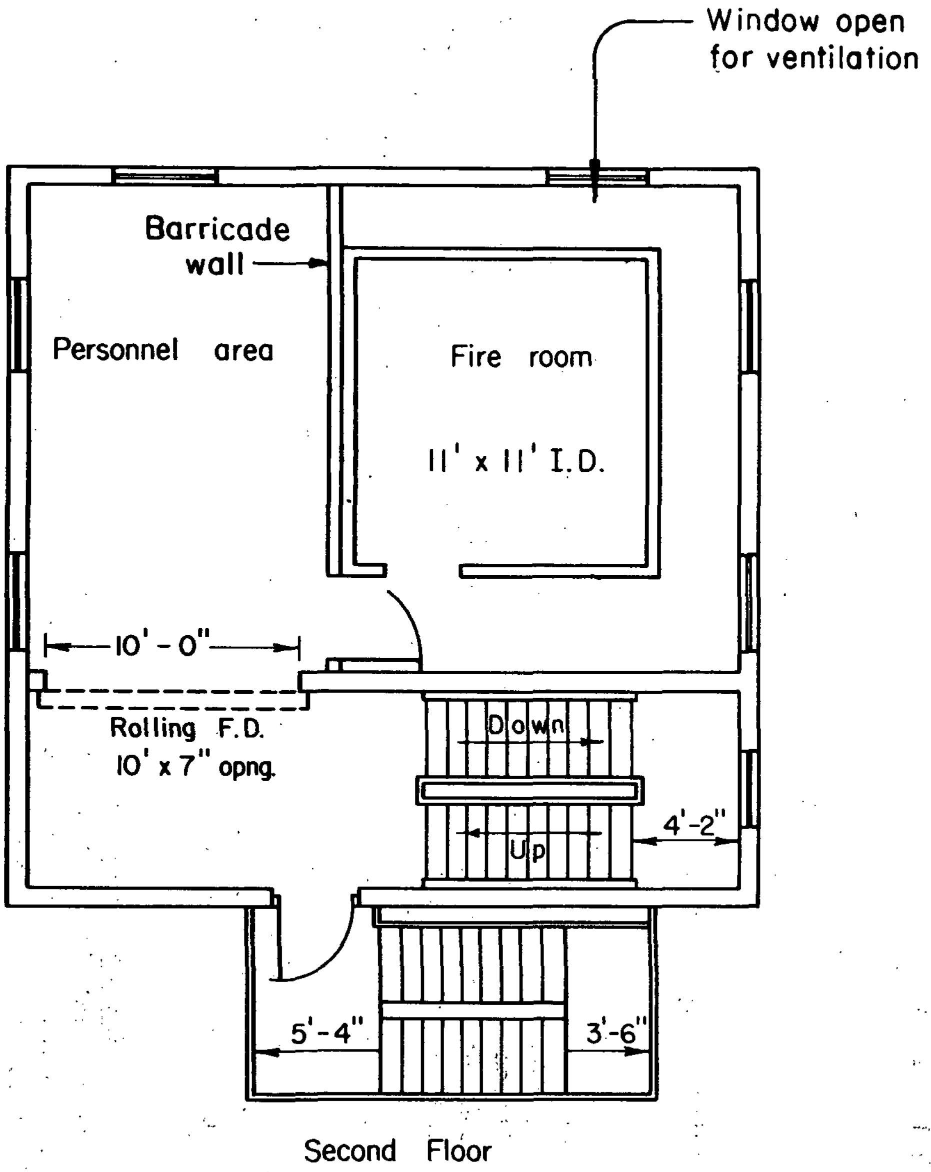


FIGURE 2. ARRANGEMENT OF FIRE ROOM AND BARRICADE IN THE FIRE TRAINING TOWER.

Each fire room was 11 ft by 11 ft square with an 8 ft-high ceiling and one door and one simulated window on opposite sides of the room. The basic construction of 2 x 4 studding topped with conventional 5/8-inch dry wall was used for each fire situation. However, varying wall surface treatments were used for the different room ensembles. The walls, floor, and ceiling were made in sections and assembled in the fire training tower as needed. Ceiling sections were covered with 5/8 inch dry wall material and the floor was covered with 1/2 inch plywood.

## Room Arrangement and Furnishings

### Materials Selection

The room arrangement used as shown in Figure 3. The "Typical Room" materials were selected on a basis of frequency of use and were purchased from normal retail outlets. The materials selected for the "Improved Room" and the "Space-age materials" room were based primarily on suggestion from NASA-Houston personnel familiar with both commercial products having a high degree of fire resistance and, of course, the materials developed for space applications. Since a door was not used at the entrance to the fire rooms, a door was added to each fire load by placing it against one wall as shown.

Table 1 lists furnishings and materials included in the four basic fires. Explanations of material choices specific to each room are given below under the respective room heading. A listing of the weights for each item used is given in Table 2.

Typical Room. Consultation with Ohio Bedding, Columbus, Ohio, indicated that "typical" bedding construction should be as shown in Table 1. Other choices of materials for this room are based on recommendations from NASA personnel and observations of typical home furnishings available in local outlets. Unpainted pine end tables, bookcase, and bureau made it possible to use the same solid wood construction for these items in all rooms with changes being made only in the surface finish applied.

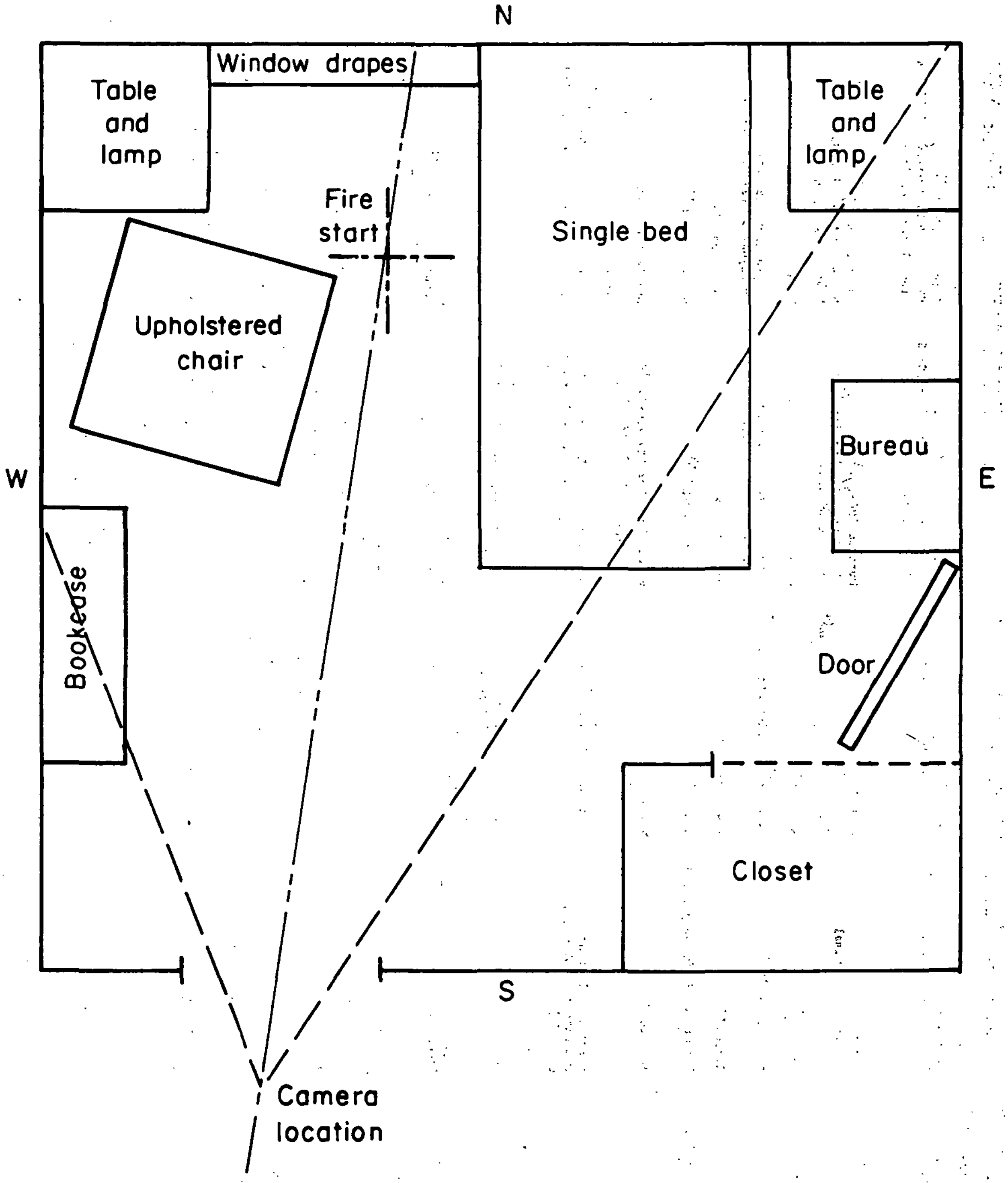


FIGURE 3. FURNISHINGS ARRANGEMENT AND CAMERA LOCATION

TABLE 1. LIST OF FURNISHING AND MATERIALS INCLUDED IN FOUR BASIC FIRES(a)(b)

| Furnished Item | Typical Room | Improved Room | Space-Age Room | Typical Room with Space-age Bed |
|---|---|---|---|---|
| **Mattress Components**(c) | | | | |
| Mattress cover | Cotton | Nomex (6) | Durette 400-1 (13) | Durette 400-1 (13) |
| Mattress padding | Cotton felt + sisal pad(1.1) | HR foam--3-lb density (7) | HR foam--2-lb density(7) + L-3203-6<br>Fluorel treatment (14) | HR foam--2-lb density(7) + L-3203-6<br>Fluorel treatment (14) |
| **Box Spring** | | | | |
| Cover | Cotton | Nomex (6) | Durette 400-1(13) | Durette 400-1(13) |
| Padding | Cotton felt + sisal pad(1.2) | HR foam--3 lb (7) | HR foam--2 lb(7) + L-3203-6 (14) | HR Foam--2 lb(7) + L-3203-6 (14) |
| Frame | Wood | Fire-retardant paint on wood(4.2) | L-3203-6(14) on wood | L-3203-(14) on wood |
| **Hollywood Frame** | Metal (2) | Metal (2) | Metal (2) | Metal (2) |
| **Headboard** | Wood--pecan (3.1) | Formica(8) on wood--white oak (2) | Norgan laminated with FX impregnated fiber glass (15) | Norgan laminated with FX impregnated fiber glass (15) |
| **Bedspread** | Cotton (2) | Nomex (6) | Beta glass (9) | Beta glass (9) |
| **2 Sheets and 1 pillow cover** | 50% Cotton + 50% polyester (2) | Nomex(6) | Durette 400-6 (13) | Durette 400-6 (13) |
| **Blanket** | Acrylic (2) | Nomex (6) | Needle batt Durette 400-11 (13) between 2 plies of Durette 400-2 (13) | Needle batt Durette 400-11 (13) between 2 plies of Durette 400-2 (13) |
| **Pillow** | Polyester fiber and 50% cotton + 50% polyester cover (2) | HR foam--3 lb(7) and Nomex ticking (6) | HR foam--2 lb(7) + L-3203-6 (14)<br>Cover--2 plies Durette 400-6(13) | HR foam--2 lb(7) + L-3203-6 (14)<br>Cover--2 plies Durette 400-6 (13) |
| **Auxiliary Furniture** | | | | |
| End Tables | Wood--pine(5.1) | Formica(8) on wood--pine(5.1) treated with fire-retardant paint (4.2) | L-3203-6(14) + Scheuffelin paper (18) on wood-pine (5.1) | Wood--pine(5.1) |
| Lamps | Ceramic (3.2) | Ceramic(3.2) | Ceramic (3.2) | Ceramic (3.2) |
| Lamp shades | Paper parchment(3.2) | Fiberglas(9) | Durasan--5 mil (16) | Paper parchment (3.2) |
| **Upholstered Chair** | | | | |
| Upholstery | Polypropylene | Proban treated wool(10.1) | Durette 400-6(13) | Polypropylene |
| Frame | Wood--oak (2.1) | FR paint(4.2) on wood--oak | Wood (oak) + L-3203-6 (14) | Wood--oak (2.1) |
| Padding | Polyurethane | HR foam--3 lb(7) | HR foam--2 lb(7) + L-3203-6(14) | Polyurethane |
| **Bureau** | Wood--pine (2.2) | Formica(8) on wood--pine(2.2) treated with fire-retardant paint (4.2) | L-3203-6(14) + Scheuffelin paper(18) on wood--pine (5.1) | Wood--pine (2.2) |
| **Bookcase** | Wood--pine (2.3) | Formica(8) on wood--pine (2.2) treated with fire retardant paint(4.2) | L-3203-6(14) + Scheuffelin paper(18) on wood--pine (5.1) | Wood--pine (2.2) |
| **Floor Covering** | | | | |
| Carpet | Nylon--jute backing(2.4) | Untreated wool (10.2) | Fiberglas (17) | Nylon--jute backing(2.4) |
| Pad | Fiber pad(2.5) | HR foam--3 lb (7) | HR foam--2 lb(7) + L-3203-6 (14) | Fiber pad(2.5) |
| **Wall Covering** | Paint (4.1) | Sodium silicate board(11) + Fiberglas wall cover(9) | 1/4 inch Laminite(18) + Durasan--5 mil wall covering(16) | Paint (4.1) |
| **Ceiling** | Paint (4.1) | Ceramic ceiling tile (12) | 1/4-inch Laminite(18) + Ames wood panels(19) + Plastic foam panels(d) (20) | Paint-cotton(4.1) |
| **Drapes** | Polyester-cotton(2) | Fiberglas(2) | Beta-fiber(9) | Polyester-cotton(2) |
| **Door** | Hollow core--birch(5.2) | Solid wood (5.2) | Norgan laminted with FX impregnated fiber glass (15) | Hollow core--birch(5.2) |

(a) Numbers in parenthesis respectively refer to material suppliers and significant trademark or designation given in Table 1-A.
(b) A listing of furnishing weights is given in Table 2.
(c) Single bed mattress-39 in. x 74-1/2 in.
(d) Cellulose--urea-formaldehyde formulation developed by NASA Houston and prepared by Battelle.

## TABLE 1-A. FOOTNOTES TO TABLE 1.

| Code No. | Supplier | Location | Material Trade Name or Design |
|---|---|---|---|
| 1.1 | Ohio Bedding | Columbus, Ohio | Youkon |
| 1.2 | | | Youkon |
| 2 | Lazarus Department Store | Columbus, Ohio | -- |
| 2.1 | | | Model No. 851-230 |
| 2.2 | | | Bailey - 1439 |
| 2.3 | | | Bailey - 1202 |
| 2.4 | | | Lee - 7503-711 |
| 2.5 | | | Startex |
| 3.1 | Furniture Warehouse | Columbus, Ohio | |
| 3.2 | | | |
| 4.1 | Sherwin-Williams | Columbus, Ohio | Rogers Celeste White Latex |
| 4.2 | | | Kem Gard Latex Paing |
| 5.1 | Hilliard Lumber Company | Hilliard, Ohio | Mastercraft - 1731 |
| 5.2 | | | -- |
| 6 | DuPont | Wilmington, Delaware | Nomex |
| 7 | Scott Paper Company | Chester, Pennsylvania | HR Foam |
| 8 | Arco Linoleum and Rug Company | Columbus, Ohio | Flat Cut Regency Walnut (Formica 3855) |
| 9 | Owens-Corning Fiberglass Corp. Textile Development Laboratories | Ashton, Rhode Island | -- |
| 10.1 | Collins & Aihman | Albermarle, North Carolina | Fontant |
| 10.2 | | | Alpine |
| 11 | BASF-Wyandotte Chemical Cellasto Division | Ypsilanti, Michigan | Palusol |
| 12 | Armstrong Cork Company | Lancaster, Pennsylvania | Ceramaguard |
| 13 | Monsanto | St. Louis, Missouri | Durette |
| 14 | Raybestas-Manhattan | North Charleston, S. Carolina | Refset L-3203-6 |
| 15 | Air-Transmission Systems Inc. | San Francisco, California | Norgan |
| 16 | Allied Chemical | Morristown, New Jersey | Duratan |
| 17 | Carolina Narrow Faline Company | Winston-Salem, North Carolina | U.S. Coast Guard Quality |
| 18 | NASA (Houston) | Houston, Texas | |
| 19 | NASA (Ames) | | |
| 20 | Battelle-Columbus<br>NASA (Houston) | Columbus, Ohio<br>Houston, Texas | |

TABLE 2. WEIGHTS OF FURNISHINGS USED IN EACH FIREROOM[a]

| Furnished Item | Typical Room | Improved Room | Space-Age Room | Mixed-load Room |
|---|---|---|---|---|
| Mattress | 53 | 32 | 27 | 27 |
| Box Spring | 44 | 42 | 39 | 39 |
| Hollywood Frame | 20 | 20 | 20 | 20 |
| Headboard | 18 | 21 | 46 | 46 |
| Bedspread | 2.5 | 2.5 | 4.5 | 4.5 |
| 2 Sheets and 1 Pillow cover | 2.5 | 2.5 | 3 | 3 |
| Blanket | 2.8 | 2.5 | 5 | 5 |
| Pillow | 1.5 | 3 | 1 | 1 |
| Auxiliary Furniture | | | | |
| End Tables (2) | 23 each | 28 each | 23 each | 23 each |
| Lamps and Lamp Shades (2) | 7.5 each | 7.5 each | 6 each | 7.5 each |
| Upholstered Chair | 49 | 45 | 39 | 49 |
| Bureau | 43 | 55 | 46 | 43 |
| Bookcase | 23 | 29 | 24 | 23 |
| Floor Covering | | | | |
| Carpet | 61 | 66 | 68 | 61 |
| Pad | 29 | 21 | 11 | 29 |
| Wall Covering | -- | 226[b] | 156[c] | -- |
| Ceiling | -- | 148 | 54[d] | -- |
| Drapes | 2.5 | 2.5 | 3 | 2.5 |
| Door | 37 | 80 | 110 | 37 |

---

[a] Weight in pounds.

[b] 210 lb sodium silicate board + 16 lb fiberglass.

[c] 138 lb Laminite + 18 lb 5-mil Durasan.

[d] 47 lb Laminite + 2 lb NASA Ames panels + 5 lb NASA Houston panels.

Improved Room. The bureau, end table, and bookcase, were identical to the unfinished pine furniture used in the "Typical Room" for comparison purposes, and the front side of the headboard were surfaced solely with Formica. Norgan is commercially available and was planned for use in this room but no furnishings constructed from or surfaced with Norgan could be located. Therefore, it was felt that Formica, because of its wide distribution and usage, would be more representative of an improved fire resistant material. The fire-retardant paint specified for the box-spring and upholstered chair frames was also applied to the backside of the headboard and also to the bureau, end tables, and bookcase prior to Formica surfacing. This was done to impart better overall fire retardance and to provide protection to those areas for which lamination with Formica was impossible or impractical.

Discussions with NASA-Houston resulted in the choice of BASF sodium silicate board as wall covering because of its high degree of fire protection and ease of installation. A Nomex blanket was substituted in this room for the Proban-treated wool blanket originally planned since a source of the latter could not be located.

Space Age. Selection of the 400 series of Durette fabrics rather than the 420 series was prompted by the greater availability of the 400 series. Changes in the type of Durette fabrics employed have resulted from recommendations given by the supplier. Asbestos was eliminated as recent findings have implicated asbestos as a carcinogen and also because asbestos is not a space-age material. Polyimide plus Fiberglas and Halar were not used because of material and fabrication costs beyond the budget of this program. The substitute structures were arrived at through discussions with NASA-Houston. The base furniture for these structures was identical to the unfinished pine used in the Typical and Improved rooms for comparison purposes.

ADP and Kel-F treatments to have been applied respectively to the mattress foam and ceiling were, as a result of discussions with NASA-Houston, regarded as unnecessary and deleted.

Sheuffelin cellulosic ceiling tiles could not be obtained in time from the designated supplier so the 1/4 in. Laminite used as wall covering was also used for the ceiling. In addition, two treated wood panels (foot square) from NASA-Ames and 25 NASA-Houston developed plastic-foam panels (foot square) were selectively positioned on the Laminite.

## Materials Preparation

All mattress and box spring construction along with chair upholstering was done by Ohio Bedding of Columbus, Ohio. Construction and preparation for each room is described below under the respective room headings.

Typical Room. The end tables, bureau, bookcase, and door were stained with Hanna's 4905 Traditional Mahogany Wood Stain and finished with two coats of Hanna's Swan Spar Clear Satin Varnish.

Improved Room. One heavy coat of Sherwin-Williams Kem Gard Fire Retardant Latex Paint was applied to the box-spring frame, end tables, bureau, bookcase, upholstered chair frame, and back-side of the headboard. Formica 2855 was then selectively laminated over the bureau, end tables, bookcase, and front side of the headboard (that is, Formica was applied to the major portion of the outside surface area of the furniture mentioned), using 3M's Fastbond 30 contact cement. The door in this case was stained and finished as given previously for furnishings in the typical room.

The sodium silicate board wall covering was applied over the dry-wall using nails and staples. The Fiberglas wall covering was adhesively bound to the sodium silicate board using 3M's Scotch Grip 77-N pressure sensitive adhesive.

The ceramic ceiling was of a concealed suspension nature.

Space Age Room. One heavy coat of the L-3203-6 Fluorel treatment(*) was applied by spraying to the box-spring frame, mattress and box-spring foam, and upholstered chair frame and foam. Two heavy coats of the L-3203-6 Fluorel treatment were applied by spraying to the end tables, bureau, bookcase, and carpet padding. Sheuffelin paper was then laminated to the end tables, bureau and bookcase using 3M's 4715 contact cement.

The 1/4 inch Laminite wall covering was nailed in place while the Durasan wall covering was adhesively bound to the Laminite using 3M's 4715 contact cement.

Combinations of nails and washers were used to secure the NASA-Ames wood panels and NASA-Houston plastic foam panels to the ceiling.

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(*) 550 g Fluorel L-3203-6 dispersed in 2600 g methyl ethyl-ketone.

Typical Room with Space-Age Bed. The mattress, box spring, and headboard were constructed as described for the Space Room. The end tables, bureau, bookcase, and door were furnished identically as those in the Typical Room.

## Igniter Load

As indicated earlier, it was required that the igniter load be large enough to cause complete room involvement in at least some cases, but not so large that it dominated the fire load otherwise arranged. Newspaper seemed to be a reasonable type of material for the fire start and the trials centered about the ways in which such material might be used for the ignition. In addition to the newspaper, other combustibles were arranged about the room as part of the room load that was imagined to be brought in by the occupant. These included

(1) 40 pounds of books arranged in the bookcase located along the west wall of the fire room,

(2) 7 to 8 pounds of clean clothes hung from hangers in the closets located in the southeast corner of the fire room,

(3) One book open on the floor near the bookcase, one book on the table in the northeast corner, and a few magazines on the tables and bureau,

(4) About five pictures, on illustration board but unframed, hung on the west, north, and east walls of the fire room.

These items were used in each room and no experiments were conducted to evaluate the influence of the individual items. Their location in all portions of the room was expected to contribute to fire spread when irradiation and heat convection in those areas was large enough to bring about ignition.

Initial trials of the newspaper to be used for ignition were made in metal wastebaskets, about 13 inches in diameter and 14 inches high, that held about one pound of crumpled newspaper. Two thermocouple positions were tried, one located along the middle of the side of the basket, and the other 6 inches up and 6 inches out from the top edge. The position above the basket registered a maximum of only 140 F and the maximum temperature of the side of the basket was 300 F. The contents burned rapidly for about 8 minutes and were reduced to smoldering residue in 13 minutes. It was concluded that this ignition source was too small to assure the ignition desired.

As an alternative, a basket formed from wire mesh was tried with the same amount of crumpled newspaper. The maximum temperature registered by the thermocouple above the basket reached 400 F in brief intervals in this trial and the contents were reduced to smoldering ash in 5 minutes. Nevertheless it was concluded that neither of these trials produced enough heat laterally to be good ignition sources for the trial rooms.

Finally, 3 pounds of newspaper in folded sections equivalent to the local Sunday edition was tried. In this trial the sections of newspaper were strewn in an array from the seat of an upholstered chair, to the floor, and up onto a bed adjacent. To ignite this, crumpled newspaper in the wire mesh wastebasket was lit and the basket put on its side so that it was in contact with the newspaper sections on the floor. This arrangement was closely copied in all subsequent rooms and is shown in the fire room photographs included in the Results and Discussion Section. The location of the ignition source with respect to the room arrangement is shown in Figure 3, identified as "Fire Start".

Each room was assembled at least 24 hours prior to the time of ignition, and heaters were placed in the rooms during this interval to assure reasonable and similar temperature and humidity conditions for the ignition. The values measured for each fire start are shown in Table 3.

TABLE 3. TEMPERATURE AND HUMIDITY CONDITIONS FOR THE EXPERIMENTAL FIRES

| | | In Room | | Outside Air | |
|---|---|---|---|---|---|
| Date | Fire Room | Temperature °F | Humidity % | Temperature °F | Humidity % |
| 10/3 | Preliminary Room | 72 | 50 | | |
| 10/10 | Typical Room | 63 | 33 | 56 | 34 |
| 10/17 | Improved Room | 63 | 42 | 50 | 55 |
| 10/24 | Space-age Room | 60 | 58 | 50 | 74 |
| 10/31 | Mixed load Room | 60 | 48 | 49 | 61 |

## Instrumentation and Sampling

Continuous surveillance of selected products of combustion was arranged for the experimental fires. The considerations and choices for each of the instrumentation and sampling problems are discussed in the following paragraphs.

In order to keep sampling probes as short as possible, one wall of the fire room was built adjacent to the barricade. The access opening in the barricade is close to the doorway to the fire room for the same reason. Samples for monitoring purposes were collected at three locations: inside the fire room at about the middle of the wall adjacent to the barricade and about 36 inches from the floor, at the doorway, and at the ventilation duct. The information collected at each of these was as follows

| | Inside Room | Doorway | Duct |
|---|---|---|---|
| Smoke density | -- | X | X |
| Ventilation rates | -- | X | X |
| $CO/NO_x/O_2/HC$ | X | -- | -- |
| Heat Irradiation | -- | X | -- |
| Particulate/aldehydes | X | -- | -- |
| HCl | X | -- | -- |
| HCN | X | -- | -- |
| HF | X | -- | -- |

The sampling probe inside the fire room extended about 3 feet into the room and was located in the vicinity of the chair and wastebasket. A pump provided a continuous flow of gases through this probe so as to maintain sufficient flushing of the sampling system.

## Temperature Measurements

Chromel-alumel thermocouples, 26 gage, were placed in a number of locations intended to show the time of participation of the individual items of furniture in the fire, and the overall progress of the fire throughout the fire room. The thermocouple locations are summarized in Table 4. Generally, the thermocouples were placed with the bead in contact with the surfaces present at the location, or, in those cases where practical, the bead was inserted through a hole in the upholstery so that

## TABLE 4. THERMOCOUPLE LOCATIONS

| Thermocouple Locations | Channel Number | | | |
|---|---|---|---|---|
| | 10/10 | 10/17 | 10/24 | 10/31 |
| Ventilation duct, outer end | 0 | 0 | 0 | 0 |
| NW corner, 41 in. above floor | 1 | 1 | 1 | 1 |
| Bed headboard, ~ 41 in. above floor | 3 | 3 | 3* | 3 |
| NE corner, 41 in. above floor | 4 | 4 | 4 | 4 |
| At ceiling above drapes | 5 | 5 | 5 | 5 |
| In carpet, below drapes | 6 | 6 | 6 | 6 |
| In carpet, 30 in. S, 51 in. E | 7 | 7 | 7 | 7 |
| Under pad, 30 in. S, 51 in. E | 8 | 8 | 8 | 8 |
| In center of bed, under spread | 9 | 9 | 9* | 9 |
| In pillow | 10 | 10 | 10* | 10 |
| In chair, corner near ignition | 11 | 11 | 11 | 11 |
| In bureau, middle of top front edge | 12 | 12 | 12 | 12 |
| In bookcase, middle of top front edge | 13 | 13 | 13 | 13 |
| In ventilation diffuser, in ceiling center | 14 | 14 | 14 | 14 |
| Above center of doorway, inside room | 15 | 15 | 15 | 15 |
| At pitot tubes, top 1/3 doorway | 16 | 16 | 16 | 16 |
| At pitot tubes, middle 1/3 doorway | 17 | 17 | 17 | 17 |
| At pitot tubes, bottom 1/3 doorway | 18 | 18 | 18 | 18 |
| At radiometer, 15 in. above floor | 19 | 19 | 19 | 19 |
| In movie camera box | 20 | 20 | 20 | 20 |
| At gas analyses sample probe | 21 | 21 | 21 | 21 |
| At HX, aldehyde sample probe | 22 | 22 | 22 | 22 |
| Above center closet doorway, in room | 23 | 23 | 23 | 23 |
| Inside TV camera box | 24 | 24 | 24 | 24 |
| At ceiling, NE corner | 25 | 25 | 25 | 25 |
| Center of door, east side | 26 | 27 | 26 | 26 |
| Center of door, west side | 27 | 26 | 27 | 27 |
| In chair, topcenter of back | 28 | 28 | 28 | 28 |
| Above ceiling, 30 in. S, 41 inc. E | | 36 | | 36 |
| At top nightstand, NW corner | | | | 37 |
| NASA tile A | | | 37 | |
| NASA tile B | | | 36 | |
| At ceiling, 30 in. S, 41 in. E | | | | 39 |
| Under drapes, 41 in. above floor | 2 | 38 | 38 | 38 |
| Horizontally arranged across doorway, 2/3 up from floor | | | | |
| West | | | | 41 |
| to | | | | 42 |
| East | | | | 43 |
| | | | | 44 |
| | | | | 45 |
| Above ceiling near closet | | 37 | | |
| Tile made at BMI | | | 39 | |
| Tile from Dow | | | 40 | |

(*) Not pertinent, 2nd trial 10/24/72

it responded to the temperature reached by the textile and not directly to the incident heat irradiation.

Each thermocouple was attached to a channel of a Digitem recorder, Model DAS-1, arranged to scan the channels at the rate of about 2-1/2 channels/second and print out the millivolts found for each. Thus, in each experiment the entire set of thermocouples was scanned and recorded every 14 to 20 seconds depending on the total number of thermocouples used. The data were transcribed to magnetic tape and then plotted by the computer. The entire set of data assembled in this way are presented in Appendix A.

## Ventilation

The fire room may be ventilated in several different ways and the choice may be anticipated to have considerable bearing on the results obtained in the experimental fires. In our prior experience, air entered the fire room by way of a doorway and, because it was cooler than the room air, flowed along the floor, thus forming a layer through which it was possible to see entirely across the fire room. At the same time the accumulation of smoke in the room had reduced visibility above this layer to only a few feet and the smoke could be seen leaving the room by the same doorway that admitted the fresh air. Thus the door openings served simultaneously to supply air to the fire and to vent the combustion products; in many circumstances, the doorway is the major opening for such transport to occur. For the present program the doorway was planned to be the sole source of air to the fire room and an open window in the training tower, see Figure 3, insured a continued supply of fresh air for that purpose.

One ventilation duct opening was installed in the fire room which was connected to 8 feet of duct terminating in the space above the fire room. This duct was used without blower so that the relative importance of natural convection through this opening could be observed. At the normal blower circulation rate of four room volume changes per hour, the impressed circulation of a blower was expected to be relatively unimportant during the fire periods compared to the circulation through the open doorway, and would serve only to shorten somewhat the smoldering periods that were anticipated.

Transducerized pitot tubes offered the best means for measurements of air flows in the range of temperatures anticipated. The flow measurements at the doorway were of greatest importance and three pitot tubes were located there. Another pitot tube was located in the ventilation duct. The locations of these pitots within the openings must be regarded as compromise choices to provide maximum information with a minimum number of sampling sites. For the doorway, the opening was visualized as being divided into thirds: the middle and top thirds were monitored at the centers to provide data on the efflux of combustion gases, and the bottom third was monitored at its center to provide data of air flow into the room. For the ventilation duct, a single pitot was located at the center of the opening at the outlet end.

For this purpose, 1/8 inch Kiel probes were used with Statham Model PM 197 pressure transducers for readout of the pressure data. This arrangement of apparatus supplied an output of 1 volt at 15 to 20 ft/second flow rates and could be used to estimate flows between about 10 and 70 ft/second under these experimental conditions.

## Heat Irradiation

Heat irradiation levels were measured by a Hy-Cal radiometer, Model R-2040-15-072, equipped with a sapphire window as a radiation filter and located in the wall adjacent to the doorway and about 15 inches above the floor. The calibration curve supplied with the instrument shows the radiometer to have an output of 10 millivolts at an incident heat flux of 15.7 $\mathrm{Btu/ft^2 \cdot sec}$ and was used to measure flux levels between about 0.1 and 5.6 $\mathrm{Btu/ft^2 \cdot sec}$ during the experiments. An enlargement of the calibration curve was used to obtain estimates for low heat flux levels during the initial time periods of the experiments between 0.1 and 1.0 $\mathrm{Btu/ft^2 \cdot sec}$. The time dependent curves obtained in this way are of uncertain precision but serve to characterize the differences in the initial buildup of the experimental fires. The expanded curve, with the values used for its construction, is shown in Figure 4.

Since this radiometer could receive radiation over a 150° angle, the irradiation levels obtained are regarded as essentially integrated values of the heat flux at that site.

## Smoke Density

Smoke densities were measured vertically across the doorway and the ventilation duct so as to obtain relative values for the smoke being convected through each of these openings. Both the light sources and the photomultiplier tubes were protected from smoke deposition by nitrogen gas

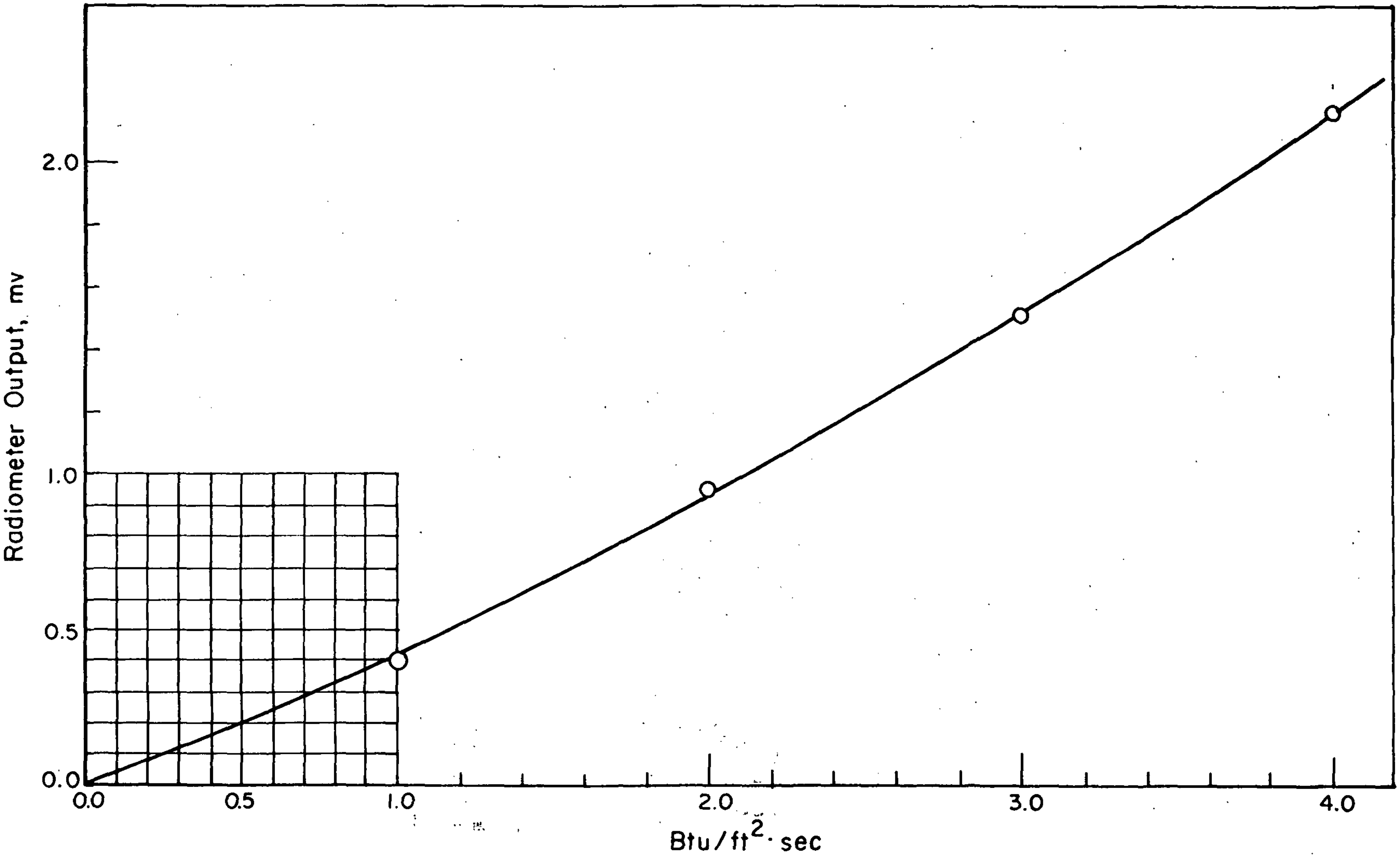

FIGURE 4. EXPANDED CALIBRATION CURVE FOR RADIOMETER

that flowed past the optics and then passed through tubulatures extending along the light path. The photomultiplier circuit was based on the 1P21 tube and Signetics operational amplifier No. 741; the wiring diagram for that circuit is shown in Figure 5. Typical plots obtained for the experiment of 10/17/72 are illustrated in Figure 6. Light transmission values between 100 percent and 0.01 percent were recorded continuously at each location.

## Gas Analyses

Table 5 lists the instrumentation used for continuous monitoring of a number of gaseous components of the combustion gases. For the hydrocarbon measurements a heated sample line was used to maintain sample temperature at about 300 F until the flame ionization hydrocarbon analyzer was reached. This tended to minimize loss of hydrocarbon by condensation during sampling. All other components were analyzed from a common stainless steel manifold. Prior to entering this manifold the gases passed through a large ice-water trap and particulate trap so as to maintain suitable moisture levels for the analytical instrumentation. An additional dry-ice trap was employed for NO analysis.

In addition, a number of constituents were analyzed as integrated samples representing the entire fire period from ignition to the start of water application. These integrated samples were collected at constant flow rate during the fire period so that the results obtained represent time-averaged samples. The constituents measured in this way were HF, HCl, HCN, and aliphatic aldehydes.

For HF analyses, the sample was drawn through a Vycor probe so that the HF was largely converted to $SiF_4$ according to the method of Dorsey and Kemnitz.(1) This volatile gas was then absorbed in impinger tubes containing $H_2O$ and the resulting solution analyzed for $F^-$ by the fluoride ion electrode. The only interference reported for this electrode is due to $OH^-$ to which the electrode is about 1/10 as sensitive as for $F^-$. This interference was eliminated by adjustment of pH of the samples collected.

Cyanide was analyzed by ion-selective electrode which shows interference to sulfide ion (which must be absent), chloride ion (if $10^6$ times the $CN^-$ concentration) bromide ion (if 5000 times the $CN^-$ concentration), and iodide ion (if 10 times the $CN^-$ concentration). The absence of sulfide was qualitatively confirmed in these samples and the analyses for chloride plus bromide ion do not indicate significant interference. The $CN^-$ concentrations are believed valid to ± 10 percent.

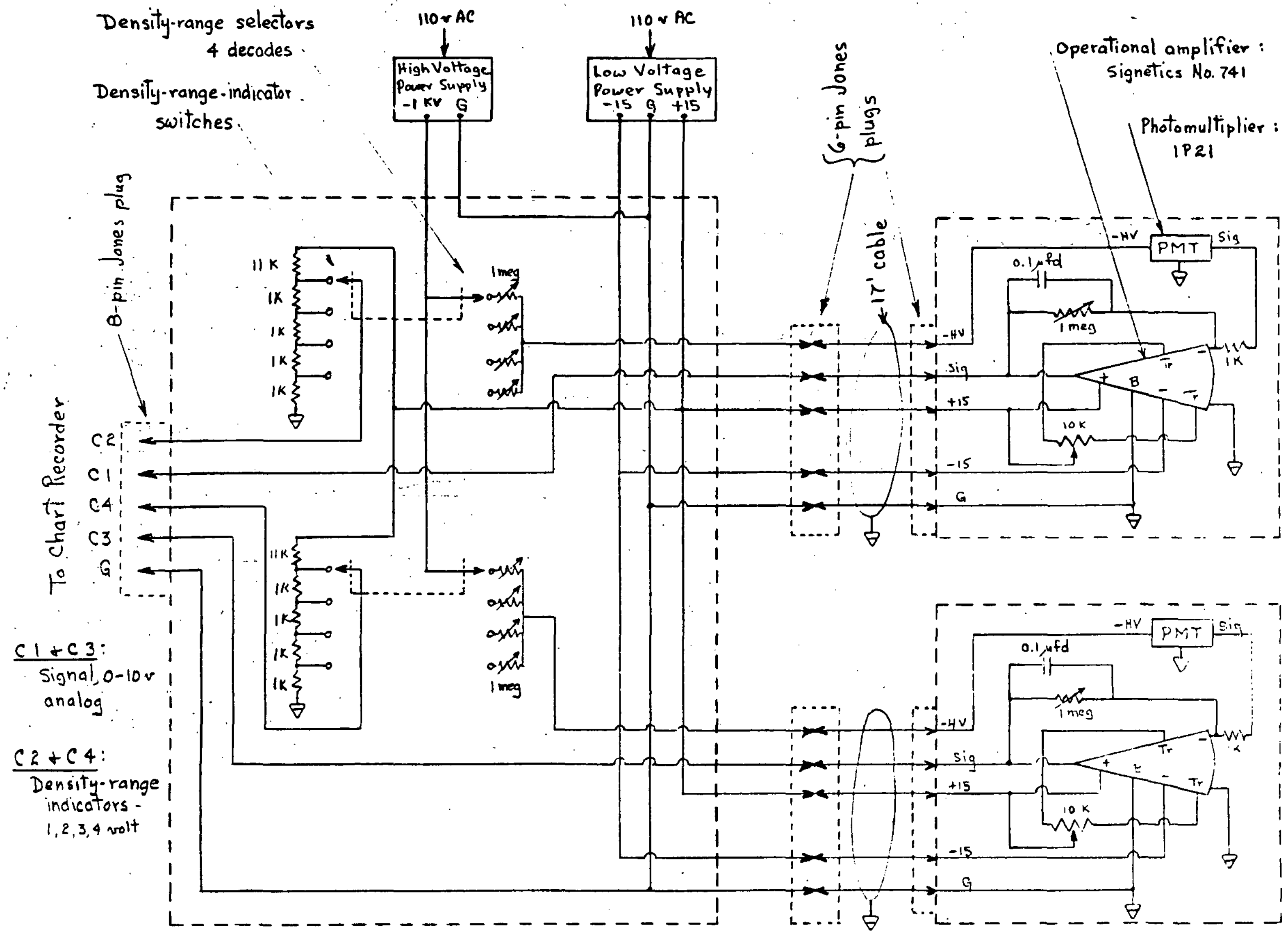

FIGURE 5. SCHEMATIC WIRING DIAGRAM FOR SMOKE DENSITY MEASUREMENT

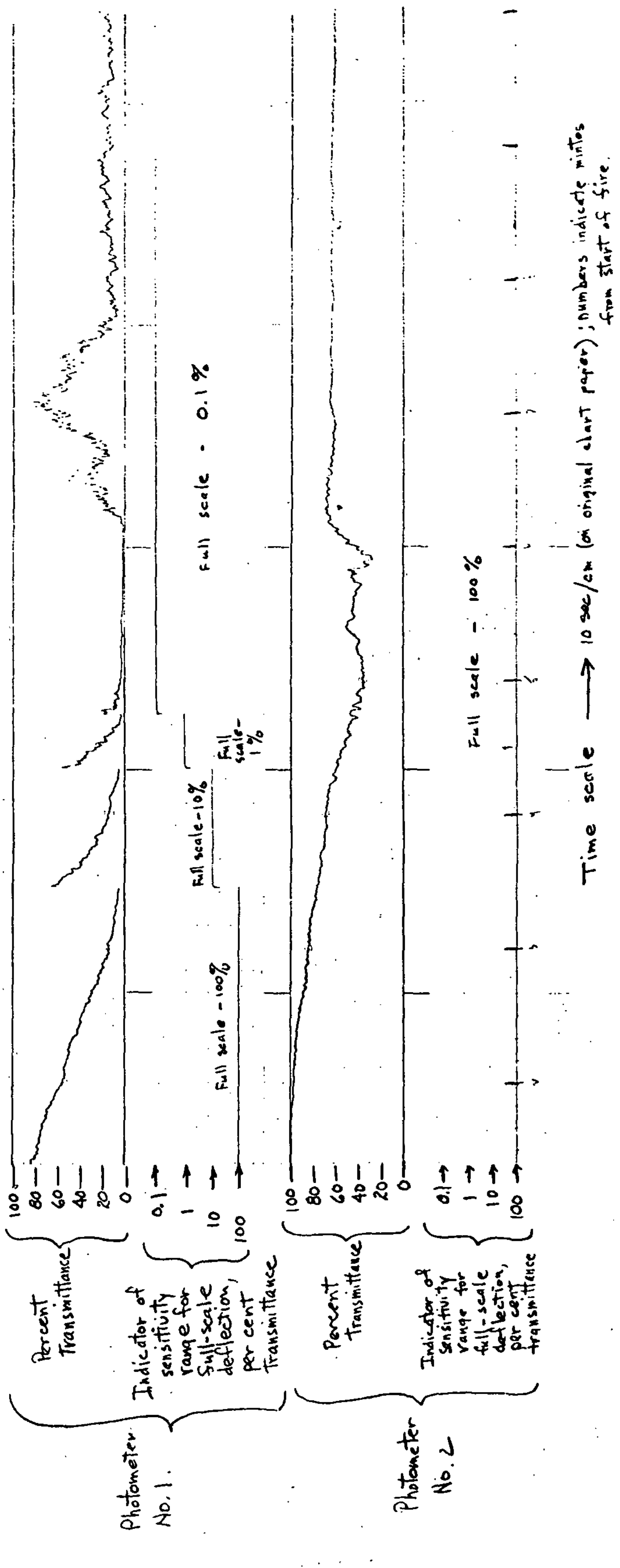

FIGURE 6. TYPICAL PHOTOMETER TRACES

TABLE 5. GASEOUS EMISSION INSTRUMENTATION USED IN FIRE STUDY

| Pollutant | Instrument | Range (a) | Principle of Operation | Comments |
|---|---|---|---|---|
| Total HC | Beckman Model 402 | 0-120,000 | Flame Ionization | Continuous, fast response, portable with selected elevated temperature sampling line and oven |
| $NO_x$ | Faristor | 0-5000 | Electrochemical (dry) | Continuous, fast response, portable; $SO_2$ interference can be accommodated |
| NO | Beckman Model 315 | 0-1000 | NDIR | Continuous, portable; water must be removed (dry ice trap) |
| $SO_2$ | Faristor | 0-5000 | Electrochemical (dry) | Continuous, fast response, portable; no $NO_2$ interference |
| CO | Beckman Model 215A<br>Olsen-Horabi | 0-1250<br>0-10% | NDIR<br>NDIR | Continuous, portable; water and $CO_2$ interference can be accommodated |
| $CO_2$ | Beckman Model 215A | 0-20% | NDIR | Continuous, portable; water interference can be accommodated |
| $O_2$ | Beckman Model 715 | 0-25% | Amperometric | Continuous, portable |

(a) ppm except as noted.

Sample line for total HC measurements connected directly to fire-room (No trapping) using Heated sample line ( ~ 300 F)

All other pollutants were analyzed via a common stainless steel manifold. Up stream from manifold, the sample gas passed through a large ice-water trap and particulate trap. An additional dry-ice trap was employed for NO analysis.

Chloride ion was determined by titration with $Hg(NO_3)_2$ as a measure of the HCl produced. For this purpose $CN^-$ was first destroyed by peroxide. Any bromide present would be determined along with chloride.

Aliphatic aldehydes are of considerable toxicological importance in combustion processes and have been determined by forming the bisulfite addition product. Ketones are also measured by this method. The methods used for this determination are given in the next section.

## Particulate and Condensible Materials

A major source of difficulty in sampling condensible vapors arises from the need to separate such portions from the significant quantities of soot, tars, water, and smoke particles that are usually present. For water soluble vapors such as HF, HCN, and HCl the hot gases were filtered and led directly into water-filled gas scrubbers for collection based on their solubility in that solvent. In the case of organic vapors the basis for separation is much less well-defined. For this program it was decided to try the particulate sampling train designed by the Environmental Protection Agency for collection of particulate and condensible vapors from flue gases of combustion systems. Thus, using this sampling train, a gas sample was drawn through tubes packed with glass wool and then through a glass fiber filter, all at 250 F, where solids and materials condensible at 250 F were removed. The gas stream then flowed through ice-cold sodium bisulfite solution contained in Greenfield-Smith impinger tubes where aliphatic aldehyde vapors and some ketones were retained as the bisulfite addition product. The method of Wilson(2) was used for this analyses and the results were expressed as formaldehyde equivalent to the addition product determined.

The components of the sampling train used for this purpose are shown schematically in Figure 7.

## Photographic and TV Monitoring

A photographic record was made of each experimental fire using 16 mm Ektachrome film. Since the burn times for the rooms could not be predicted, the camera was operated at about four frames per second so that fires of nearly 1 hour duration could be monitored with a 400 foot reel of film. The camera was placed in a box of 1/2 inch Transite having a Vycor window. The box was continuously swept with cylinder nitrogen which vented along the outer surface of the window thereby protecting the window against deposition of smoke during the fire. The location of the camera just outside the doorway of the fire room is shown in Figure 3.

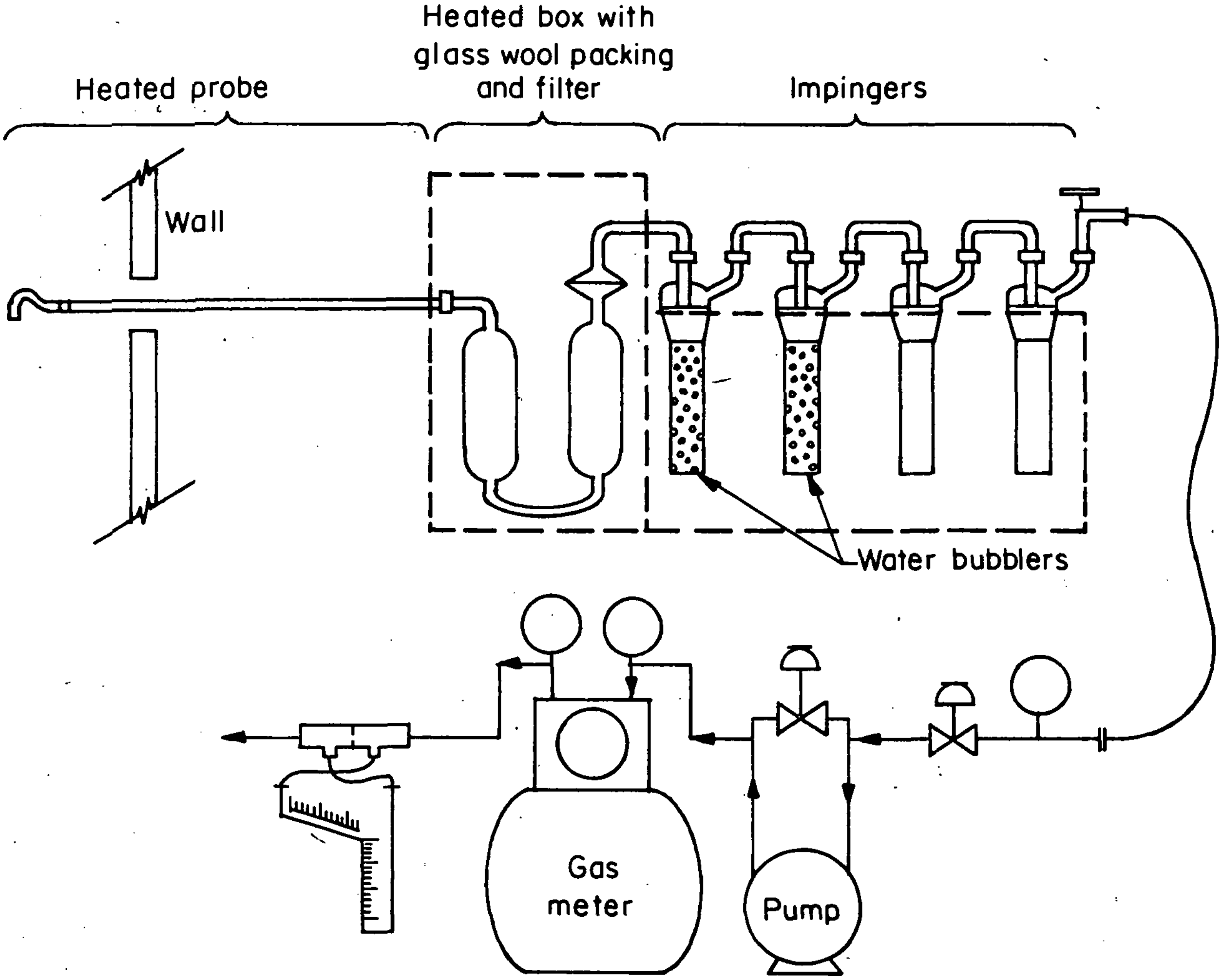

FIGURE 7. PARTICULATE AND ALDEHYDE SAMPLING TRAIN

These arrangements for photographic coverage were adequate for all except the Typical Room fire during which the film melted as it threaded through the camera and the photographic record for the final portion of that fire was lost. In subsequent use the box was further protected with a loose-fitting cover of asbestos cloth as an additional heat barrier.

Since the fires could not be observed directly, some additional means was needed to permit the observation needed to guide those recording data of the fire. For this reason a TV camera was also used with a monitor for viewing and with a TV tape unit to provide a record of the pictures obtained. This record, preserved in "real time" was used to provide a time scale for the photographic film record. The TV camera was placed alongside the photographic camera in a similar Transite box.

## The Experimental Procedure

Each room was built in sections and stored so that it and the appropriate furnishings formed a "kit" for the experimental fire arrangement. The walls were made in sections about 3 ft x 8 ft, the ceiling in three pieces about 3.5 to 4 ft wide and 11 ft long, and the floor in two pieces about 5.5 ft x 11 ft arranged for bolting together to form the room. Floor coverage and wall and ceiling surface treatments were generally applied after room assembly was completed, and then the furnishings were put into the room and thermocouples placed and tested. Heaters were placed in the room during construction and heating was continued for at least 24 hours after furnishing was completed so as to adjust the temperature and humidity of the room for the fire trial.

Each instrumental analysis or sampling procedure was calibrated or adjusted on the morning of the fire trial and the record of each measurement was started simultaneously with the signal to ignite the newspaper in the wastebasket. All records except those of temperature were discontinued when sufficient room involvement had occurred to demonstrate the fire response of the ensemble under trial.

At the signal to discontinue, a window of the training tower was opened from the outside and firemen of the Columbus Fire Department entered the corridor area for approach to the fire room. As soon as preliminary fire control activities were completed, they removed the pitot tubes and camera equipment from the doorway and proceeded to put out the fire. As soon as practical after this was completed, the door to the personnel area was opened and photographic records of the remains of the contents of the fire rooms were obtained.

A schedule of one fire per week proved practical and was maintained for the four trials that were made.

## RESULTS AND DISCUSSION

The visual evidence provided by TV and photographic coverage of the four room fires shows clearly that these rooms responded very differently to a common ignition condition. In particular

(1) The Typical Room ignited easily and burned rapidly in just the same manner observed for the preliminary room fire used to establish the ignition conditions. See Figures 8 and 9. The fire was stopped after 8.5 minutes because of the excessively large degree of fire development.

(2) The Improved Room showed substantial improvement over the Typical Room in that there was slower fire spread, but the relatively complete consumption of the room that resulted, and the large amounts of smoke that was generated, made it clear that substantial further improvement in performance was needed. See Figures 10 and 11. The fire was stopped after 29 minutes when complete room involvement had produced the high degree of damage shown.

(3) The Space-age Room did not ignite under the common ignition condition and so demonstrated a substantial improvement in fire resistance for those room components closest to the ignition fire, e.g., rug, chair, drapes, and bed. This fire essentially burned out in 12 minutes. The second and larger ignition arrangement used for this room ensemble demonstrated that this room can burn, but the time required for the ignition to take place confirmed the substantial improvement in fire resistance available with this room ensemble. See Figures 12, 13, 14, and 15. Thus, the second fire burned for 27 minutes before room involvement began, apparently because of a hole burned in the floor in the northwest corner of the room. In 6 minutes more the high degree of damage shown in Figure 15 was produced.

(4) The Mixed Room ensemble demonstrated a much moderated fire development obtained by placing the fire-retardant bed from the Space-age Room in a room ensemble otherwise identical with that of the Typical Room. This ensemble illustrated the improvement in fire spread

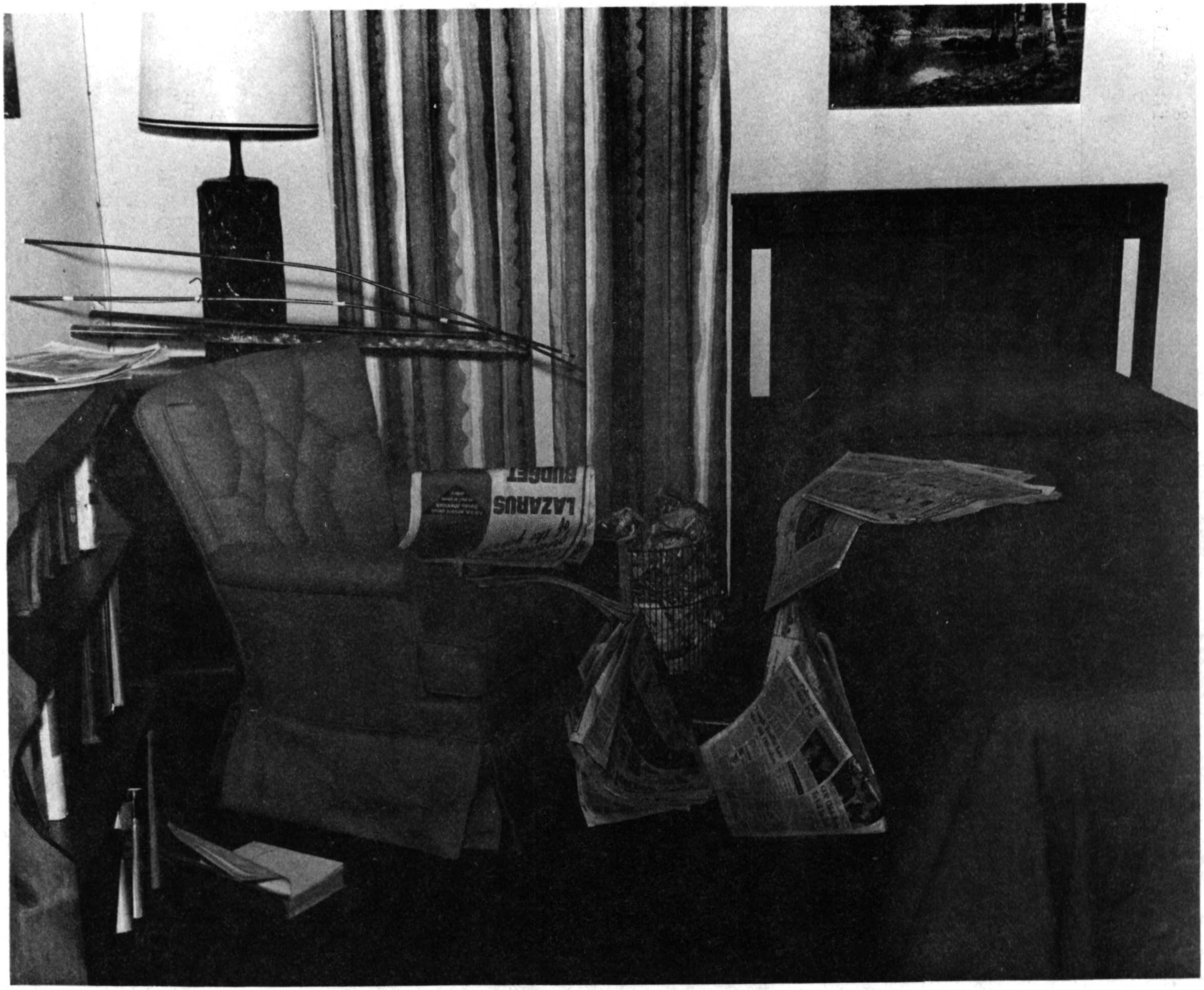

FIGURE 8. "TYPICAL" ROOM BEFORE IGNITION

FIGURE 9. "TYPICAL" ROOM AFTER FIRE

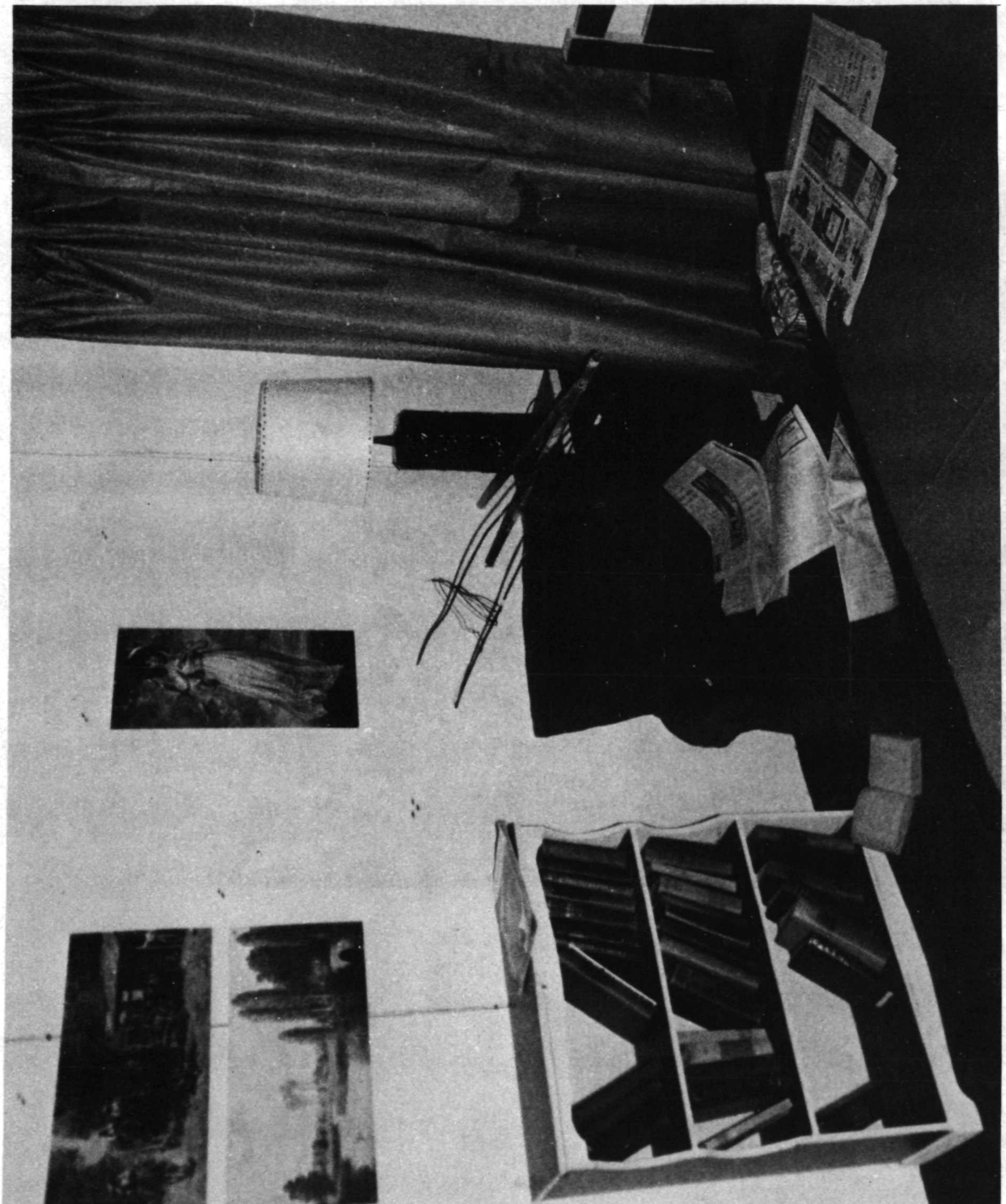

FIGURE 10. "IMPROVED" ROOM BEFORE IGNITION

FIGURE 11. "IMPROVED" ROOM AFTER FIRE

FIGURE 12. "SPACE-AGE" ROOM BEFORE 1st IGNITION

FIGURE 13. "SPACE-AGE" ROOM AFTER 1st FIRE

FIGURE 14. "SPACE-AGE" ROOM BEFORE 2nd IGNITION

FIGURE 15. "SPACE-AGE" ROOM AFTER 2nd FIRE

> available by careful placement of fire retardant materials in the important paths for fire spread of an otherwise ordinary room ensemble. See Figures 16 and 17. This room was allowed to burn for 1 hour before the fire was extinguished.

These observations reveal that the ignition conditions chosen have been suitable for demonstration of the differences in fire performance for the four room ensembles. This demonstration was the primary goal of the program.

However, the measurements made during the burning of each room ensemble provide the basis for a much more detailed analysis of performance than the above observations. In order to do this, some basis must be chosen for establishing levels of importance for the numerical information that has been generated. In the following pages a few selected criteria are discussed and used for assessment of room performance and life hazard.

## Temperature Profiles and Fire Spread

In all, 126 time-temperature plots were obtained from thermocouples placed in various locations in the four fire rooms. The locations of the thermocouples are listed in Table 4 and repeated for convenience in Appendix A along with the 126 time-temperature curves.

An approximate description of the time-temperature plots obtained from this research program might be made by noting that active fire periods usually showed bulk temperatures above about 1000 F whereas in-between these fire periods the smoldering conditions usually appeared in the 200 to 500 F range. Intermediate temperatures in the range of 700 F usually were observed in times of rapid transition between active fire and smoldering conditions.

Temperatures of about 700 F also appear to lie in the middle of the range where cellulosic and organic polymers are pyrolyzed to yield combustible gases and vapors. Thus in a review of some earlier publications, Wagner(13) noted that four distinct temperature zones have been given for the thermal decomposition of wood. Two of these zones, covering the range up to 536 F were characterized by the appearance of noncombustible gases, primarily $H_2O$, arising by endothermic processes. The third zone, 536 F to 932 F was described as that of active pyrolysis under exothermic conditions that led to formation of combustible products such as CO, $CH_4$, tars, and smoke. These gases and vapors were ignitable under piloted conditions. Above 932 F the charcoal residue glowed and was consumed.

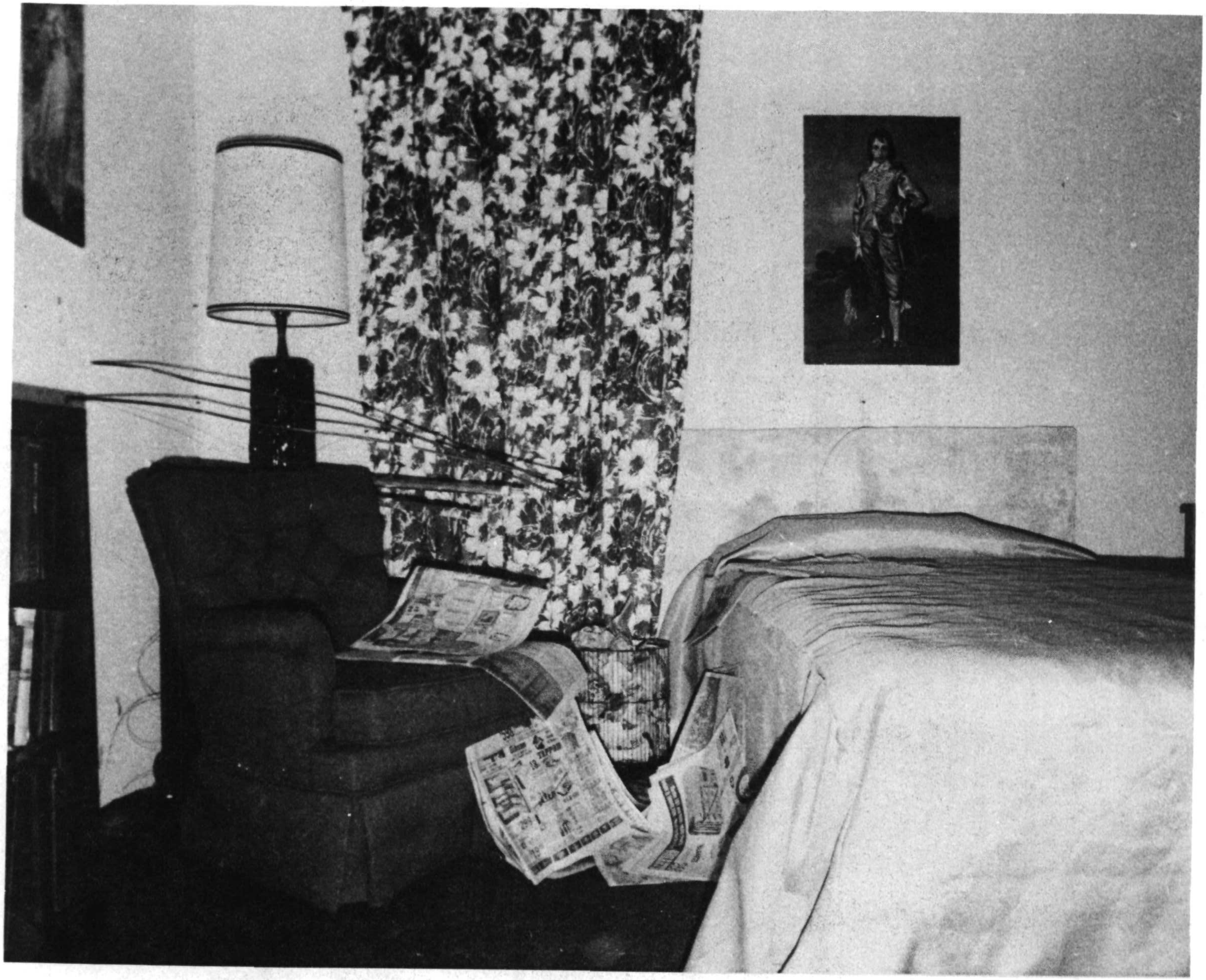

FIGURE 16. "MIXED-LOAD" ROOM BEFORE IGNITION

FIGURE 17. "MIXED-LOAD" ROOM AFTER FIRE

Similarly, for organic polymers, Wall(3) lists kinetic data from laboratory studies describing the thermal decomposition of a variety of polymers in the temperature range of about 425 F to 1022 F, in which the organic monomer is one of the decomposition products. This range of pyrolytic conditions can be assumed to include the solution of combustible decomposition products. Thus, it may safely be concluded that pyrolysis of these materials occurs generally in the same temperature range as the active pyrolysis range given previously for wood. These considerations have led in this work to the choice of 700 F as an approximate representation of the boundary between active fire zones and smoldering. In Figures 18, 19, 20, and 21, the apparent boundary between fire and smoldering is shown for selected times during each fire experiment.

In those Figures, the square of each diagram represents a plan view of the room at the specified elevations above the floor, that is, at 3 to 4 feet and 7 to 8 feet above the floor (at ceiling). These elevations represent zones where sufficient thermocouples were located to give some approximate idea of the isotherms that existed. The temperature conditions are shown at times selected from the plots of gas temperatures at the sampling probe (No. 21), at the middle of the ceiling (No. 14), and above the open doorway, inside the room (No. 16). The times chosen represent times during which gas temperatures at these locations were passing through maximum values and are taken to represent times of peak fire activity. In each diagram, the shaded areas represent those in which temperatures are everywhere above 700 F and which are interpreted to represent the active flame area. Although the boundary curves cannot be drawn with any great precision, and then only in the 3 to 4 foot elevation data, comparison of the four rooms reveals the differences in fire spread noted from visual evidence.

It is of interest to compare these times of peak fire activity with another estimate of fire activity based on the variations in oxygen concentration in the fire rooms. Thus Huggett(4) has presented an approximate correlation of flame spread rates over solid fuels with the heat capacity of the gas environment per mole of $O_2$. This correlation, shown in Figure 22 for paper, has been examined for other fuels and Huggett concludes(5) that organic fuels cease to burn when the heat capacity of the atmosphere reaches the range of 40 to 50 cal/°C per mole $O_2$ at atmospheric pressure. Indeed, the correlations for other fuels(*) frequently show zero fire spread at even lower heat capacities per mole $O_2$ than the correlation shown for paper. Thus this correlation for paper may be assumed to represent the greatest tolerance that will be met for continued fire spread with oxygen depletion.

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(*) Data presented at NFPA meeting in St. Louis, Missouri (1973).

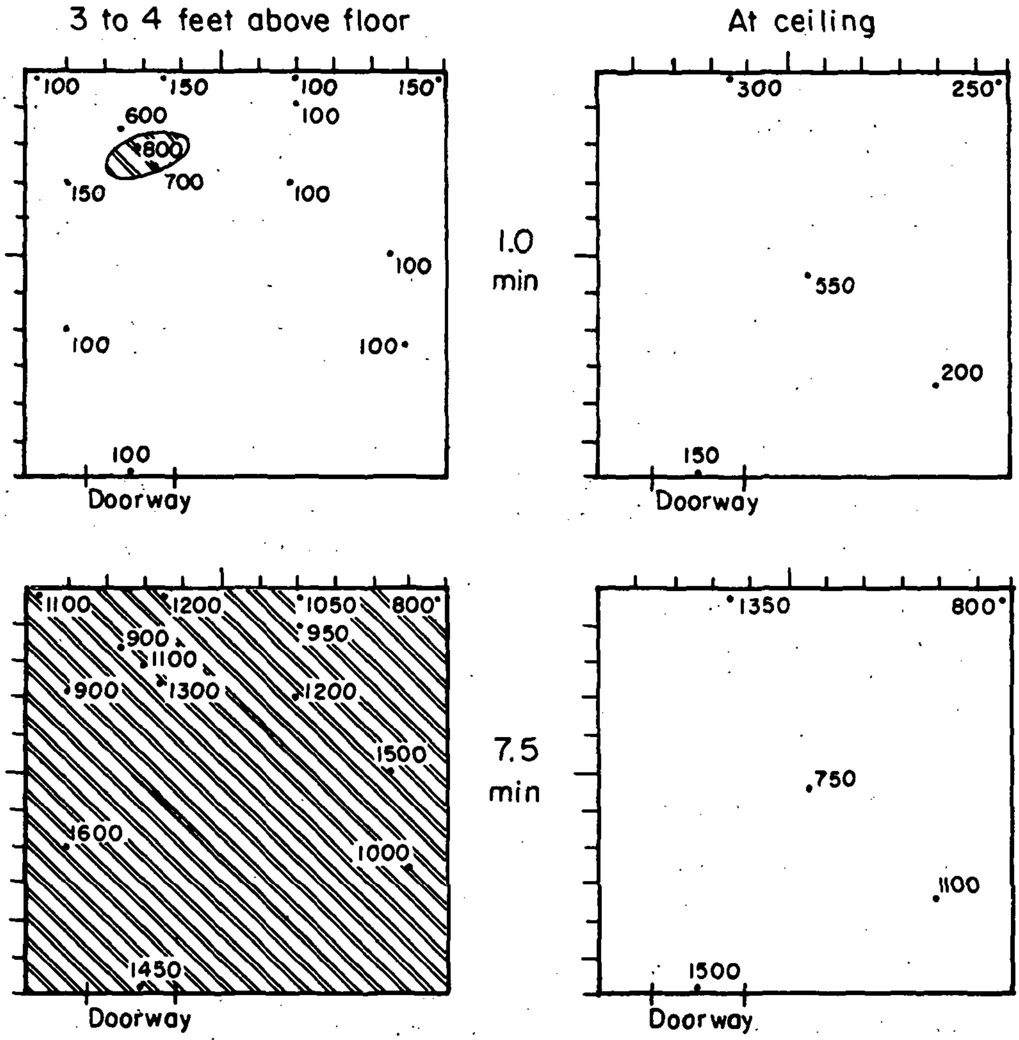
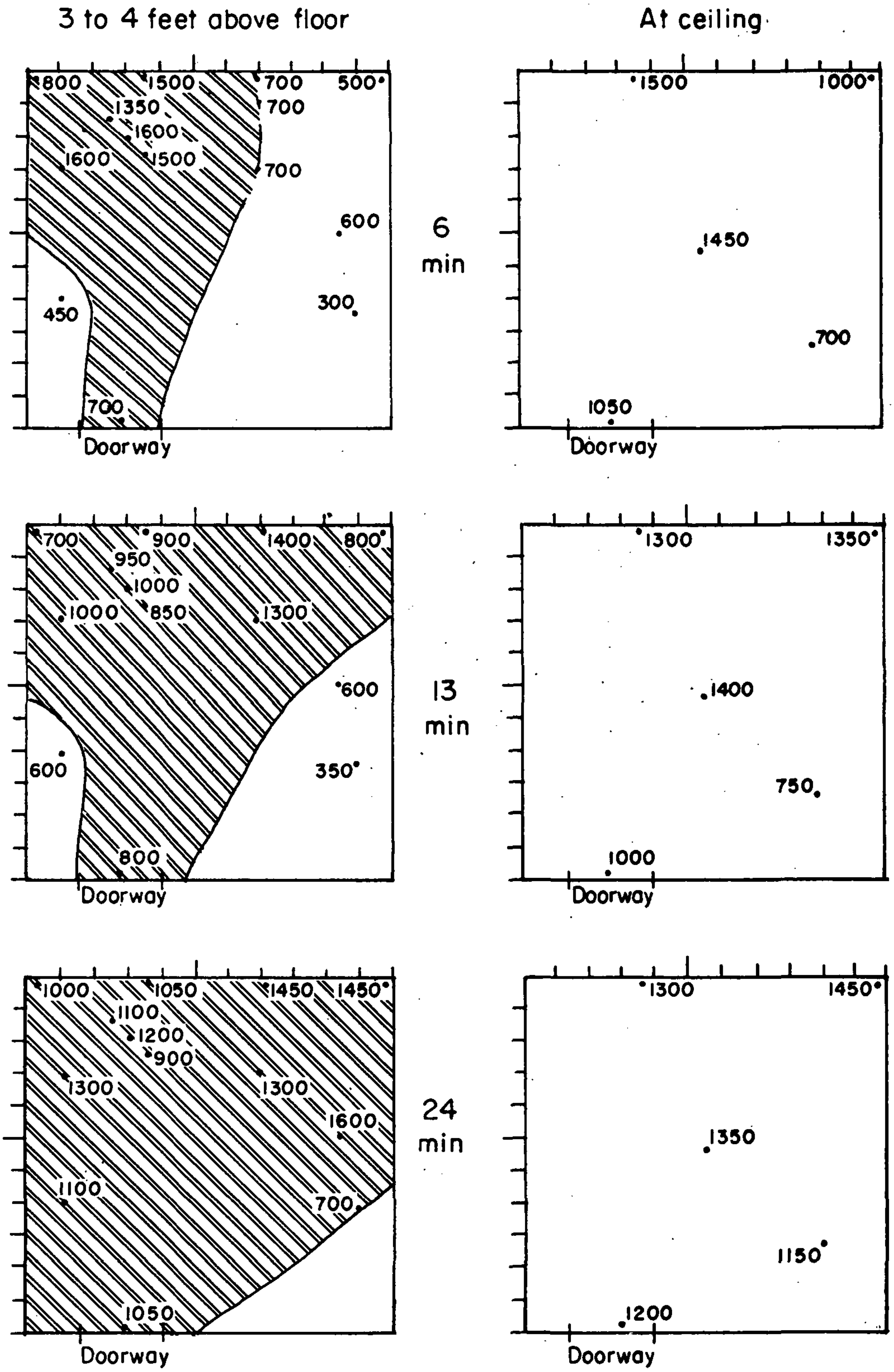


FIGURE 18. FIRE SPREAD DIAGRAMS FOR TYPICAL ROOM
(700°F contour shown only at 3 to 4 foot level)



3 to 4 feet above floor

At ceiling

FIGURE 19. FIRE SPREAD DIAGRAM FOR IMPROVED ROOM
(700° F contour shown only at 3 to 4 foot level)

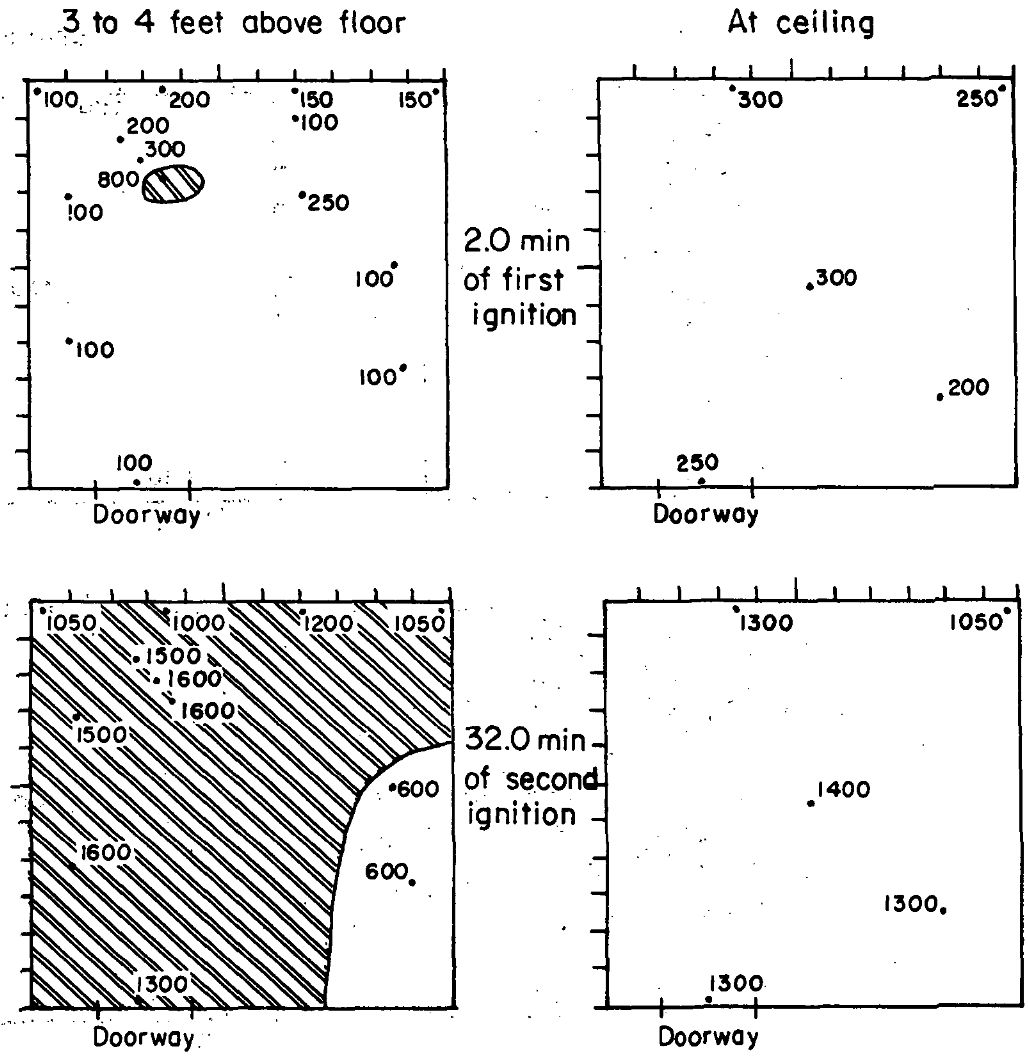


FIGURE 20. FIRE SPREAD DIAGRAM FOR SPACE-AGE ROOM
(700°F contour shown only at 3 to 4 foot level)

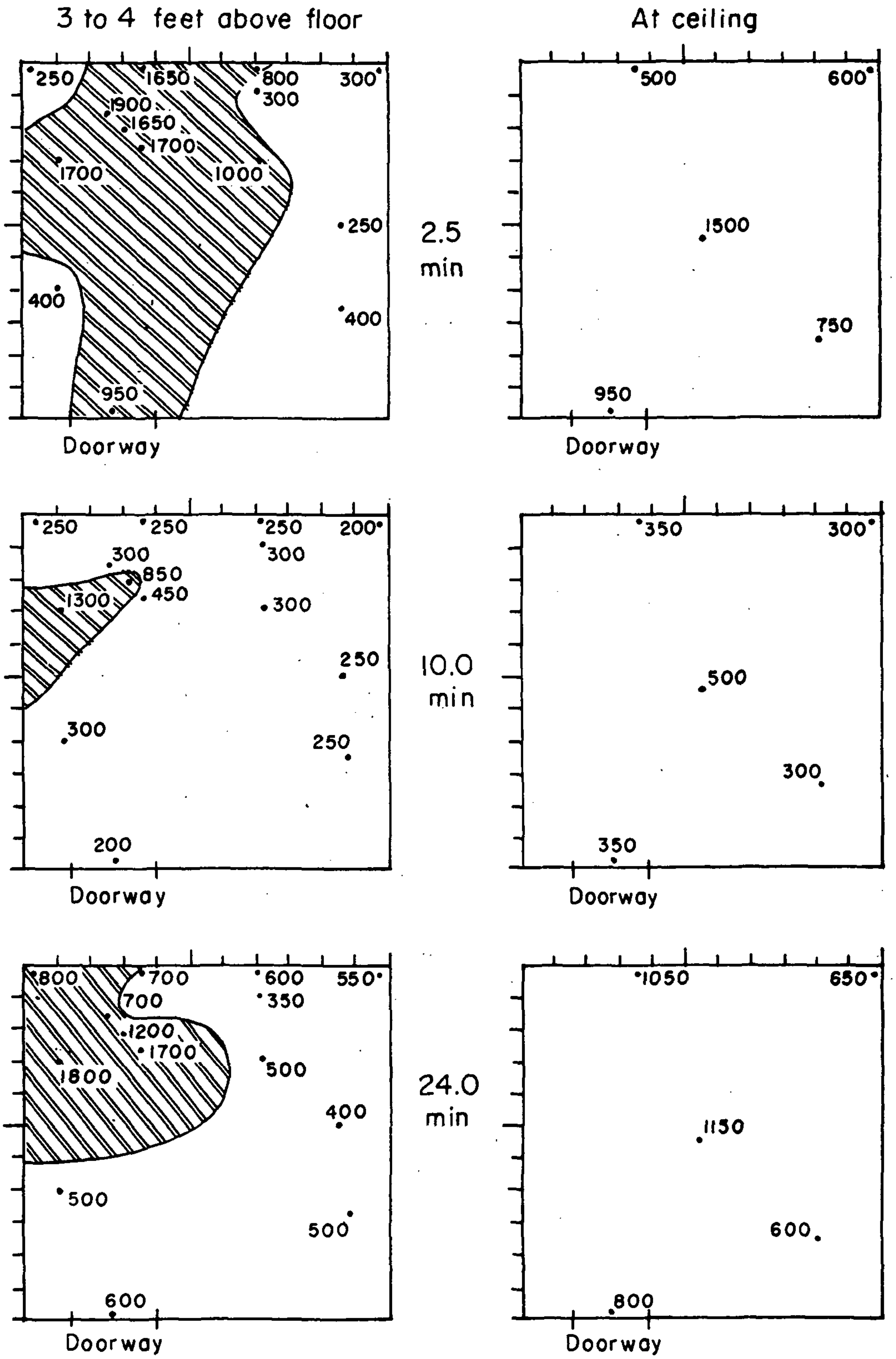


FIGURE 21. FIRE SPREAD DIAGRAM FOR MIXED-LOAD ROOM
(700°F contour shown only at 3 to 4 foot level)

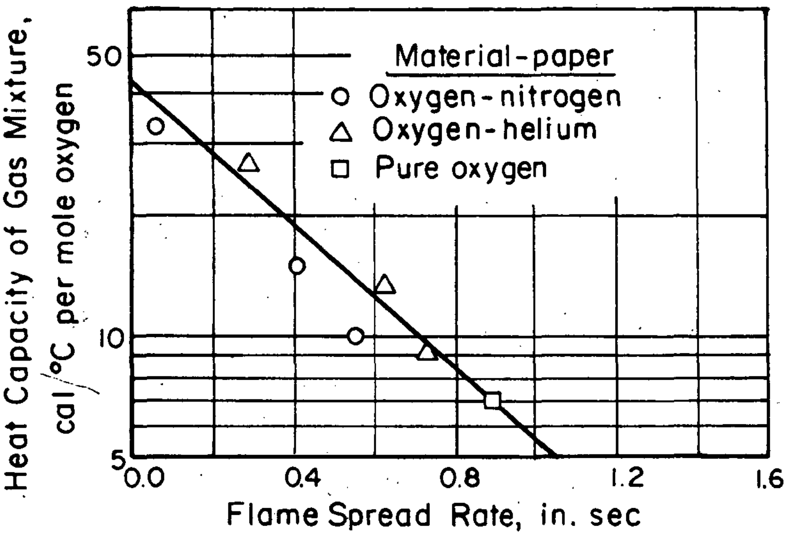


FIGURE 22. RATE OF FLAME SPREAD FOR PAPER AS A FUNCTION OF HEAT CAPACITY (4)

For the present purpose, the implications of the above correlation can be visualized if we note that the gas mixtures of interest are largely $N_2$, $CO_2$, and $O_2$ and that the molar heat capacities of such mixtures are relatively insensitive to variations in composition in the range of interest experimentally. Thus estimated values of $C'p$, the heat capacity in calories per degree C per mole $O_2$, appear as follows

20.9 percent $O_2$ + 79.1 percent $N_2$ = 33 cal/°C mole $O_2$

16 percent $O_2$ + 84 percent $N_2$ = 43

16 percent $O_2$ + 4.9 percent $CO_2$ + 79.1 percent $N_2$=44

Based on the correlation for paper shown in Figure 22, $C'p$ values of about 44 represent almost a zero fire spread rate. Compared to the fire spread rate at $C'p = 33$ for normal air this represents perhaps a ten-fold decrease. On this basis, the active fire periods in our fire experiments might be expected to occ only when ambient oxygen concentrations are above about 16 percent. All other time periods may be anticipated to represent weak flame and smoldering conditic when smoke and toxic organic vapors are expected to evolve. The estimate of periods for active fire spread based on the experimental oxygen concentration curves are compared in Table 6 with the times selected to represent peak fire activity based on heat accumulations in the room. These estimates for fire spread and peak fire activity will be compared with the time variations in heat irradiation and smoke accumulation in later sections.

In summary, temperature distributions in the fire rooms can be used t describe areas of active burning at selected times, and it has been concluded that 700 F can be used as a reasonable estimate of the boundary between active fire and smoldering zones. In this way the distributions of fire in each room have been plotted for selected times corresponding to maximum accumulations of heat in the room. These times for maximum heat accumulation are taken to represent times of maximum fire activity. Published data, showing the dependence o fire spread rates on ambient $O_2$ concentrations, lead to the conclusion that su active fire periods probably would be confined to those times when ambient $O_2$ > about 16, so that the experimental $O_2$ concentration curves represent an estimate of fire and smoldering periods in each fire.

## Irradiation Effects

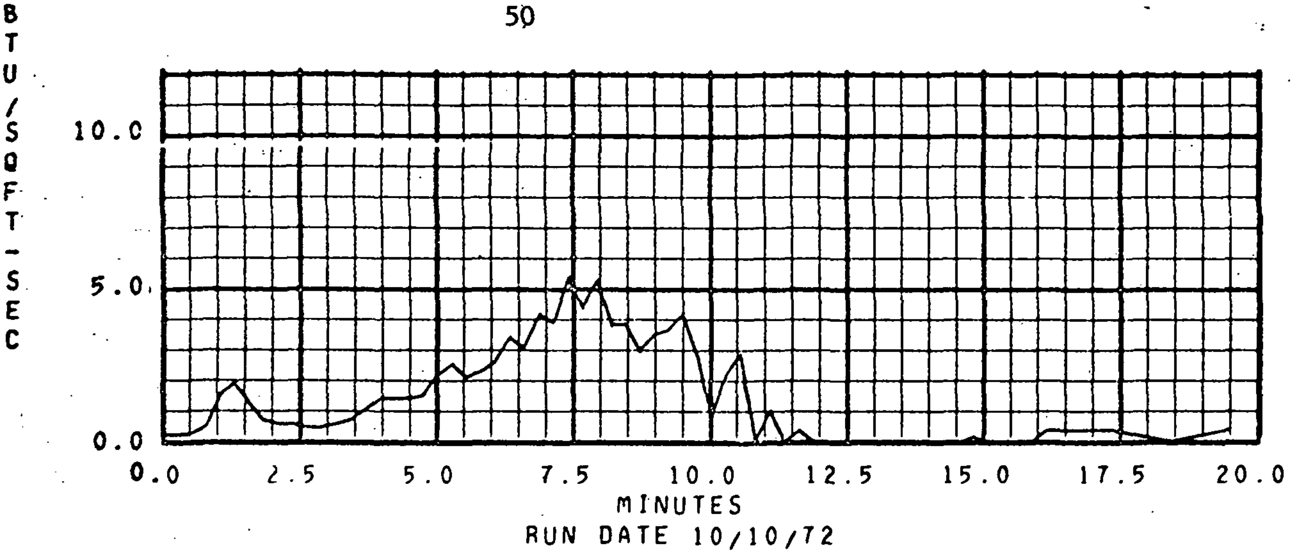
The heat irradiation curves shown in Figures 23 and 24 graphically illustrate the differences in fire intensity obtained for the four Fire rooms. The low-range heat irradiation curves shown in Figure 25 were obtained using the expanded calibration curve discussed on page 22, and have superimposed on them two irradiation levels, marked A and B, that serve to help in interpretation of these irradiation curves.

TABLE 6. COMPARISON OF ESTIMATES OF FIRE ACTIVITY FROM FIRE ROOM PERFORMANCE DATA

| | Time from Ignition, Minutes | |
|---|---|---|
| | showing > 16% Oxygen Concentration[a] | for gas temperatures in rooms[b] |
| Typical Room | 0 to 1.7 | 1.0<br>7.5 |
| Improved Room | 0 to 6.5<br>8 to 12.8 | 6<br>13<br>24 |
| Space-Age Room | all | 2.0 after first ignition |
| | all | 32.0 after second ignition |
| Mixed-Load Room | 0 to 1.2 | -- |
| | 2.2 to 3.0 | 2.5 |
| | 8 to 25 | 10 and 24 |

[a] Assumed necessary for active burning and fire spread. Data show time span in which $O_2$ exceeded 16 volume percent at sampling probe.

[b] Peak gas temperature times assumed to represent maximum burning conditions.



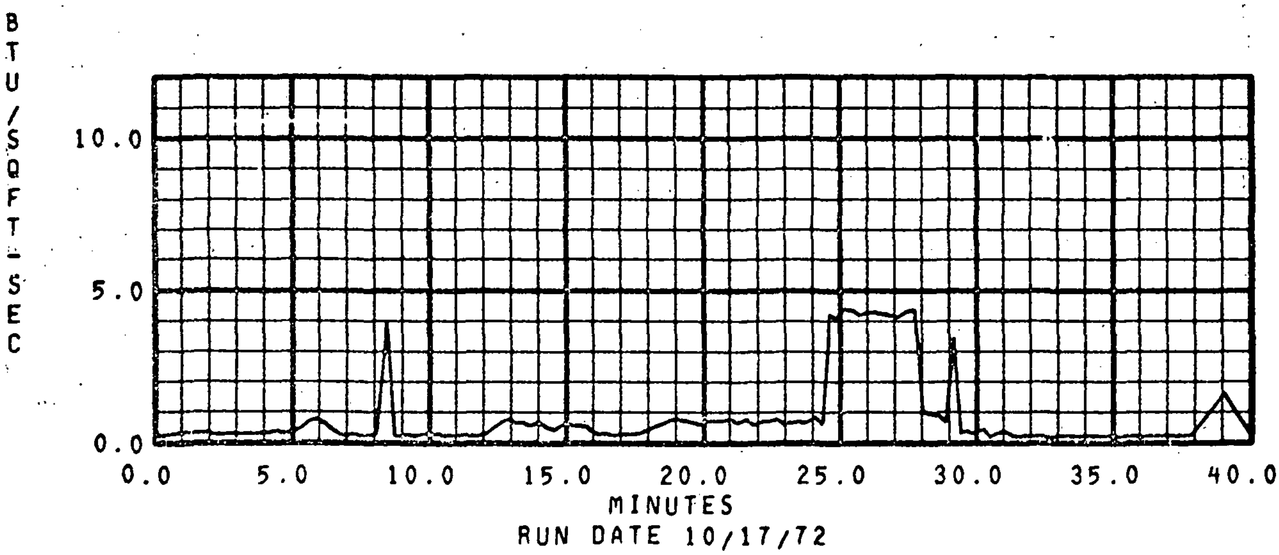
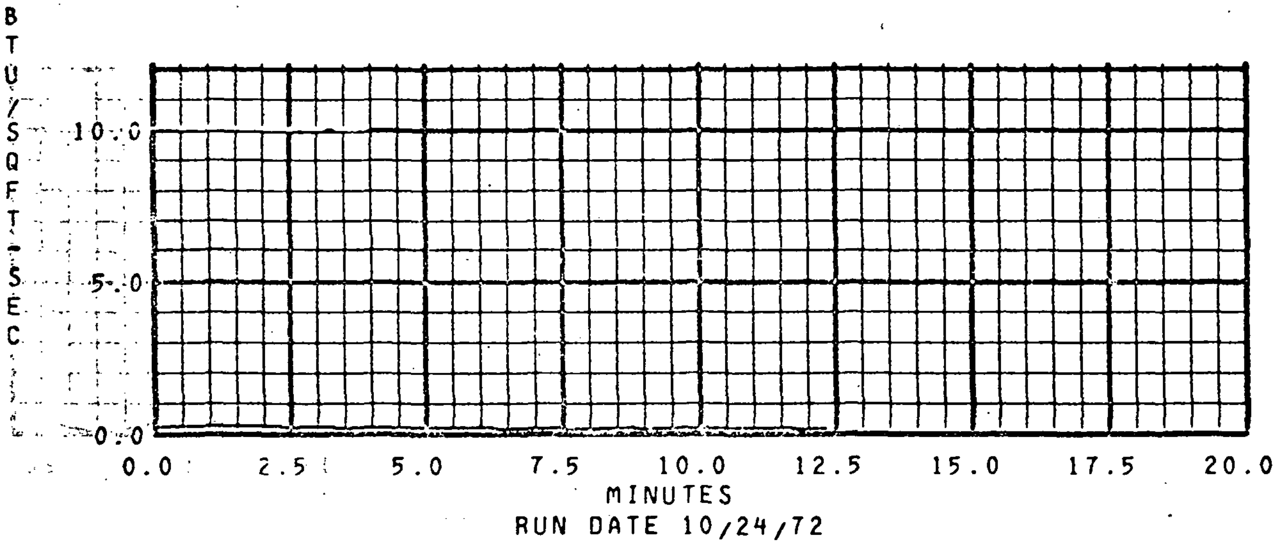
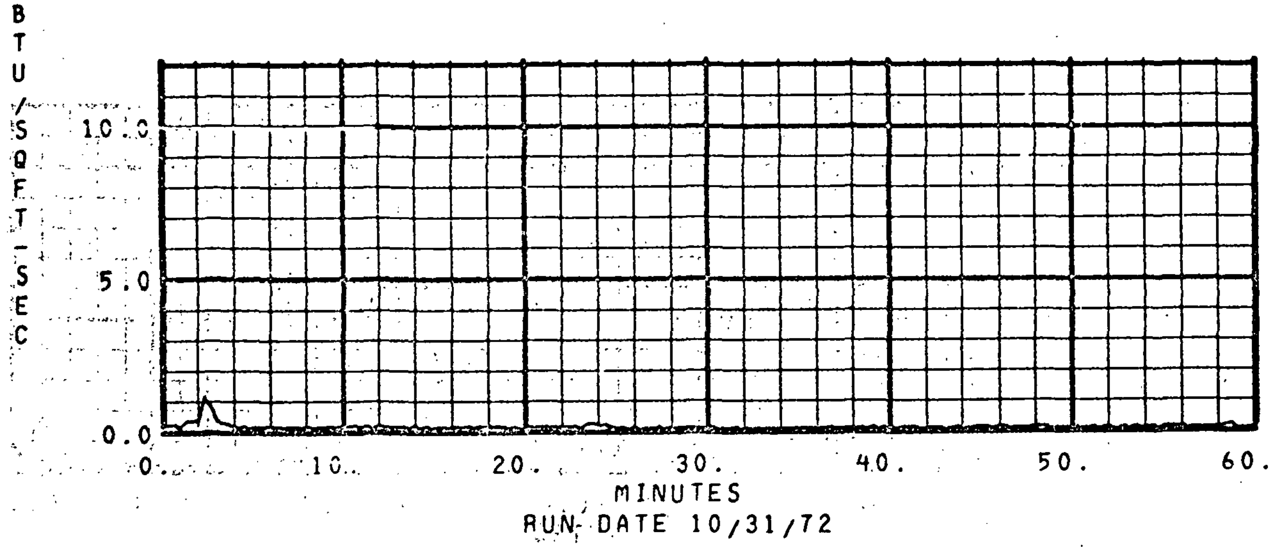


FIGURE 23. HEAT IRRADIATION CURVES FOR THE "TYPICAL" AND "IMPROVED" ROOM FIRES





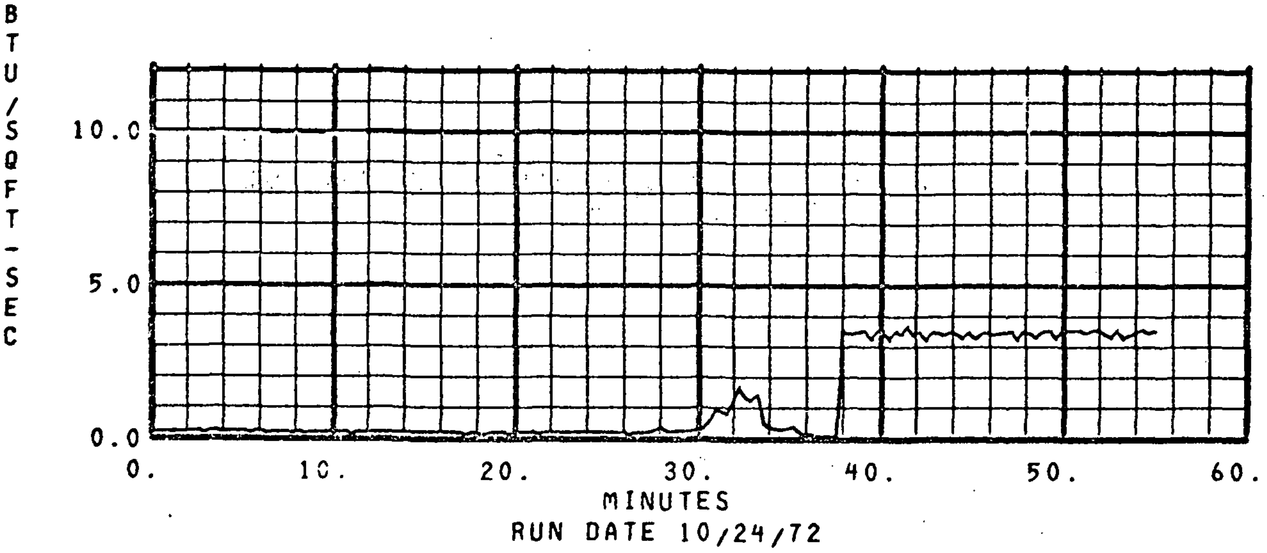


FIGURE 24. HEAT IRRADIATION CURVES FOR THE "SPACE-AGE" AND "MIXED-LOAD" ROOM FIRES

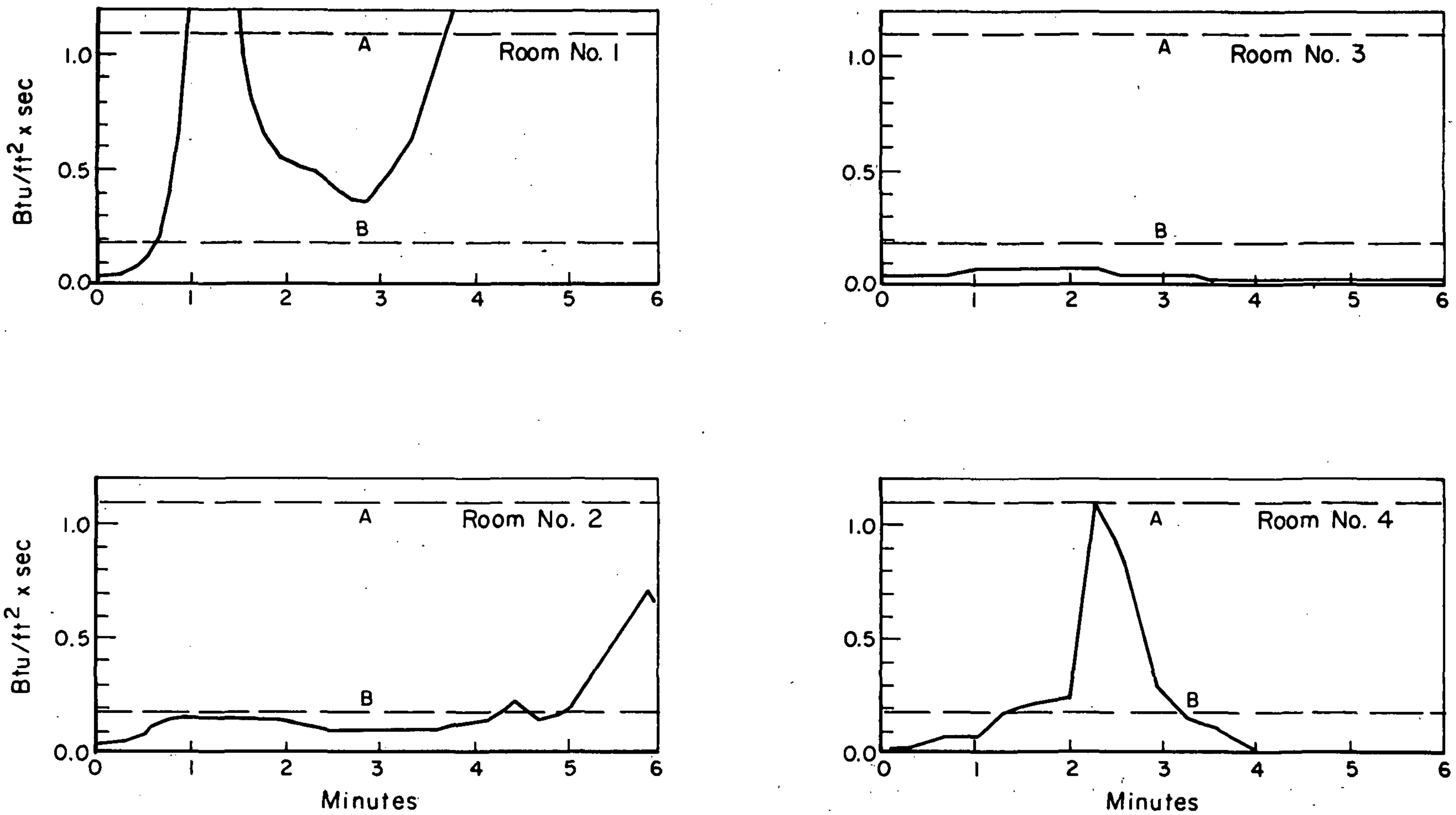


FIGURE 25. COMPARISON OF HEAT IRRADIATION LEVELS IN THE INITIAL PERIOD OF EACH ROOM FIRE

The level B, represents 0.18 Btu/ft$^2$ sec and is said(6,7) to be the irradiation level for exposed skin that will produce pain after 1 minute exposure. The other level, A, represents 1.1 Btu/ft$^2$ sec and is the minimum level found(8,9) to produce piloted ignition of wood. Level B can be taken to represent a threshold condition of discomfort, or a stimulus to awaken an occupant of the fire room in question.

With this basis for specification of critical environmental conditions for an occupant, the four room fires can be compared on the basis of irradiation hazard. Thus in Figure 25, the irradiation level in the Typical Room rises so rapidly to the piloted ignition level that severe burning of skin might be anticipated almost as soon as the pain is sensed. If we imagine an occupant of the room about as far from the ignition site as is the radiometer, about 9 feet, the hazard due to irradiation becomes appreciable in the Typical Room after about 50 seconds and remains so for the duration of the fire. Comparison of this irradiation curve with the curves for the other experimental room fires indicates a substantial decrease in irradiation due to the slower burning of the Improved Room, and an appreciable delay in the pulse of heat irradiation for the Mixed-load Room which is similar to the Typical Room except for the insertion of a much improved bed from the Space-age Room. The Space-age Room curve represents essentially the heat from the igniter load and shows no appreciable hazard to the occupant at the assumed distance.

It is of interest to note that the times of peak fire activity selected in Table 6 for the Typical Room compare well with the peaks in the heat irradiation curve for this room in Figure 23 and 25.

## Smoke Accumulation

The optical densities of the smoke measured in the doorway and in the ventilation duct of each fire room are shown in Figure 26 and 27. In each case where substantial fire spread occurred, the initial flareup of the fire is followed by oxygen depletion and consequent evolution of large amounts of smoke which temporarily reach light transmission levels of 0.01 percent or less (optical densities $> 4$). If we are to assess the hazard due to smoke by estimation of the changes in visibility that occur, it is necessary to specify the distance above the floor at which viewing is to be done.

Because of the circulation pattern for air into the fire room and the convection of hot gasses out, the smoke accumulation is layered horizontally, usually with maximum density near the ceiling and minimum near

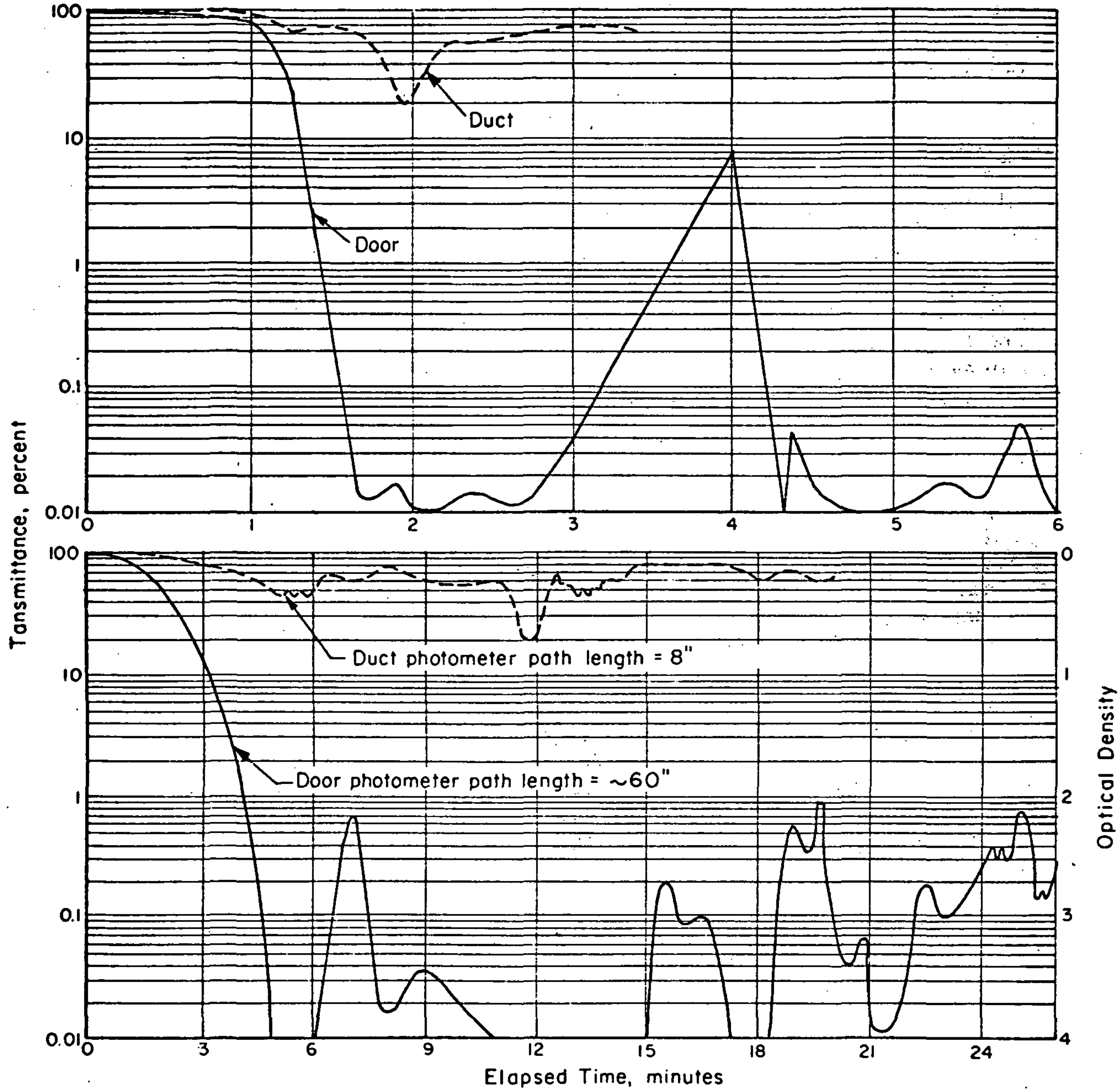


FIGURE 26. SMOKE DENSITY CURVES FOR TYPICAL AND IMPROVED ROOMS

Upper Figure - Typical Room
Lower Figure - Improved Room

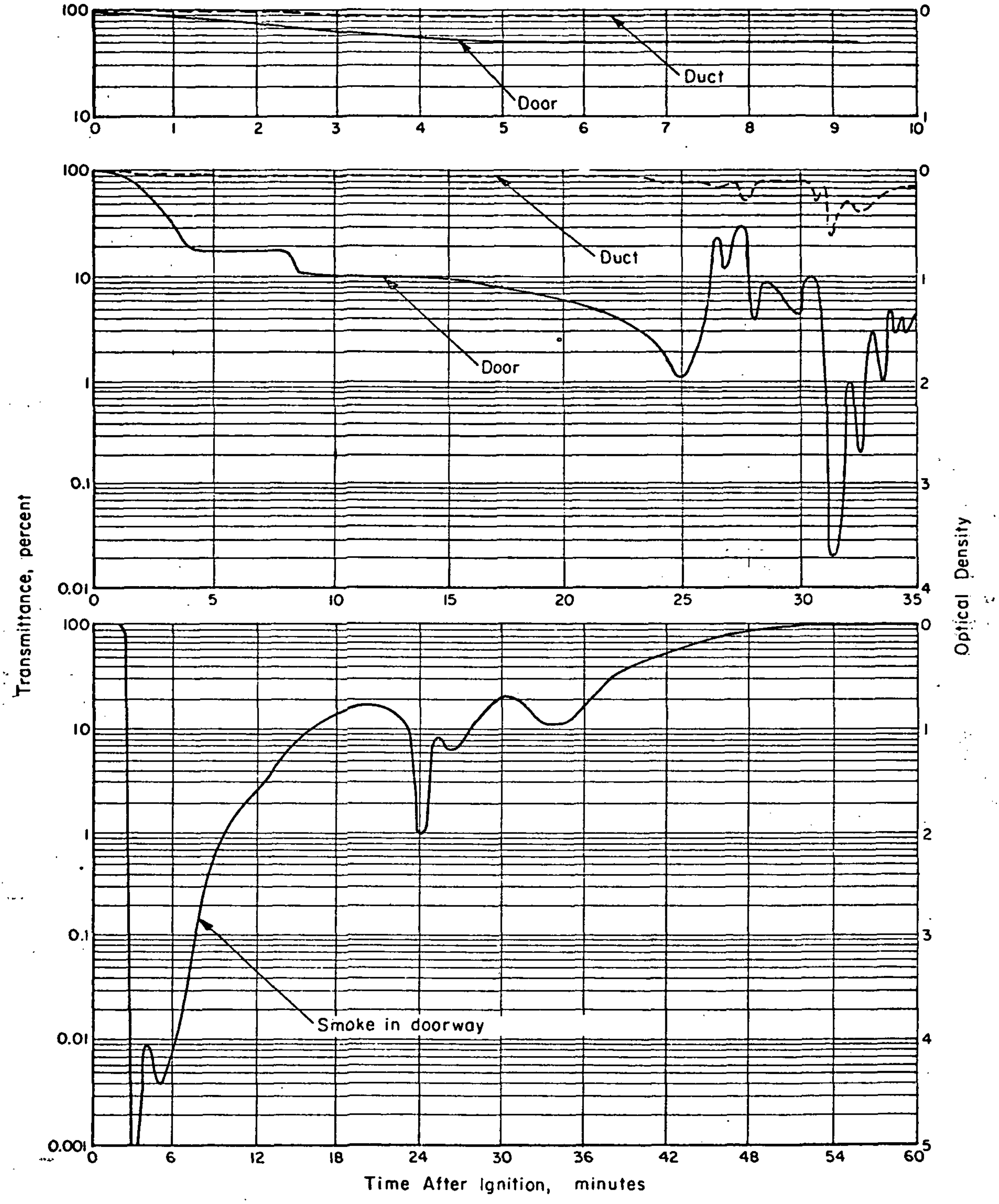


FIGURE 27. SMOKE DENSITY CURVES FOR SPACE-AGE AND MIXED-LOAD ROOMS

Top Figure - Space Age Room, First Fire
Middle Figure - Space Age Room, Second Fire
Bottom Figure - Mixed-Load Room

the floor. In the present research the smoke density was measured vertically so that the results represent an averaged value. Assuming that this averaged value can be taken as typical of normal viewing elevations, somewhere between 3 and 6 feet above the floor, the experimental curves can be used in assessment of hazard along with the heat and toxic gas data. The curves of Figures 26 and 27 show that in each fire the smoke density increases very rapidly soon after the first large flare-up of fire and then oscillates considerably with fire activity and convection.

In an assessment of the relationship between visibility and smoke density, Silversides(10) showed that at an optical density of 0.4/meter a st standard light source is just visible at a distance of about 4 feet. With this relationship, the time at which light transmission falls below 10 percent in the present study corresponds to the time when an assumed occupant of each fire room would be unable to see the doorway of the room (through which he might escape) if it is about 4 to 5 feet distant from him. The times estimated in this way are of the same order as the heat irradiation hazard times and these two quantities along with toxic gas accumulation represent an approximate assessment of the initial hazard. Since there are no available data on the reaction of an occupant to the combined effect of heat, smoke, and toxic gases at the hazard-threshold level, these assessments of hazard are of more value as a means to compare the individual rooms than as a realistic expression of human survivability. A summary comparison of these estimates of hazards for each room is undertaken in the discussion of toxic gas accumulations during the same periods.

A comparison of these smoke accumulation curves with the time estimates of active and peak fire activity in Table 6 indicates a complex relationship probably because in some cases the fire activity results mainly in consumption of previous smoke accumulations and in others the generation of smoke by the fire activity predominates.

## Toxic Gas Accumulation

The results of the continuous gas analyses carried out during each fire are summarized in Figures 28,29,30,31 and 32; the data for the other components collected during the fires and analyzed as single integrated samples are presented in Table 7, and summarized in Table 8. Finally, an attempt has been made to express the relative hazard represented by these gas concentrations.

Some systematic interrelationships are noticeable, but in general the concentration changes with time show rather complex interdependences that require further experimental investigation. It can be seen that the analytical results for $O_2$, $CO_2$, and CO vary in consistent manner such that

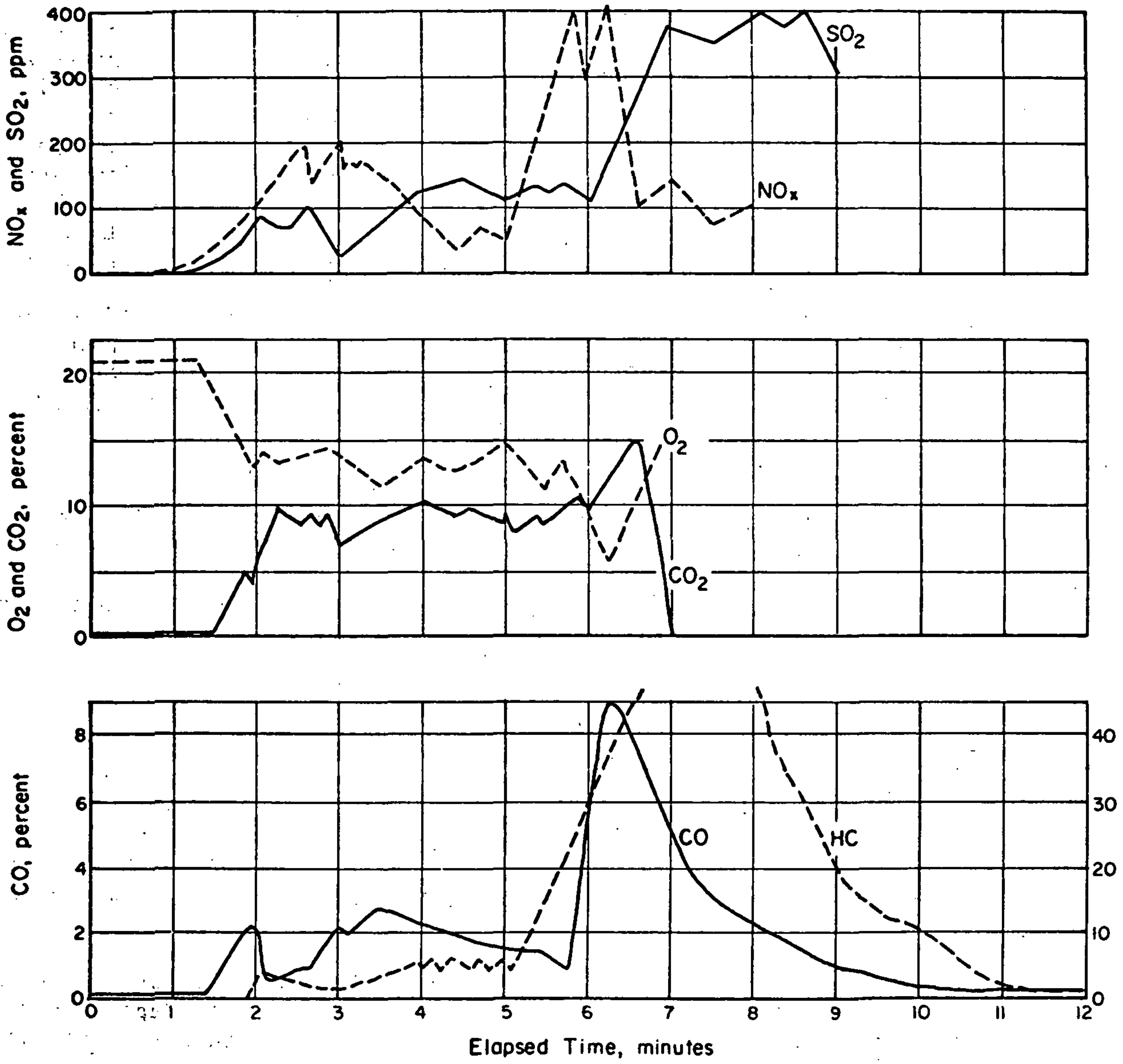


FIGURE 28. GAS ACCUMULATION CURVES FOR THE TYPICAL ROOM EXPERIMENT

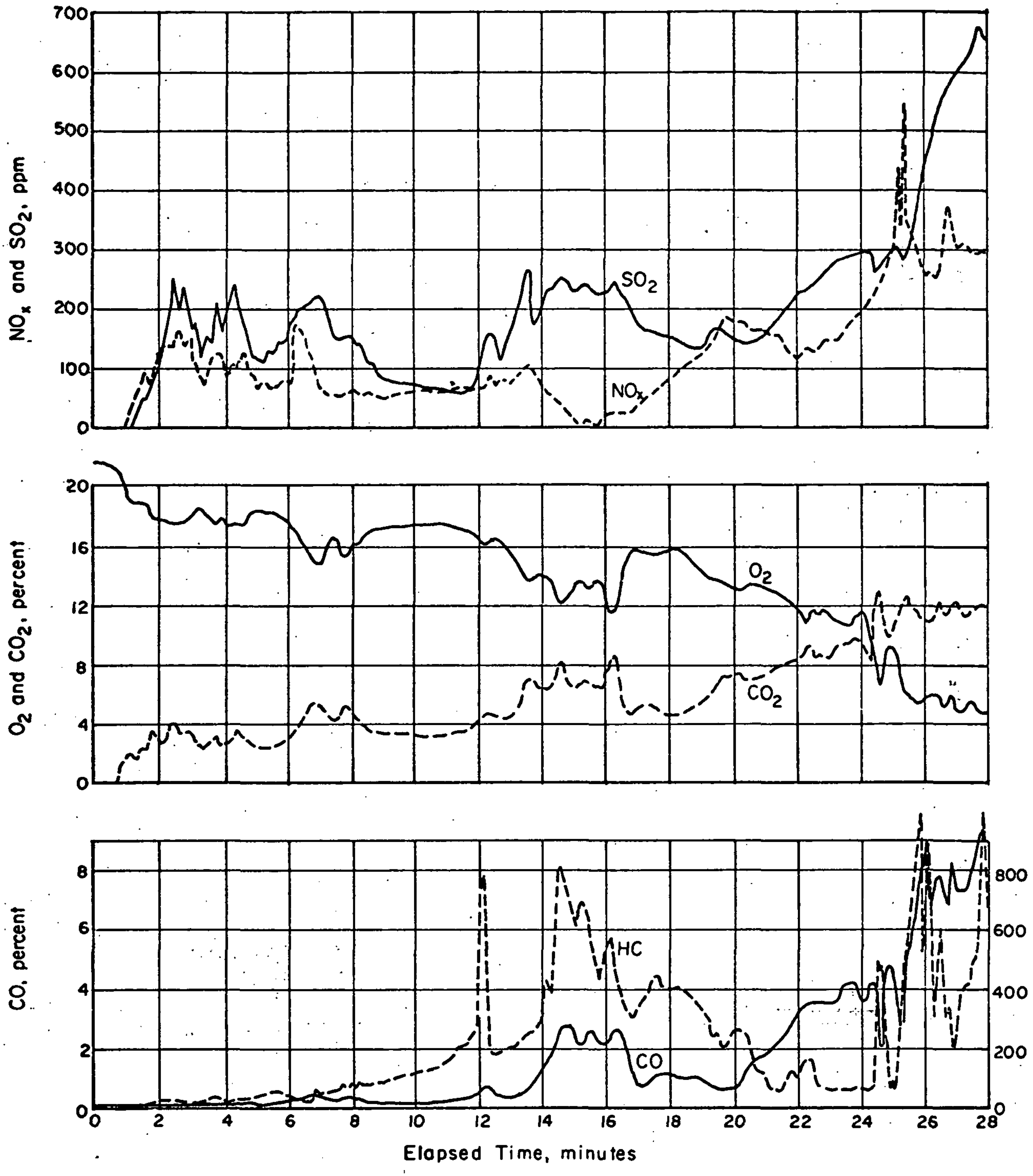


FIGURE 29. GAS ACCUMULATION CURVES FOR THE IMPROVED ROOM EXPERIMENT

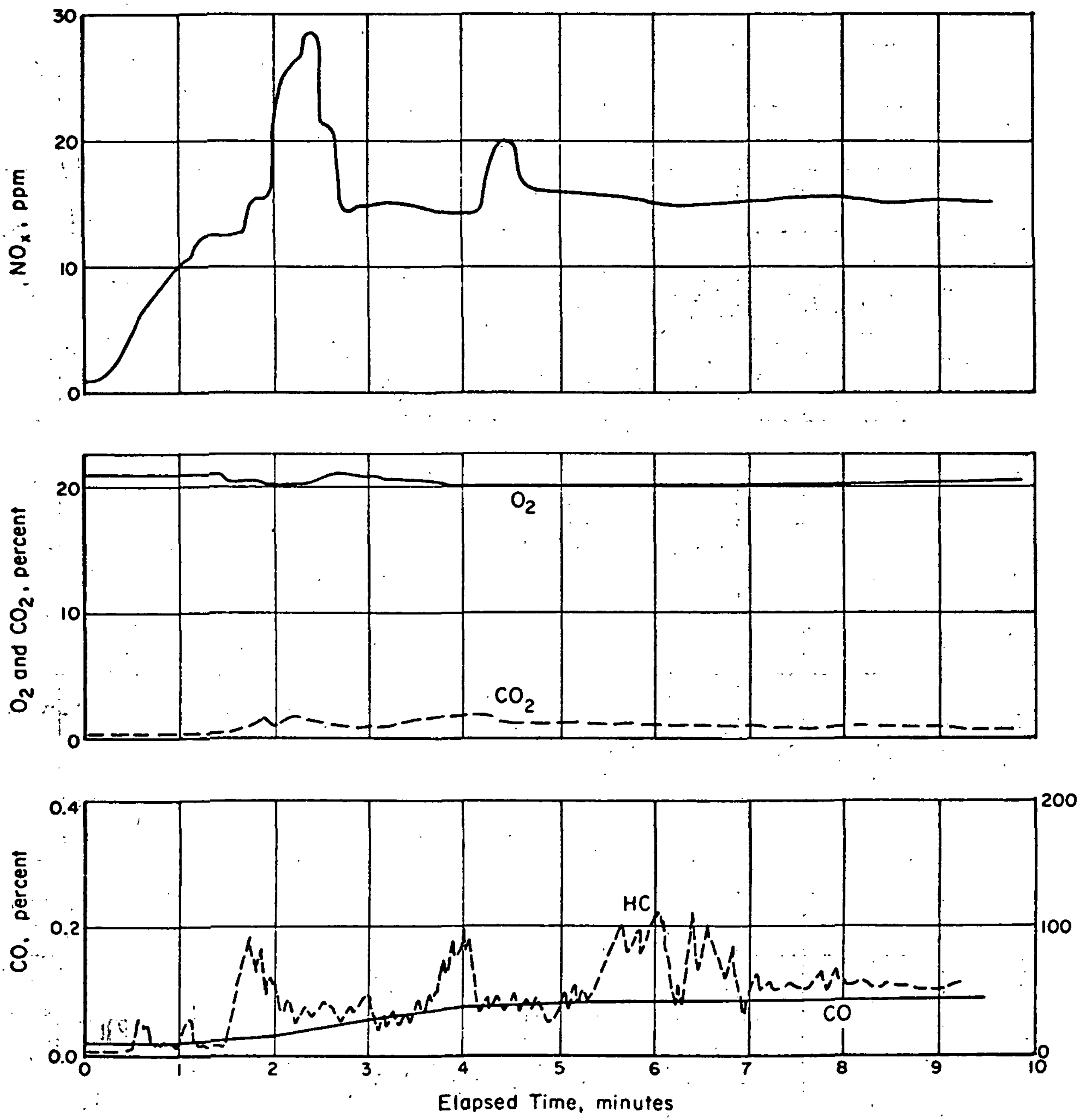


FIGURE 30. GAS ACCUMULATION CURVES FOR THE SPACE-AGE ROOM; 1st IGNITION

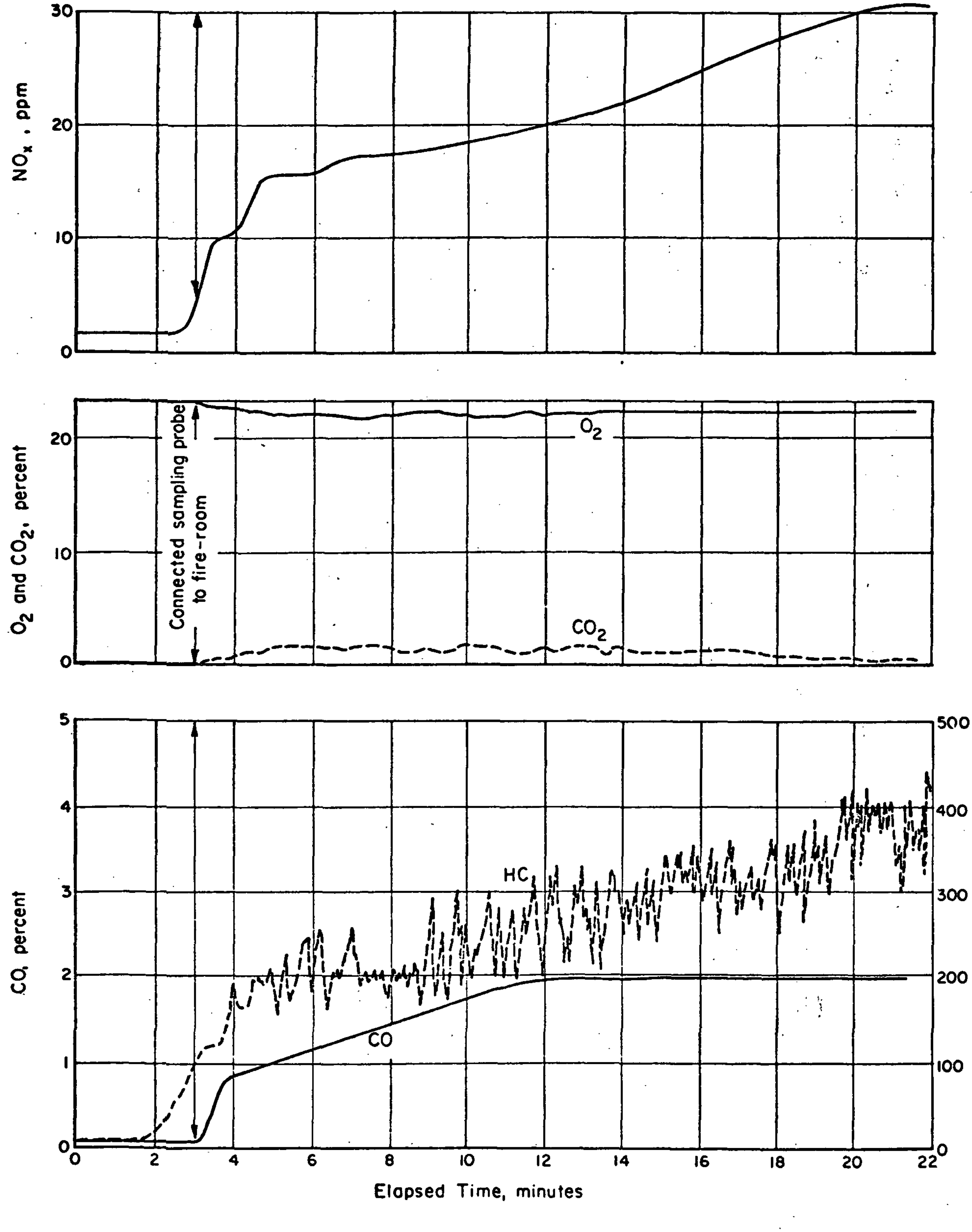


FIGURE 31. GAS ACCUMULATION CURVES FOR THE SPACE-AGE ROOM; 2nd IGNITION

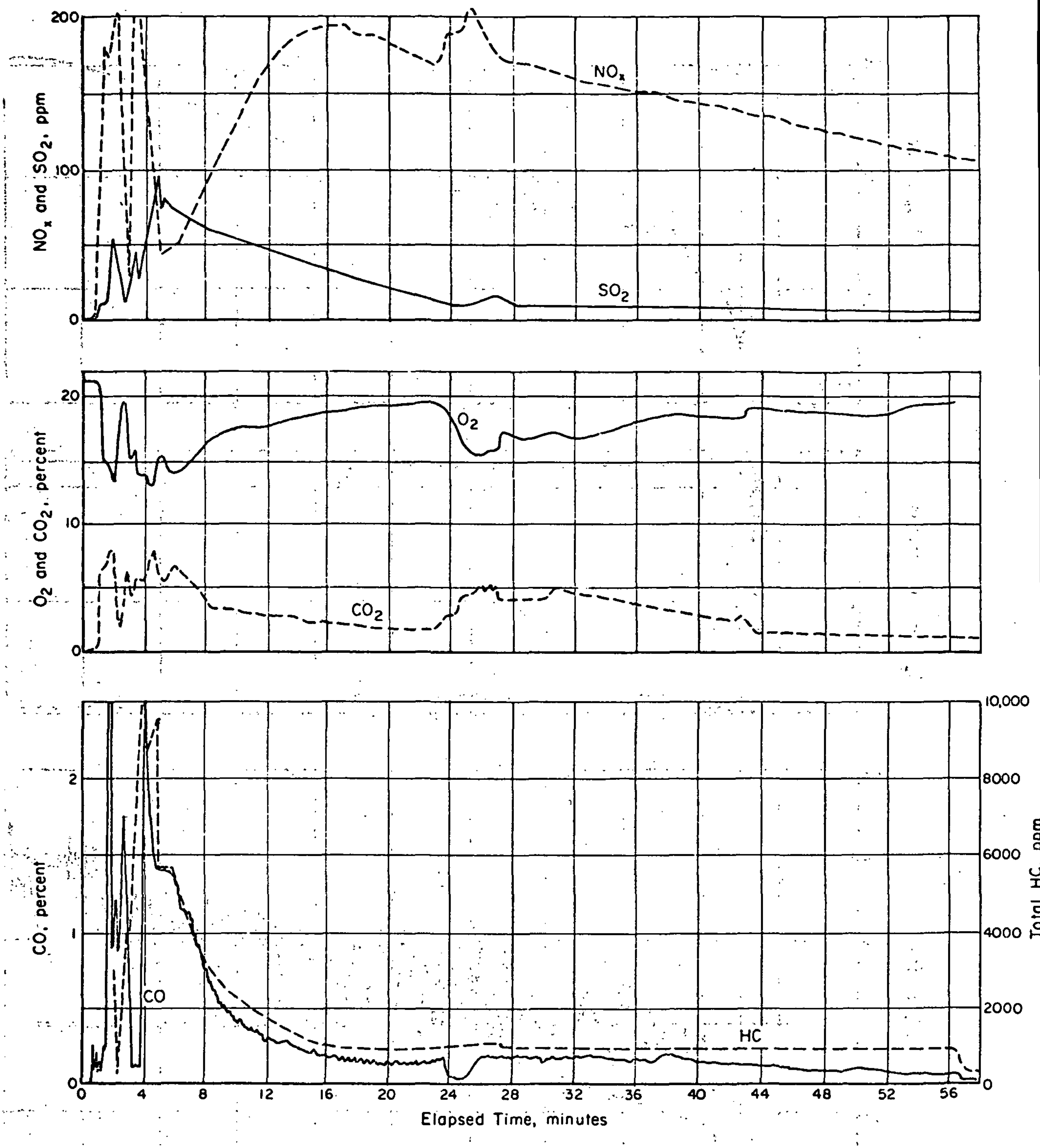


FIGURE 32. GAS ACCUMULATION FOR THE MIXED-LOAD ROOM EXPERIMENT

TABLE 7. AVERAGE CONCENTRATIONS(1) OF SOME SPECIES IN THE ATMOSPHERES OF FULL-SCALE ROOM FIRES:DETAILS

| Fire No. | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| Sample Type | ALD. | HX | ALD. | HX | ALD. | HX | ALD. | HX |
| Date of Fire | 10/10/72 | 10/10/72 | 10/13/72 | 10/17/72 | 10/24/72 | 10/24/72 | 10/31/72 | 10/31/72 |
| Sample | | | | | | | | |
| Collection Time, min. | (2) | (2) | 28 | 28 | 31 | 31 | 58 | 58 |
| Volume, cf | 0.18 | 2.1 | 2.43 | 19.3 | 2.85 | 21.8 | 5.7 | 40.0 |
| Volume, SCF(3) | 0.18 | 2.1 | 2.45 | 18.9 | 2.86 | 21.6 | 5.8 | 39.6 |
| m$^3$(3) | 0.0051 | 0.059 | 0.069 | 0.534 | 0.081 | 0.610 | 0.161 | 1.12 |
| Meter Temp., F | 56 | 60 | 56 | 70.6 | 58 | 66.3 | 55 | 68.7 |
| Meter Pressure, in. Hg | 29.80 | 29.80 | 29.34 | 29.34 | 29.40 | 29.40 | 29.56 | 29.56 |
| Moisture, percent(4) | | 20(4) | | 9.25 | | 1.29 | | 5.01 |
| Particulate,(5) | | | | | | | | |
| On glass wool, g | | 0.104 | | 1.54 | | 0.031 | | 0.406 |
| On filter, g | | 0.191 | | 0.20 | | 0.0038 | | 0.0122 |
| Total, g | | 0.295 | | 1.74 | | 0.035 | | 0.418 |
| (g/m$^3$) | | (4.96) | | (3.25) | | (0.057) | | (0.372) |
| Aldehydes,(6) mg | 0.78 | | 122.2 | | 4.2 | | 43.2 | |
| (mg/m$^3$) | (153) | | (1760) | | (52) | | (263) | |
| Cl,(7) mg | | 8.0 | | 205 | | 6.3 | | 37.3 |
| (mg/m$^3$) | | (135) | | (383) | | (10.3) | | (33.2) |
| F,(7) mg | | 0.13 | | 0.30 | | 0.38 | | 0.13 |
| (mg/m$^3$) | | (2.2) | | (0.56) | | (0.62) | | (0.12) |
| CN,(7) mg | | 46.0 | | 60.3 | | 1.50 | | 6.7 |
| (mg/m$^3$) | | (770) | | (113) | | (2.5) | | (6.0) |

(1) Samples collected at constant rate during entire duration of fire experiments.
(2) Sampling systems plugged after about 2 to 3 minutes operation.
(3) SFC corrected to 70 F, 1 atmosphere, m$^3$ calculated at 68 F (20 C) and 1 atmosphere.
(4) Water content of hot inlet gases from sampling probe. Run 1 uncertain.
(5) Includes solids and condensed material, 250 F.
(6) Separate sampling train, expressed as HCHO.
(7) Collected after separation of particulate, see Note 5.

TABLE 8. SUMMARY TABLE: AVERAGE CONCENTRATIONS(1) OF SOME SPECIES IN THE ATMOSPHERES OF FULL-SCALE ROOM FIRES

| Component | 1 (typical)(2) | | 2 (improved) | | 3 (space-age) | | 4 (mixed) | |
|---|---|---|---|---|---|---|---|---|
| | $\frac{mg}{m^3}$(3) | ppm(3) | $\frac{mg}{m^3}$(3) | ppm(3) | $\frac{mg}{m^3}$(3) | ppm(3) | $\frac{mg}{m^3}$(3) | ppm(3) |
| Particulate(4) | 4960 | -- | 3250 | --- | 57 | -- | 372 | -- |
| Chloride ion | 135 | 92 | 383 | 260 | 10.3 | 7.0 | 33.2 | 22.5 |
| Fluoride ion | 2.2 | 2.8 | 0.56 | 0.71 | 0.62 | 0.79 | 0.12 | 0.15 |
| Cyanide ion | 770 | 710 | 113 | 105 | 2.5 | 2.3 | 6.0 | 5.6 |
| Aldehyde (as HCHO) | 150 | 120 | 1760 | 1410 | 52 | 42 | 263 | 210 |

(1) Samples collected at constant rate for entire duration of fire experiment.

(2) Gas sampling systems plugged after 2 to 3 minutes and so sample represents the initial period of substantial smoke evolution.

(3) mg/m$^3$ at 68 F (20 C) and 1 atmosphere; ppm on volume basis.

(4) Total particulate and condensate at 250 F.

the total oxygen equivalent is reasonably constant. Further, the accumulations of hydrocarbons and CO tend to occur simultaneously as might be expected if they are taken as an expression of oxygen deficiencies. Usually, CO values reached levels above one percent as $O_2$ concentrations fell below about 15 percent, and spikes of extreme CO concentrations accompanied $O_2$ levels below about 10 percent. These observations are broadly consistent with the conclusion reached earlier that smoldering and pyrolysis are expected to predominate at $O_2$ levels below 16 percent.

The $SO_2$ and $NO_x$ concentration curves show considerable variation and do not necessarily respond consistently to the same variations in oxygen level. Undoubtedly some changes seen in these and other concentration curves are related to the times when the fire spreads to different components of the room, but the identification of such gaseous products with individual furnishing items in the rooms cannot be made in these experiments.

An assessment of the hazard represented by each of these gases individually can be attempted by comparing the measured concentrations with published data on the response of man and animals to the gases when separately present in air. However, the complexities of the combined physiological response expected for mixtures such as found in these fires are such that the conclusions serve more as a basis of comparison of the results for these experimental fires than as a statement of human survivability.

Insofar as an occupant of the room is concerned, the hazard due to smoke, heat, and flames has become severe in all but the Space-age Room after about 3 to 5 minutes, so that interest in the hazard due to toxic gases might be expected to center on the additional risk arising from such gases during an early fire period, say the first 10 minutes. Occupants of areas adjacent to the fire room would be exposed to this risk over longer periods of time as a result of convection processes out of the fire room, but differing degrees of dilution of these gases with ambient air make that assessment uncertain. For this latter purpose detailed analyses of convecting gases at the doorway and ventilation duct would be required.

With these considerations in mind, the published data for the appropriate toxic gases have been assembled in Table 9, and the measured average concentration levels found in each fire room during the first 10 minutes have been listed for comparison. In most instances, the published data that are reported represent the hazard for about 1/2 hour exposure, so that a direct comparison of concentrations shown in the Table tends to overemphasize the estimate of risk. From that table, the conditions of major importance would appear to be the HCN, CO, and $SO_2$ concentration levels since they equal or exceed the identified danger levels in Table 9. Other conditions that can be recognized as significant hazards are the high aldehyde concentration in the Improved Room fire, the peak $NO_x$ concentrations in all

TABLE 9. SUMMARY COMPARISON OF GASEOUS COMPONENT CONCENTRATIONS OF FIRE ROOM TRIALS WITH PUBLISHED VALUES FOR HAZARDOUS CONCENTRATIONS

| | Danger Level(1) | Fire Experiment(2) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| $CO_2$ | >8% (1a) | 8 | 3-4 | 1 | 3(7) |
| $O_2$ | <14%(1b) | 12 | 17 | 20 | 16 |
| CO | Ca0.1-0.2%(1c) | 1.5 | 0.5 | small | 1 |
| Hydrocarbons | (ppm) | 50,000 | 150 | | 5000 |
| $SO_2$ | 50-100 ppm(1d) | 100(400) | 200 | small | 50(100) |
| $NO_x$ | 100-150ppm(1e) | 150(300) | 100 | 15 | 100(200) |
| HCl | 1000-2000ppm(1f) | 92 | 260 | 7 | 22 |
| HF | 50-250 ppm(1g) | 3 | 0.7 | 0.8 | 0.2 |
| HCN | 100-200ppm(1h) | 710 | 105 | 2.3 | 5.6 |
| Particulate | (g/m$^3$) | 5.0 | 3.3 | 0.057 | 0.37 |
| Aldehydes | ppm(1c) | 120 | 1410 | 42 | 210 |

(1) Based on the following estimates for hazard.

- (a) $CO_2$, unconsciousness after 4 hrs, see Robison, et al.(11)
- (b) $O_2$, dizziness, fatigue, poor coordination, <14%, see Robison, et al.(11)
- (c) CO, time to collapse (minutes) = $\frac{4.5}{\%CO}$, see Robison, et al.(11)
- (d) $SO_2$, danger after 30/60 minutes, see Hafer & Yuell.(12)
- (e) $NO_x$, danger after 30/60 minutes for NO = 100-150 ppm, see Wagner.(13)
  danger after 30/60 minutes for $NO_2$ = 100 ppm, see Hafer & Yuill.(12)
- (f) HCl, danger after brief exposure, see Wagner.(13)
- (g) HF, danger after brief exposure, see Wagner.(13)
- (h) HCN, fatal after 30/60 minutes, see both Wagner(13) and Hafer & Yuill.(12)
- (i) May be quite hazardous: formaldehyde considered unsafe at 5ppm for 8 hr day, see Friedman(14), others such as acrolein are very poisonous, see(15).

(2) Units are the same as indicated under Danger level for each component. Values in parentheses indicate peak values, others are average values, during 1st 10 minutes, for those measured continuously, and for entire fire for those measured as single integrated sample.

but the Space-age Room fire, and the temporary $O_2$ depletion conditions seen during active fire periods. These are only the most easily recognizable hazards and ultimately some other conditons such as the peak hydrocarbon concentrations may prove of equal importance when the identities of individual compounds are obtained, or when the synergistic effects of the combined action is demonstrated.

The Space-age Room shows only minor accumulations of these combustion and pyrolysis products and those seen probably represent mostly the results of the newspaper ignition-fire itself. Both the Typical and Improved Rooms show significant hazard due to toxic gas formation, and the moderation of hazard obtained from the controlled fire of the Mixed-load Room is clearly noticeable.

## Burning versus Pyrolysis

Since, in each case, the flame represents the combustion of vapors produced by thermal decomposition of the furnishings, the burning of the various items used in these fire rooms is related in some way to the pyrolysis processes for each. Initially, as the flames spread from the fire-start, the ignition and burning of the fuel items represents the burning of those vapors in normal air. However, as the flames build in size the rate of consumption of oxygen in the fire chamber can temporarily exceed the convection of oxygen into the fire room and the resulting depletion of $O_2$ has a large effect on the speed of the burning processes in those flames. At this point in the fire-time the rapid buildup of heat in the fuel items is causing a rapid increase in the rate of pyrolysis so that combustible vapors begin to accumulate faster than the processes of burning can consume them. Increases in flame size along vertical surfaces lead to impingement of large turbulent flames on cool walls and ceiling which, together with the weakening of flame structure by $O_2$ depletion, leads to accumulations of smoke and combustible vapors. Eventually these processes can bring the fire chamber to the state where flame speeds are so small that the large flames become extinguished by heat lost through impingement and convection, and the room passes into a smoldering condition while the continuing convection processes start to bring $O_2$ levels back to the normal ambient value. When this recovery has been achieved, the increase in flame speed that results can cause local reignition of flame and a new cycle occurs. This cyclic, unsteady-state burning and pyrolysis cycle has been observed to be typical of room fires in which the enclosure represents some significant limitation on the accessibility of normal air to the site of the flame. It is not surprising that the rate of burning that is found, and the flammability of fuel items under these conditions, differs markedly from the observations and conclusions reached for the same items under steady-state burning conditions such as practiced in most laboratory tests of flammability.

## The Ensemble Effect

A further distinction arises between chamber fires and laboratory fire tests through the use of fire retardants. Most such retardants are intended to inhibit the flame processes occurring at the surface of the treated item so that, once a source of flame is removed, the flame goes out. In fires of the sort used in the present work, the substantial buildup of heat in a treated fuel item, as a result of uncontrolled burning of other items, causes it to continue to generate combustible gases by pyrolysis and these circulate into other parts of the chamber since burning of these at the generation site has been inhibited. These gas mixtures now can burn in the free-space of the chamber without necessarily being attached to any individual items of the fuel load. A free standing gas-phase fire of this sort is visible in the film made of the Typical Room fire in this study. The result is that a fire can be supported by both the burning of an untreated item and by the resulting pyrolysis of a treated item, whereas individually only the former would support the continuation of the burning process. This is clearly documented by the rapid burning ultimately obtained in the Space-age Room during the second ignition trial when, after 27 minutes, the ignition of one corner of the room brings about complete involvement of the fire resistant furnishing of the room in less than 6 minutes more. This effect of a mixture of combustible materials to produce burning not characteristic of any one item individually we have chosen to call the ensemble effect. The serious consequences of the ensemble effect are suggested to be a major reason why current laboratory trials of individual textiles and furnishing items fail to predict actual performance.

It should be noted that the major effects produced on a fuel item by the burning of another item in a chamber of restricted circulation are

(1) Change in convection
(2) Depletion of $O_2$ and generation of CO and $CO_2$ in a somewhat cyclic manner
(3) Generation of heat for pyrolysis.

so that, if the time-fluctuations of these were known and imitated, a reasonable reproduction of the response of that fuel item to ensemble burning conditions might be made. Further full scale fire trials may be anticipated to show that only certain combinations of variations in these time-dependent quantities are significant for fire testing purposes and in that event a programmed fire chamber might be developed to yield realistic laboratory results.

## Air-Flow Measurements

Figures 33,34,35, and 36 show the measured convection velocities found during each fire trial for air and combustion gases passing through the doorway and the ventilation duct. In that figure the flow data for

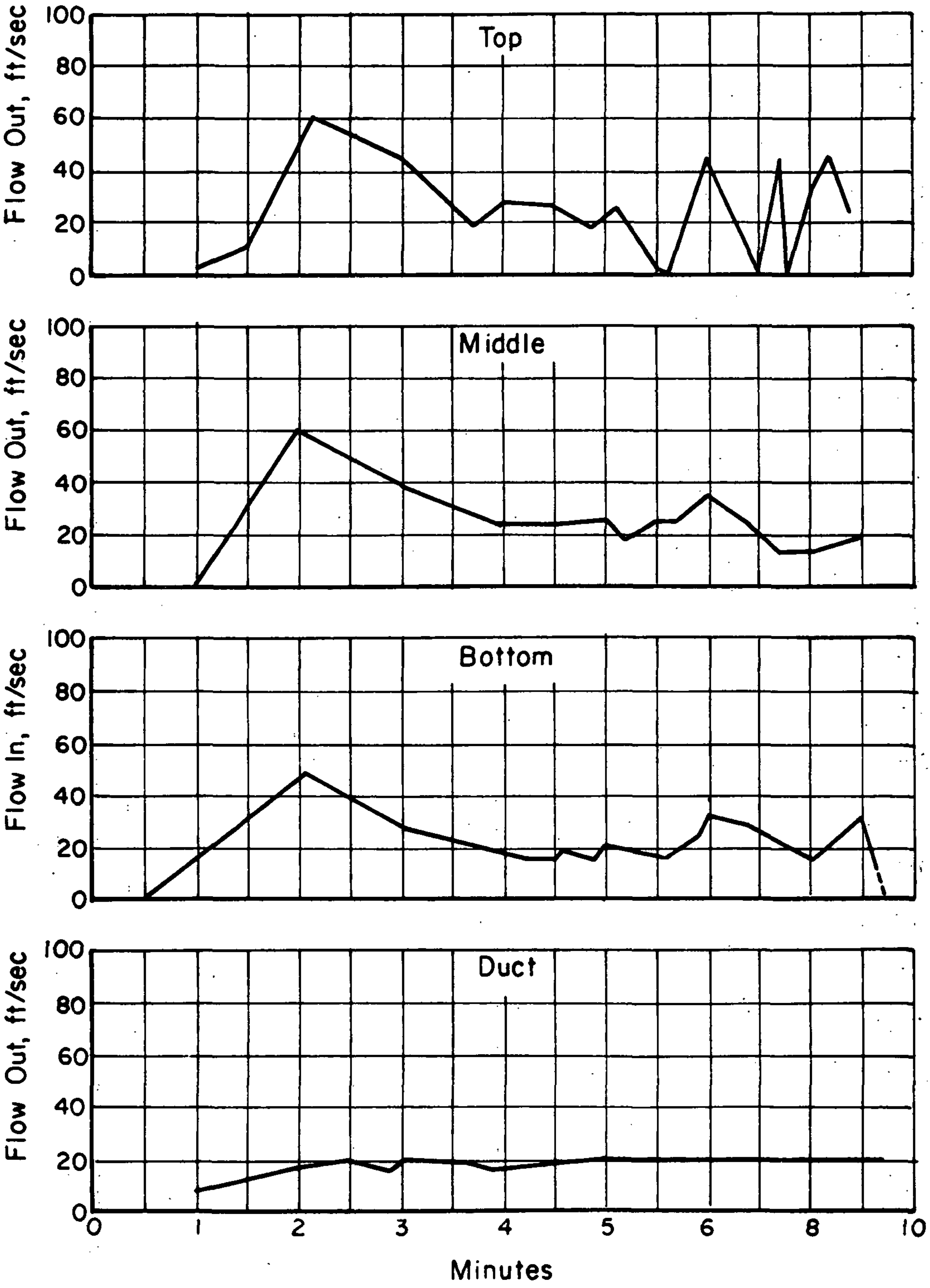


FIGURE 33. VENTILATION FLOW RATES FOR THE TYPICAL ROOM FIRE

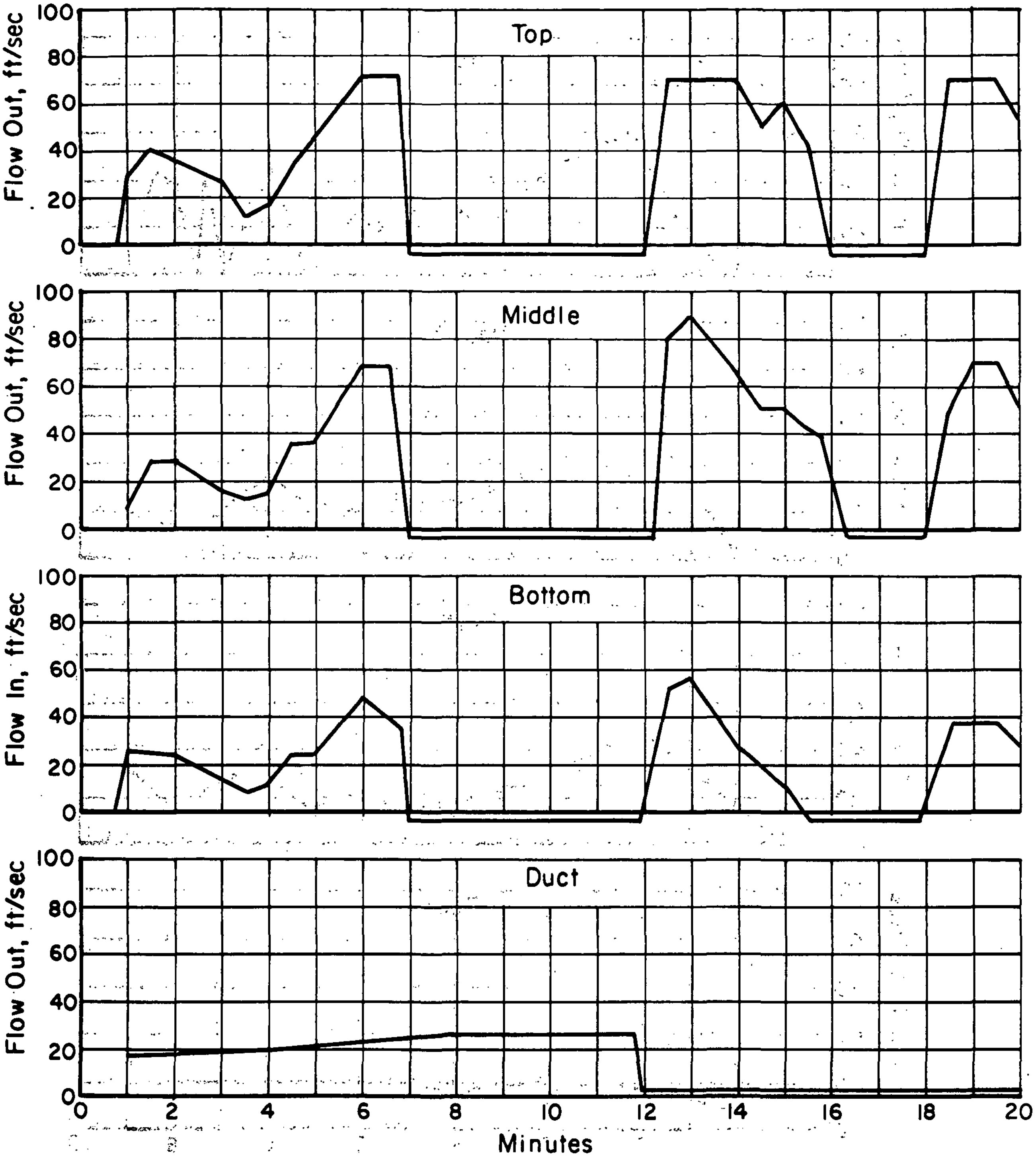


FIGURE 34. VENTILATION FLOW RATES FOR THE IMPROVED ROOM FIRE

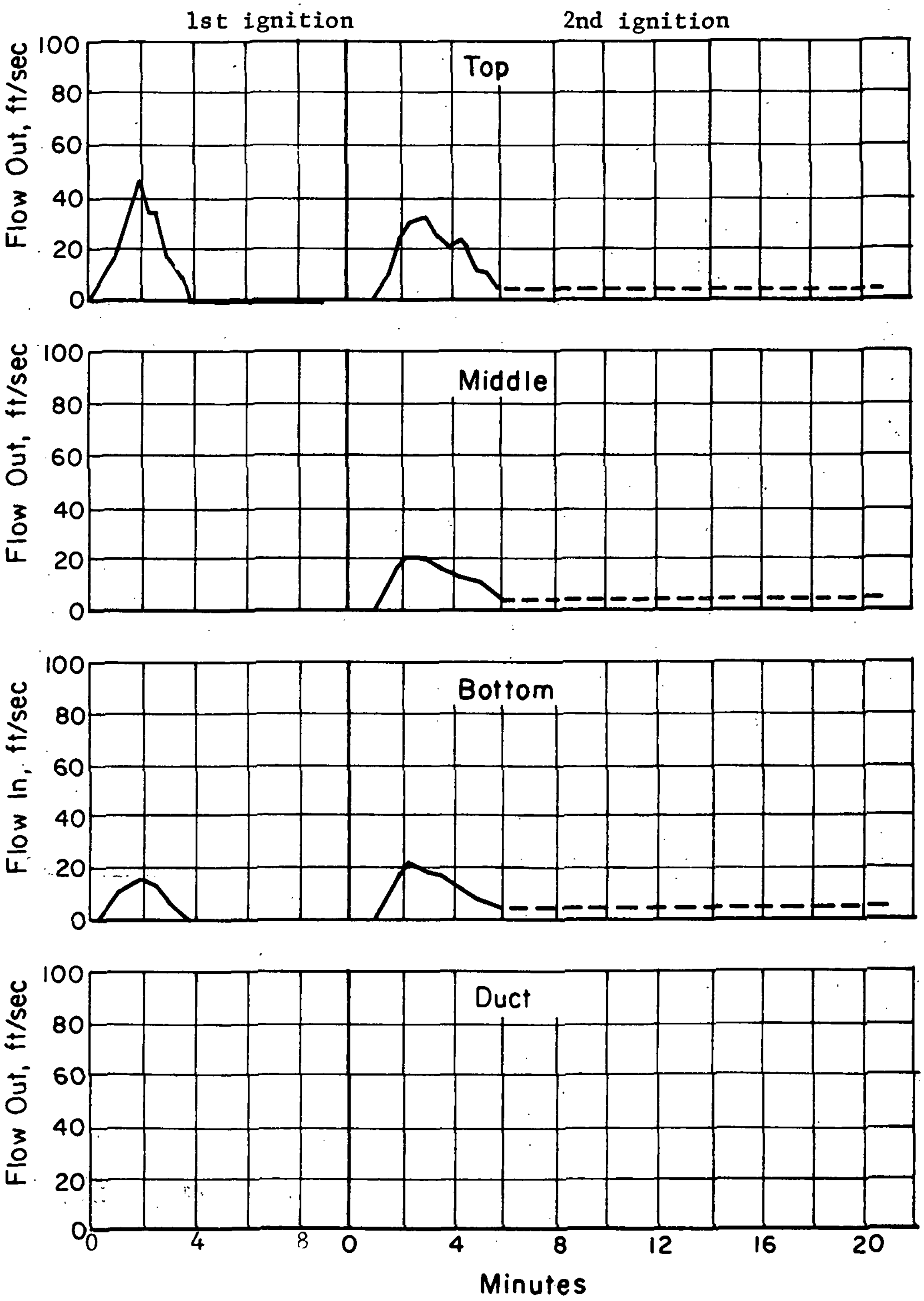


FIGURE 35. VENTILATION FLOW RATES FOR THE SPACE-AGE ROOM FIRE

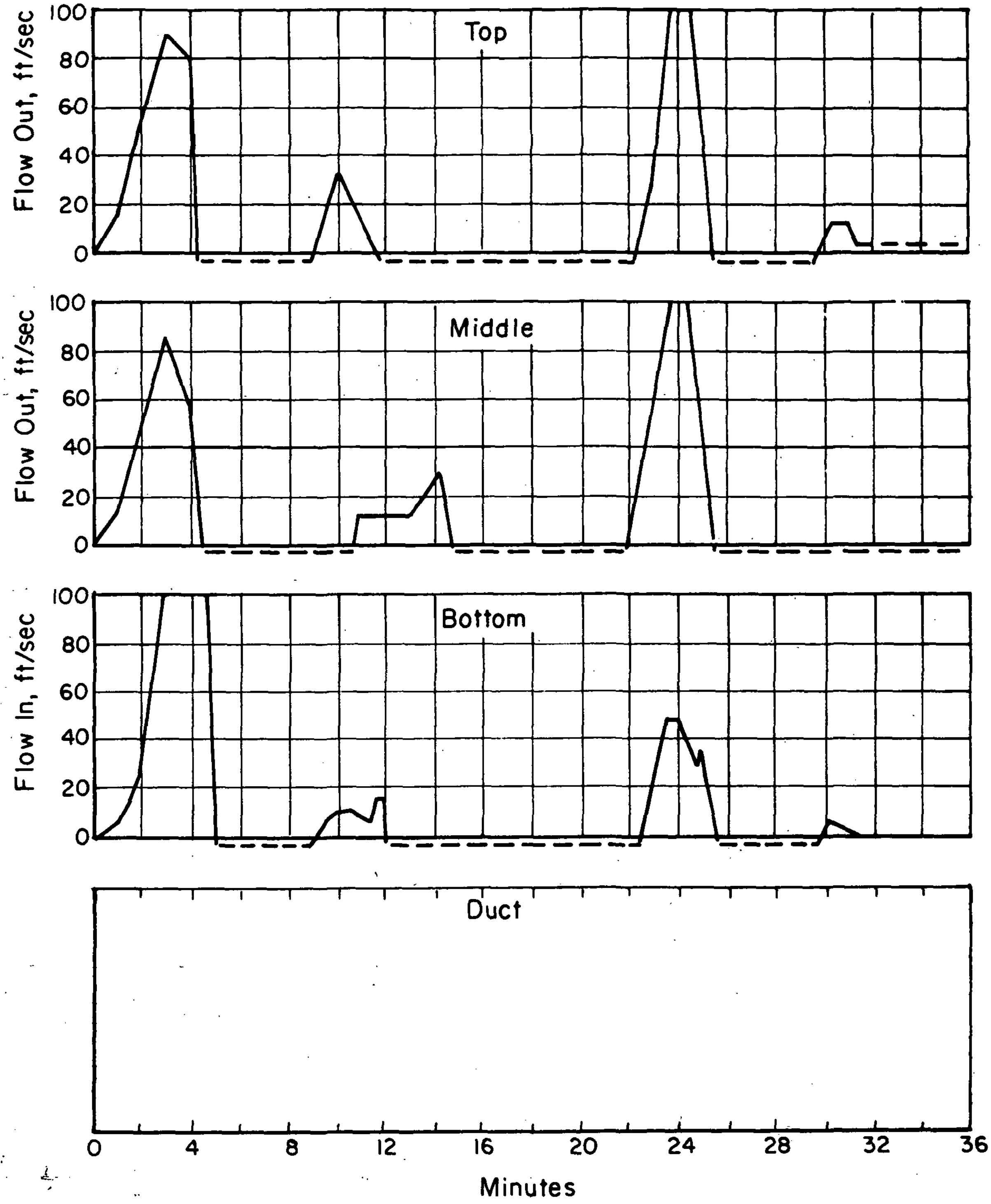


FIGURE 36. VENTILATION FLOW RATES FOR THE MIXED-LOAD ROOM FIRE

"top", "middle", and "bottom" refer to the pitot tubes located in those sections of the doorway. The pitot tubes in the ventilation duct and in the top and middle sections of the doorway were oriented to measure flow velocities out of the fire room, while that located in the bottom section was oriented to measure flow into the room. Inspection of the curves shows that there were a number of occasions when flow reversal was indicated. During these periods substantial negative flow heads were developed but these could not be measured conveniently and are shown in Figure 37 by the line drawn below zero flow. These periods of negative flow head have been examined and are believed to correspond to true reversal of flow; it is especially noteworthy that the reversal of flow is a complete reversal of flow pattern in that during the reversal, flow is outward in the bottom section of the doorway and inward in the middle and top sections. The following observations support this surprising evidence for flow reversal

(1) In separate trials the pitot tubes were shown to produce negative heads when the reversed flow direction was tried, so that the negative head seen in the fire experiments would indeed represent a reversed flow.

(2) The negative output of the pressure transducer of the pitot tube was confirmed in one of the fire-room experiments by having a liquid manometer in parallel with the transducer so that the reversal could be observed separately on that manometer.

(3) The temperature record obtained at each pitot tube was compared with the corresponding flow curve, see for example the data for the Improved Room in Figure 37, and this comparison showed that the temperature in the top and middle sections dropped sharply when flow reversal occurred probably because at the time the hot combustion gases ceased to flow out of those sections and relatively cool air from the corridor began to flow in; it should be noted that the direction of the thermal gradient in the doorway does not reverse although its magnitude is substantially reduced.

(4) The temperature at the ventilation duct grill, in the center of the ceiling, dropped sharply at the same time that the flow reversal indicated that cooler air was entering by way of the top and middle sections of the doorway, see Figure 37. Because of the flow impedance of the duct, reversal did not occur in the duct, and the gases reaching the outer end, where the duct flow was measured, were relatively cool throughout.

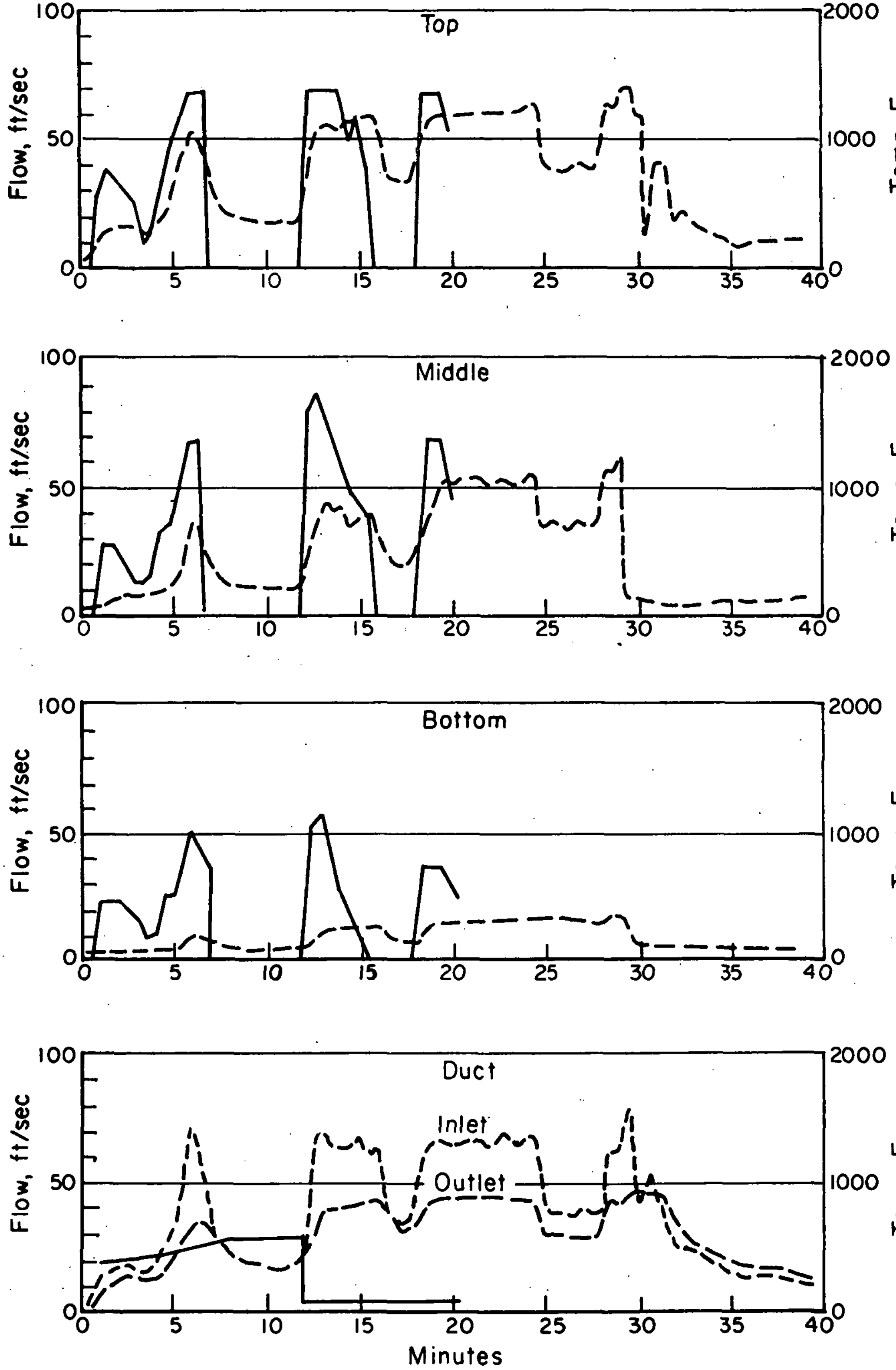


FIGURE 37. COMPARISON OF FLOW AND TEMPERATURE CONDITIONS AT THE DOORWAY AND VENTILATION DUCT IN THE IMPROVED ROOM FIRE. SOLID LINE REPRESENTS FLOW DATA AND THE DOTTED LINE REPRESENTS TEMPERATURE DATA.

This complex pattern of flow was not anticipated and its relationship to other characteristics of the fires is not clear. It would not be surprising to find that the reversal is related to the restrictions to flow posed by the ventilation arrangements used and the phenomenon requires further investigation. The occurrence of the flow reversal could be taken to imply temporary hazardous conditions along the floor of the fire room and the implications of this should be examined from the standpoint of occupants who might be seeking escape along the floor. The occurrence of the reversal should also be examined for its effect on the spread of toxic gases and smoke through adjacent areas of the building.

Since the ventilation occurred entirely by way of the doorway, which was 30 in. x 84 in., the commonly used ventilation parameter, $A(H)^{1/2}$, could be applied readily to these experiments. In this parameter A equals the area of the opening and H is its vertical height. In other work, this parameter has been used to correlate values of other characteristic quantities for chamber fires using proportionality constants derived from a series of experimental fires. Unfortunately such proportionality constants have been found to vary with chamber size, the size of the fuel elements, and the degree of insulation of the chamber so that the usefulness of these correlations in prediction of quantities for the present study is questionable. Correlations of this sort have been discussed by a number of workers, see for example Friedman(14), and Tsuchiya and Sumi(16).

No prediction value has been found for this parameter in the present study; for the convenience of others the appropriate quantities are listed below in metric terms:

$A(H^{1/2}) = (0.76 \times 2.14)\ (2.14)\ (2.14)^{1/2} = 2.37$ values in meters

W = weight of fire load Typical room = 1000 kg

Improved room = 1090 kg excluding special wall and ceiling cover.

The values of W for the other two rooms require some interpretation of the term "fire load" since certain items were not readily combustible. The values can be estimated as needed from Table 2.

## SUMMARY

A program of experimental fires has been carried out to establish the advantages offered by new space-age materials for the improved fire safety that might be provided. For this purpose four full-scale bedrooms, differing only in the materials used to furnish them, have been built and burned to provide comparative data on the fire hazards produced. Cost and availability differences were not considered.

The visual evidence provided by TV and photographic coverage of the four experimental room fires showed clearly that the rooms responded very differently to a common ignition condition.

In particular:

(1) The Typical Room, furnished from conventional retail sources, ignited easily and burned rapidly so that after 8 minutes the contents of the room were nearly destroyed.

(2) The Improved Room, furnished with materials selected as being among the best commercially available, showed substantial improvement over the Typical Room in that there was slower fire spread. However, the relatively complete destruction of the room contents that resulted, and the large amounts of smoke, made it clear that substantial further improvements were needed. This fire was stopped after 29 minutes.

(3) The Space-Age Room, furnished completely with new materials that were not yet commercially available, did not ignite under the common ignition condition and so demonstrated the substantial improvement in fire resistance available for those components close to the ignition source. A second and larger ignition arrangement showed that this room can burn, but the difficulty with which this was brought about confirmed the improved fire resistance available with use of these materials.

(4) The Mixed Room ensemble, furnished with materials identical to the Typical Room except for the substitution of the bed from the Space-Age Room, illustrated the improvement in control of fire spread available by careful placement of fire resistant materials in the important paths of fire development of an otherwise ordinary room.

In addition to these visual observations of fire development, the resulting temperatures, ventilation and convection velocities, heat irradiation levels, smoke accumulation, and a large variety of chemical combustion and pyrolysis products were monitored during each experimental fire. As might be expected, a considerable degree of interrelation was noted between the variations in ambient oxygen concentration produced in the fire room and the other fire-related quantities that were monitored.

The published data on fire spread rates have been used to deduce that active fire spread periods would be expected to occur when ambient $O_2$ concentrations are at about 16 percent or above. The temperature and heat irradiation measurements made in the present study are reasonably well interpreted on this basis and it is concluded that smoldering and pyrolytic processes characterized the times when $O_2$ levels fell below 16 percent.

This being the case, some correlation of toxic gas accumulations with $O_2$ concentration would be expected. Taken broadly, the CO, and hydrocarbon accumulations showed the expected correlation in that sharp rises in concentration accompanied the important dips in ambient $O_2$ levels that were observed. Thus, usually, CO values reached 1 percent or more as $O_2$ concentrations fell below 15 percent, and spikes of extreme CO concentrations accompanied $O_2$ levels below about 10 percent. These variations appear to be broadly consistent with the conclusion that smoldering and pyrolysis are expected to predominate at $O_2$ levels below about 16 percent.

The most significant hazards at early times in each fire were due to the rapid rise in heat flux and the abrupt obscuration of vision by smoke. The most consistent toxicity hazard was due to CO and its importance would depend on the ability of the occupant to survive the initial heat and smoke menace which characterized each fire room. Other gases and vapors were shown to reach hazardous levels in certain fire rooms and, again, their significance to an occupant would relate to the times in which such hazards occurred, and probably to the synergistic nature of the hazard arising from mixtures of such gases. The individual estimates of hazard are summarized in Table 9.

Since, in each case, the flame represents the combustion of vapors produced by thermal decomposition of the fuel item, the burning of the various items used in these fire rooms is related in some way to the pyrolysis processes for each. During periods of rapid fire spread, the rate of consumption of $O_2$ can temporarily exceed the convection of $O_2$ into the fire room and the resulting depletion of $O_2$ decreases the speed of the burning processes in those flames. Accumulated heat causes pyrolysis to continue at a rapid rate while the burning subsides to a smoldering condition, and meanwhile convection begins the process of replenishment of the $O_2$ level in the fire room. This cyclic unsteady-state burning and pyrolyses cycle is typical of room fires in which the room enclosure significantly limits ventilation.

Fire retardant items in the room are caused to pyrolyze by the heat of burning from other items in the room and so contribute to combustible and toxic vapor accumulations even though they may not have entered into the burning process. This effect of a mixture of combustible materials to produce burning and pyrolyses not characteristic of any one item individually we have chosen to call the "ensemble effect".

The major interactions of a fuel item with the burning of another item in a chamber arise through changes in $O_2$ level, accumulations of CO and $CO_2$, and radiant and convected heat reaching the fuel. Thus, if the time-fluctuations of these quantities are known and imitated, a reasonable reproduction of the response of that fuel item to ensemble burning conditions might be made. Further full-scale fire trials may be anticipated to show that only certain combinations of such fluctuations are significant for fire testing purposes and in that event a programmed fire chamber might be developed to yield realistic laboratory results.

## RECOMMENDATIONS FOR FUTURE WORK

The interdependencies that have been noted among the many fire-related variables that were monitored have revealed a glimpse of the unsteady-state relationships that result between burning and pyrolytic processes. These processes in turn describe the basis for estimation of fire hazard and the role that new materials should serve. It is clear that present-day laboratory tests based on steady-state burning conditions do not necessarily reveal the manner in which a furnishing item reacts to the actual fire conditions nor the degree to which a particular use is important because of fire spread or pyrolytic decomposition effects. The following recommendations for future work are suggested to offer a proper bases for continuation of the work that has been started. While they are thought of as extensions of the present study they could be applied to new fire hazard configurations if necessary.

(1) This phase of the recommended work is concerned mainly with fire spread and ventilation conditions that are of importance to extend the scope of the relationships already established. The immediate objectives of the work would be

(a) To examine the reproducibility of burn results and thereby determine the degree of reliability that can be placed on the observations

(b) To examine the important differences that can be anticipated by changes in ventilation arrangements, especially through windows and forced convection

(c) To examine the importance of igniter location and especially the fire spread control provided by materials used for wall and ceiling construction

(d) To examine the importance of convected gases and heat in detail by monitoring compositions at the doorway (or window) and by carrying out each fire to essentially complete burnout so that the maximum rates of evolution can be described as well as the total amounts of each convected quantity. In addition an especial effort should be made to show how the hazard arising in the first minute or two is related to the choice of materials and conditions.

For this program, full-scale bedroom arrangements are suggested similar to those used in the present study so that the results can be related to the present study. In some cases an arrangement that imitates the Mixed-Load Room would be of value. For this purpose the Space-Age Bed could be replaced by a nonflammable barrier of similar height so that the convection and fire-spread from one part of the room to another can be studied for the influence of wall, ceiling, and floor choices.

(2) This phase of the recommended work is concerned with the gas composition and heat flux variations and their effect on the performance of selected furnishing items. The objectives of this phase would be

(a) To establish the performance of individual materials under the variations of atmosphere and heat flux that occur in a real fire. Both rapid fire buildup as in the Typical Room, and also slow development as in the Improved Room would be examined

(b) To identify as far as possible the minimum set of variations that must be described in order to predict the material performances that are observed.

For this program a material would be placed on a suitable frame or furniture item and located at some distance from the furnishings where fire start occurs. Monitoring of heat and gas compositions would be made at the test material so that its performance could be related to the local conditions that arise at its site. The overall fire test configuration would again be the same as for the bedroom used in the present study.

(3) This phase is concerned with the development of a programmed laboratory test procedure that suitably imitates the performances detailed in Phases 1 and 2. Work on this phase could be undertaken simultaneously with 1 and/or 2 but should continue in time beyond those phases so that the results of each can be utilized fully. Most of this phase would be carried out in laboratory chambers of suitable simplicity in which heat fluxes and atmosphere variations are artificially produced.

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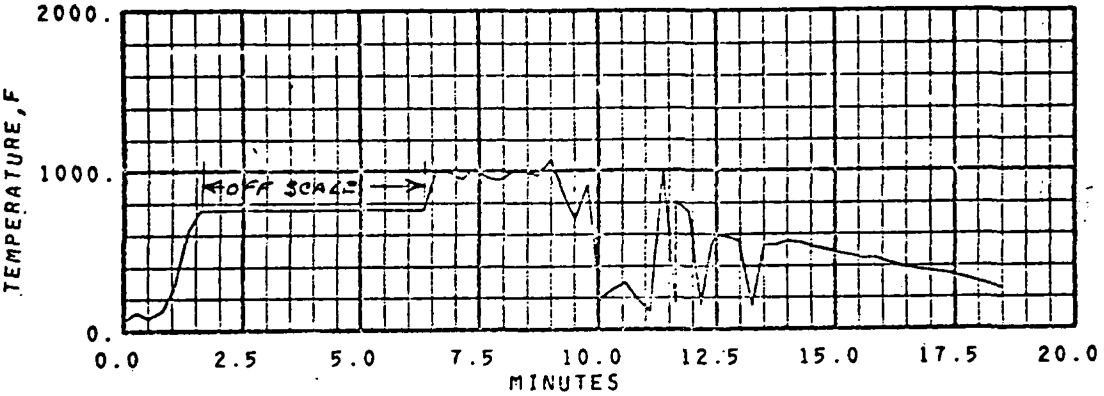
# APPENDIX A

## TIME-TEMPERATURE RECORDS

Note: For the fire of October 10, 1972 the sudden rise in the plot of temperature following the "off-scale" period represents a change of scale of the recording equipment and not a real change in temperature.



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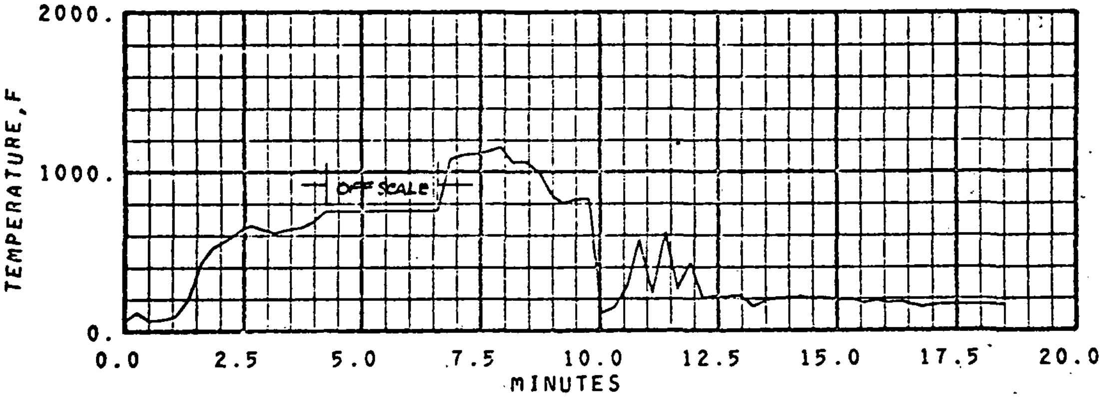

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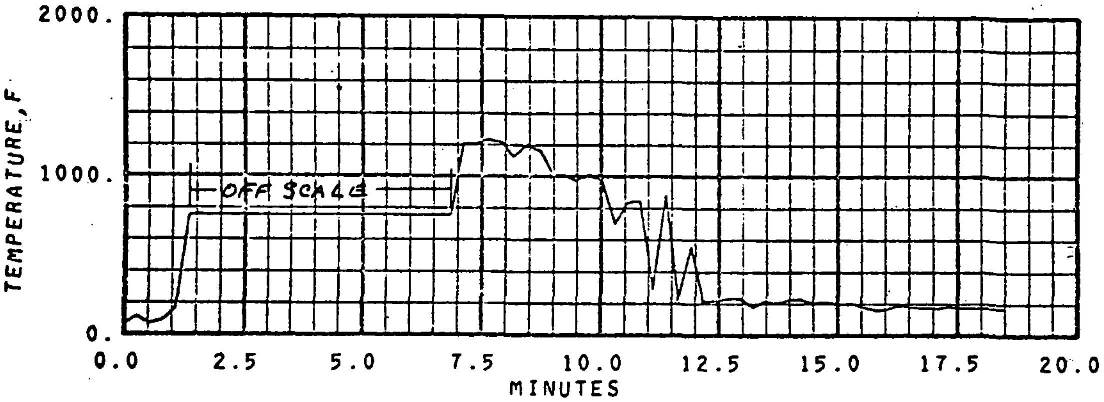

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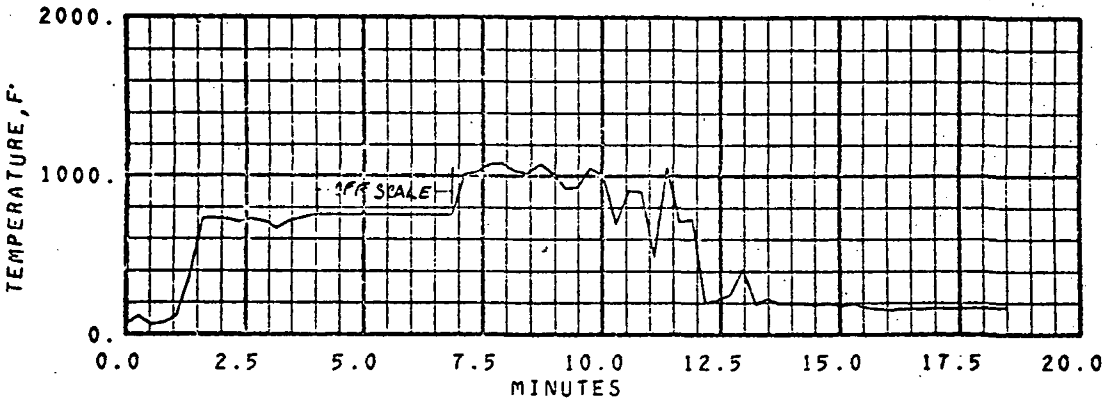

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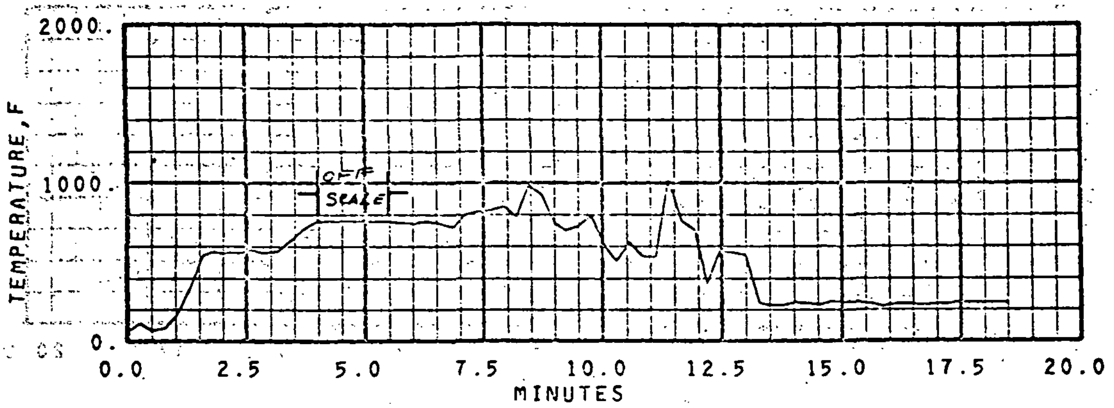

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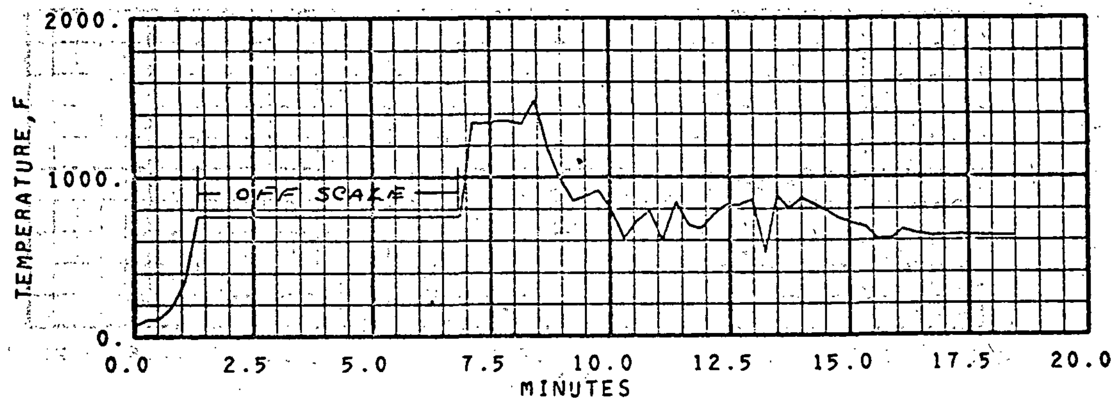

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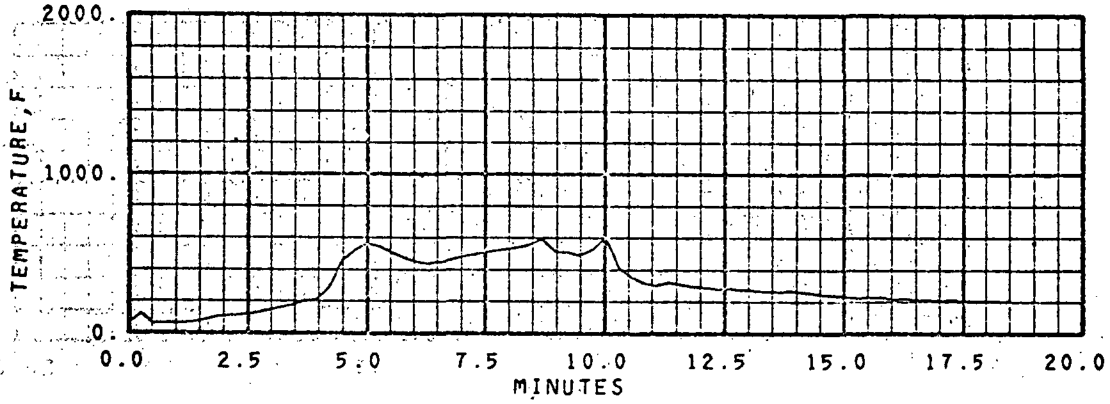

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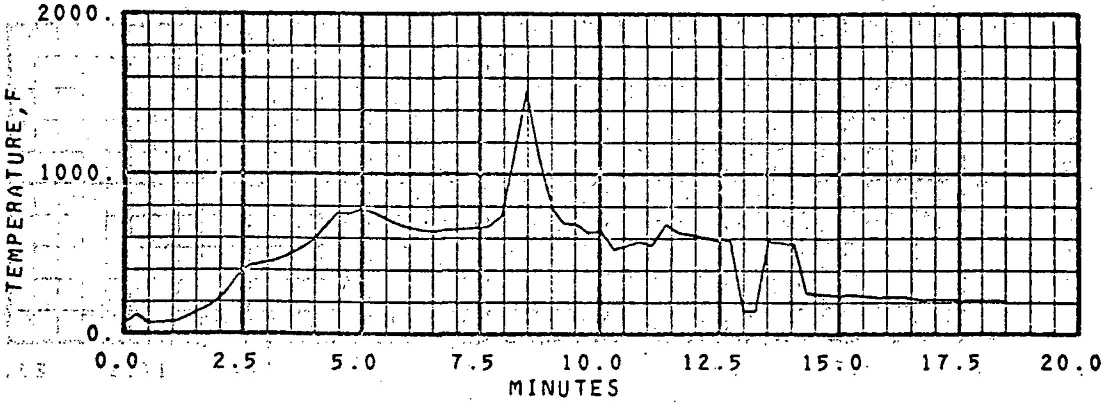

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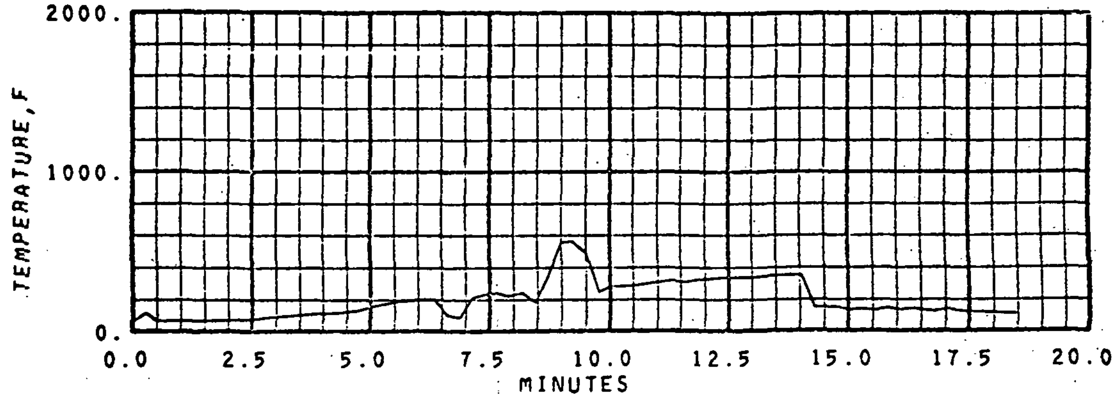

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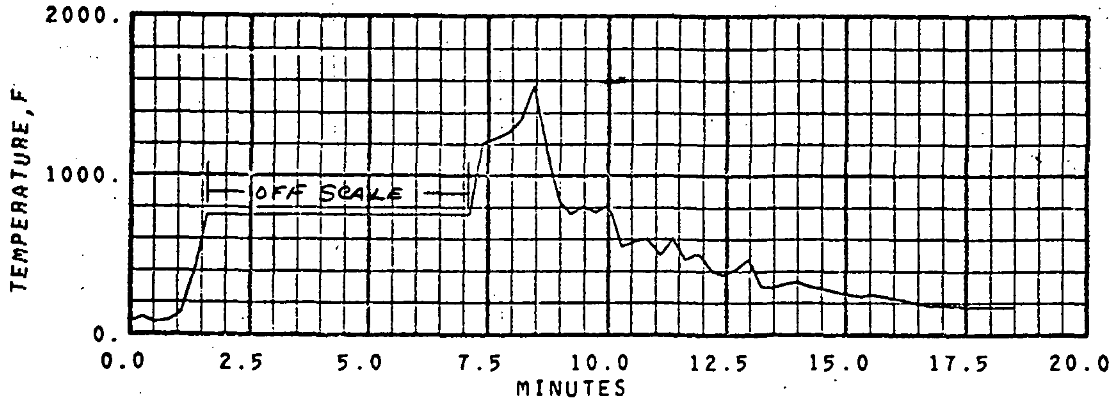

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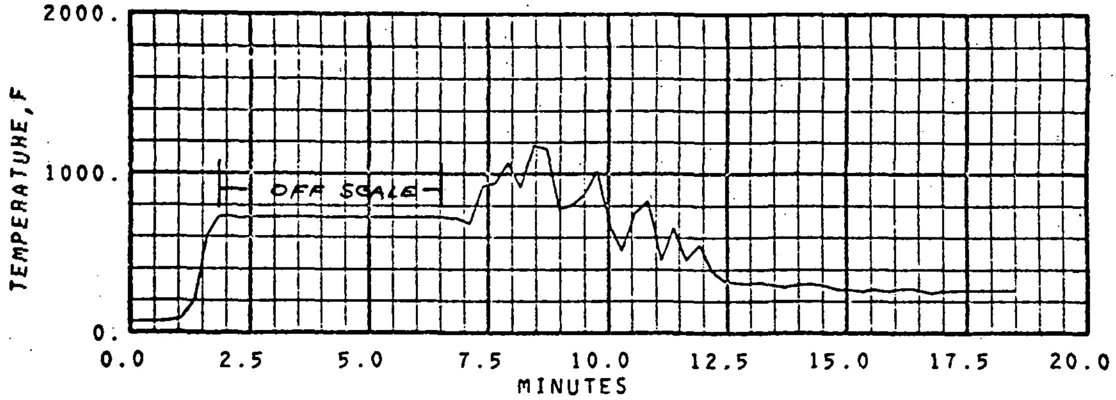

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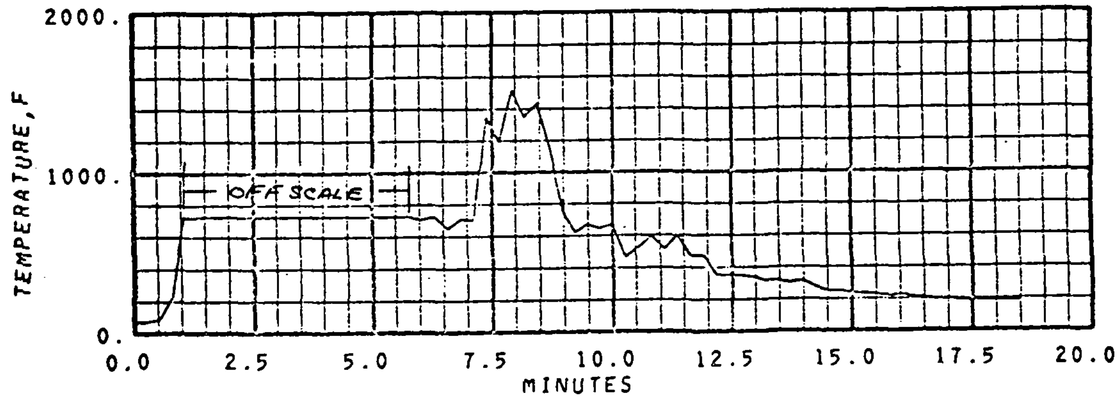

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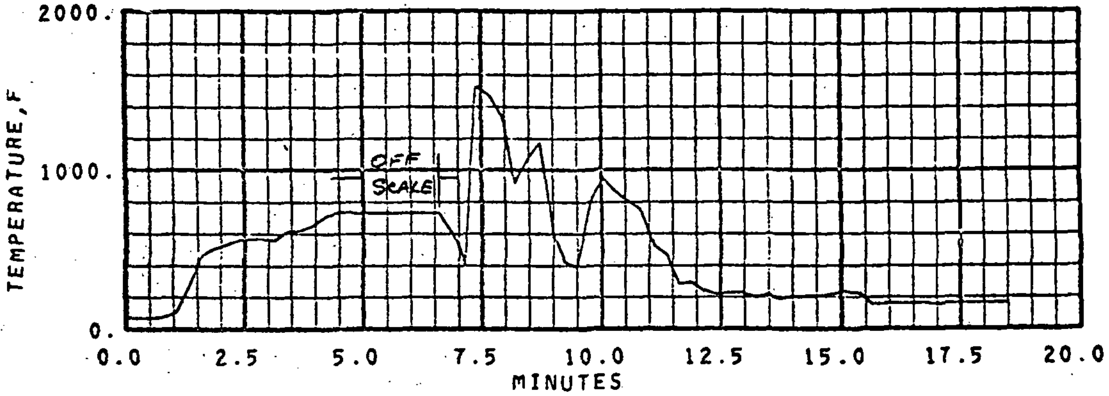

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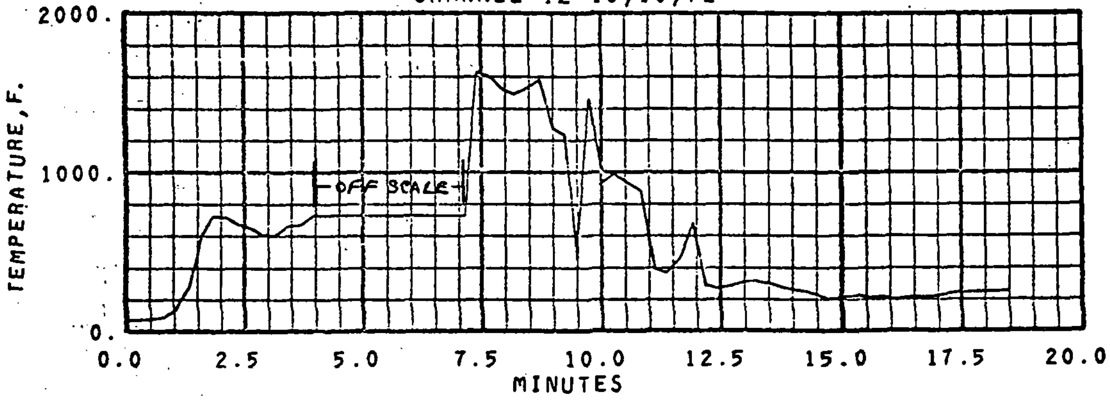

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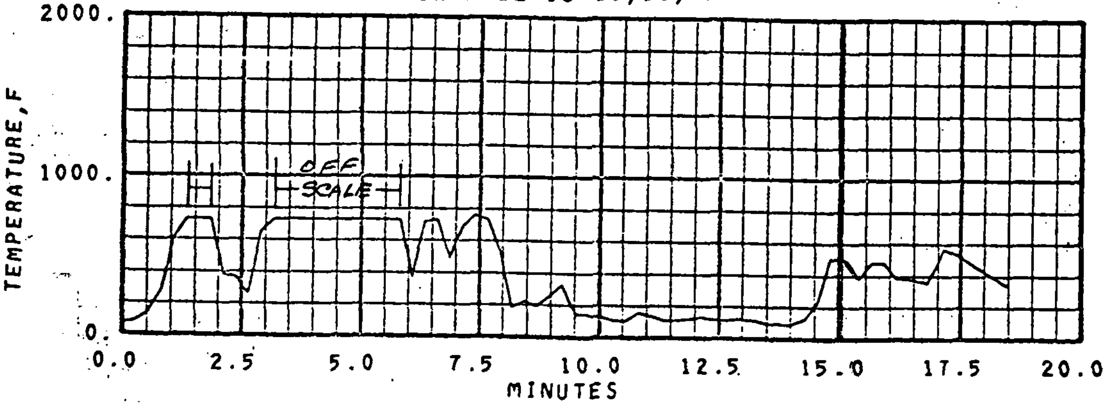

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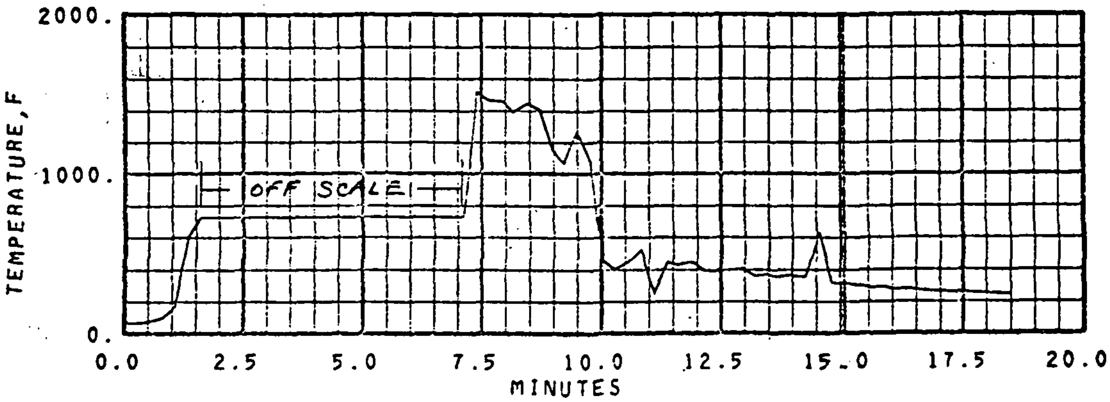

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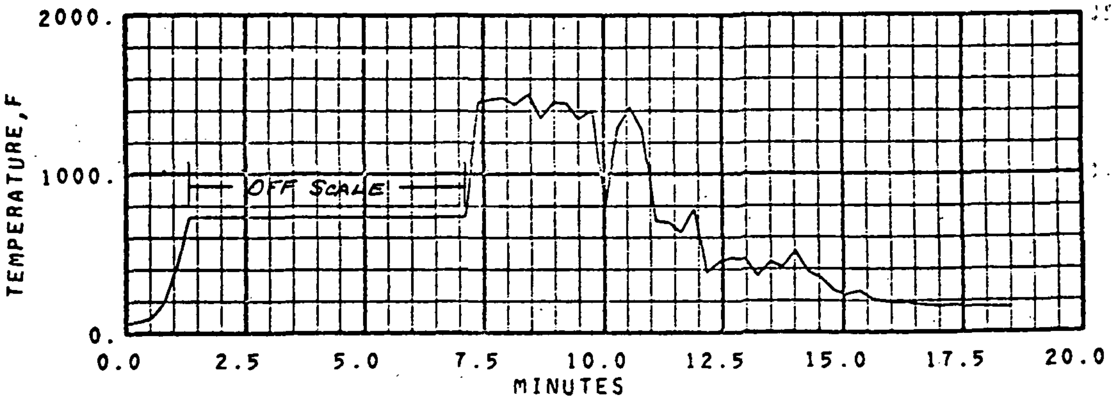

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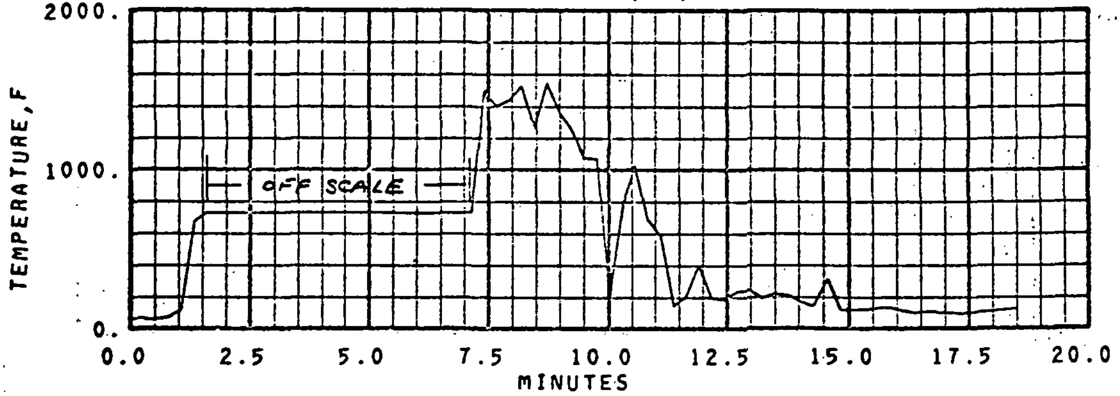

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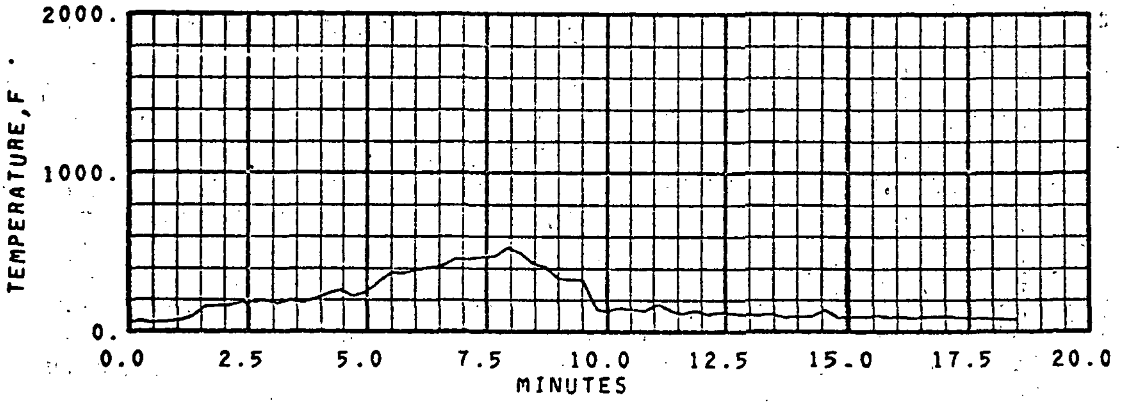

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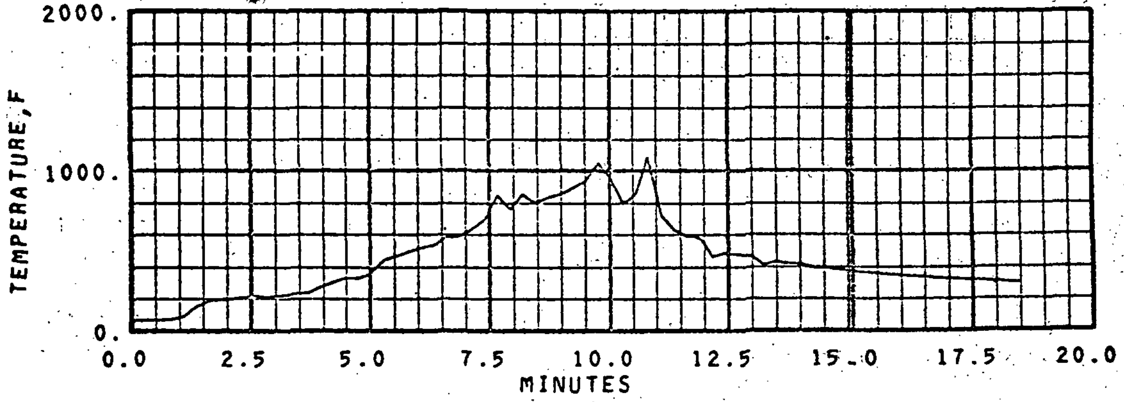

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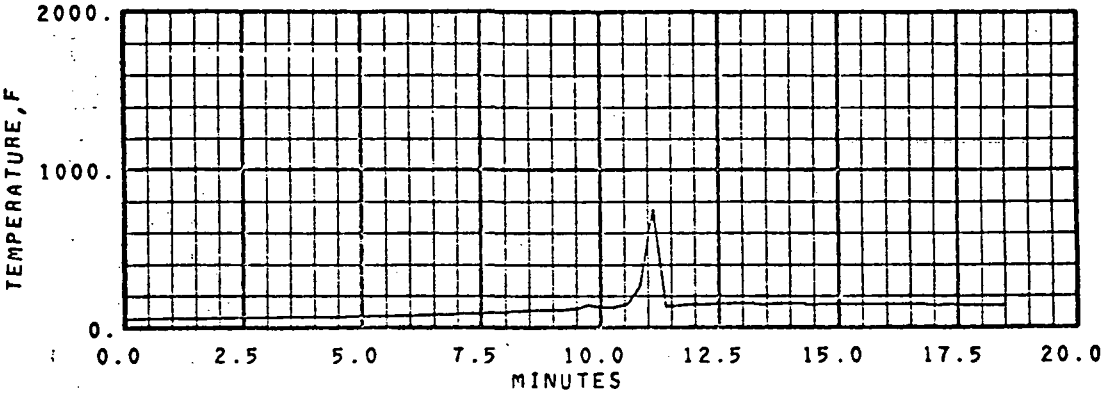

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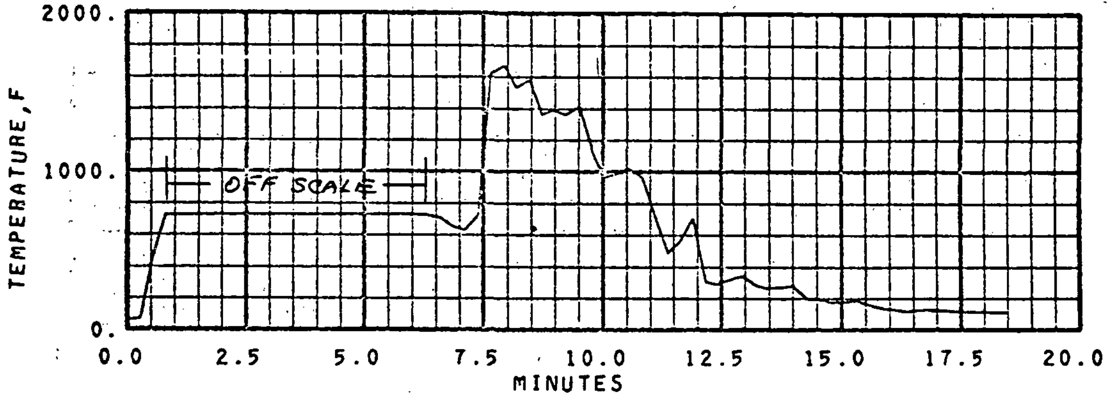

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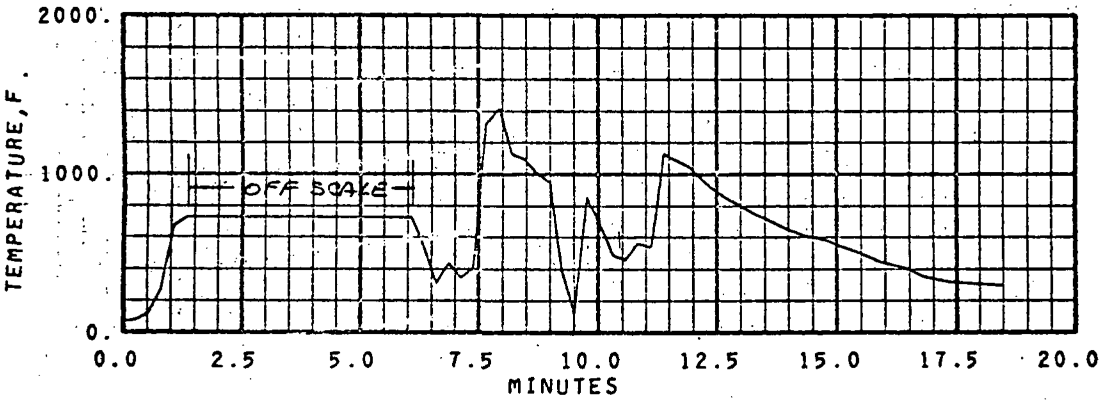
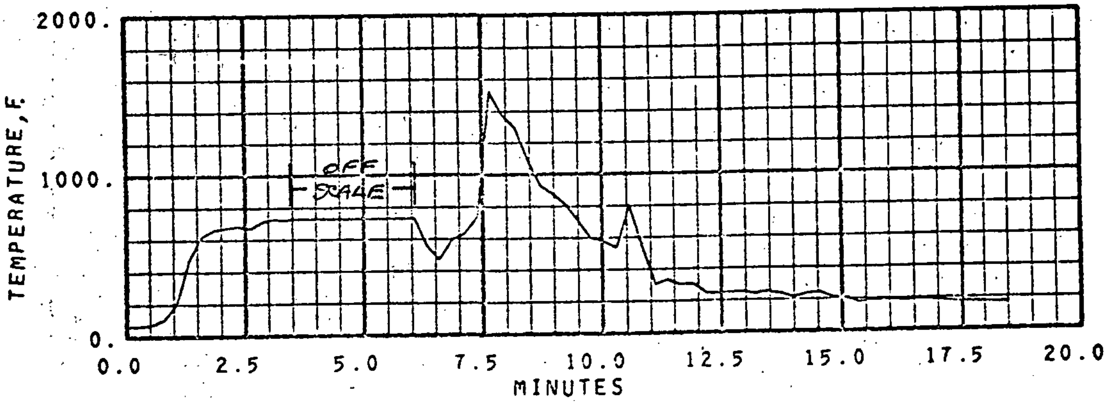
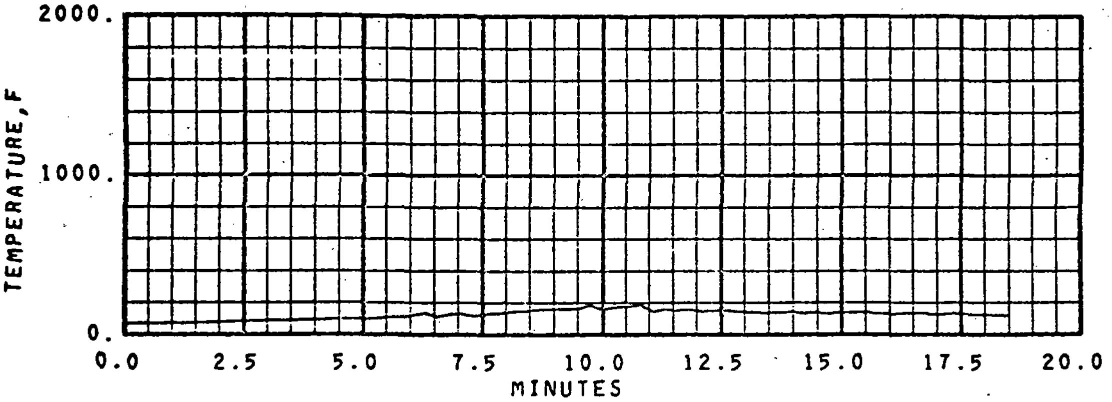


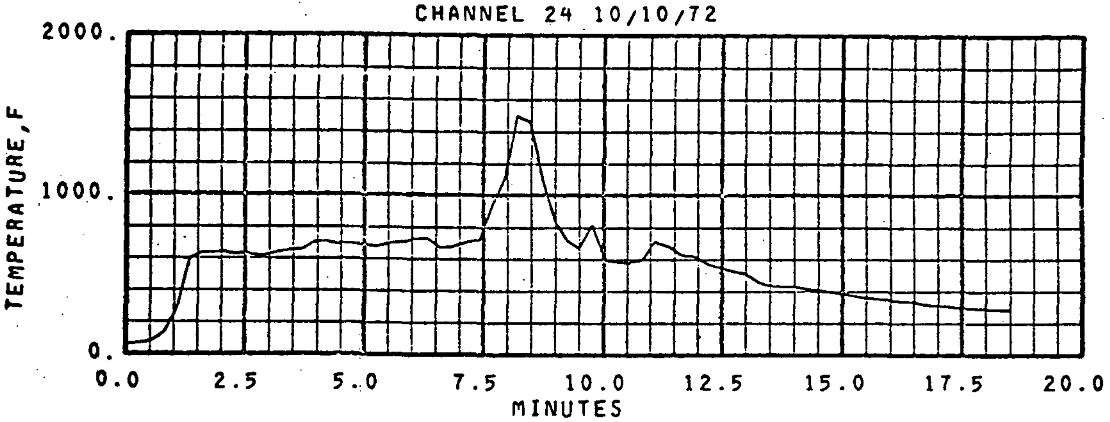
CHANNEL 22 10/10/72



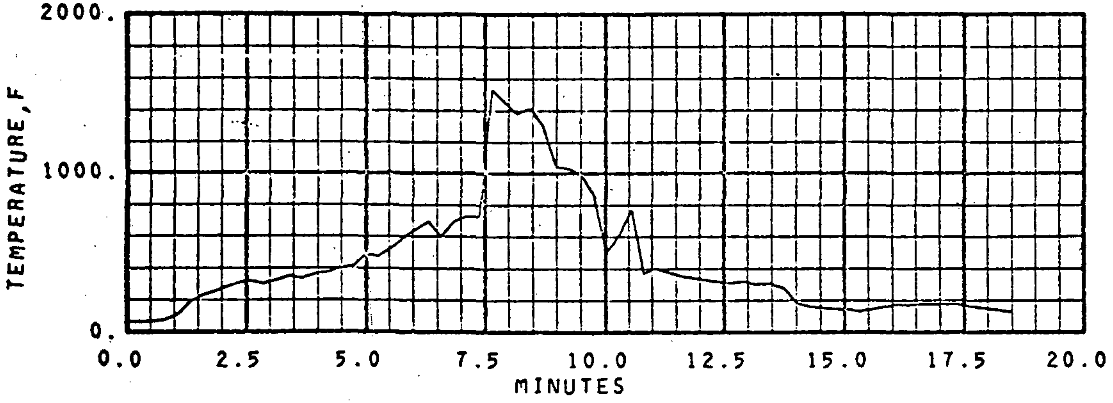
CHANNEL 23 10/10/72



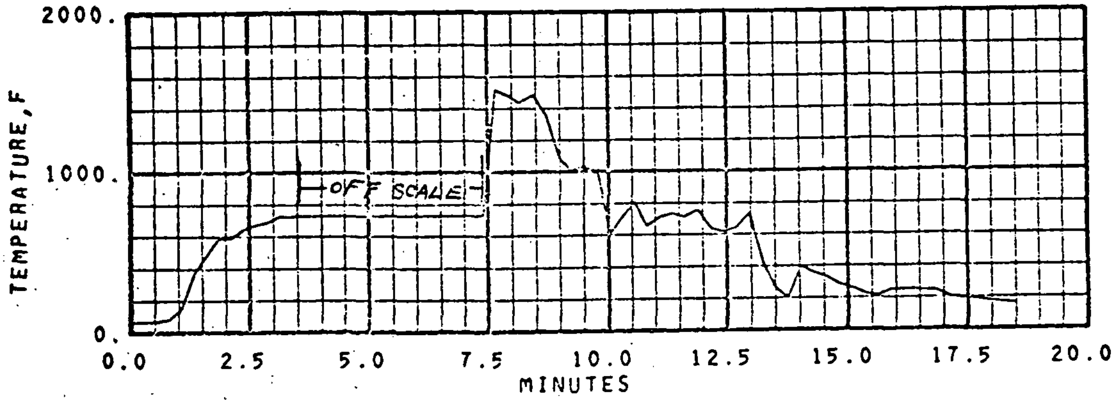
CHANNEL 24 10/10/72



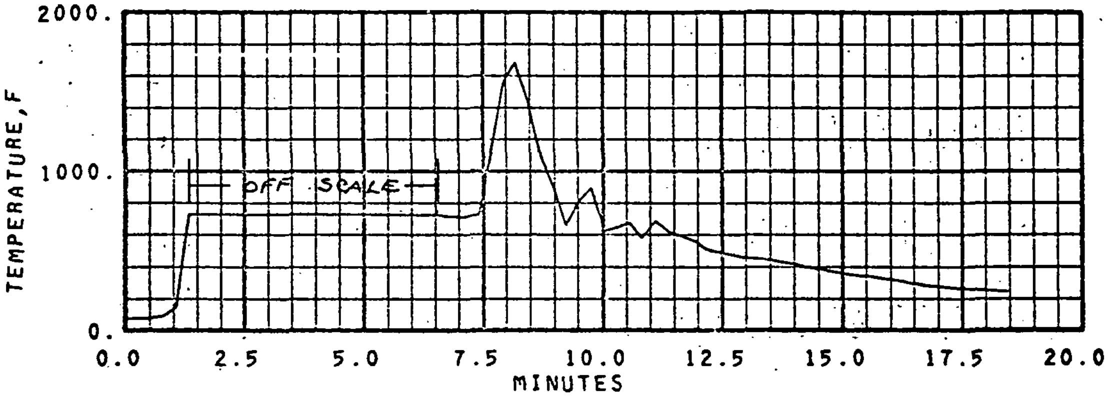
CHANNEL 25 10/10/72



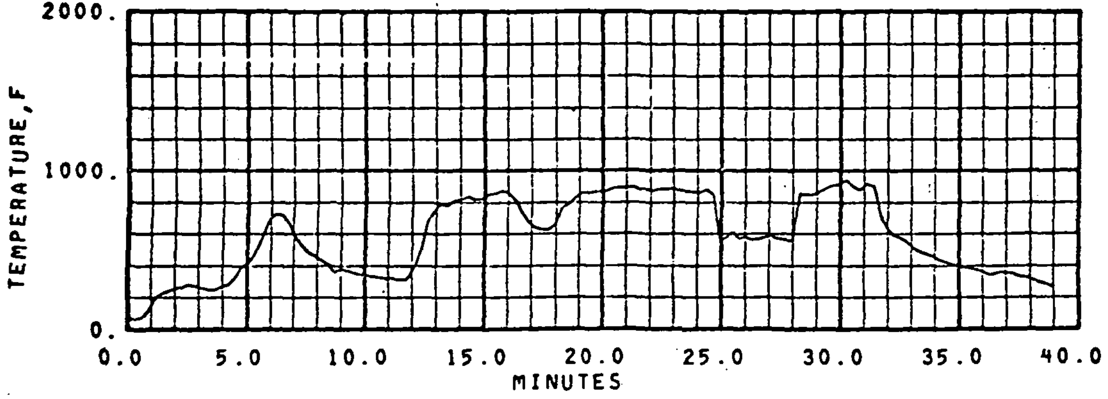
CHANNEL 26 10/10/72



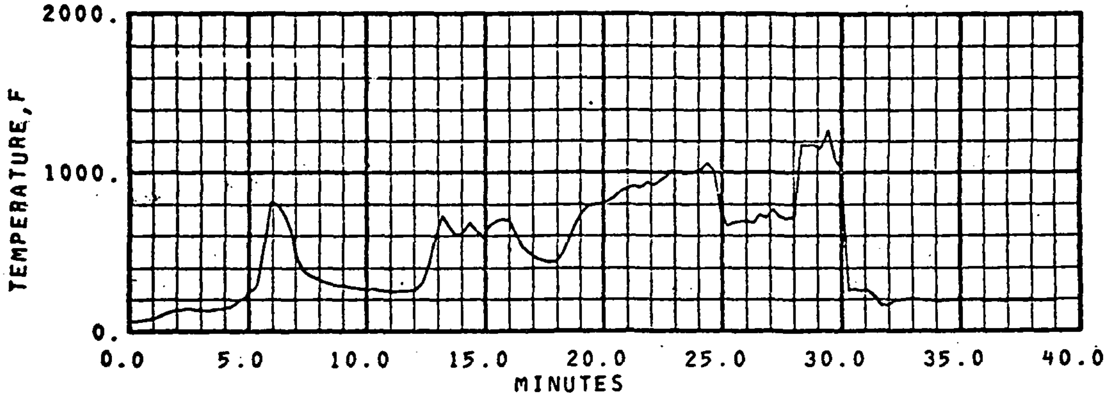
CHANNEL 27 10/10/72



CHANNEL 28 10/10/72



CHANNEL 0 10/17/72



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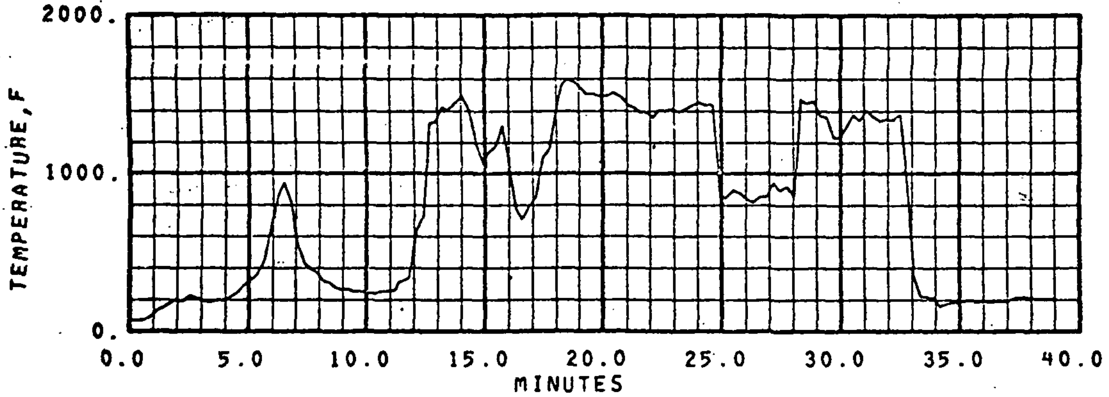
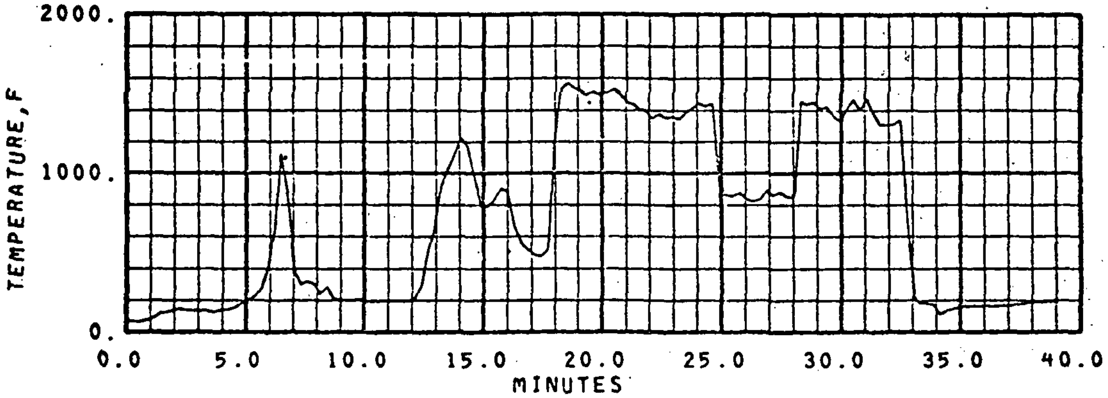
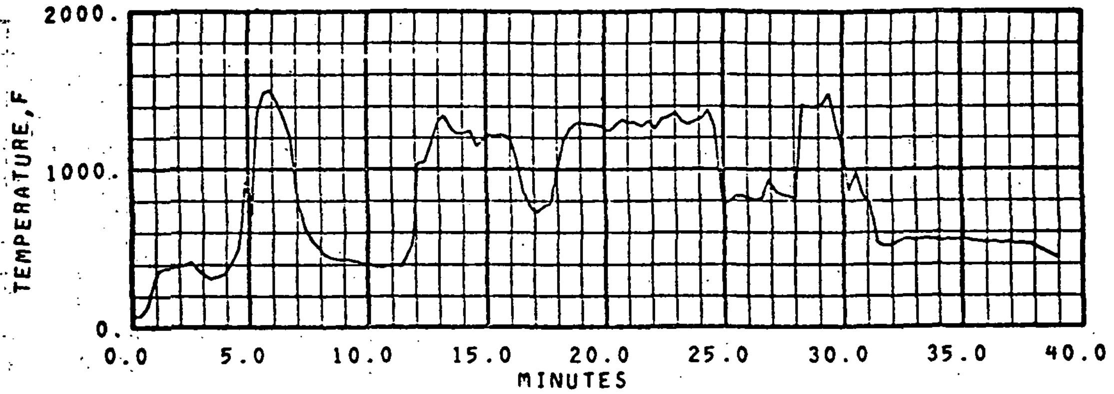


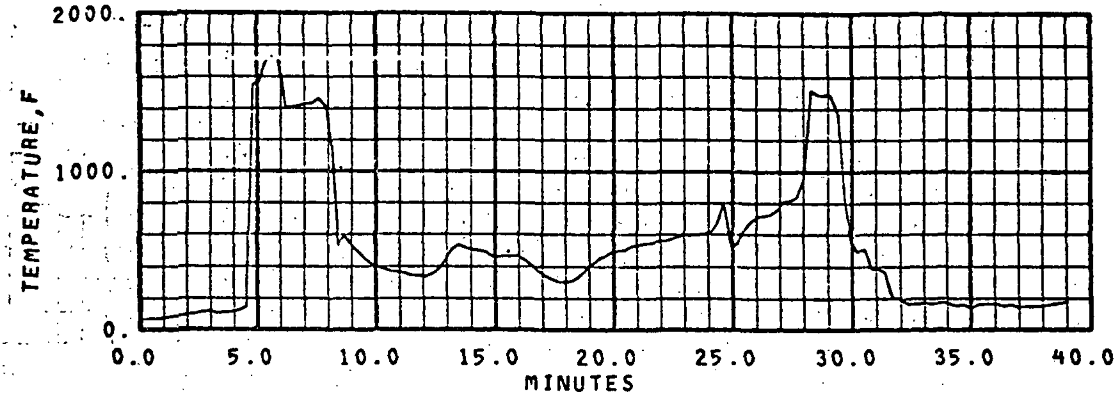
CHANNEL 3 10/17/72



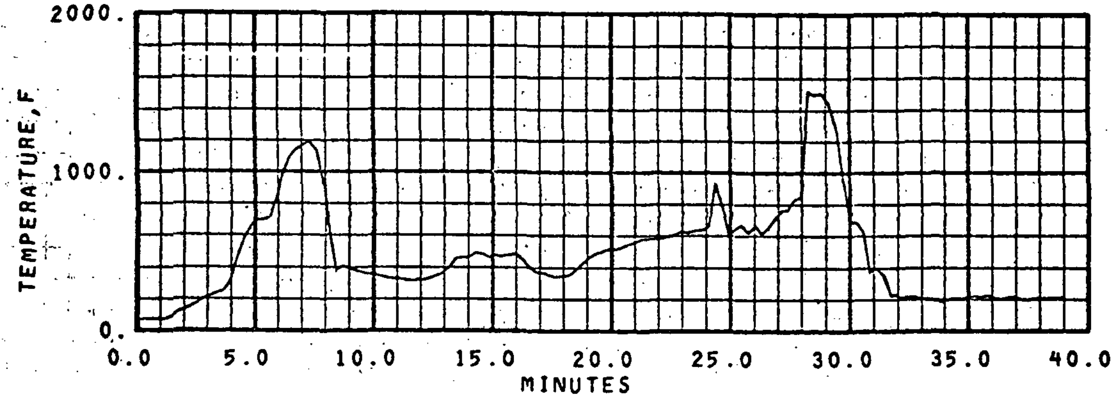
CHANNEL 4 10/17/72



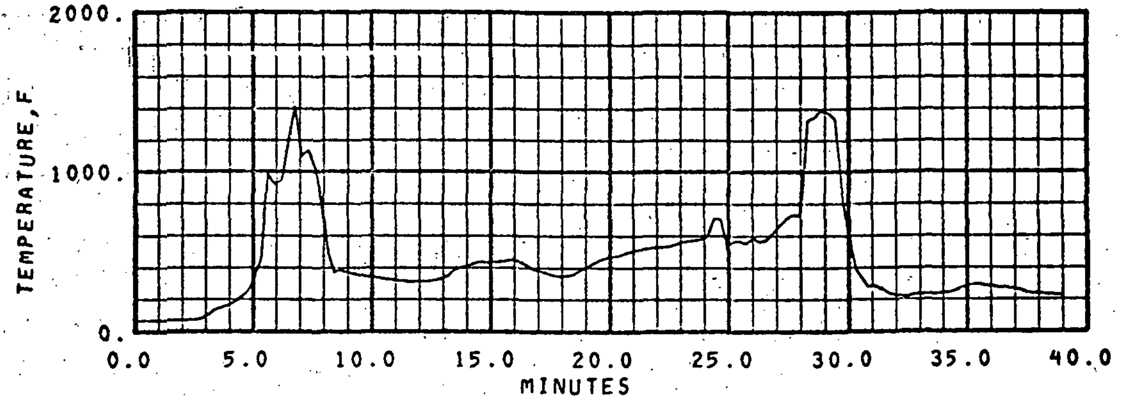
CHANNEL 5 10/17/72



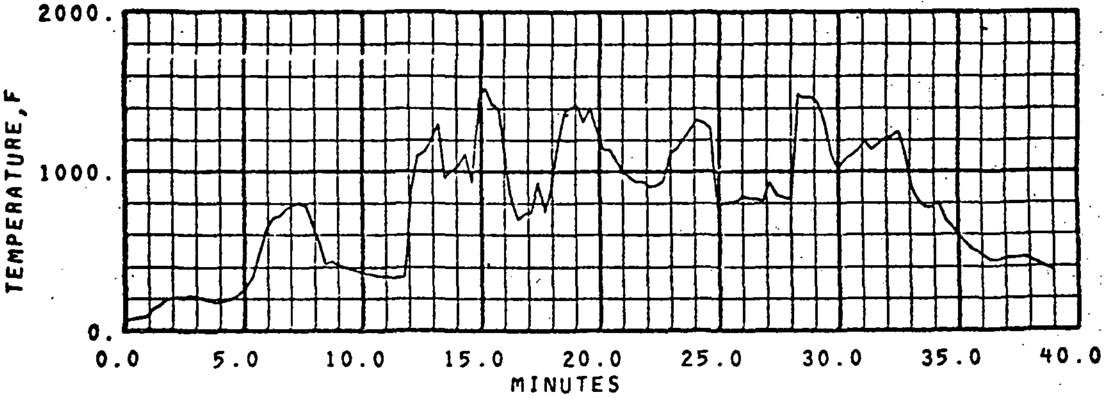
CHANNEL 6 10/17/72



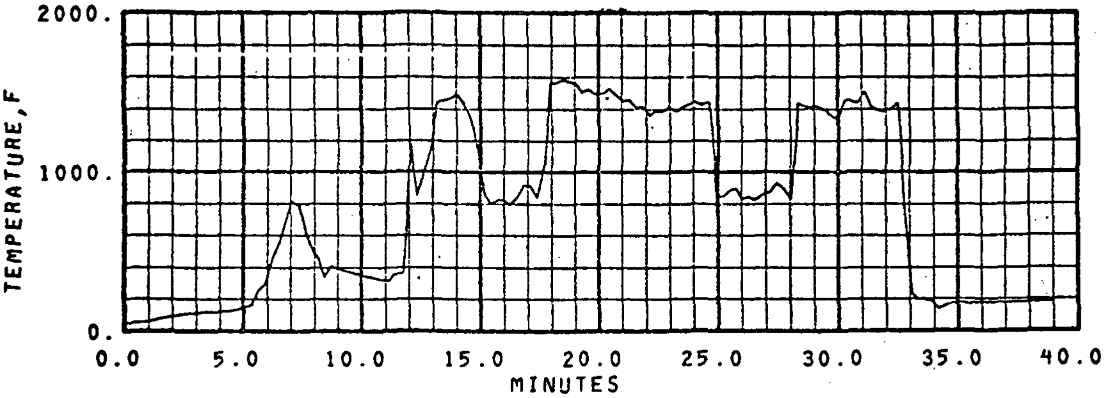
CHANNEL 7 10/17/72



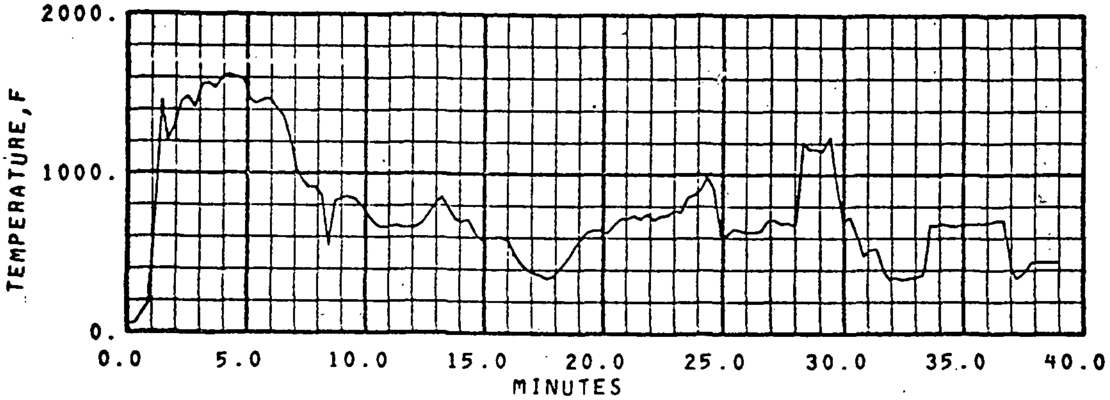
CHANNEL 8 10/17/72



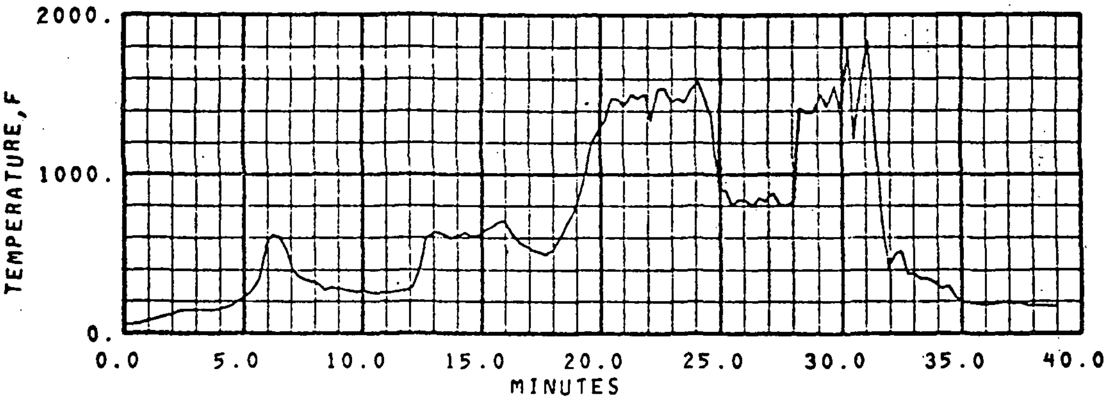
CHANNEL 9 10/17/72



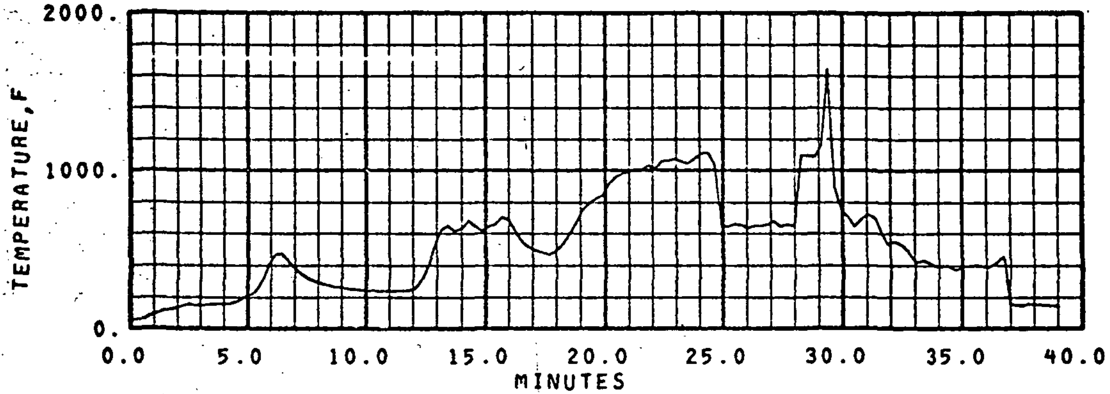
CHANNEL 10 10/17/72



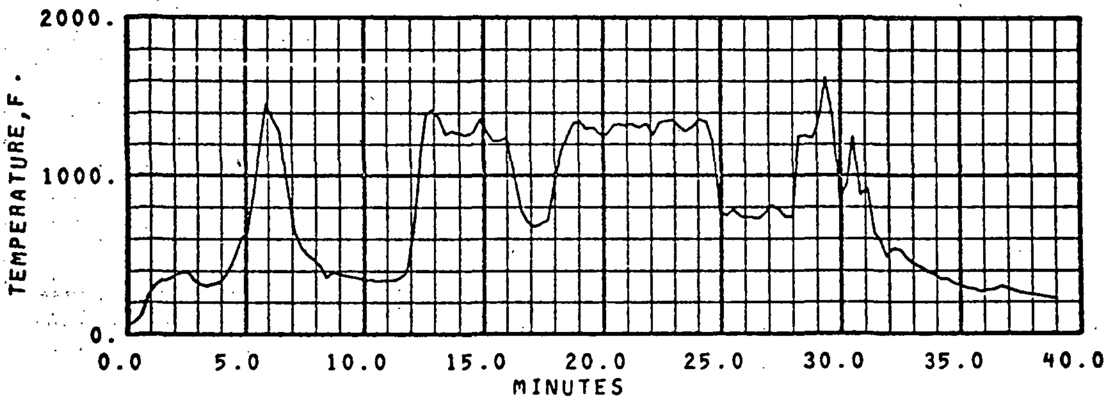
CHANNEL 11 10/17/72



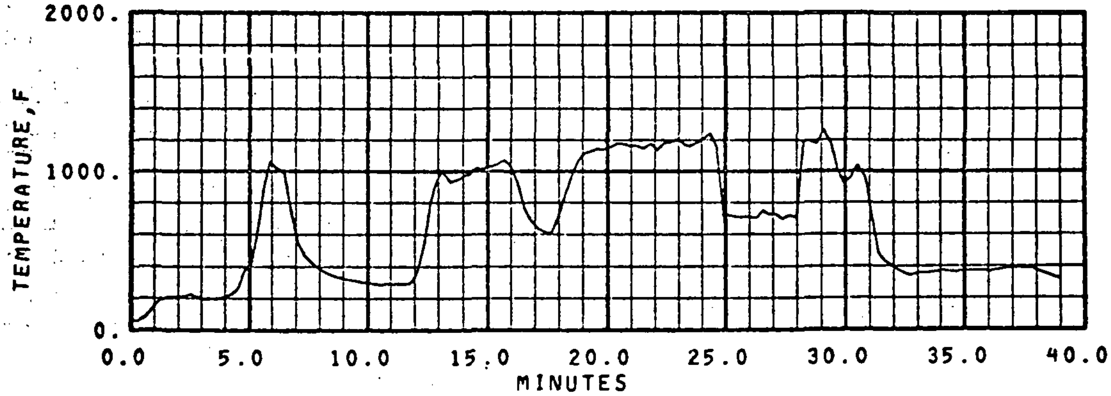
CHANNEL 12 10/17/72



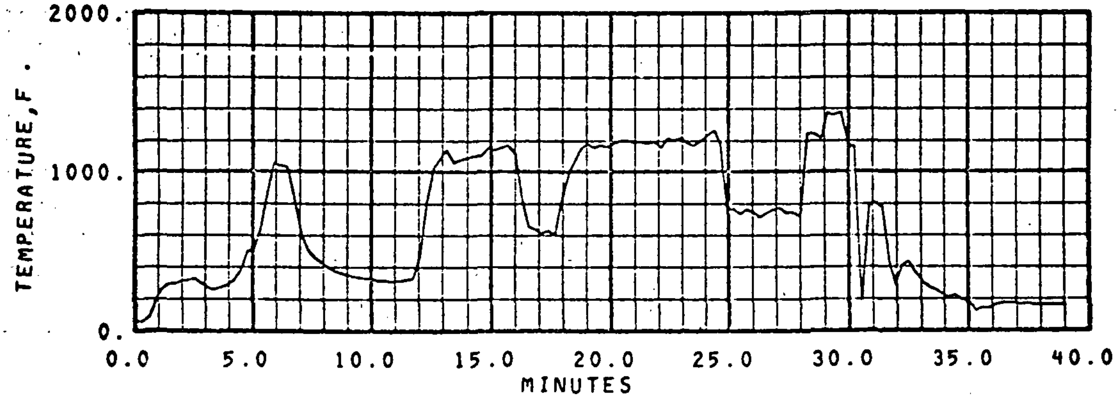
CHANNEL 13 10/17/72



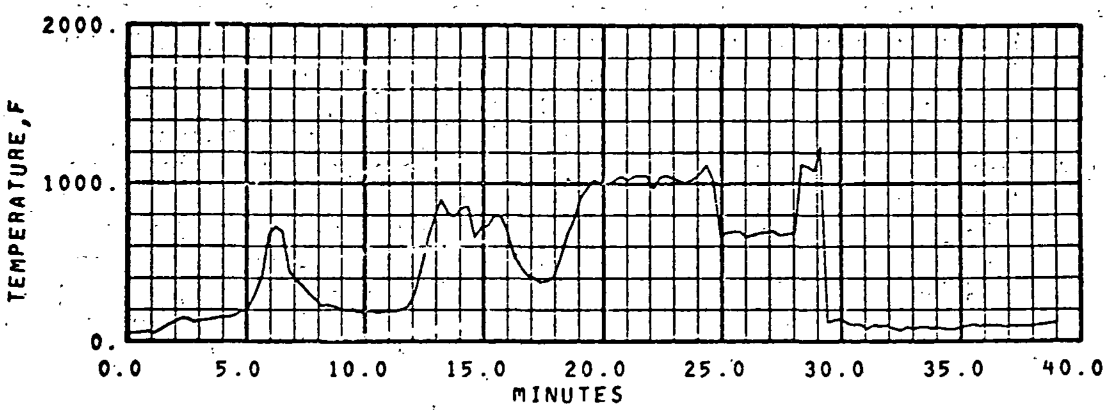
CHANNEL 14 10/17/72



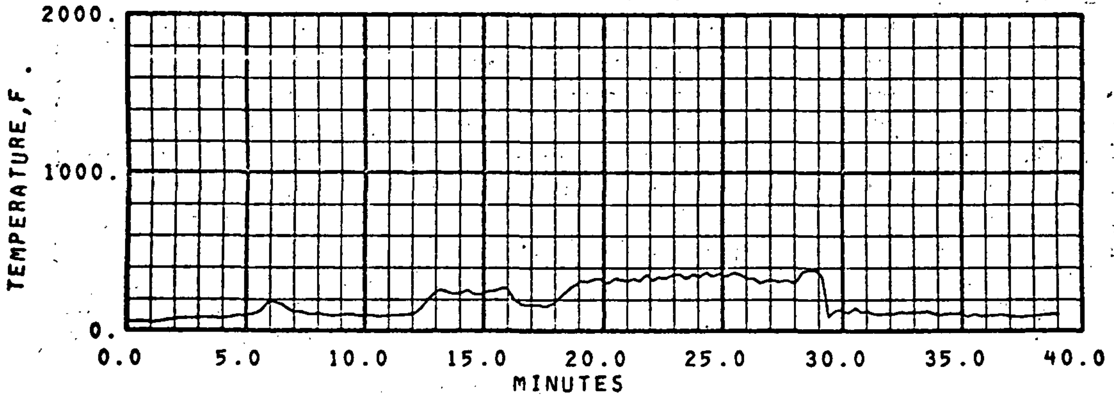
CHANNEL 15 10/17/72



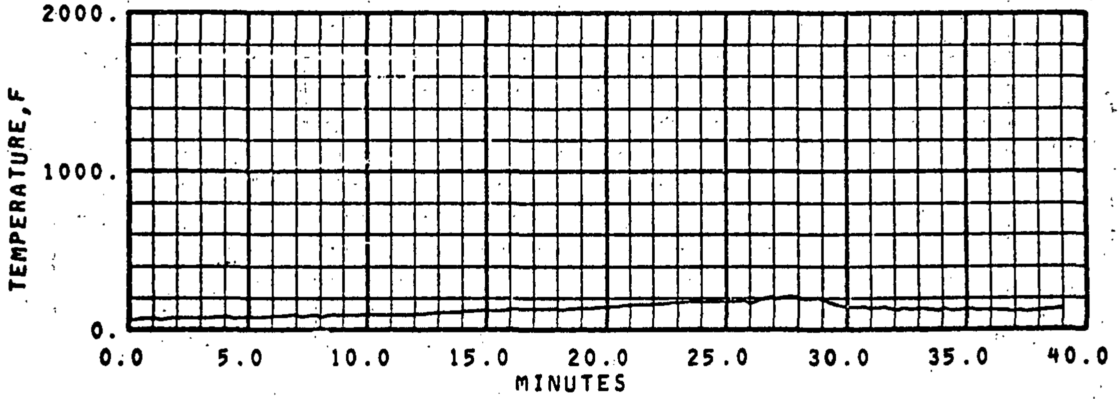
CHANNEL 16 10/17/72



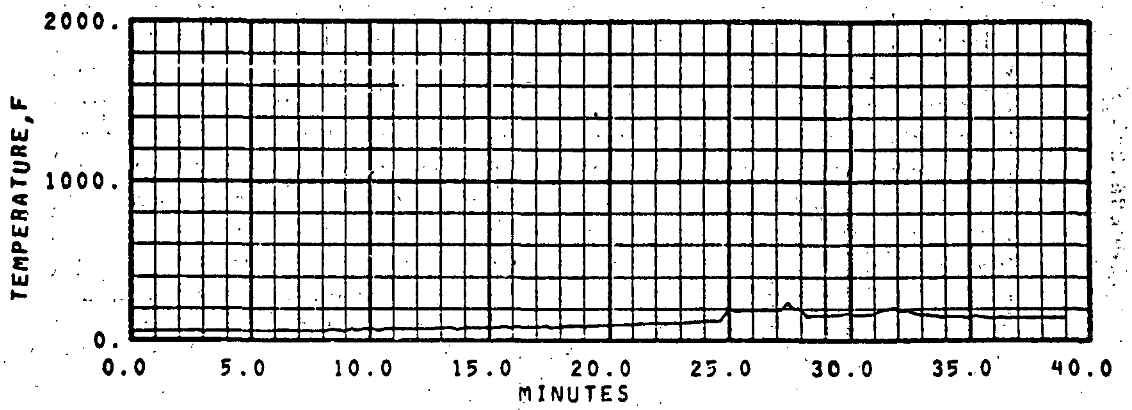
CHANNEL 17 10/17/72



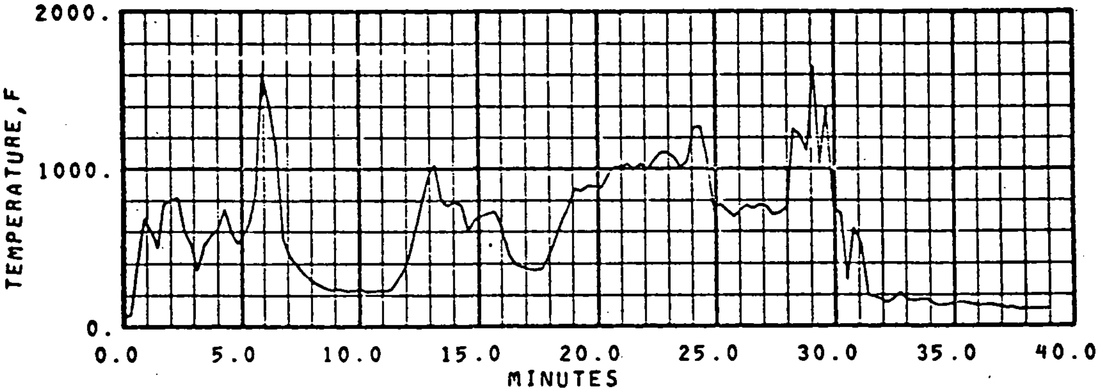
CHANNEL 18 10/17/72



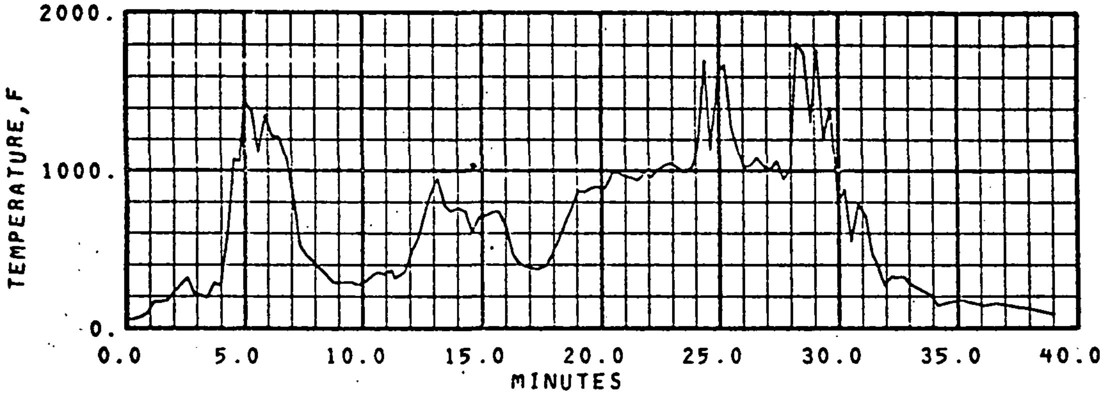
CHANNEL 19 10/17/72



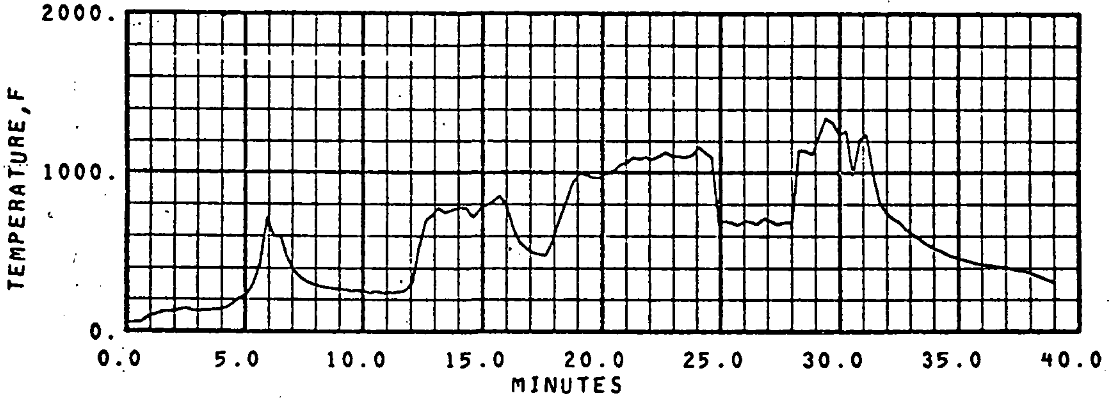
CHANNEL 20 10/17/72



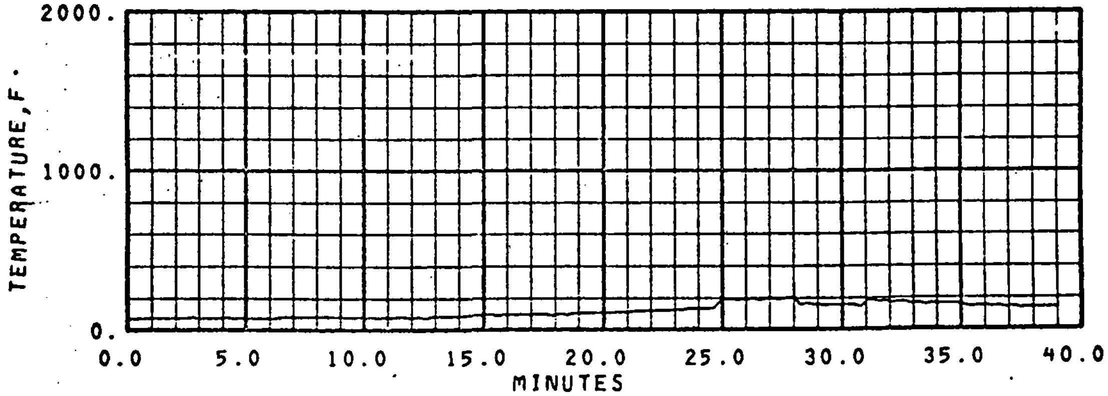
CHANNEL 21 10/17/72



CHANNEL 22 10/17/72



CHANNEL 23 10/17/72



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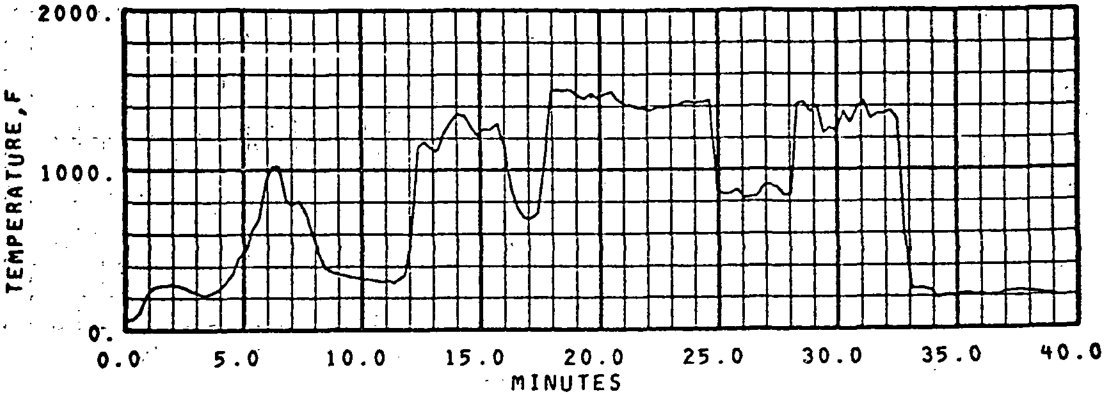
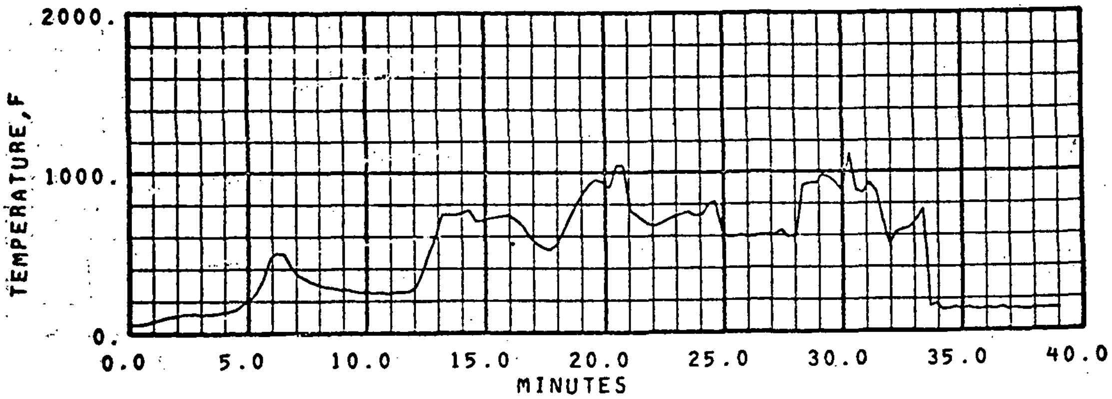
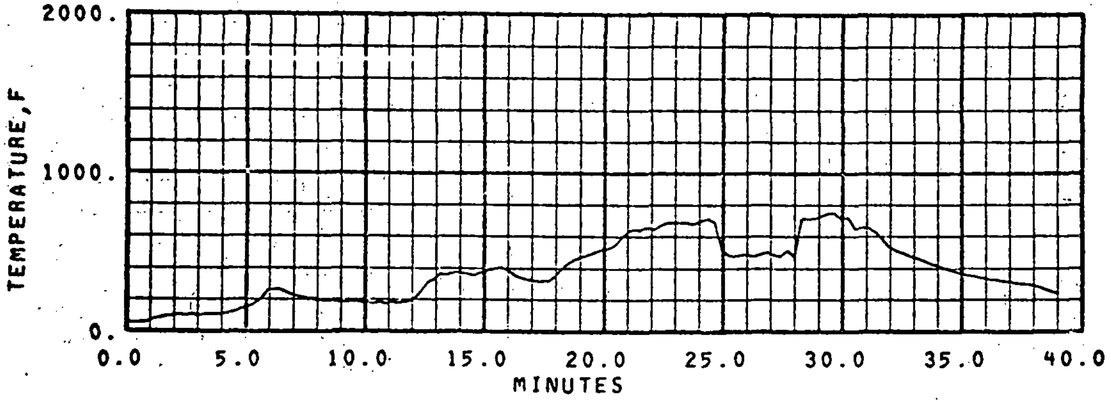


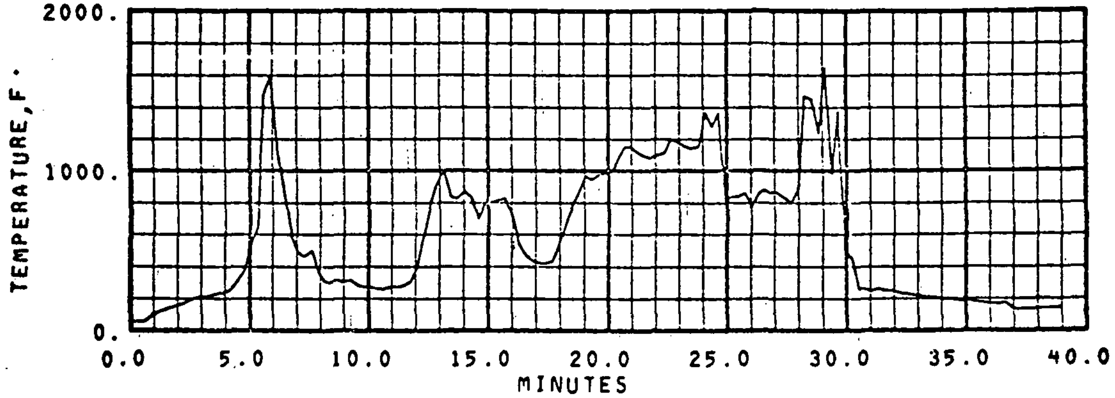
CHANNEL 25 10/17/72



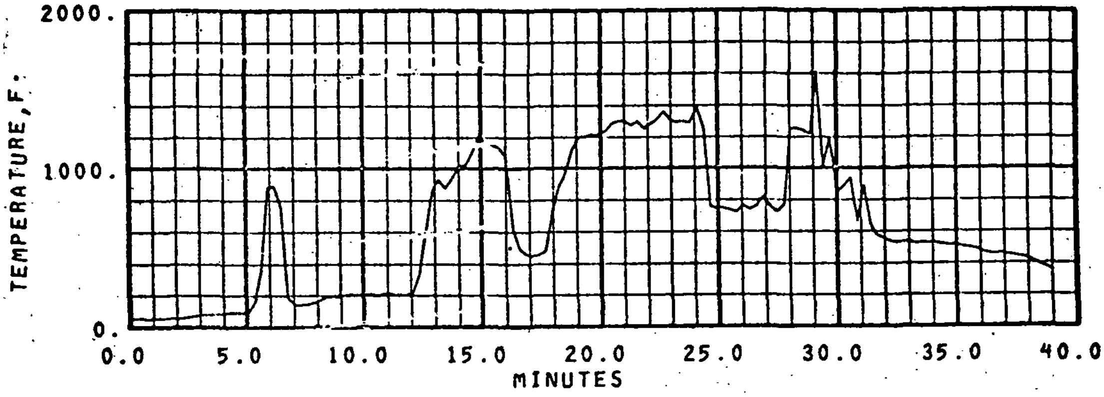
CHANNEL 26 10/17/72



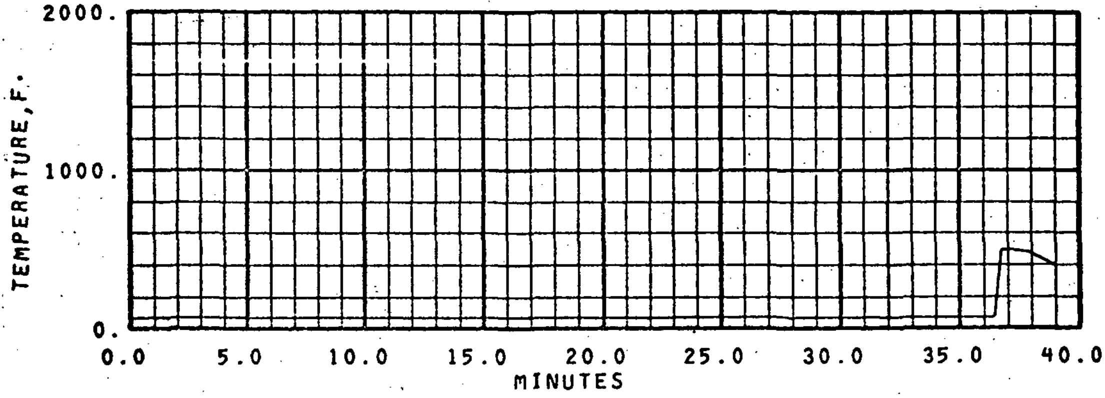
CHANNEL 27 10/17/72



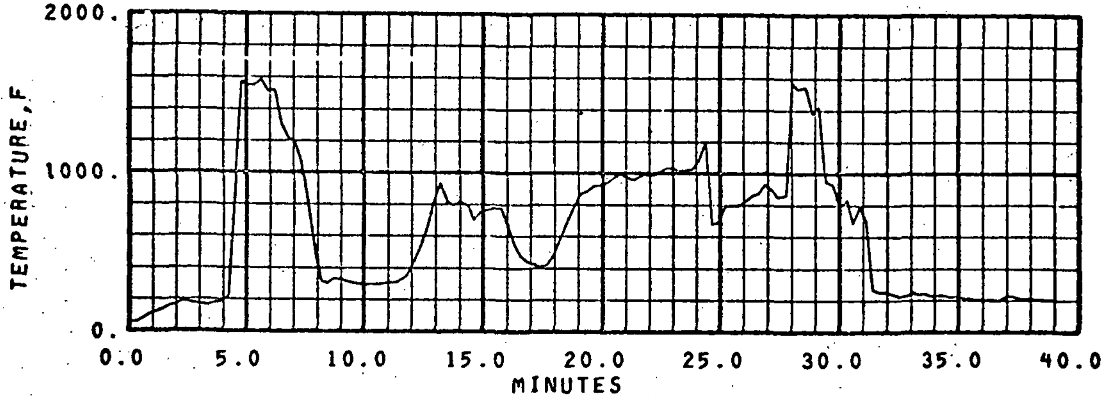
CHANNEL 28 10/17/72



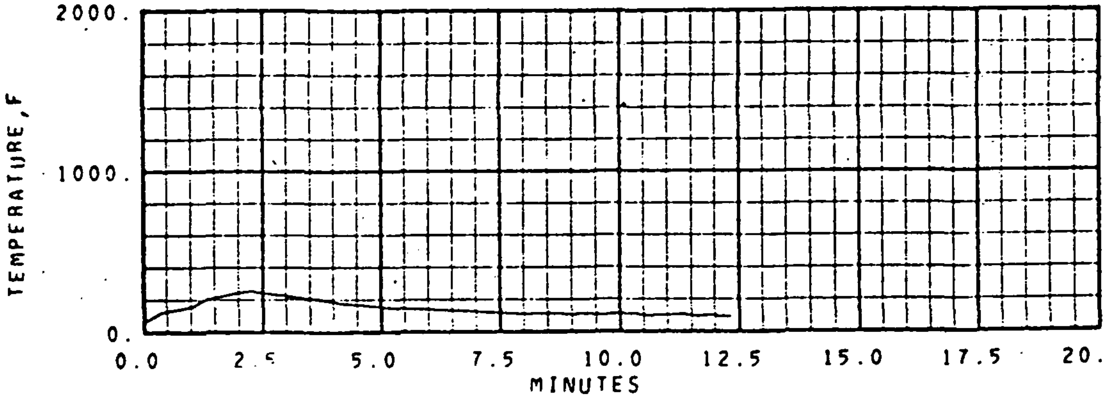
CHANNEL 36 10/17/72



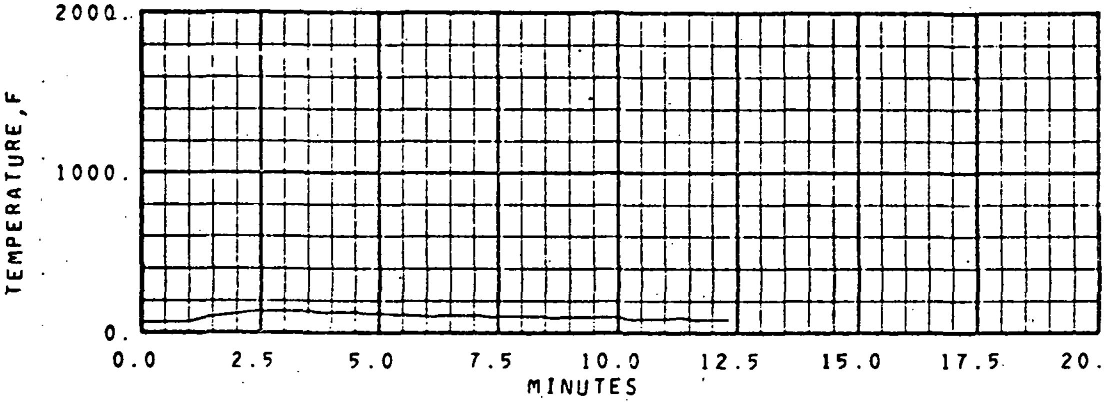
CHANNEL 37 10/17/72



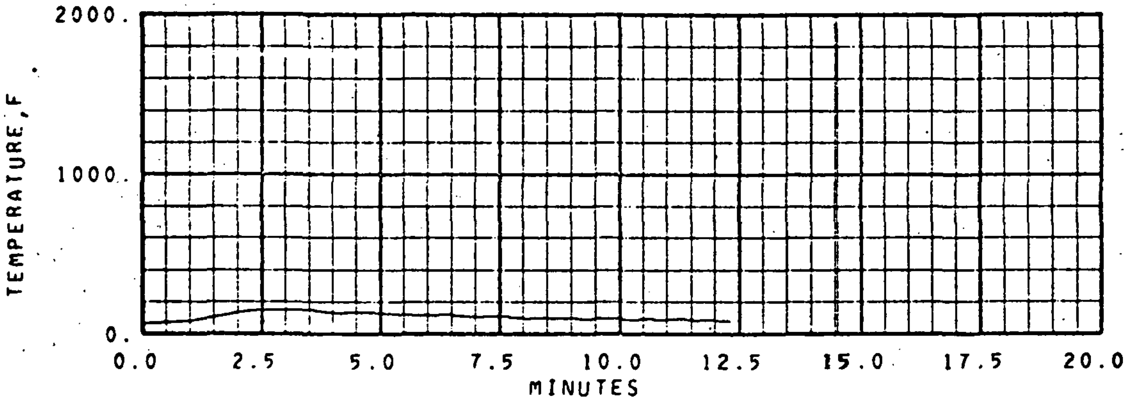
CHANNEL 38 10/17/72



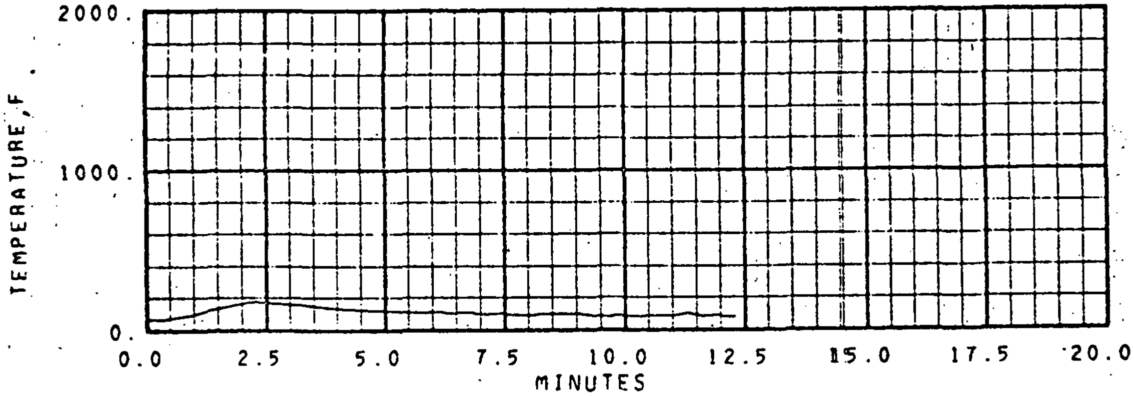
CHANNEL 0 10/24/72



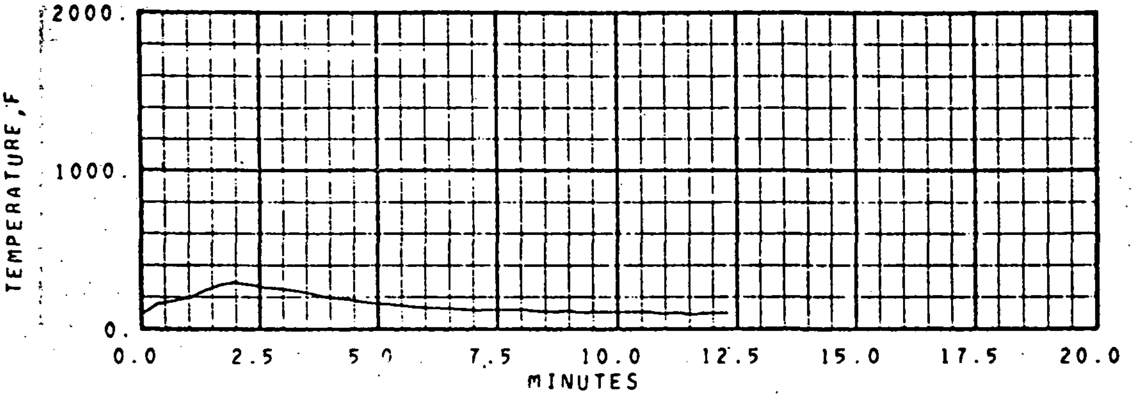
CHANNEL 1 10/24/72



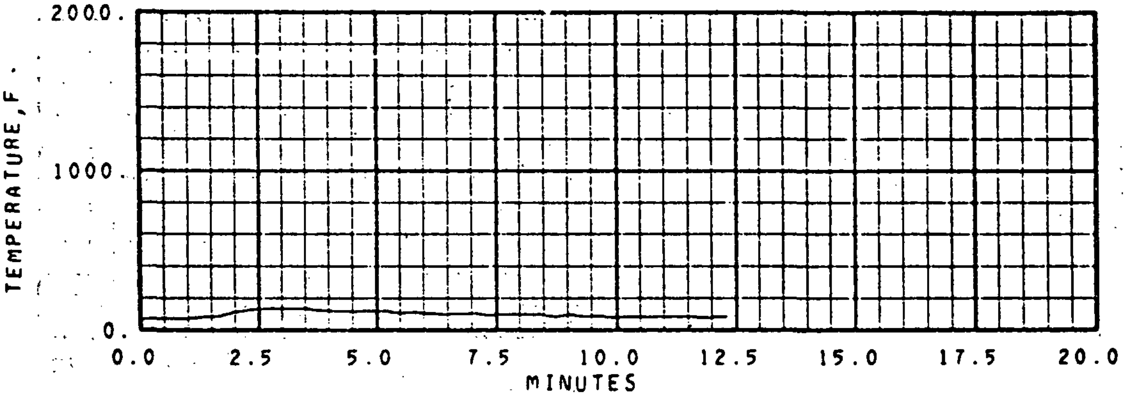
CHANNEL 3 10/24/72



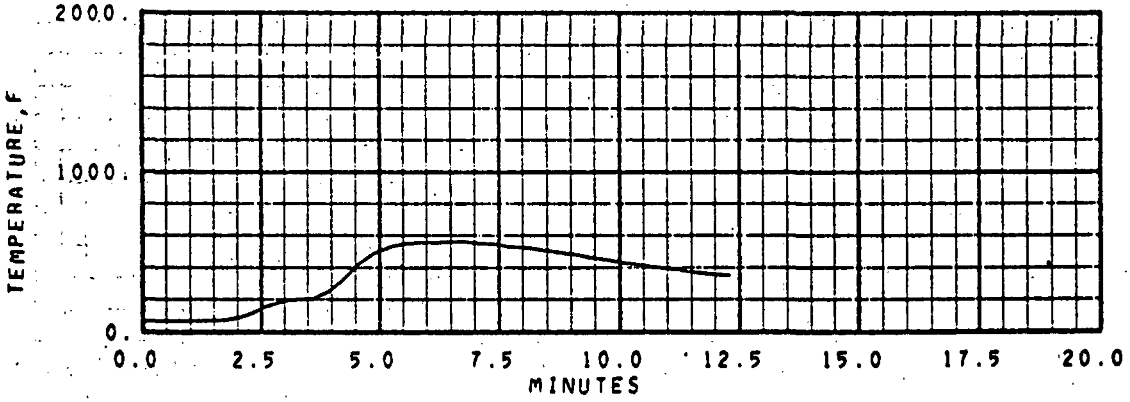
CHANNEL 4 10/24/72



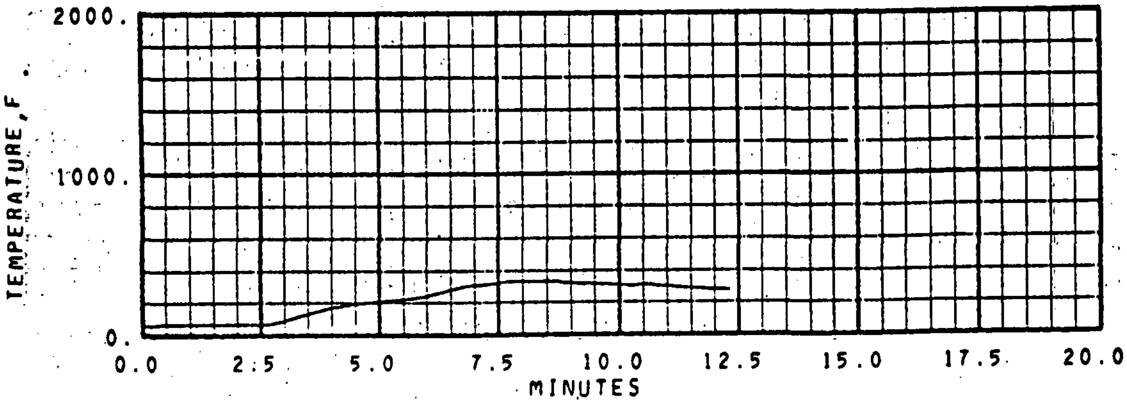
CHANNEL 5 10/24/72



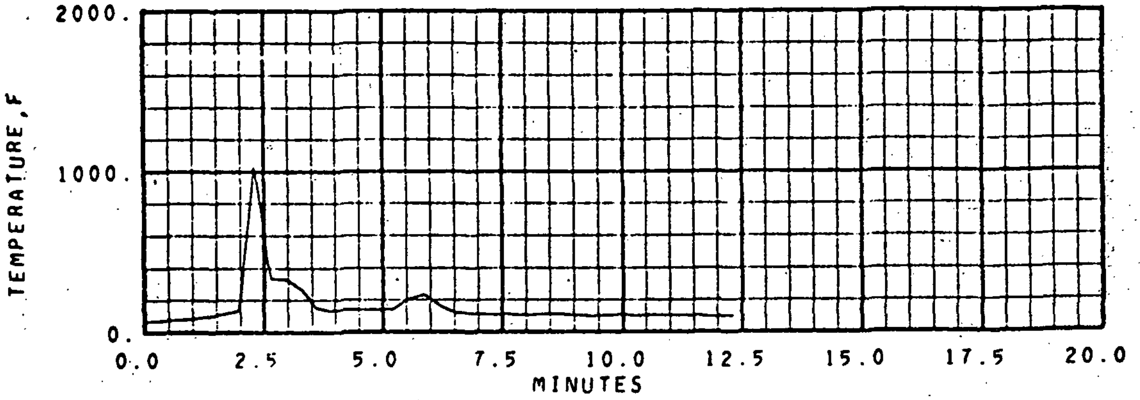
CHANNEL 6 10/24/72



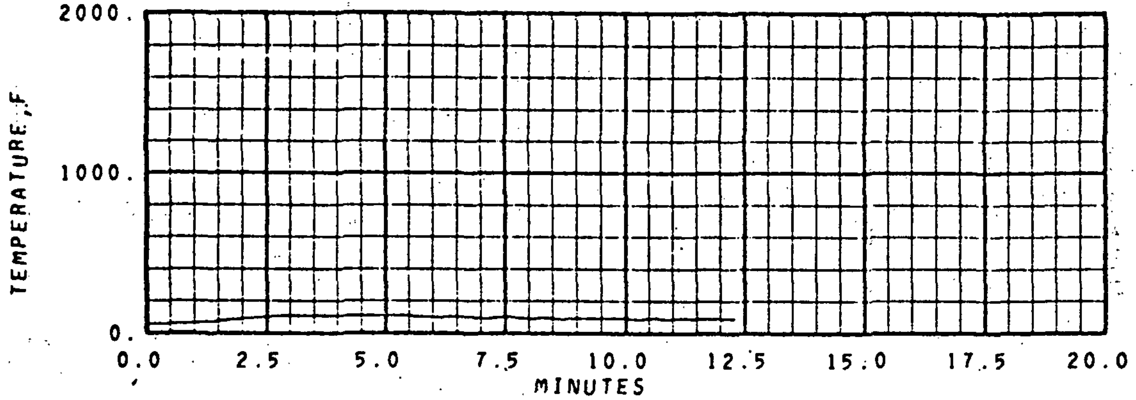
CHANNEL 7 10/24/72



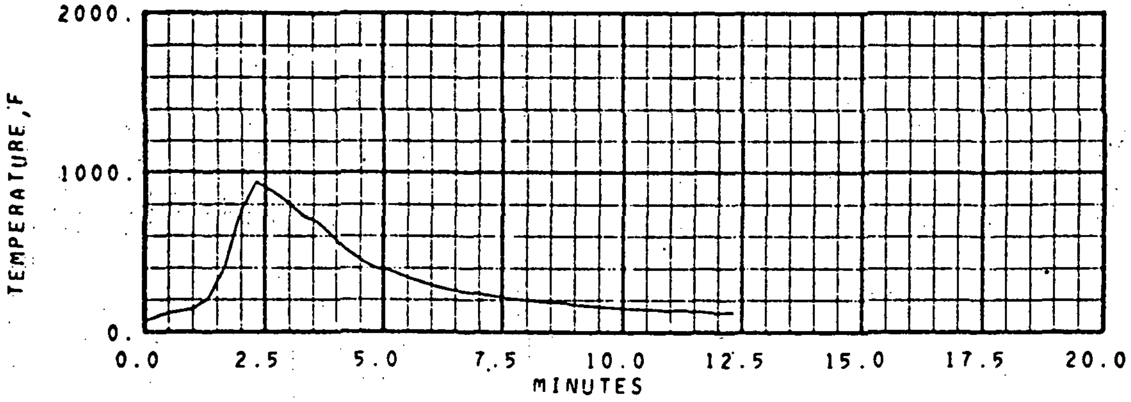
CHANNEL 8 10/24/72



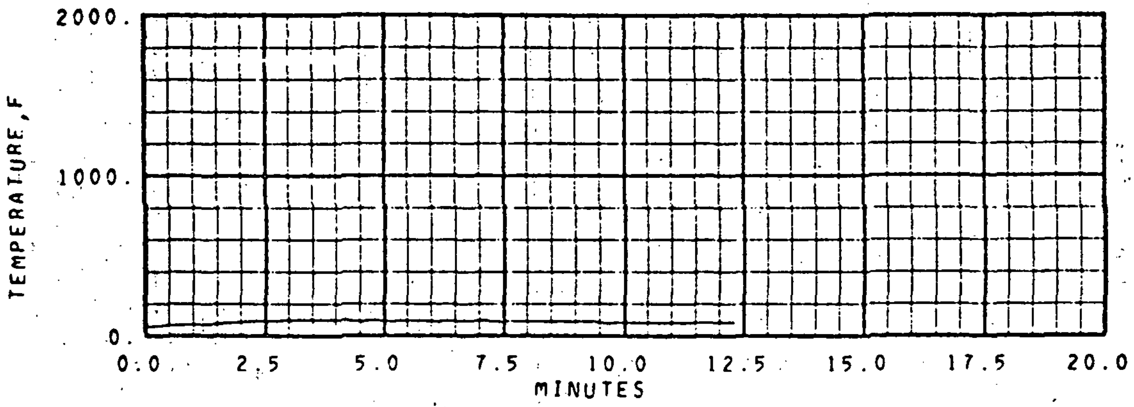
CHANNEL 9 10/24/72



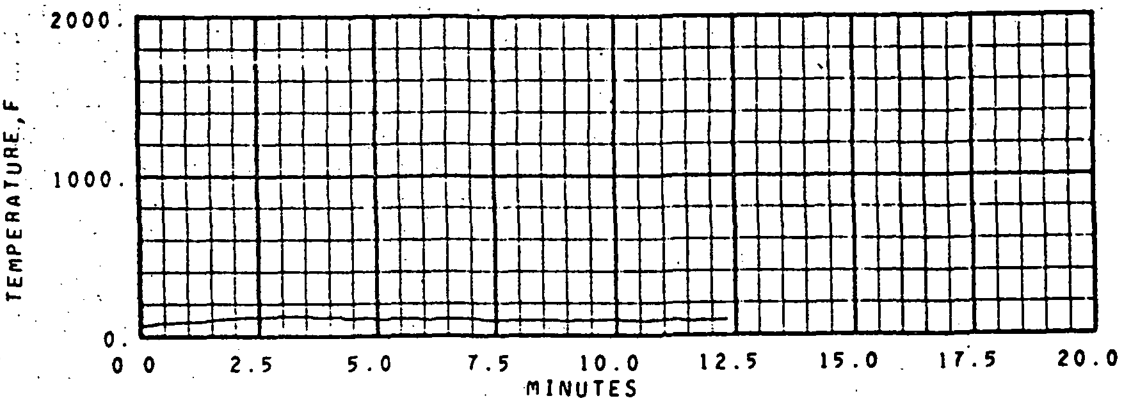
CHANNEL 10 10/24/72



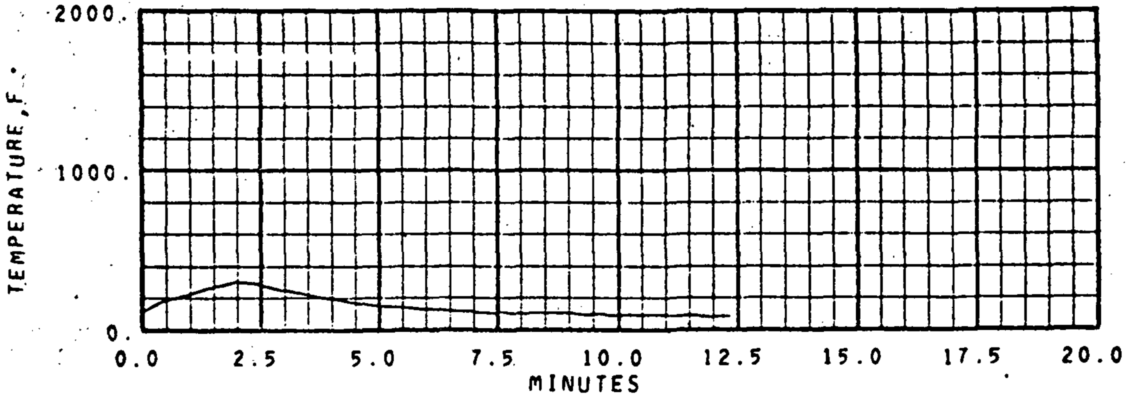
CHANNEL 11 10/24/72



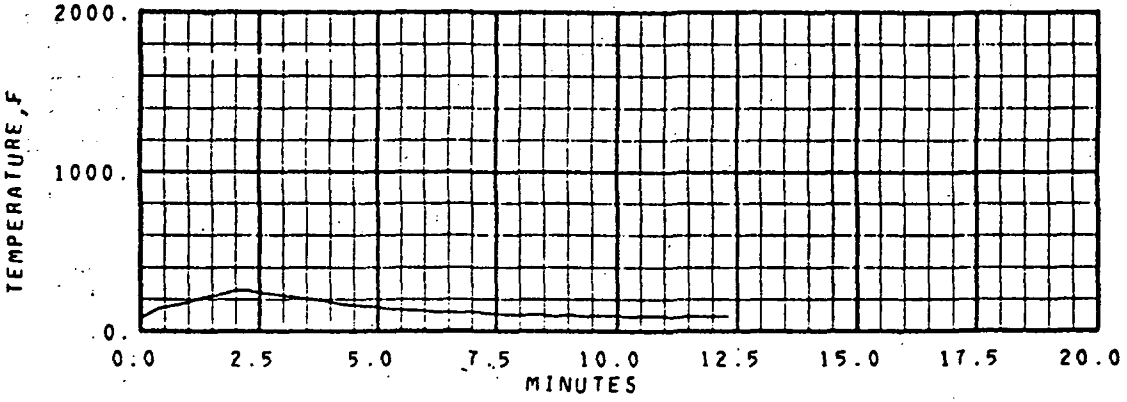
CHANNEL 12 10/24/72



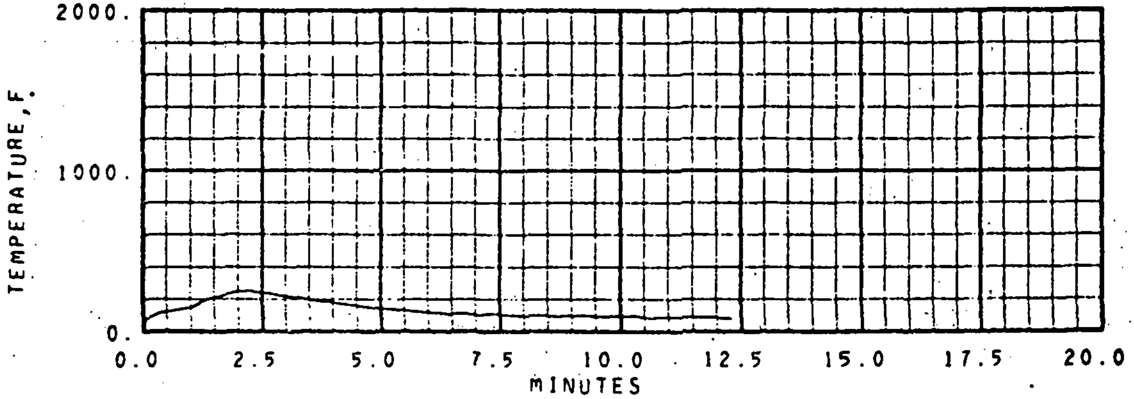
CHANNEL 13 10/24/72



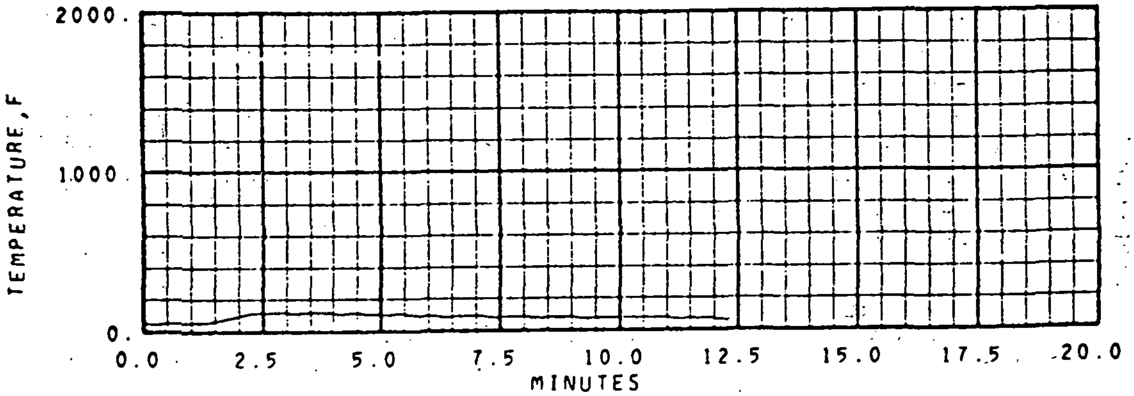
CHANNEL 14 10/24/72



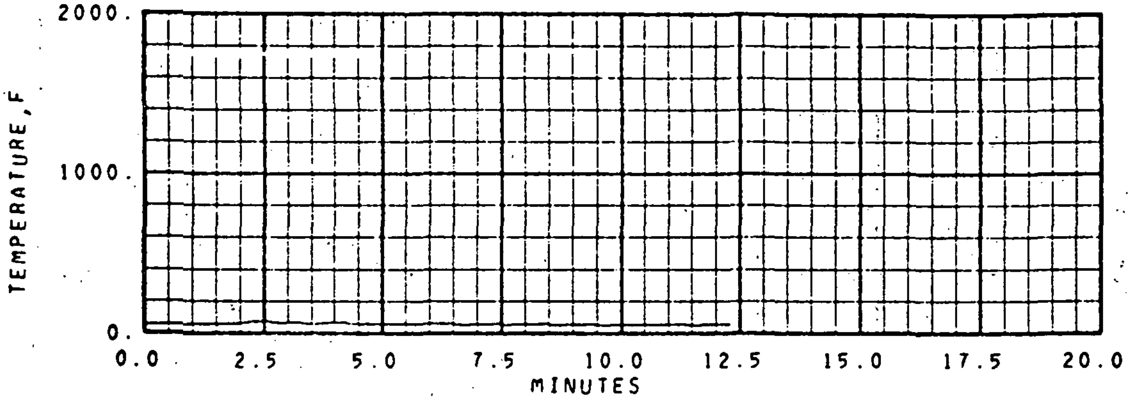
CHANNEL 15 10/24/72



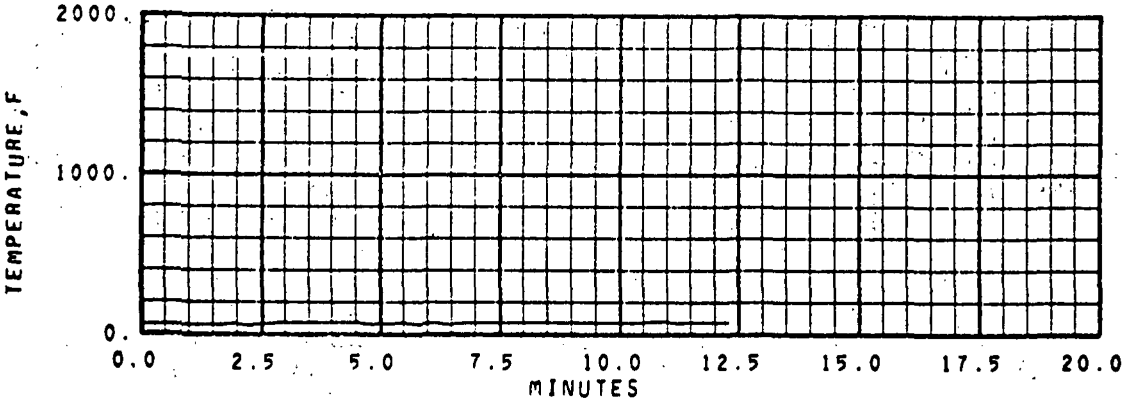
CHANNEL 16 10/24/72



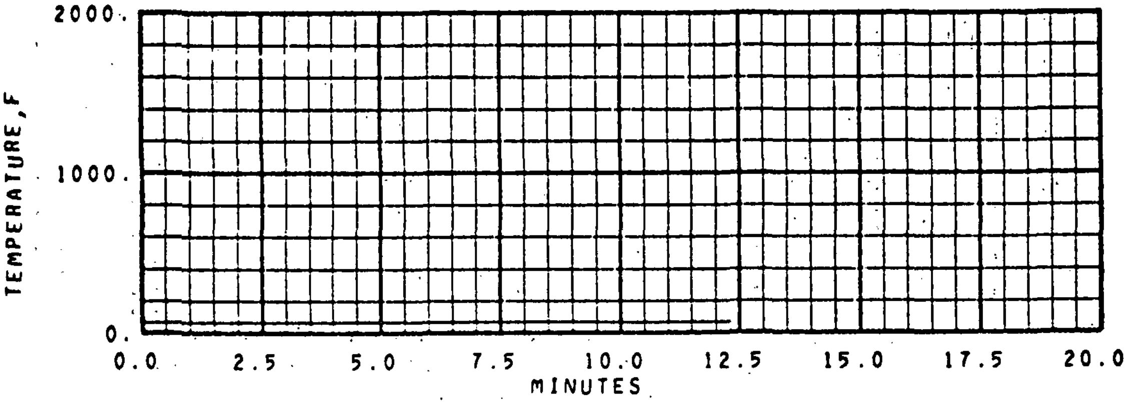
CHANNEL 17 10/24/72



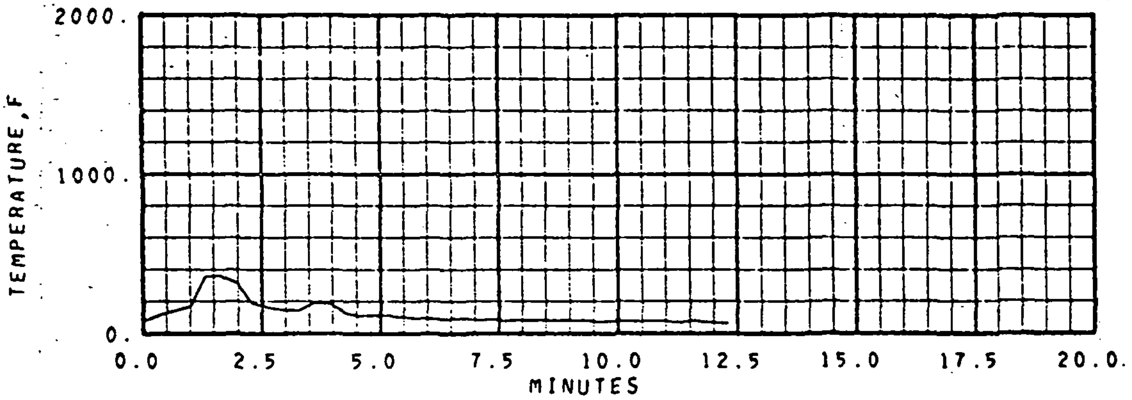
CHANNEL 18 10/24/72



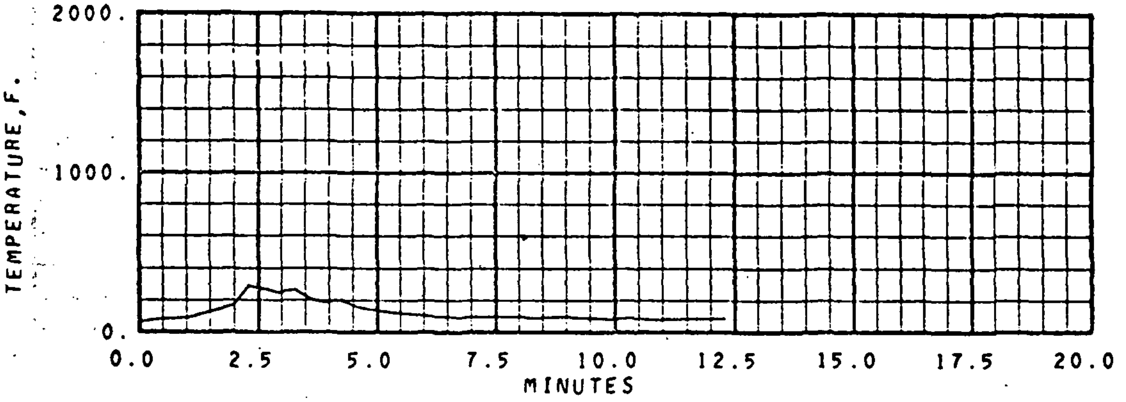
CHANNEL 19 10/24/72



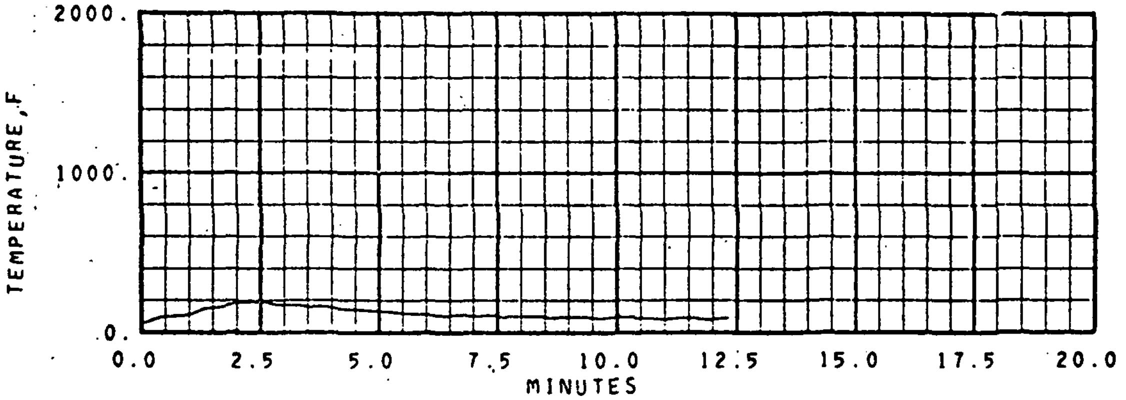
CHANNEL 20 10/24/72



CHANNEL 21 10/24/72



CHANNEL 22 10/24/72



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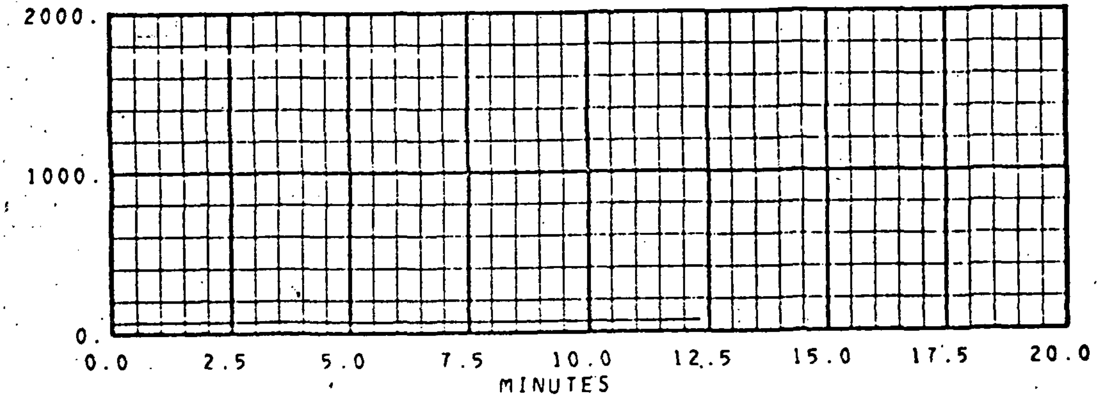
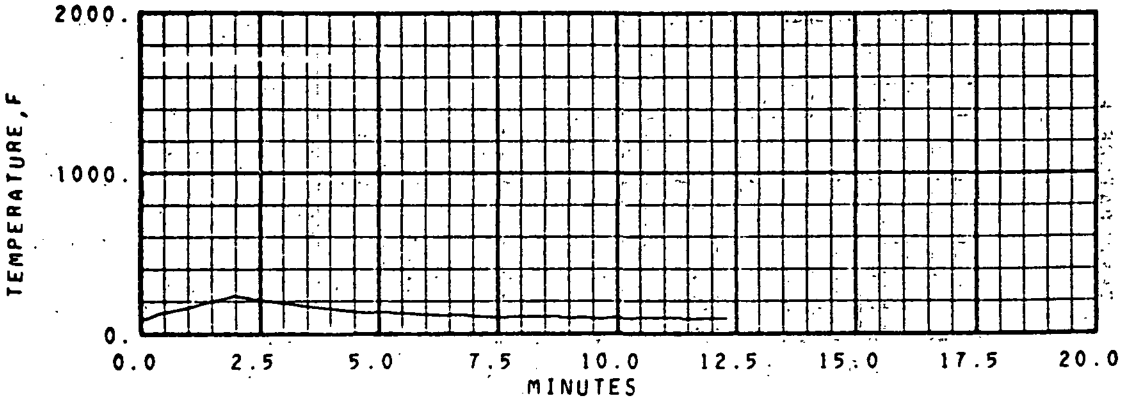
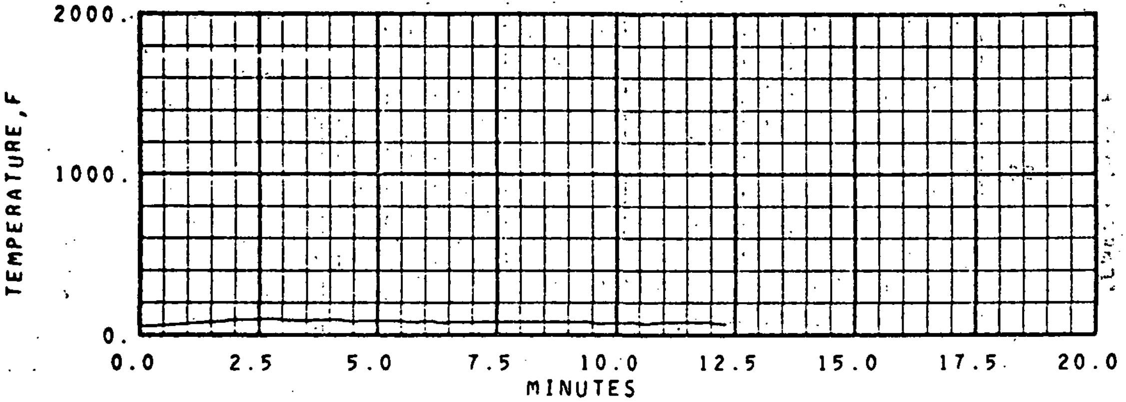


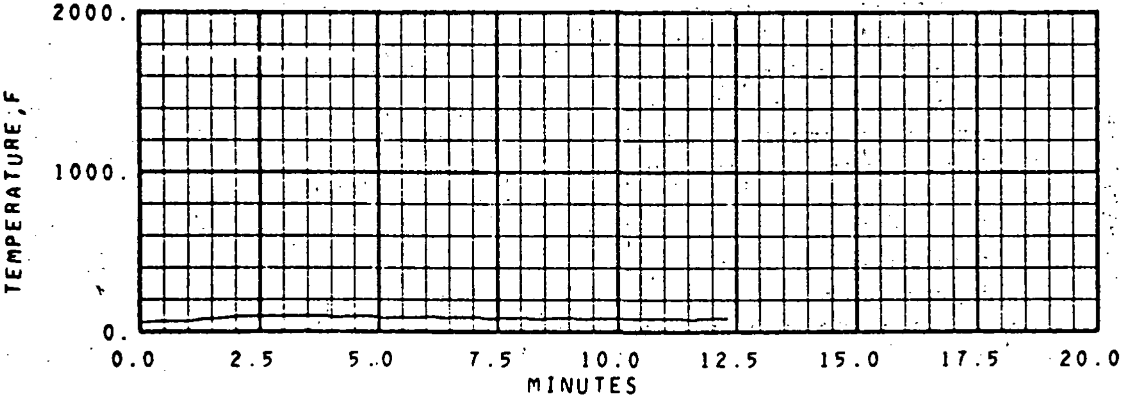
CHANNEL 24 10/24/72



CHANNEL 25 10/24/72



CHANNEL 26 10/24/72



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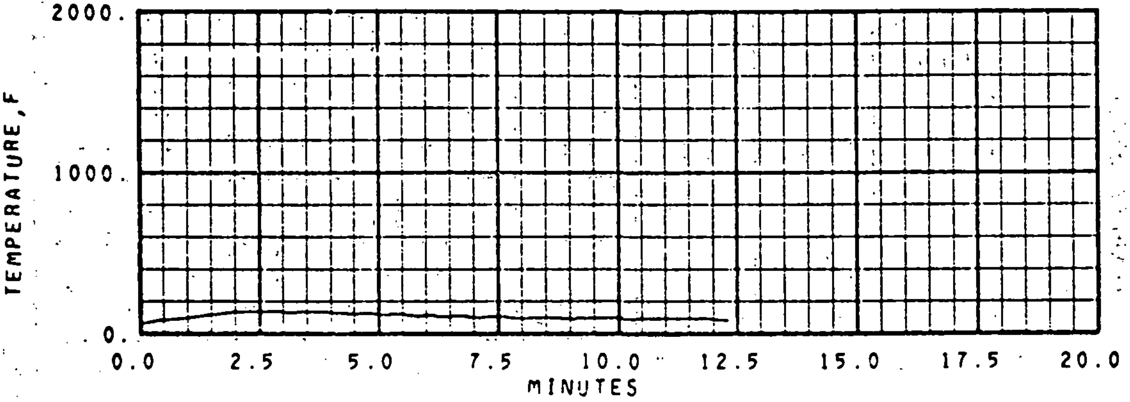
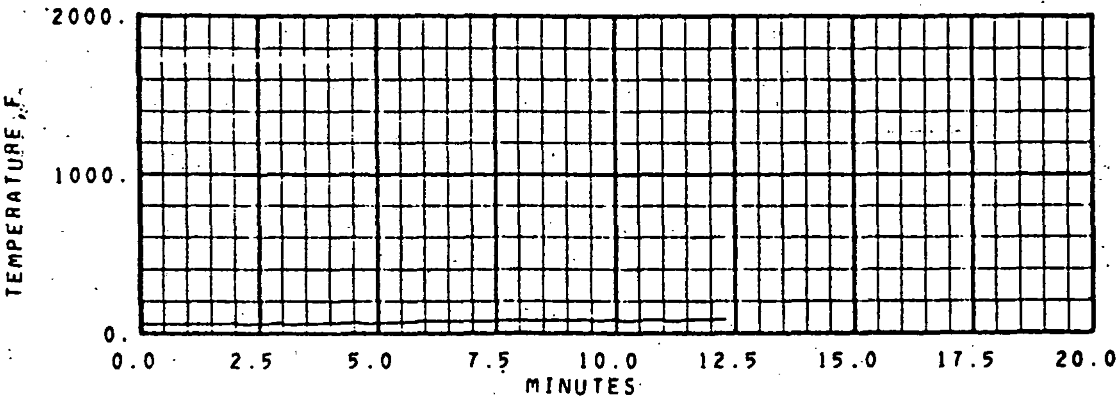
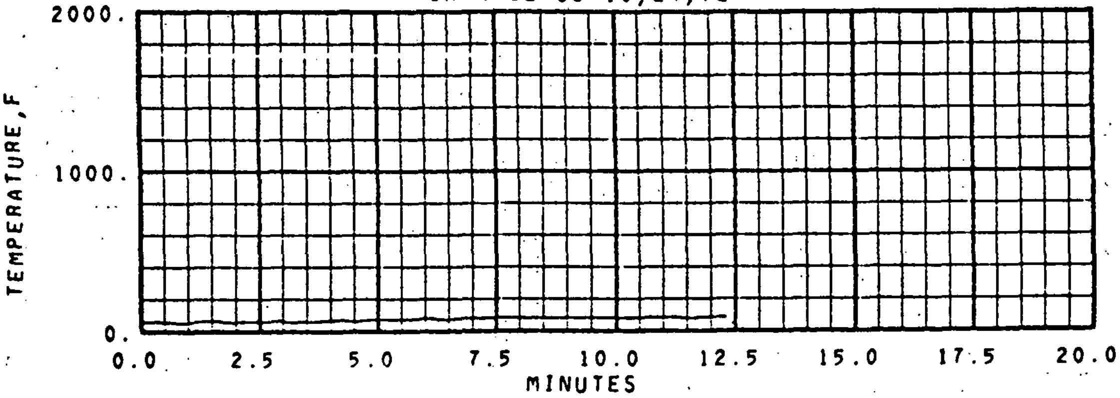


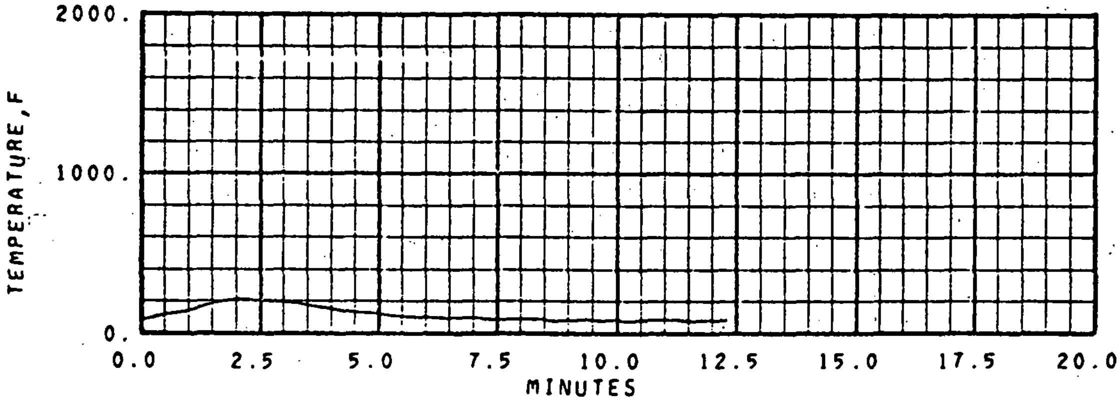
CHANNEL 28 10/24/72



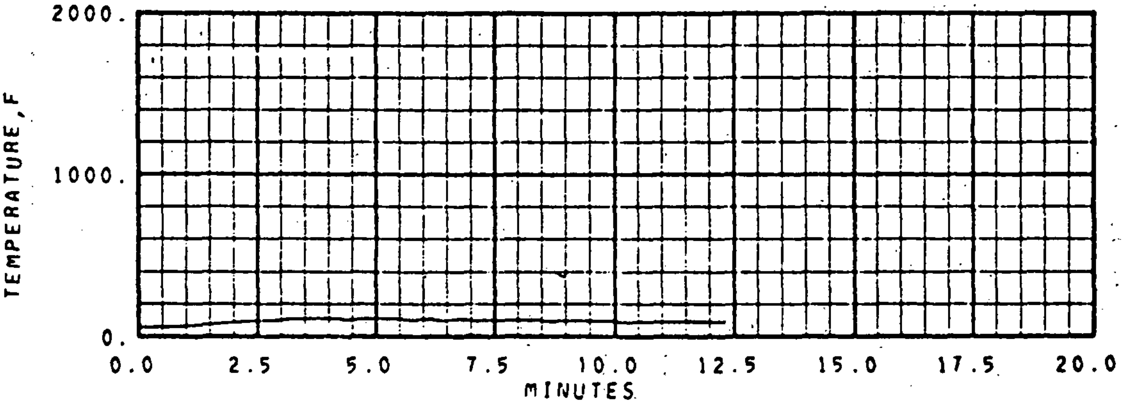
CHANNEL 36 10/24/72



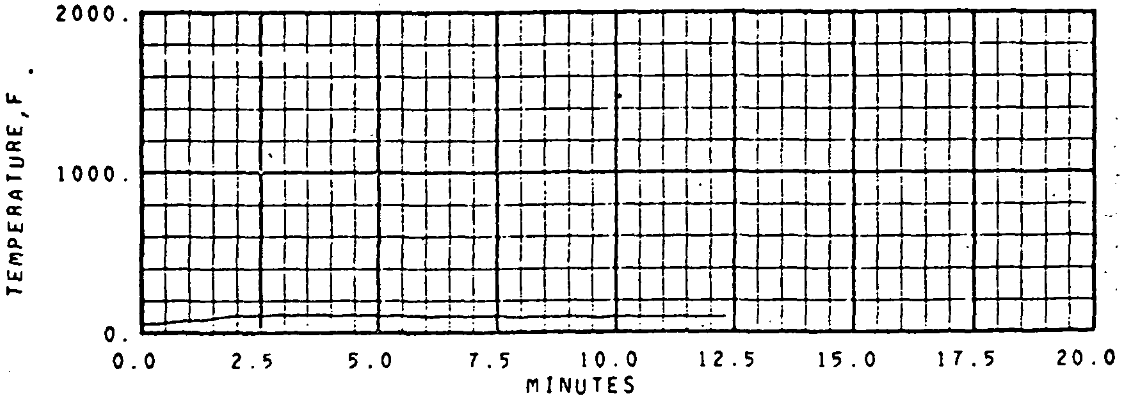
CHANNEL 37 10/24/72



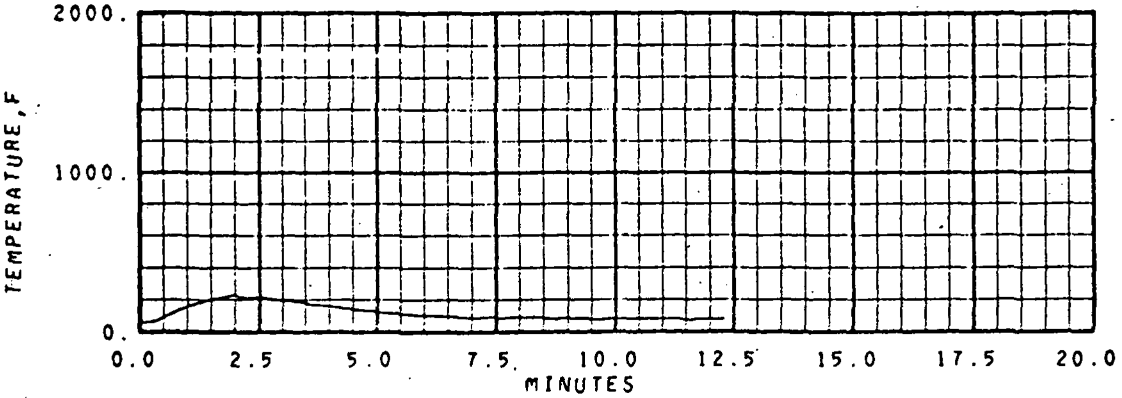
CHANNEL 38 10/24/72



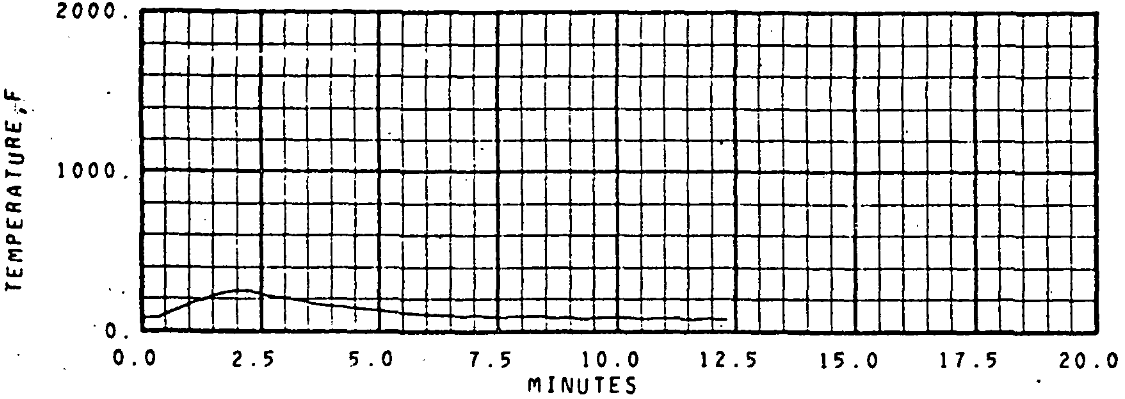
CHANNEL 39 10/24/72



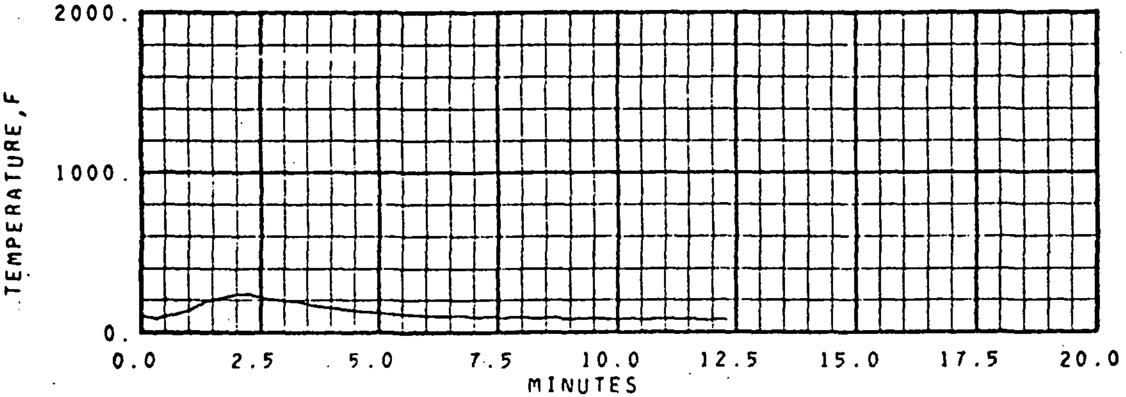
CHANNEL 40 10/24/72



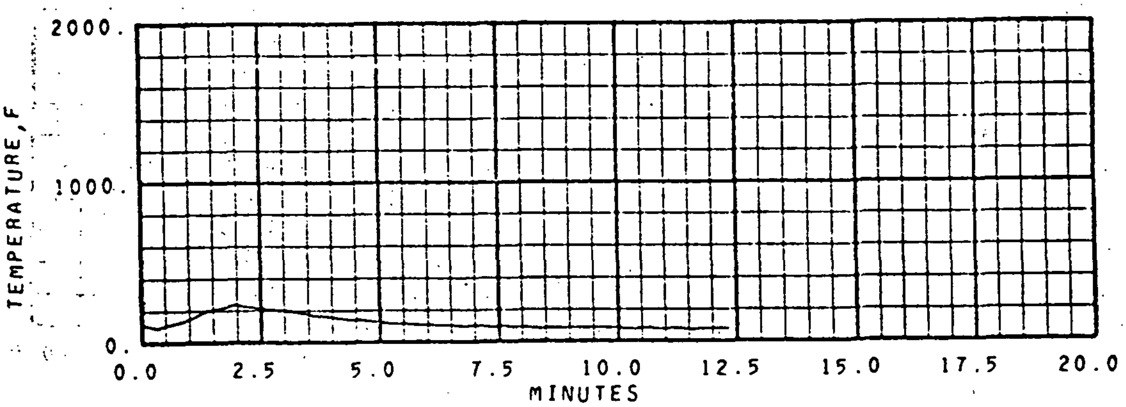
CHANNEL 41 10/24/72



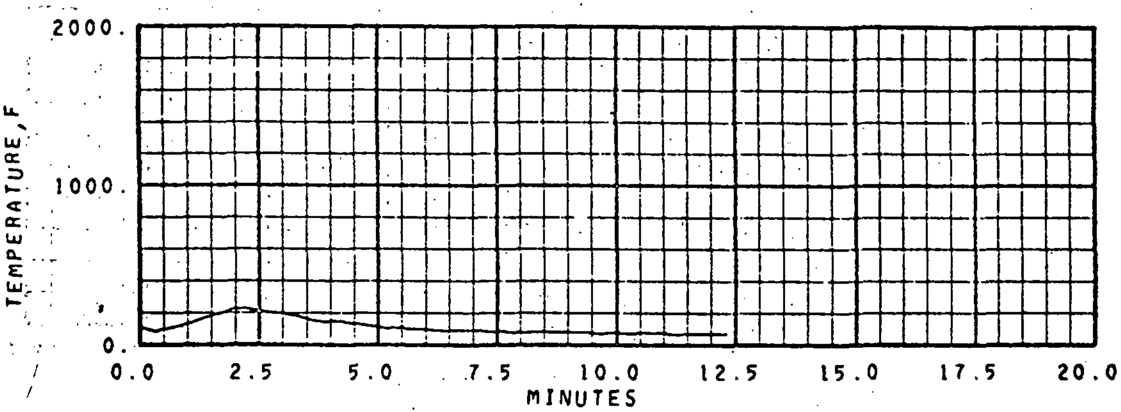
CHANNEL 42 10/24/72



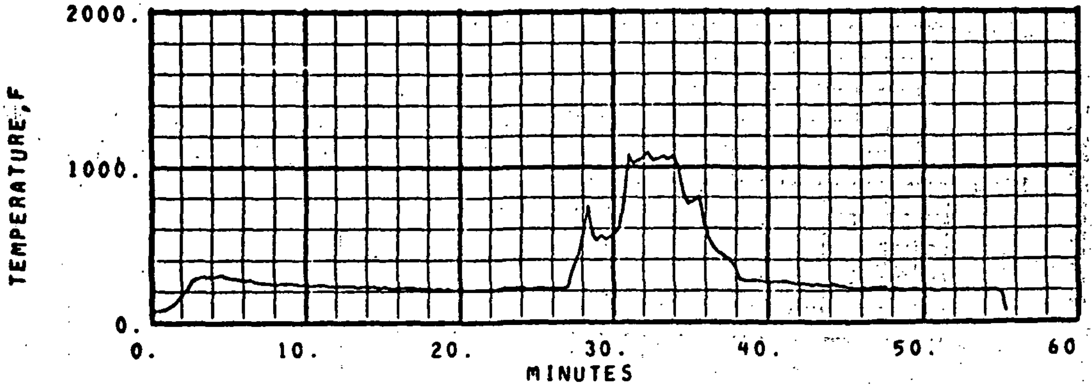
CHANNEL 43 10/24/72



CHANNEL 44 10/24/72



CHANNEL 45 10/24/72



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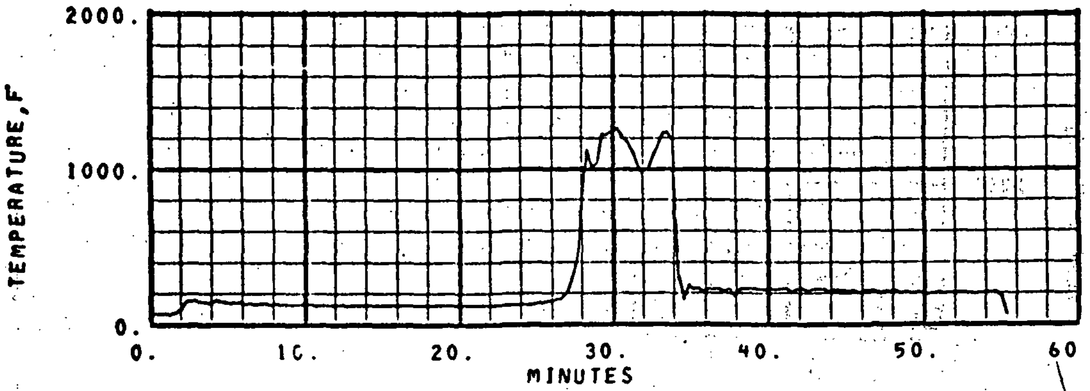

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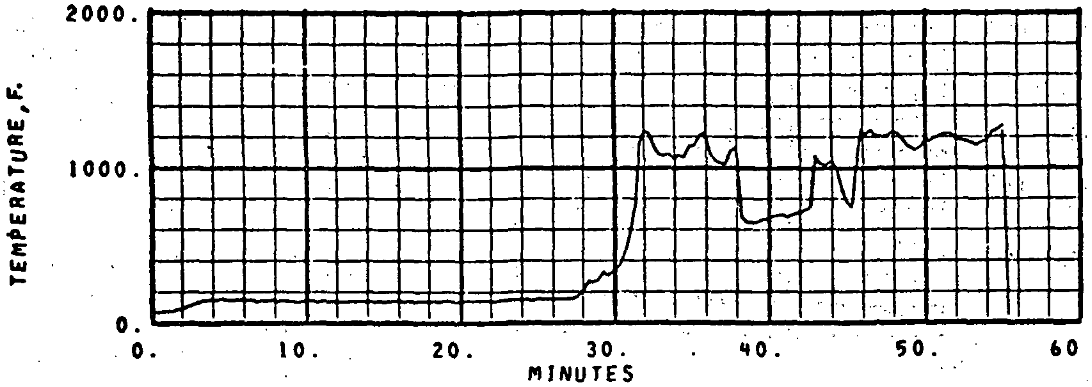
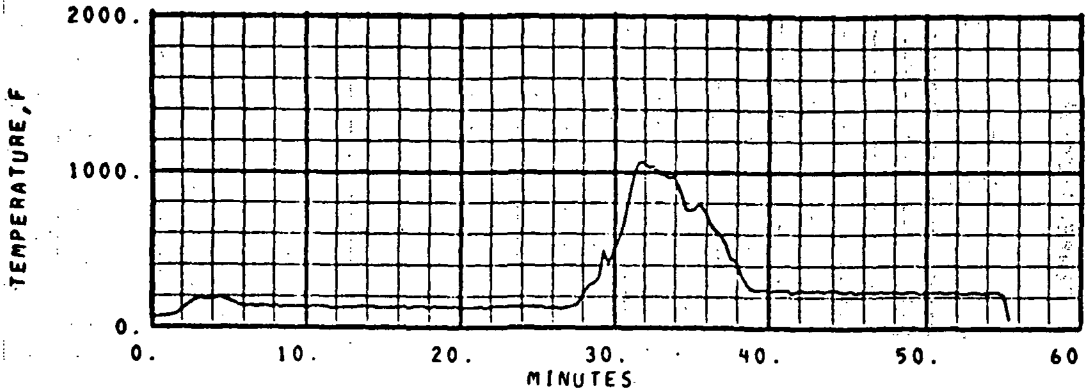
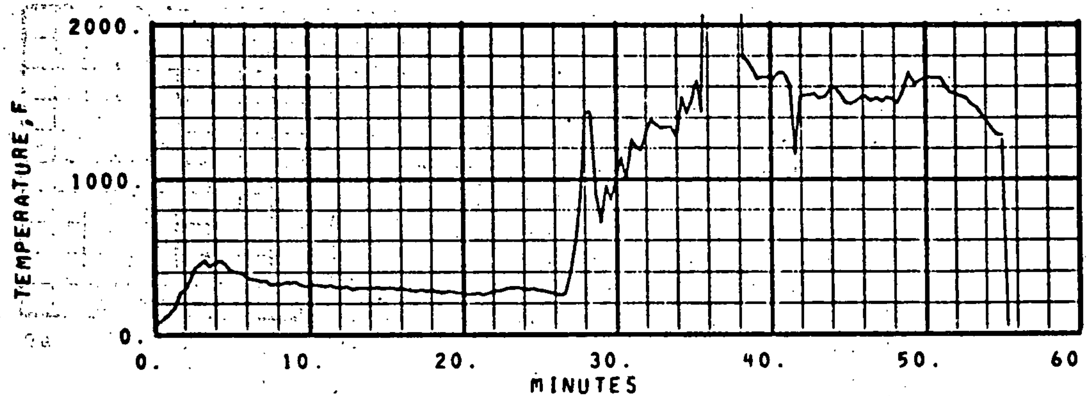


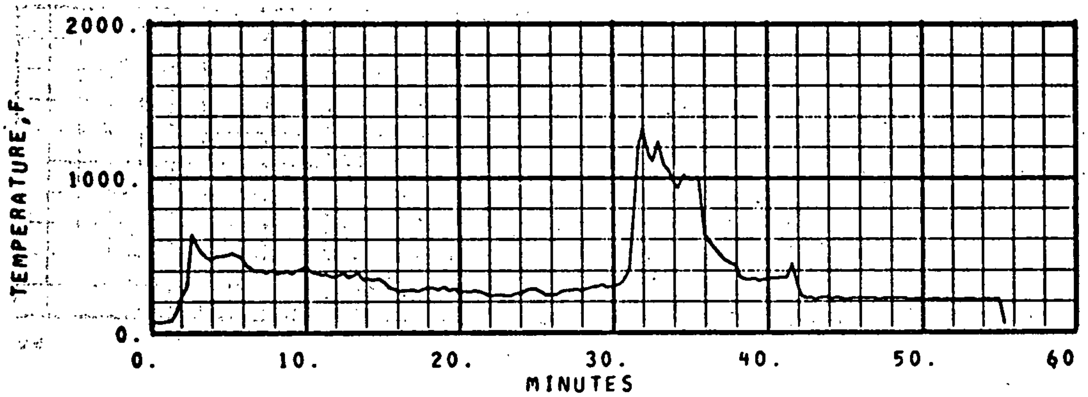
CHANNEL 3 10/24/72



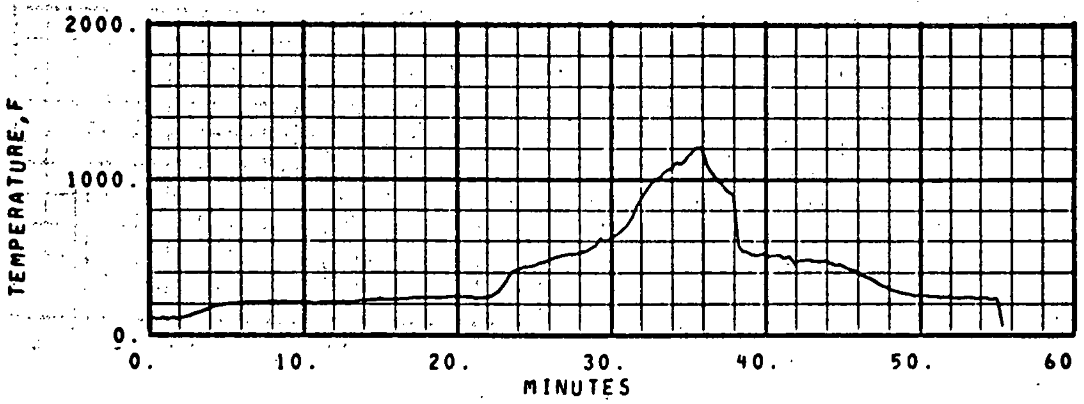
CHANNEL 4 10/24/72



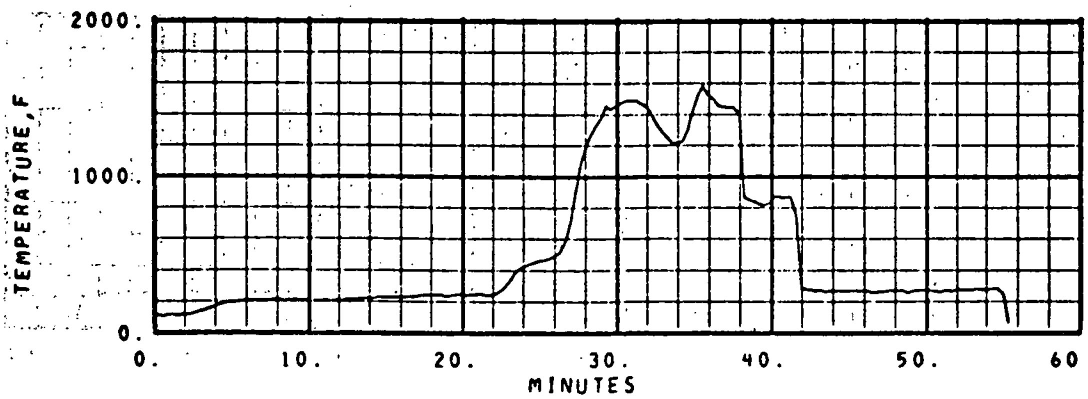
CHANNEL 5 10/24/72



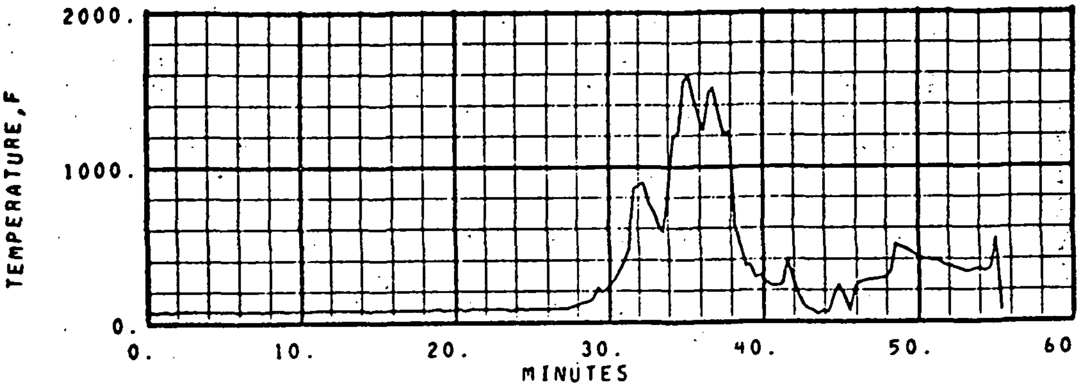
CHANNEL 6 10/24/72



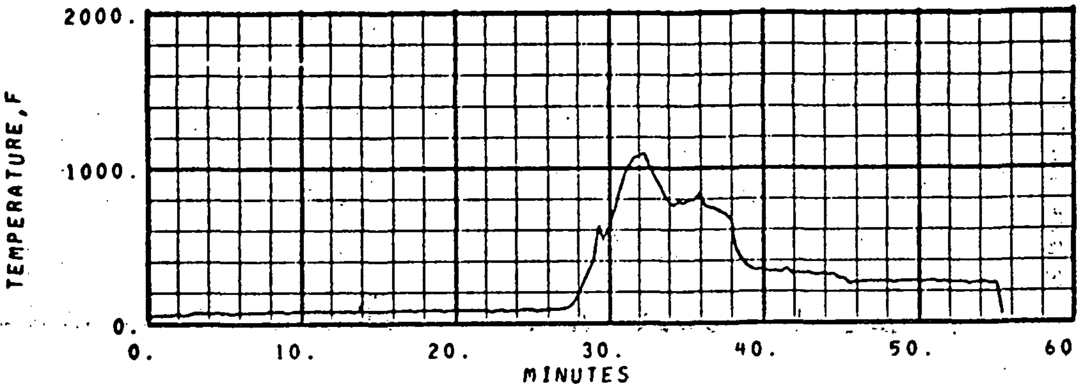
CHANNEL 7 10/24/72



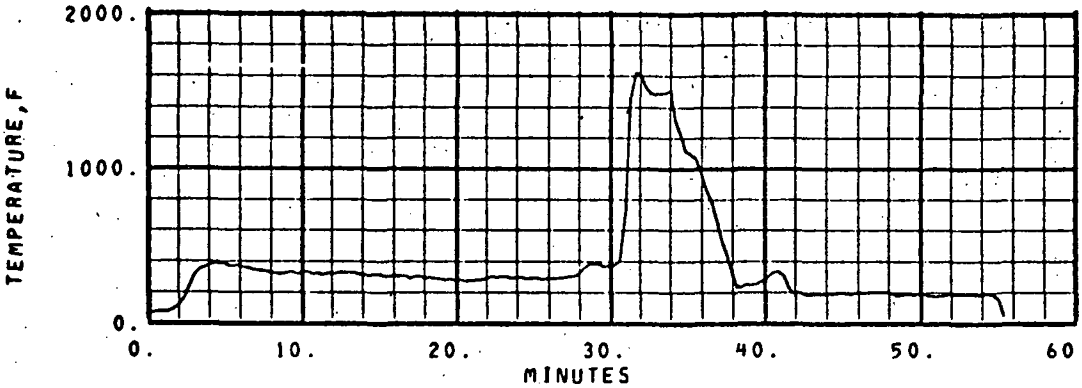
CHANNEL 8 10/24/72



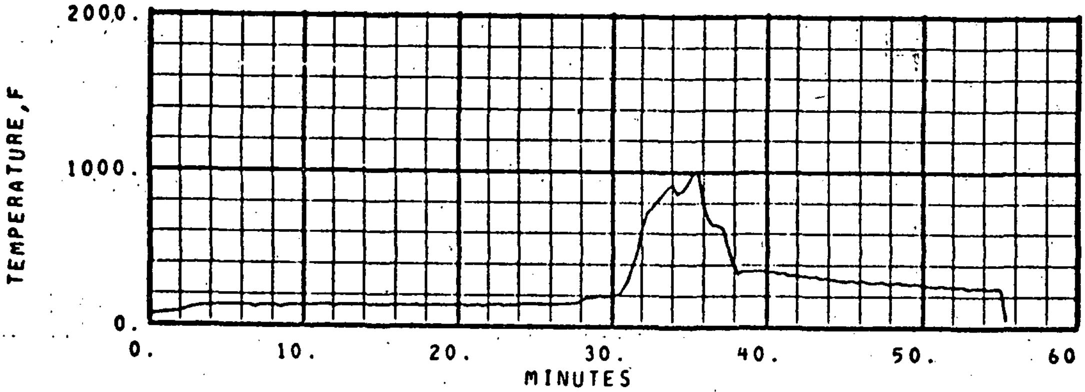
CHANNEL 9 10/24/72



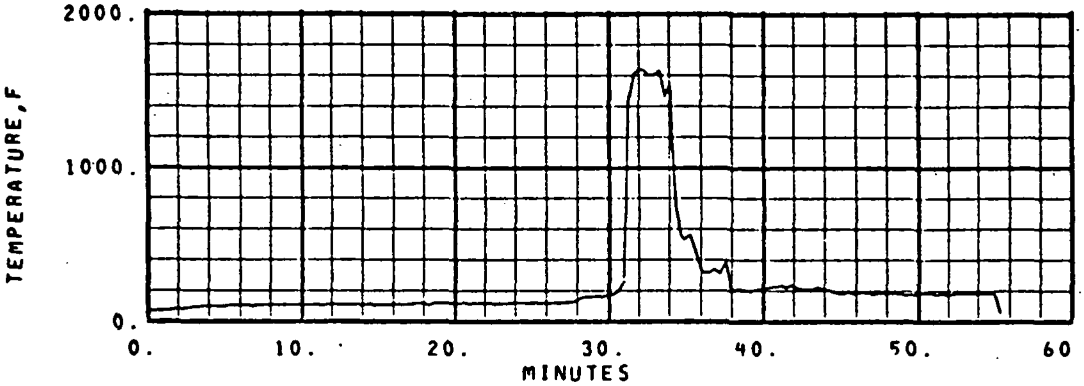
CHANNEL 10 10/24/72



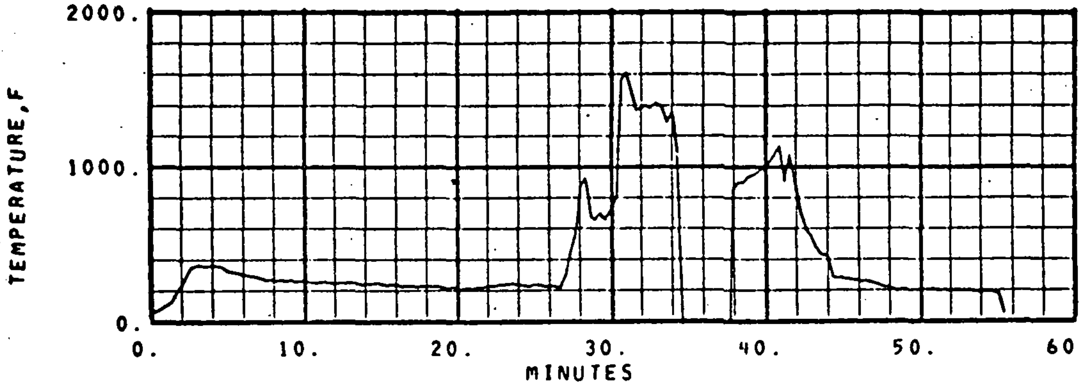
CHANNEL 11 10/24/72



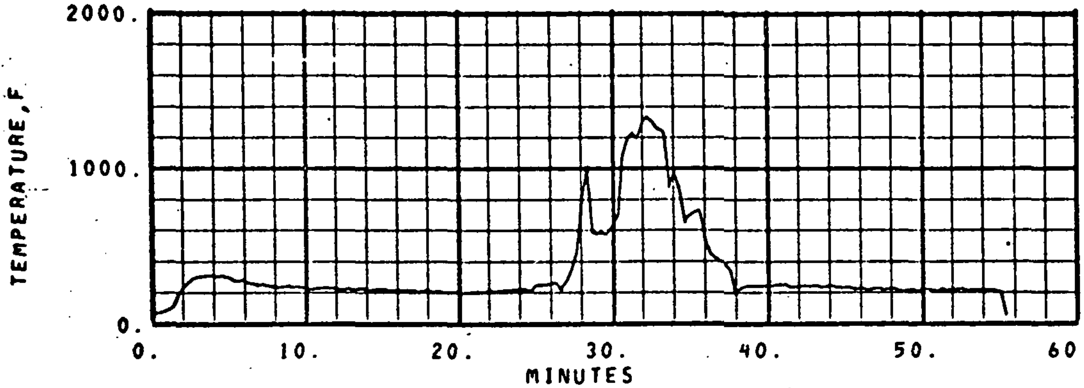
CHANNEL 12 10/24/72



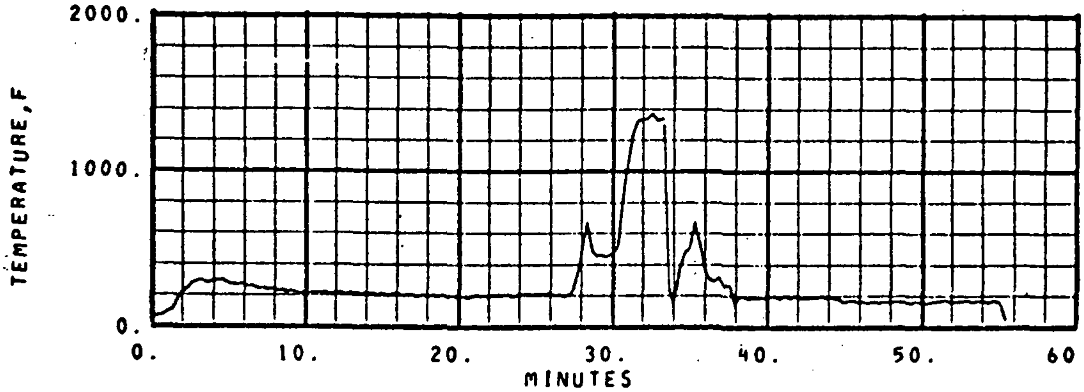
CHANNEL 13 10/24/72



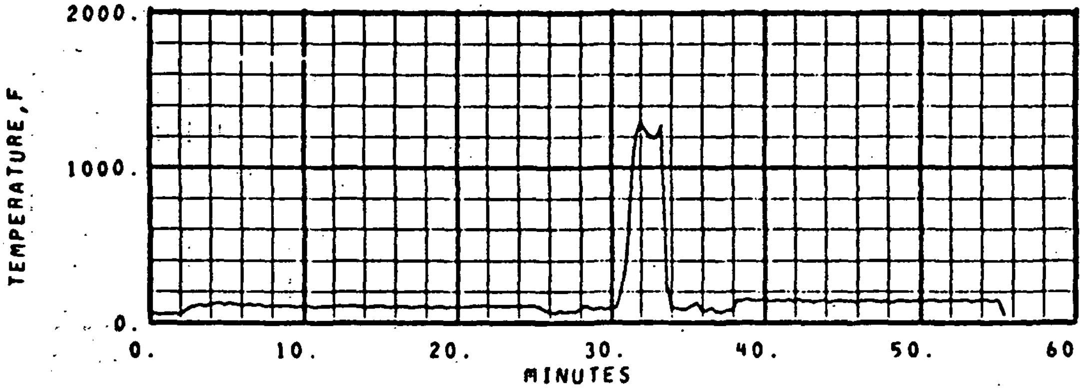
CHANNEL 14 10/24



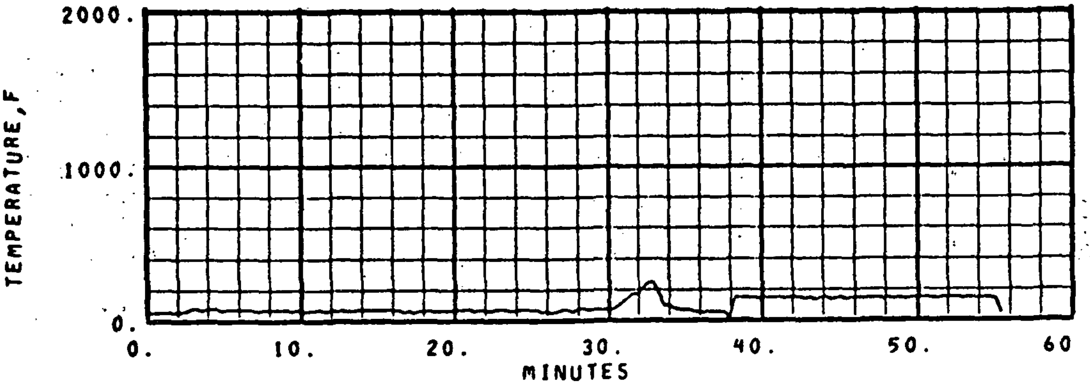
CHANNEL 15 10/24/72



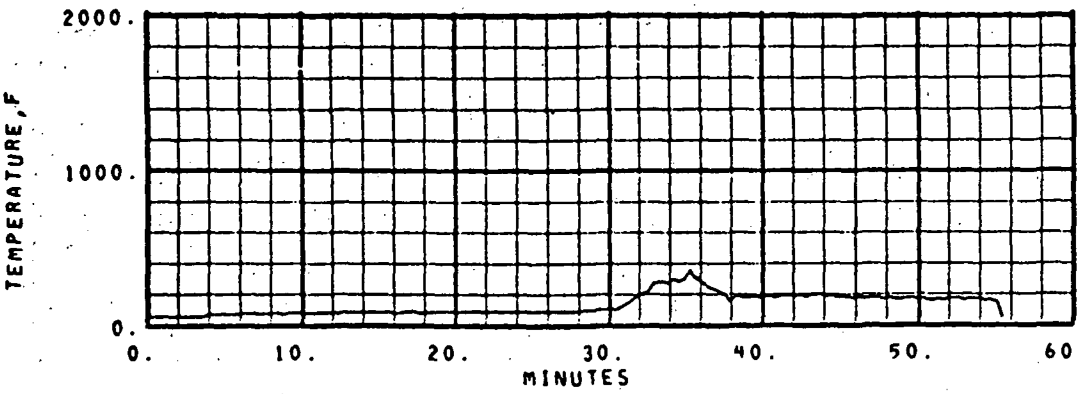
CHANNEL 16 10/24/72



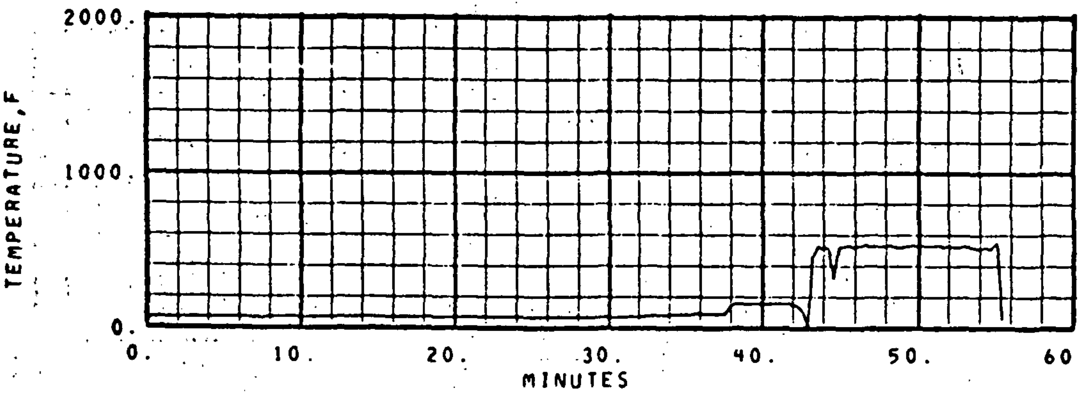
CHANNEL 17 10/24/72



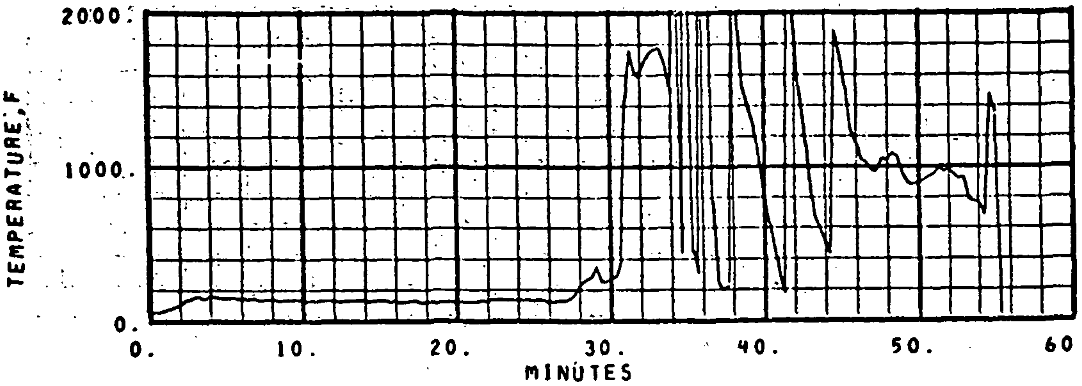
CHANNEL 18 10/24/72



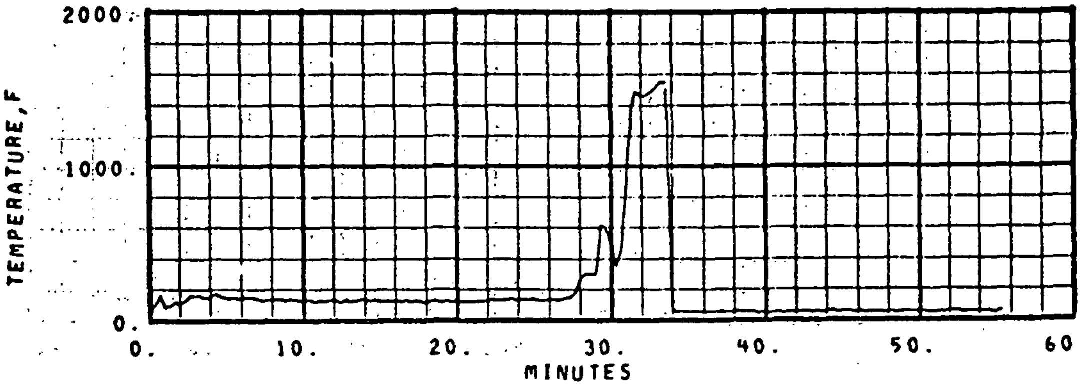
CHANNEL 19 10/24/72



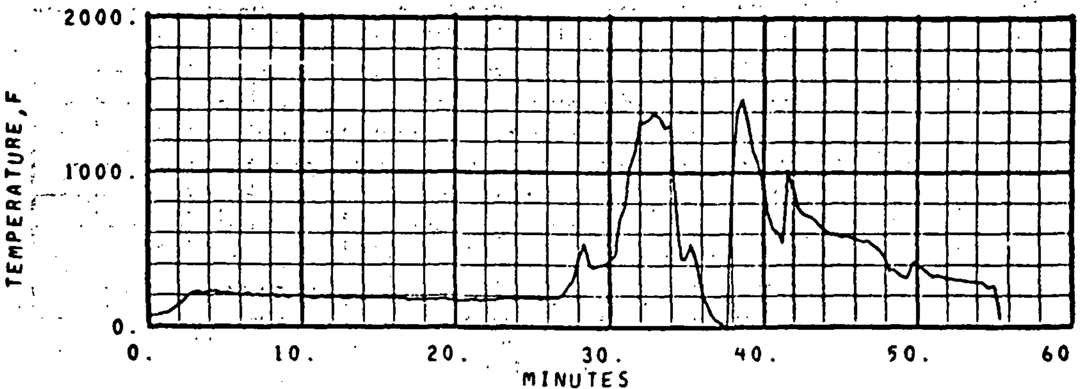
CHANNEL 20 10/24/72



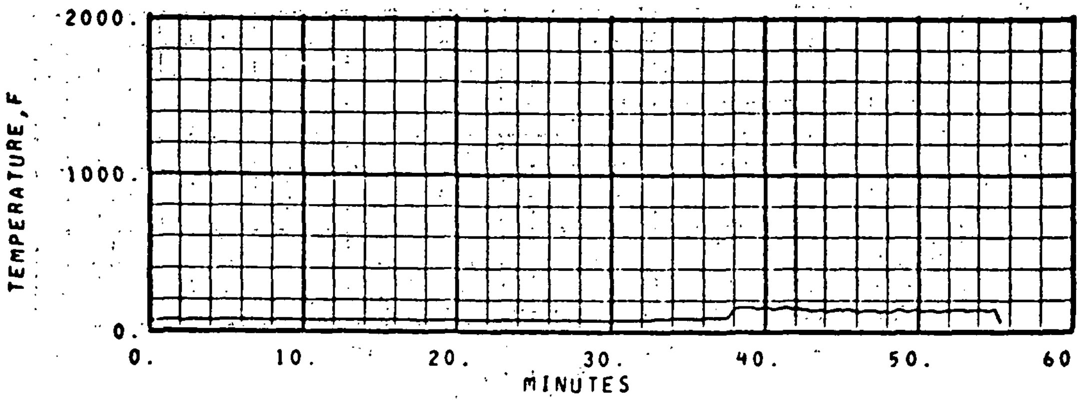
CHANNEL 21 10/24/72



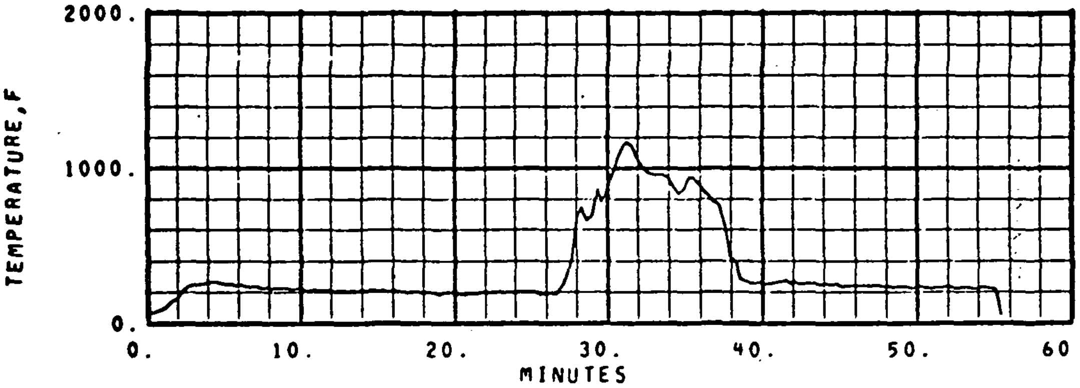
CHANNEL 22 10/24/72



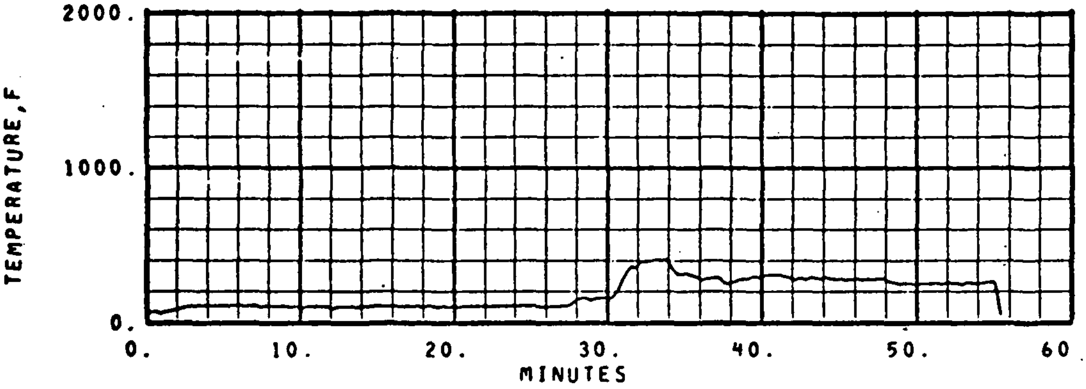
CHANNEL 23 10/24/72



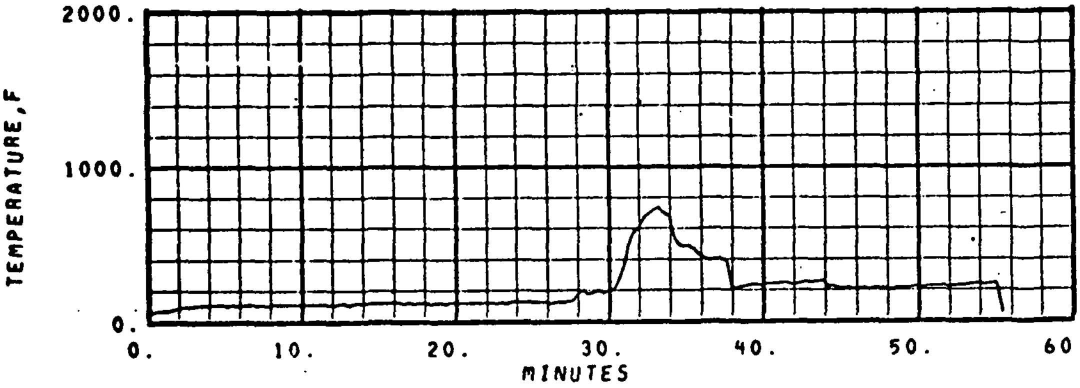
CHANNEL 24 10/24/72



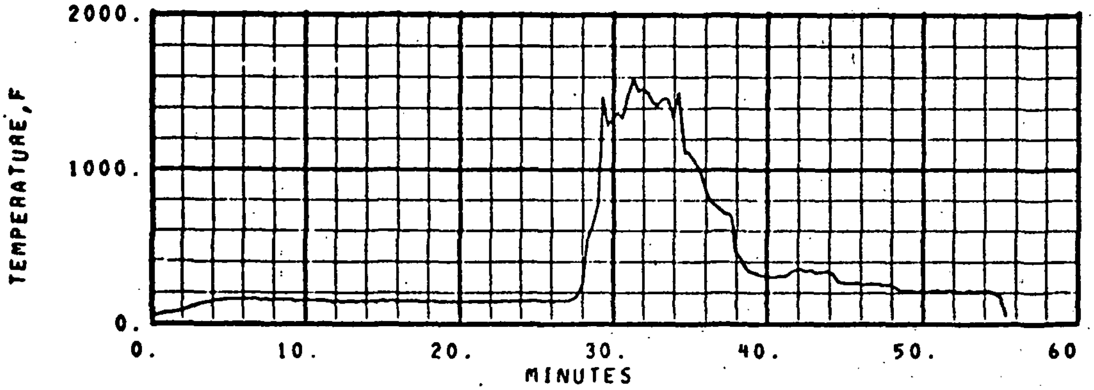
CHANNEL 25 10/24/72



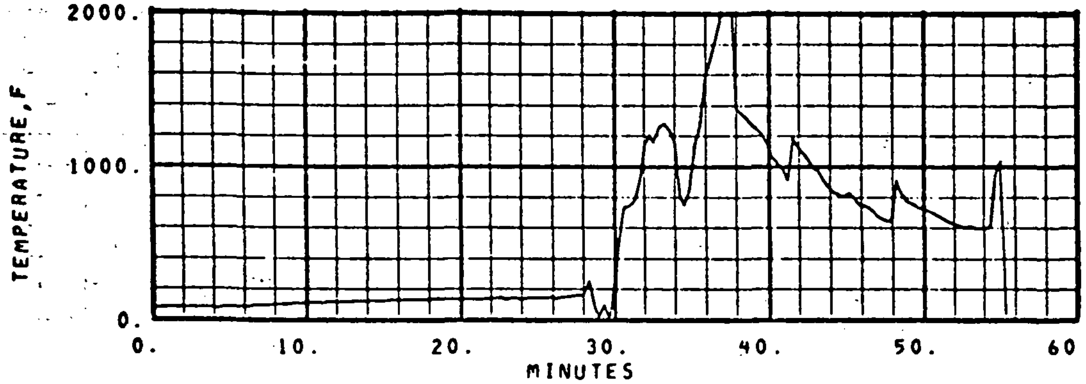
CHANNEL 26 10/24/72



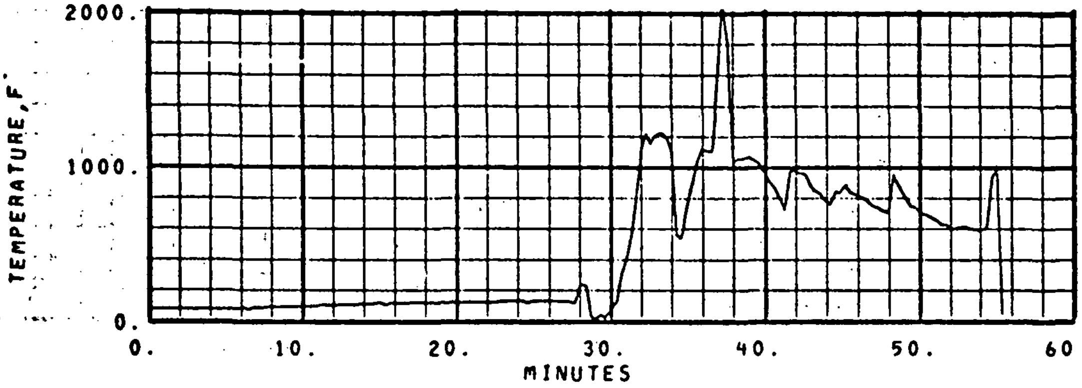
CHANNEL 27 10/24/72



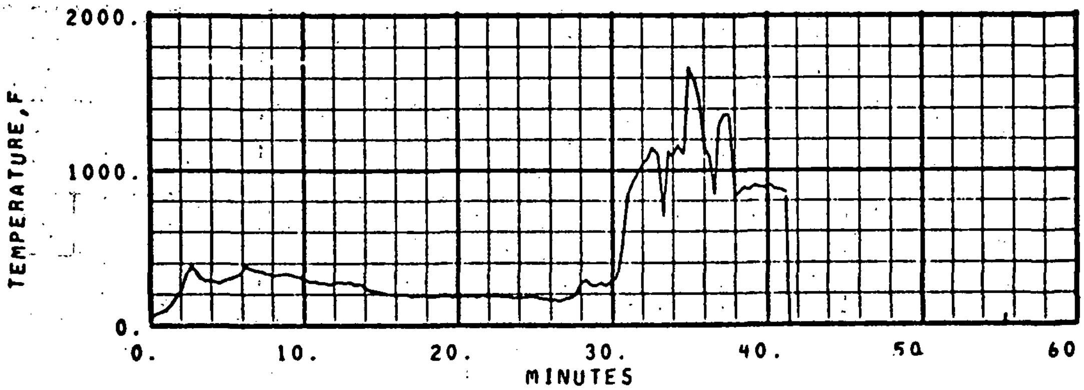
CHANNEL 28 10/24/72



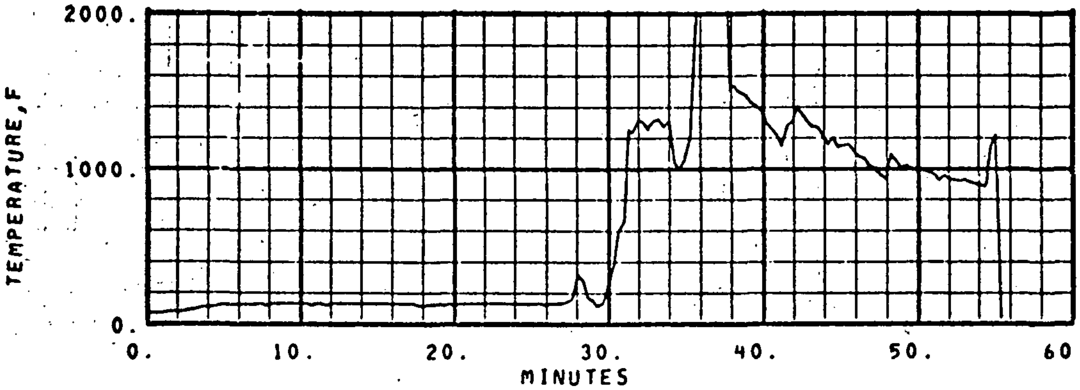
CHANNEL 36 10/24/72



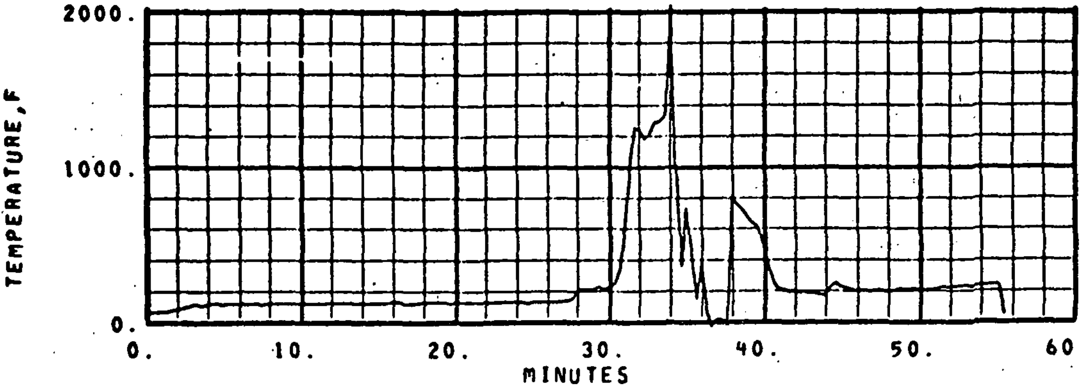
CHANNEL 37 10/24/72



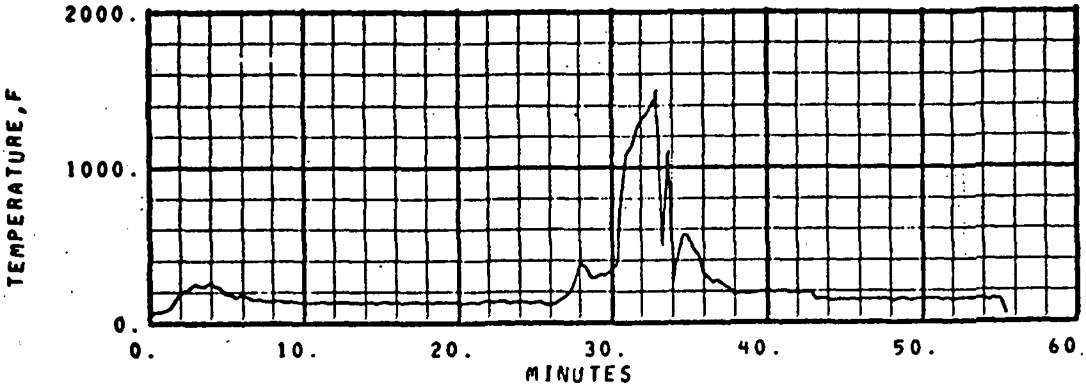
CHANNEL 38 10/24/72



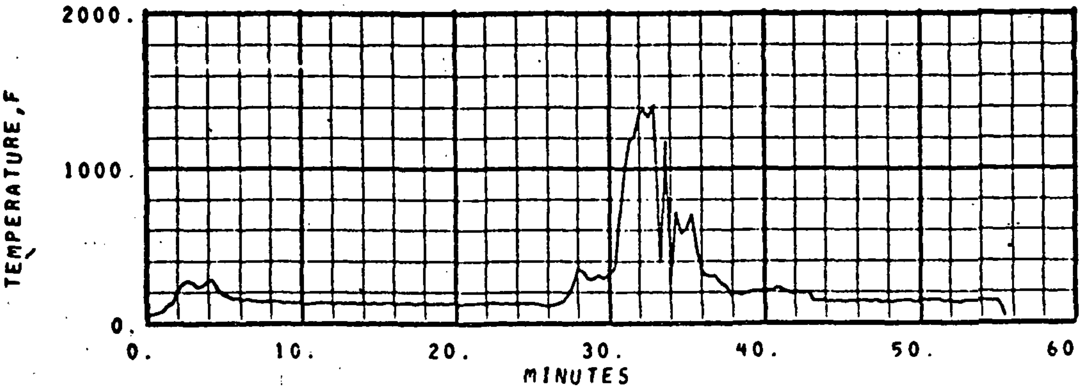
CHANNEL 39 10/24/72



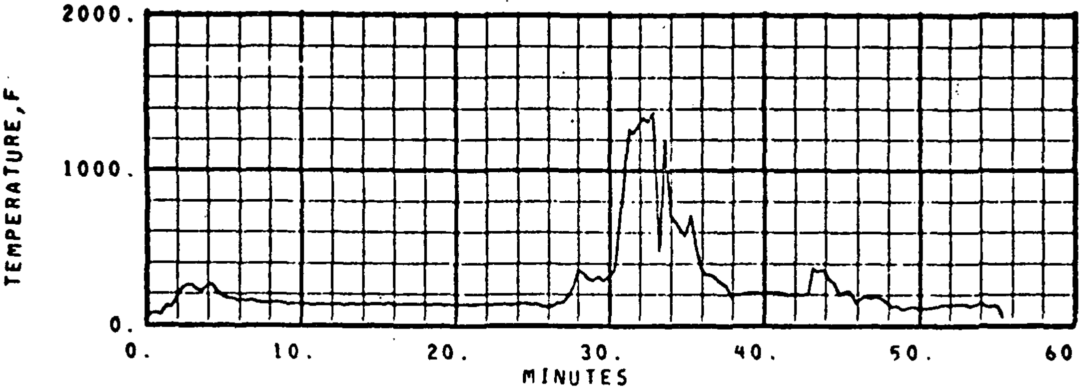
CHANNEL 40 10/24/72



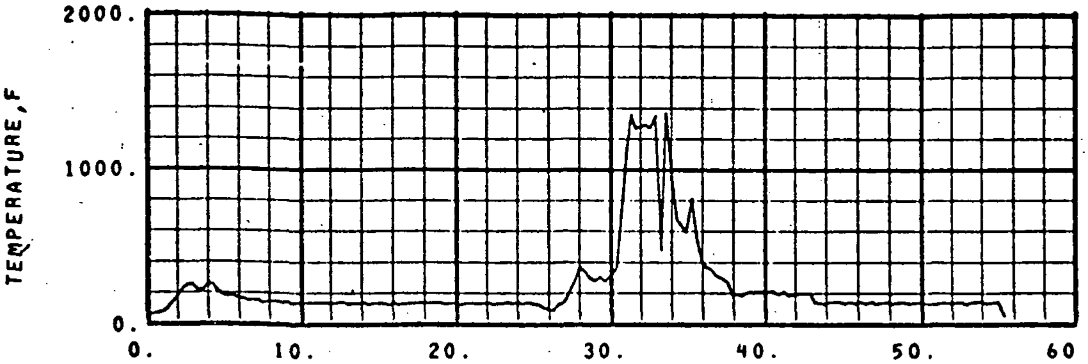
CHANNEL 41 10/24/72



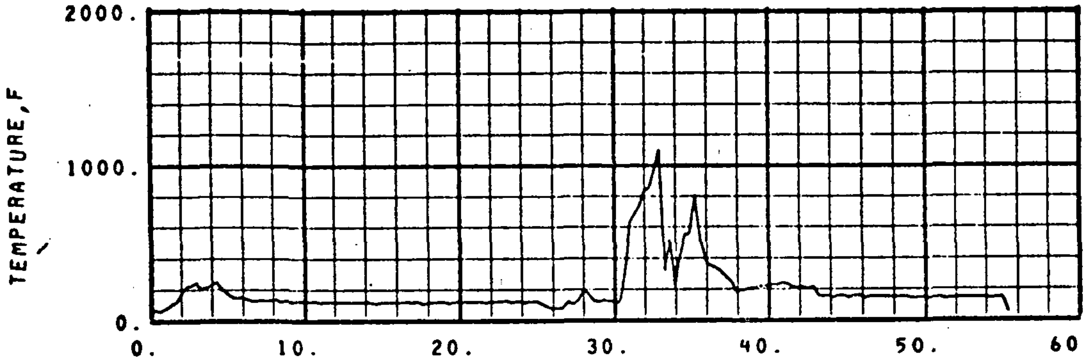
CHANNEL 42 10/24/72



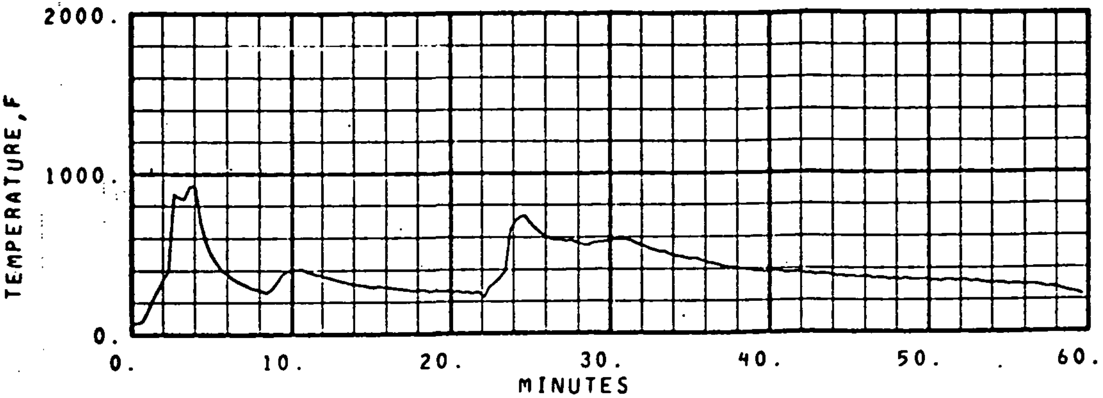
CHANNEL 43 10/24/72



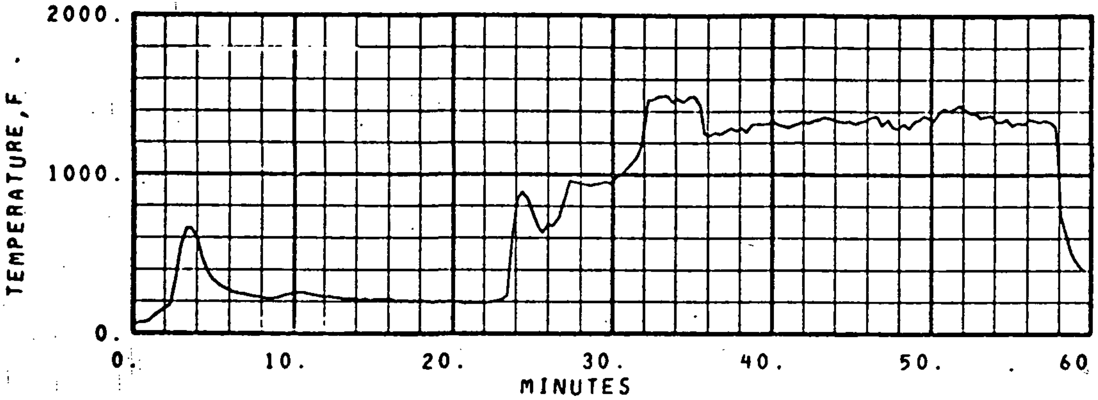
CHANNEL 44 10/24/72



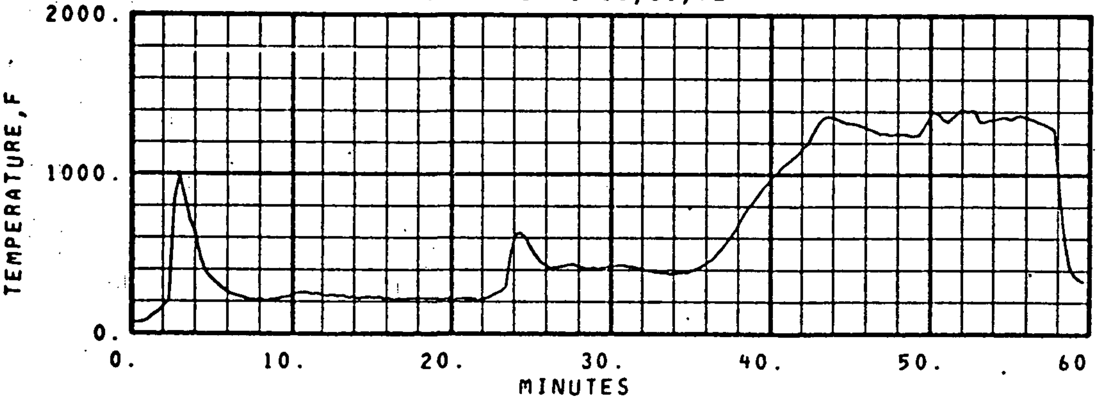
CHANNEL 45 10/24/72



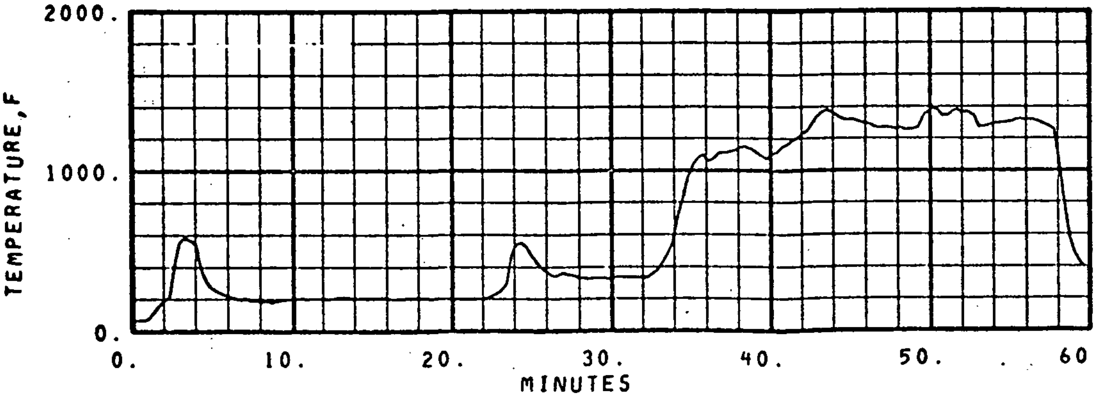
CHANNEL 0 10/31/72



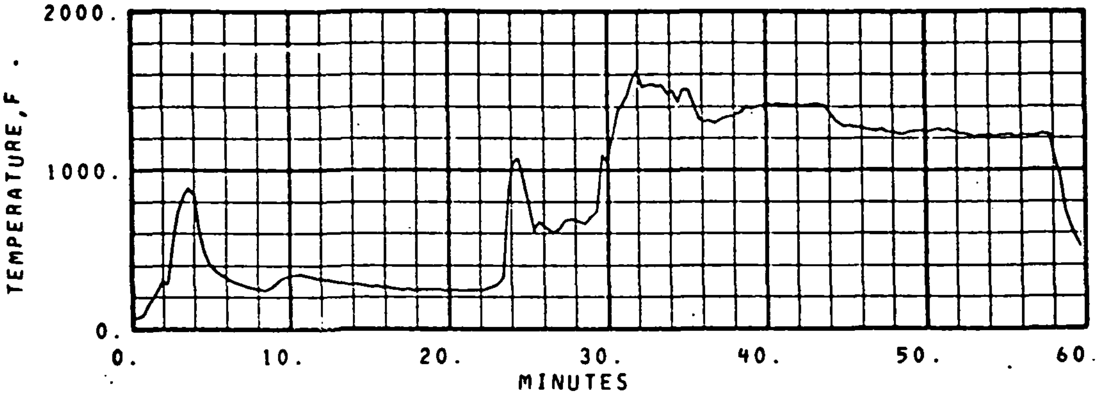
CHANNEL 1 10/31/72



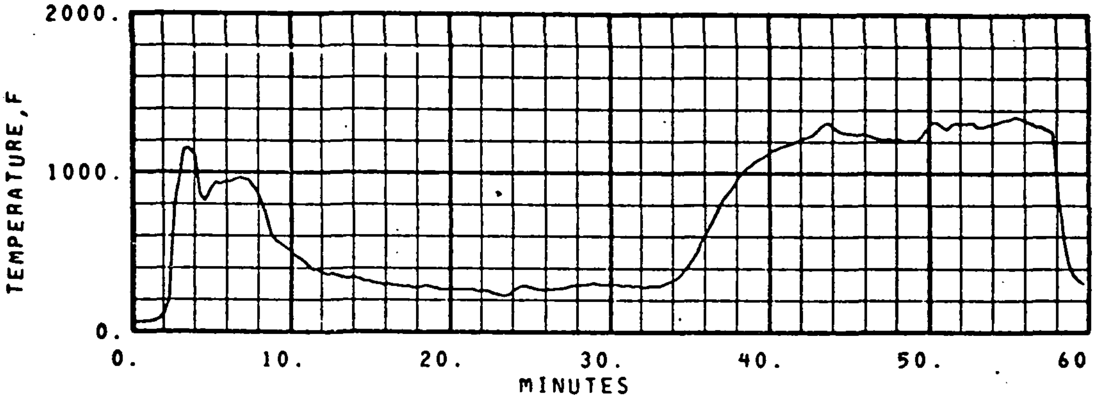
CHANNEL 3 10/31/72



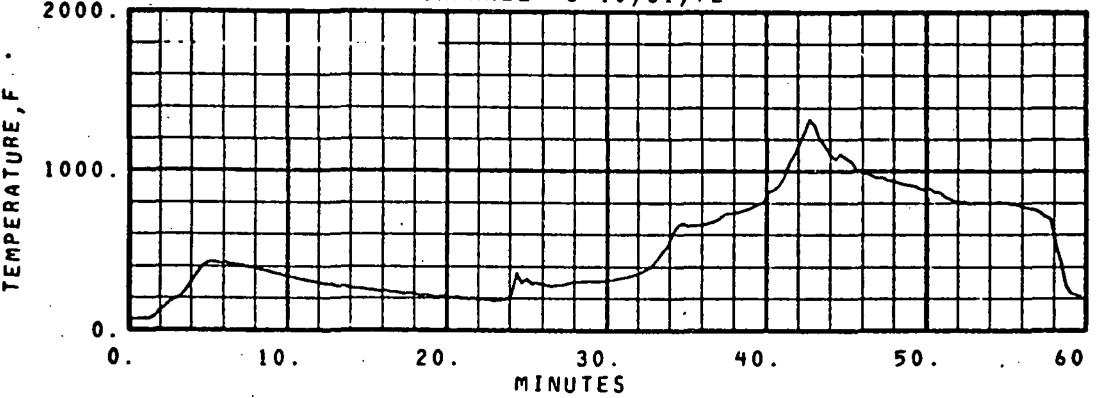
CHANNEL 4 10/31/72



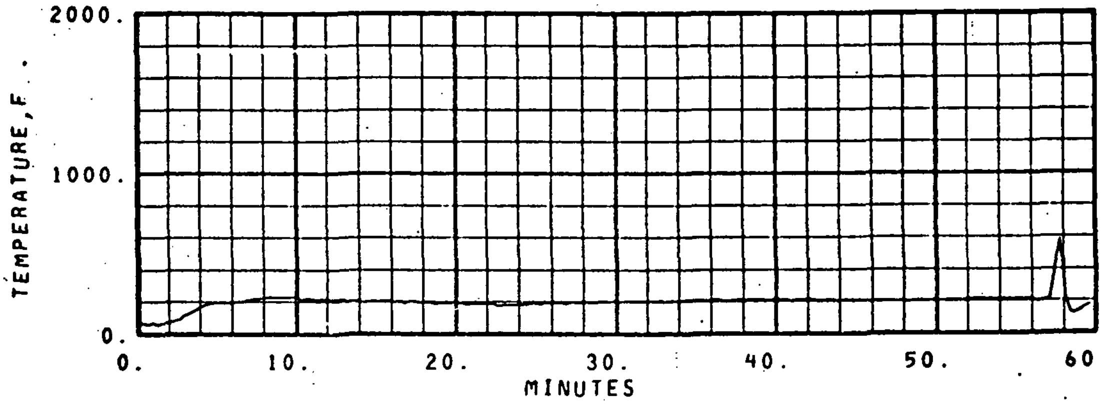
CHANNEL 5 10/31/72



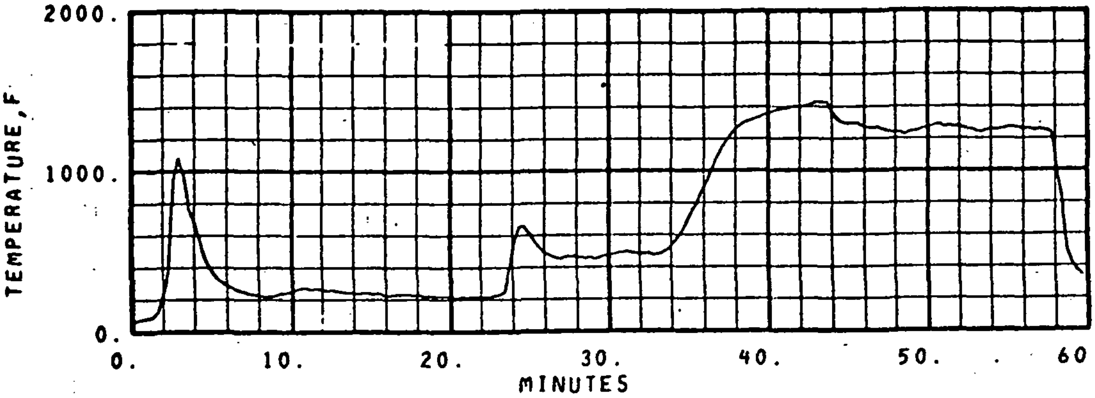
CHANNEL 6 10/31/72



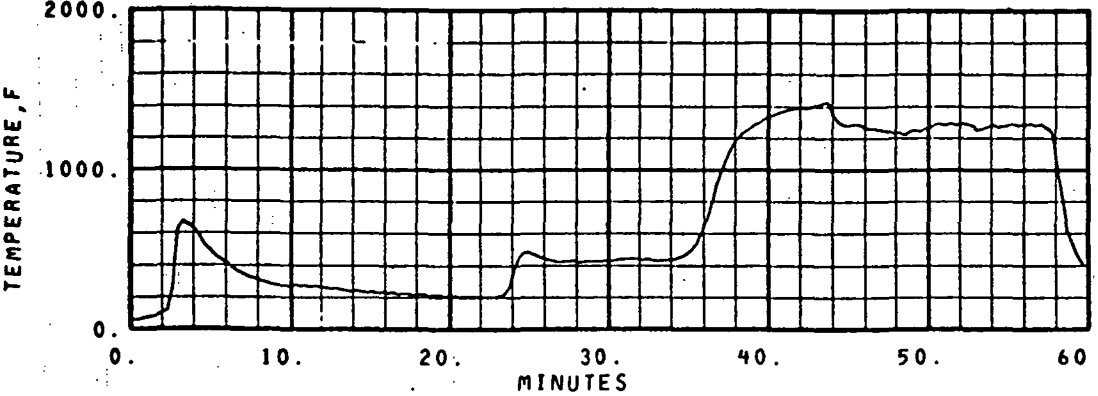
CHANNEL 7 10/31/72



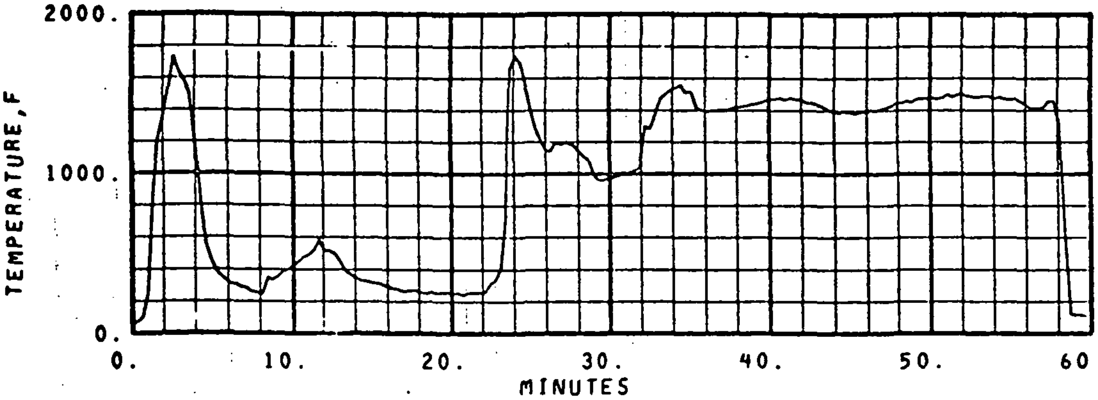
CHANNEL 8 10/31/72



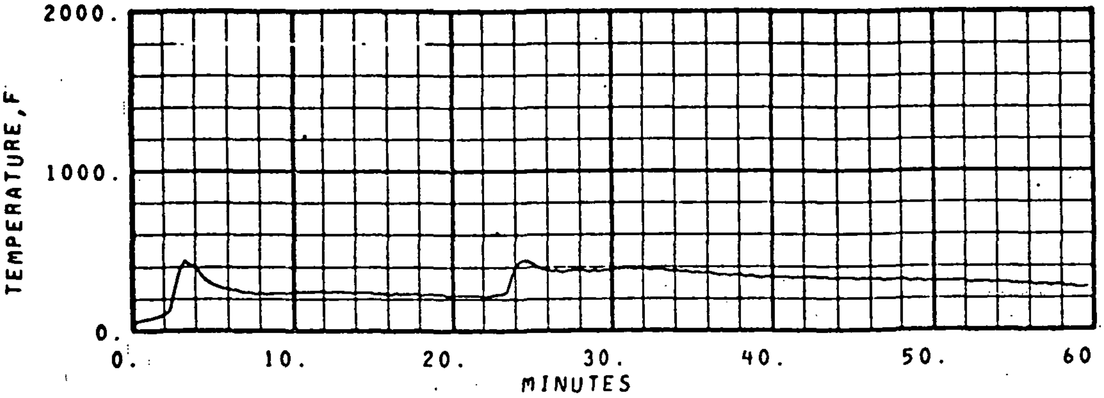
CHANNEL 9 10/31/72



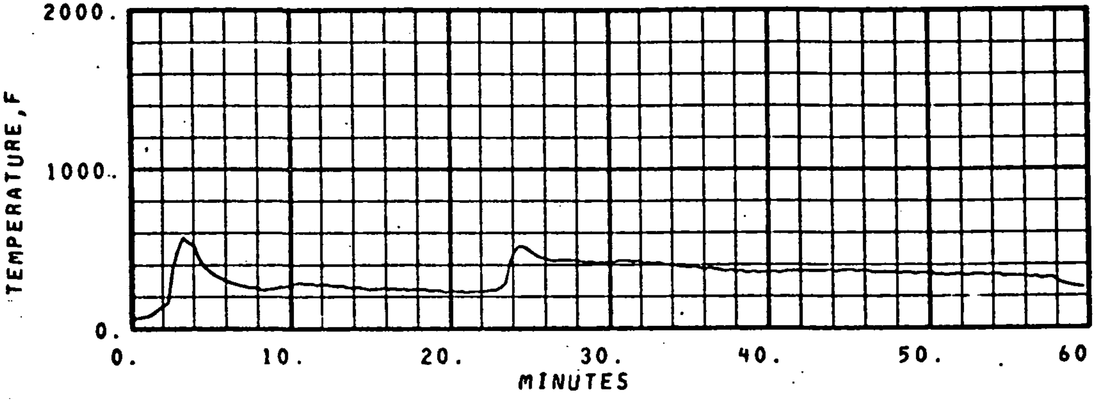
CHANNEL 10 10/31/72



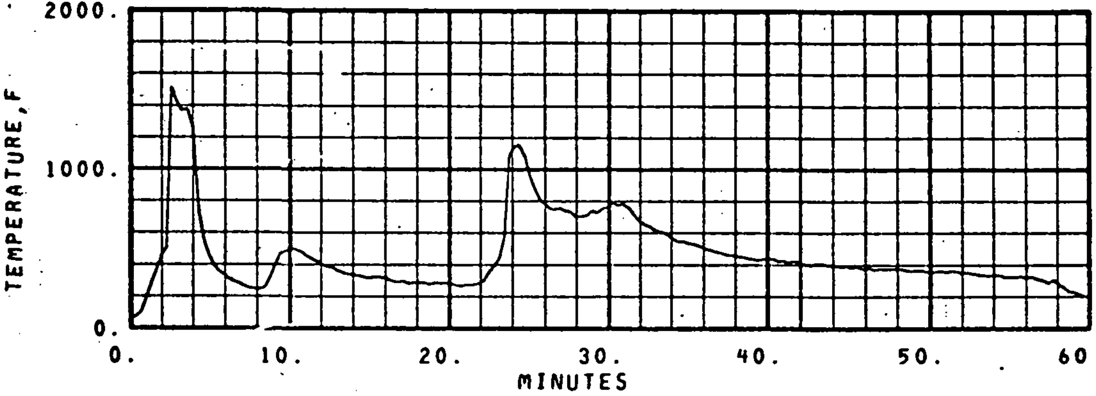
CHANNEL 11 10/31/72



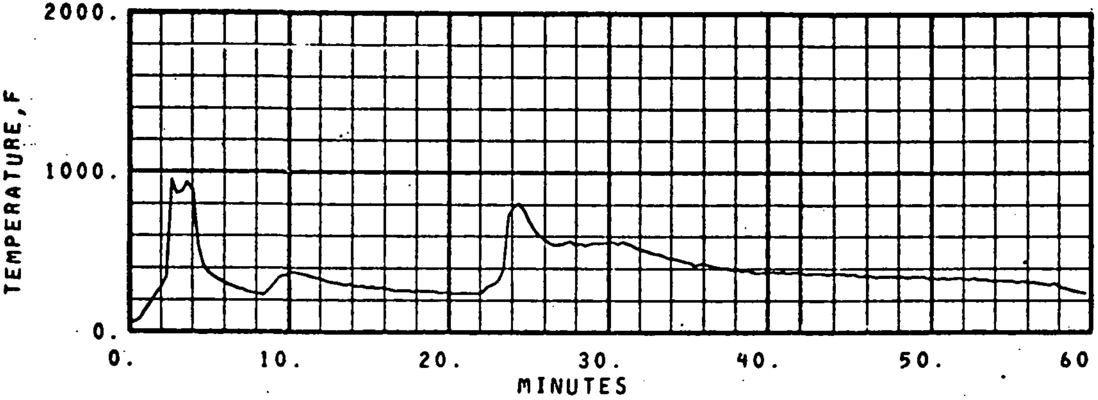
CHANNEL 12 10/31/72



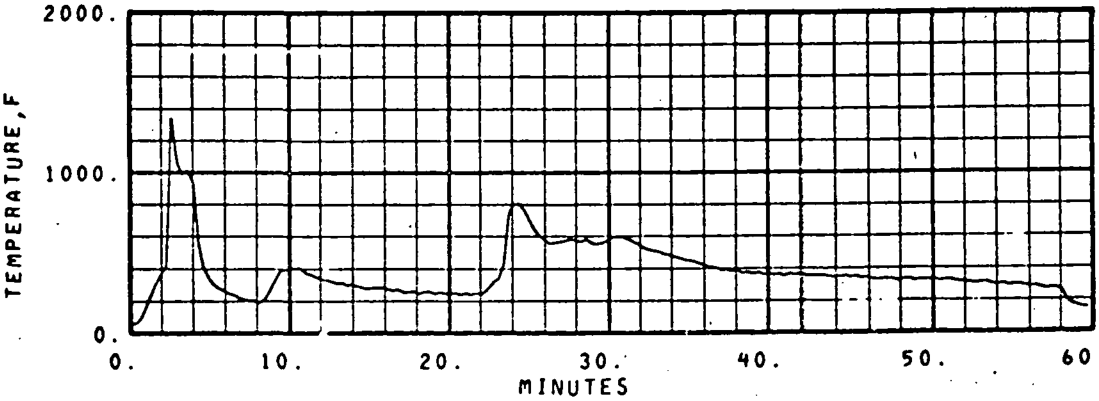
CHANNEL 13 10/31/72



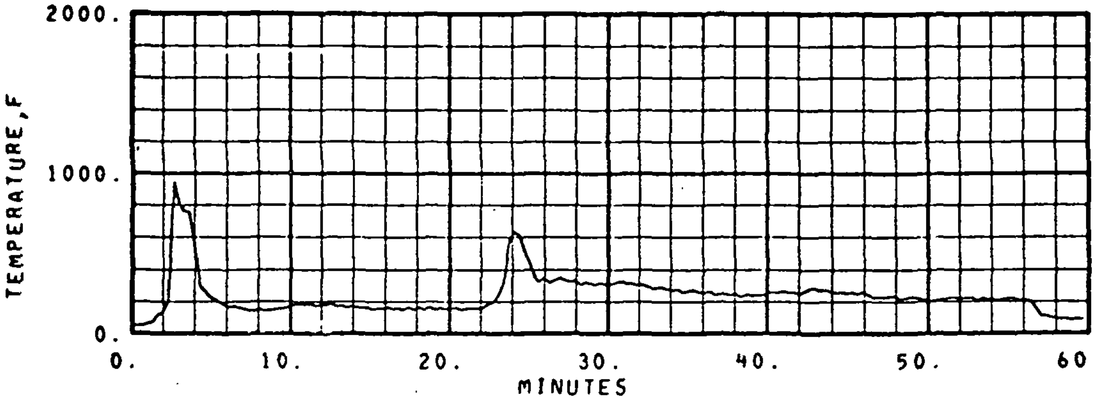
CHANNEL 14 10/31/72



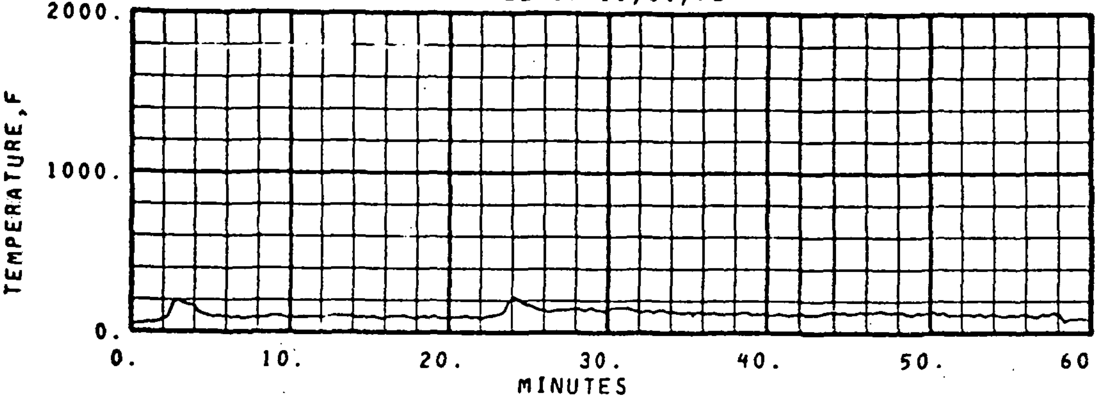
CHANNEL 15 10/31/72



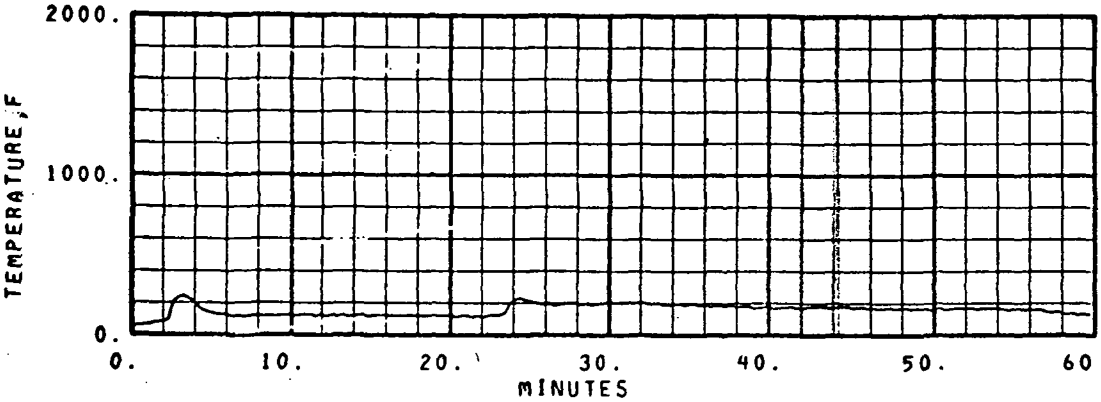
CHANNEL 16 10/31/72



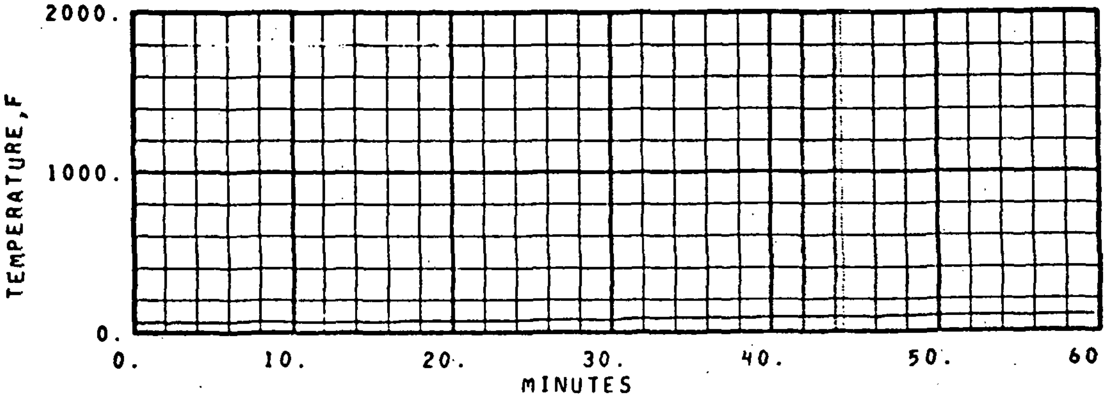
CHANNEL 17 10/31/72



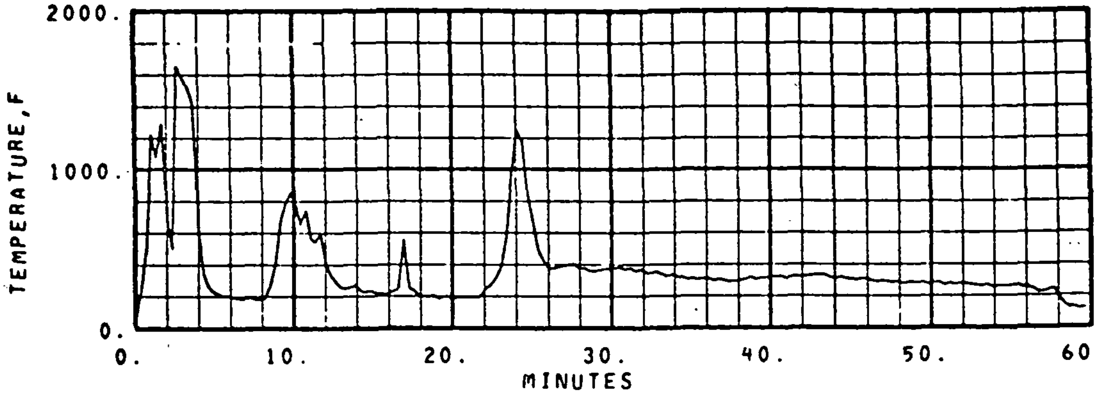
CHANNEL 18 10/31/72



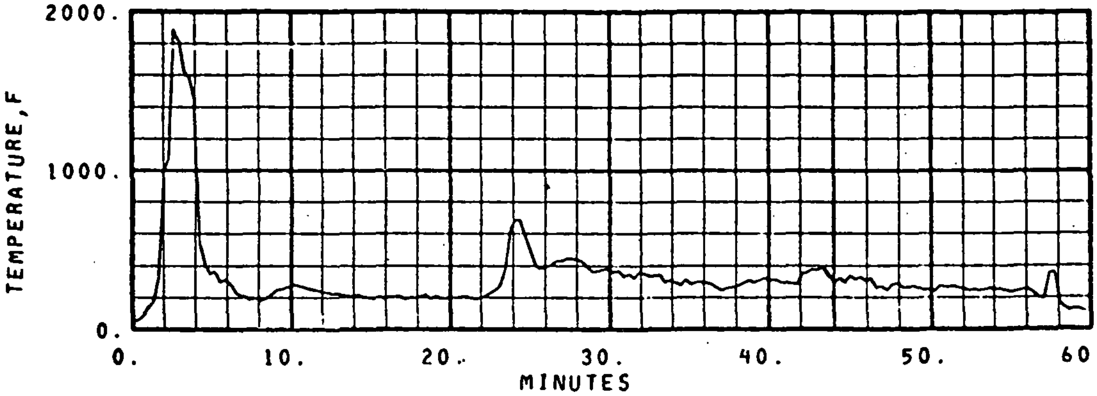
CHANNEL 19 10/31/72



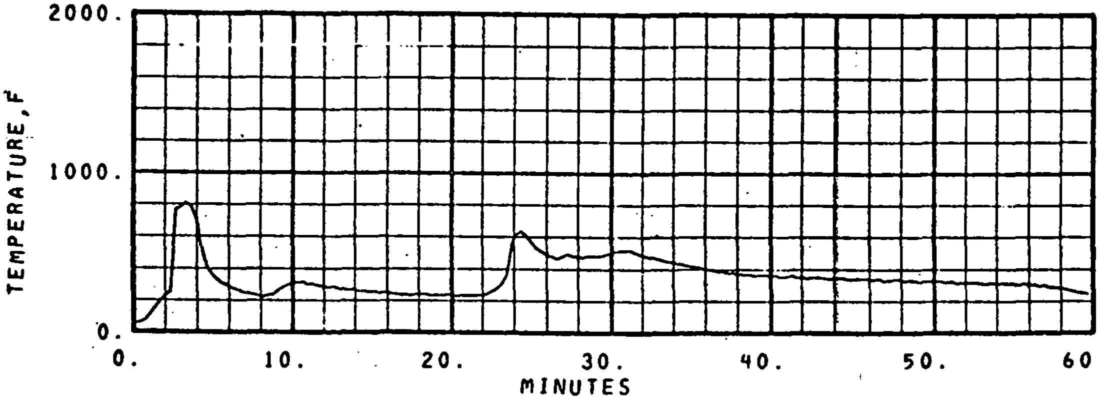
CHANNEL 20 10/31/72



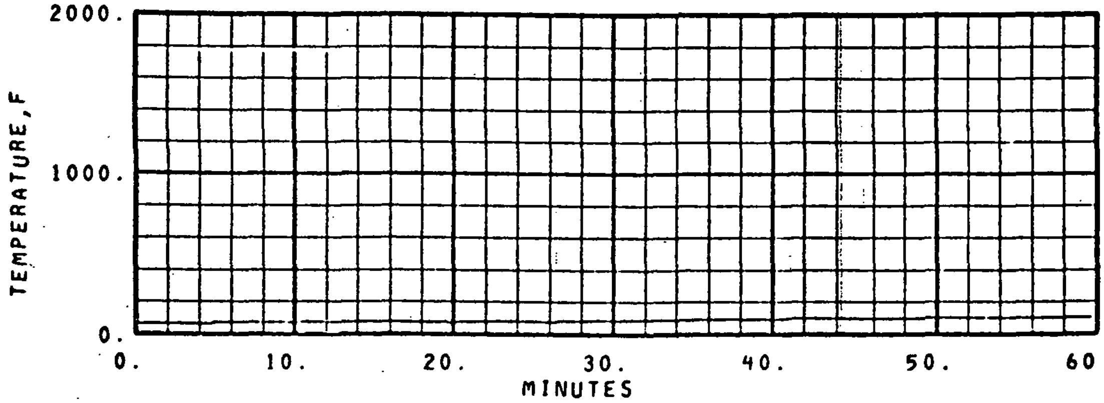
CHANNEL 21 10/31/72



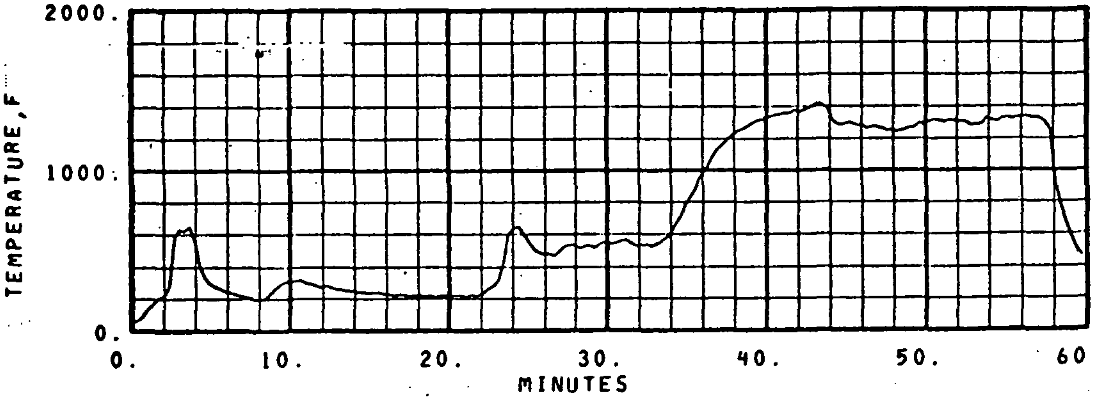
CHANNEL 22 10/31/72



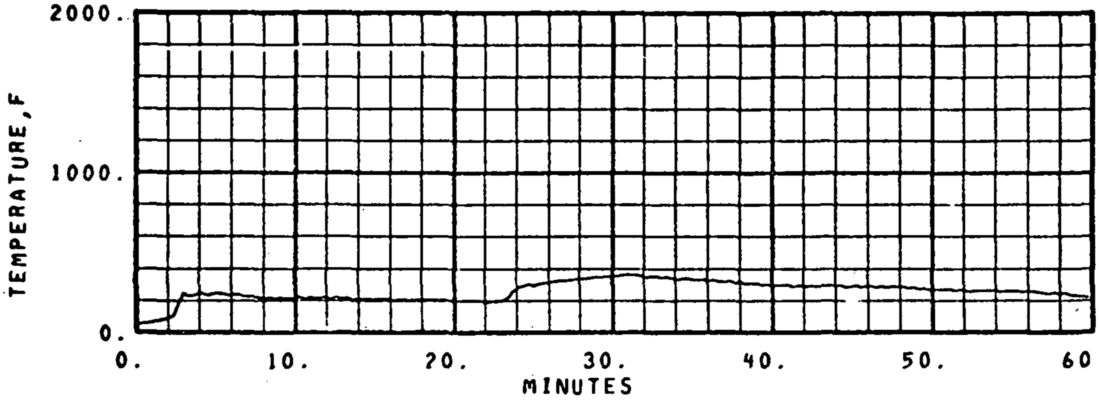
CHANNEL 23 10/31/72



CHANNEL 24 10/31/72



CHANNEL 25 10/31/72



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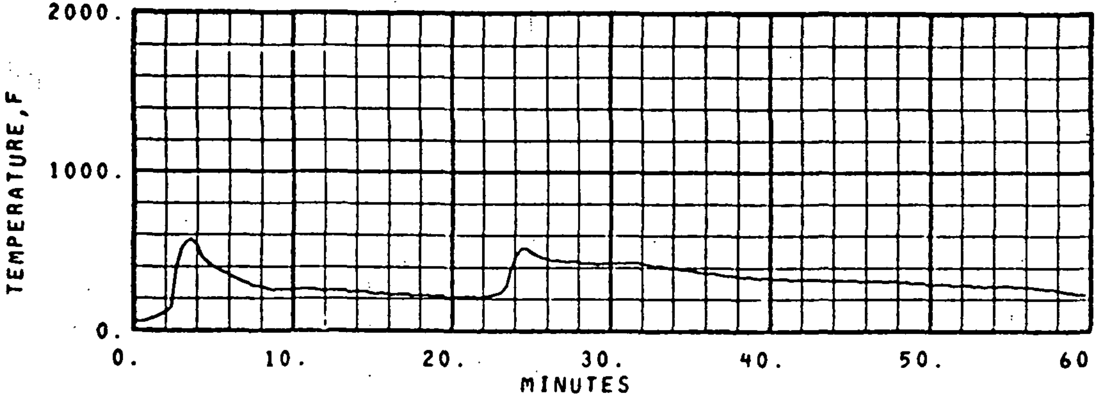

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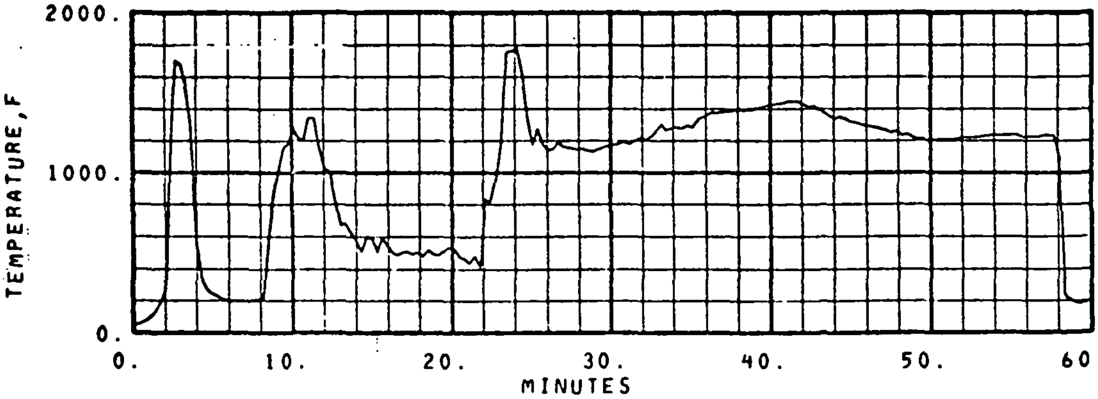

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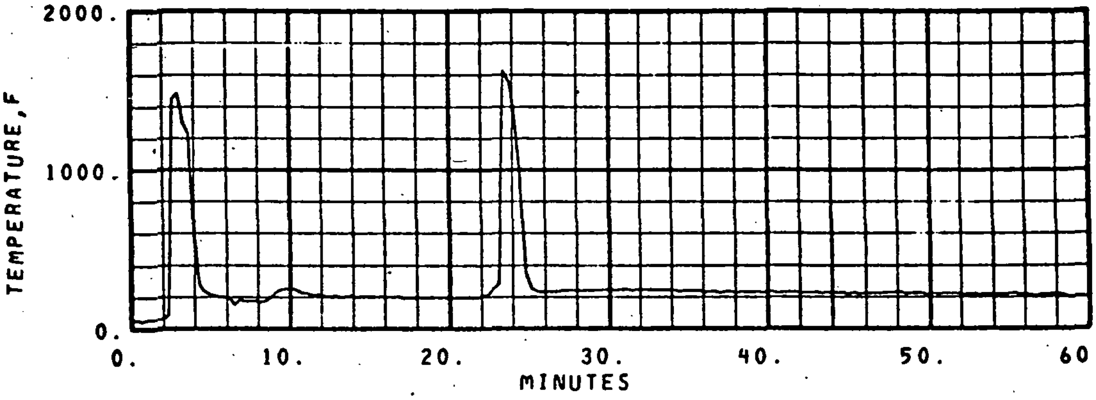

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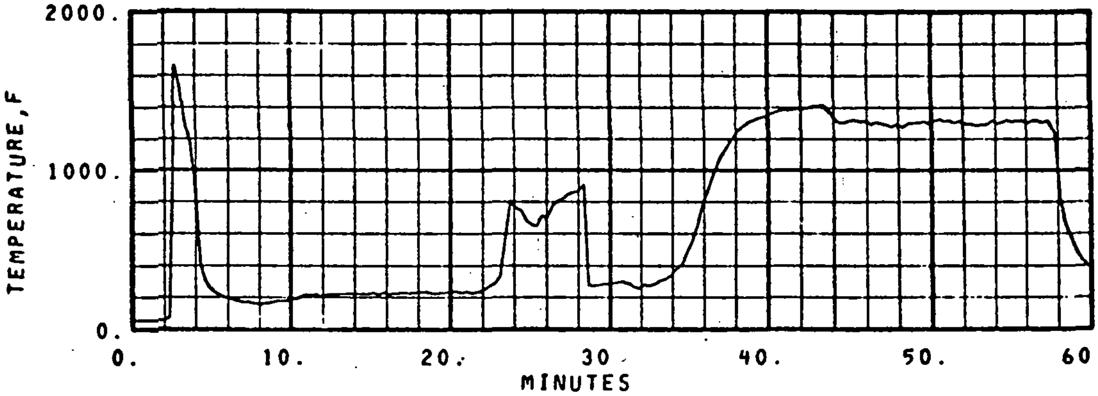

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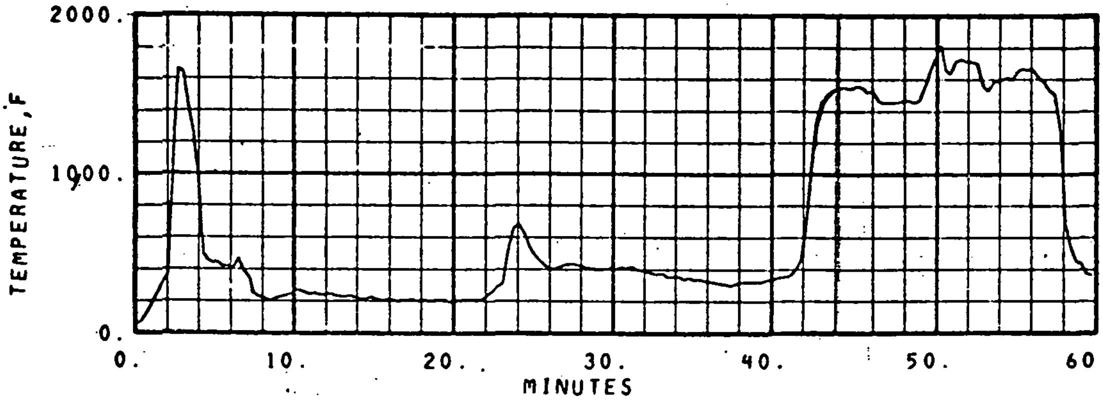

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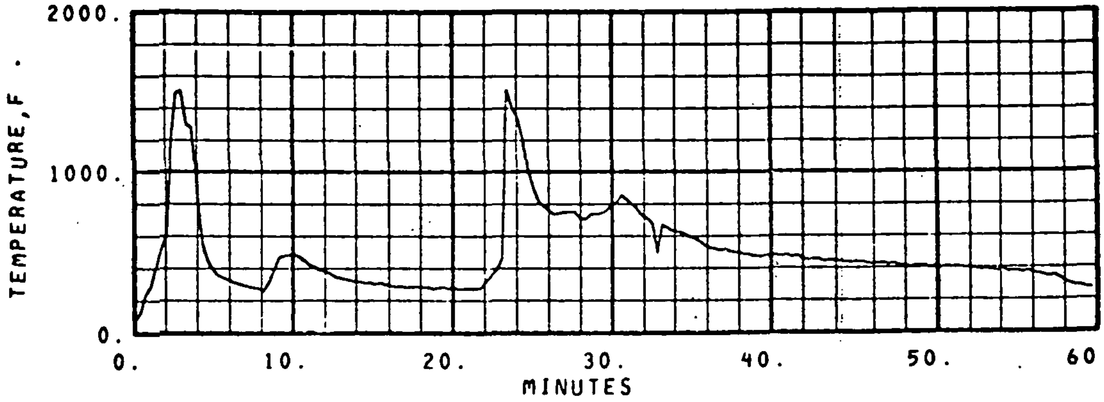

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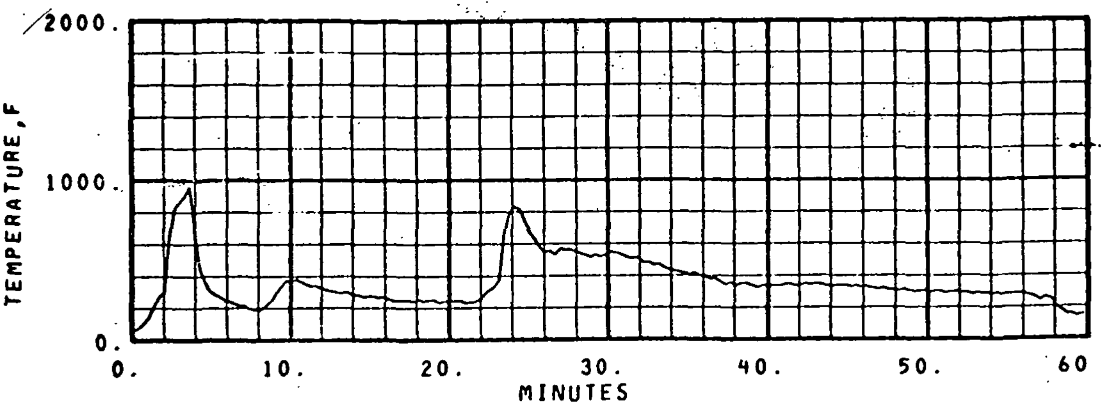

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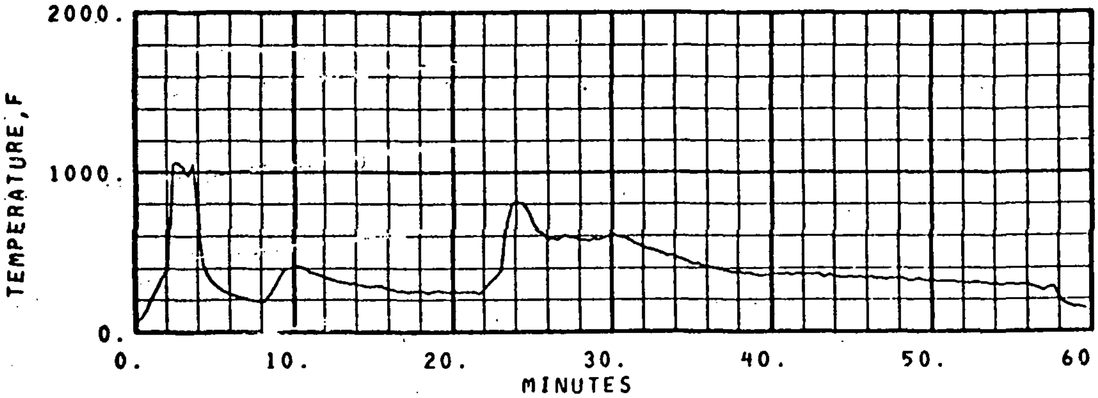

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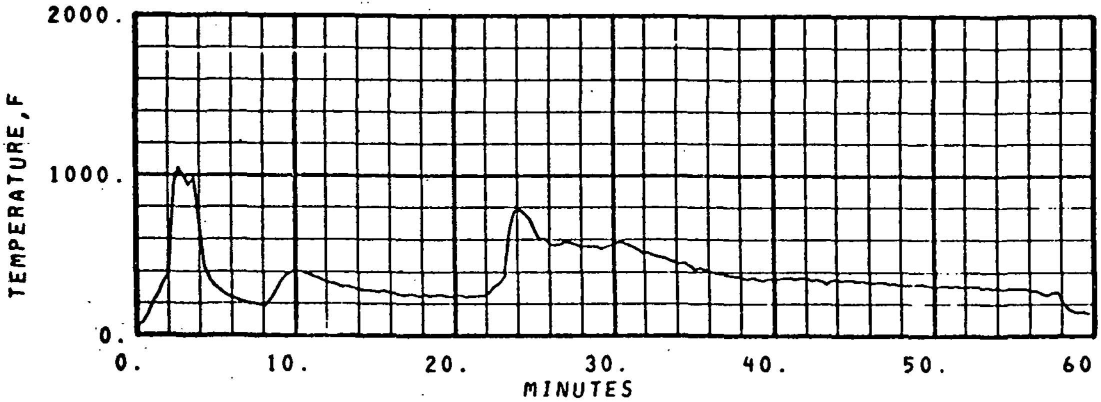

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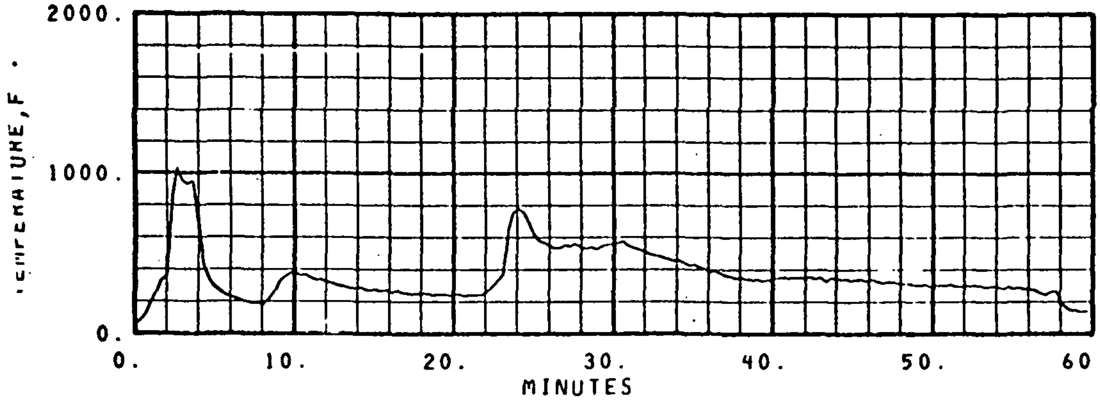

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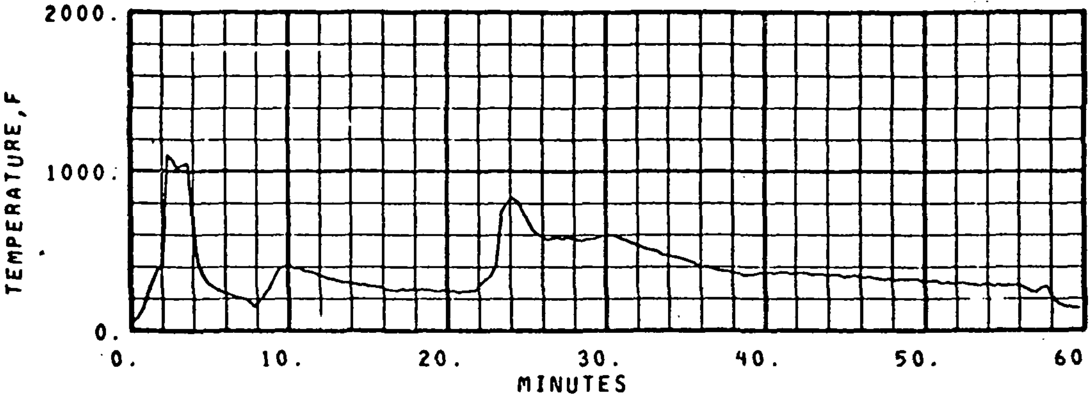

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