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DP-1242

AEC RESEARCH AND DEVELOPMENT REPORT

FIRE PREVENTION AND PROTECTION IN HOT CELLS AND CANYONS

A. J. HILL

DU PONT
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Savannah River Laboratory

Aiken, South Carolina

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AUTHOR(S) A. J. HILL, JR.

TITLE FIRE PROTECTION ~~AND VENTILATION~~ IN HOT CELLS, ~~CAVES,~~ AND CANYONS

DIVISION Separations Engineering

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March 4, 1971

TO: S. W. O'REAR

FROM: H. S. HILBORN

DOCUMENT REVIEW

Document: DP-1242

Title: Fire Prevention and Protection in Hot Cells and Canyons

Author(s): A. J. Hill

Contractual Origin: AT(07-2)-1

Present Classification: Unclassified DP Report

References:

No items were noted that, in my opinion, should be called to the attention of the AEC for patent consideration.

OSR 24-A117
(REV. 3-70)

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Savannah River Laboratory
Aiken, South Carolina 29801

(TWX: 810-771-2670. TEL: 803-824-6331. WU: AUGUSTA, GA.)

CC: L. C. Evans - J. W. Croach -
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March 4, 1971

Mr. A. F. Westerdahl, Chief
Patent Branch
Savannah River Operations Office
U. S. Atomic Energy Commission
Aiken, SC 29801

Dear Mr. Westerdahl:

REQUEST FOR PATENT REVIEW

Please review for patent matter:

DP-1242, "Fire Prevention and Protection in Hot Cells and Canyons" by A. J. Hill.

If any technical clarification is needed please call H. S. Hilborn, whose Document Review is attached.

Please telephone your comments to the TIS office (ext. 3598) and notify me by signing and returning to TIS the original of this letter. A copy is provided for your file.

If you decide to pursue a patent on any development covered, I shall be happy to supply additional information required such as appropriate references and the names of persons responsible for the development.

Very truly yours,

J. W. Croach, Director
Technical Division

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A. F. Westerdahl — Date
Chief, Patent Branch
SROO, USAEC

By: H. S. Hilborn

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DP-1242TL

... 20 1971

J. W. CROACH, DIRECTOR
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WILMINGTON

DP-1242 - FIRE PREVENTION AND PROTECTION IN HOT CELLS AND CANYONS

by A. J. Hill

The attached report, DP-1242, "Fire Prevention and Protection in Hot Cells and Canyons," is the terminal report of the study conducted by A. J. Hill on this subject. The study was initiated in February 1967 at the request of the Division of Operational Safety, who funded this study through Fiscal Year 1969. The remaining portion of the program, which was completed in January 1970, was funded by the Division of Production. Twelve Quarterly Reports were issued during this period, transmitting the results of studies by SRL as well as those done by Fenwal under purchase orders from SRL. This terminal report contains all the information transmitted in the Quarterlies, including the Fenwal reports in their entirety.

Portions of this work were presented in several papers by A. J. Hill:

"Organization of the Interventions on 'Hot' Facilities: Mishaps, Maintenance, Dismantling." Co-authored with W. D. Burch of ORNL, IAFA Symposium on Radiation Safety Problems, Saclay, France, October 13-17, 1969.

"Hot Cell, Cave and Canyon Fire Protection." 1970 AEC Fire Protection Engineers Meeting, August 11-12, 1970, Las Vegas, Nevada.

"Fire Prevention and Protection in Hot Cells." ANS Meeting Conference on Remote Systems Technology, November 15-19, 1970, Washington, D. C.

"Fire Detection and Suppression in Glove Box System." To be presented April 1971, at AEC Contractors Symposium on Safety in Plutonium Handling Facilities, Rocky Flats, Golden, Colorado.

The last paper listed represents follow-on work of the original study and resulted in an SRL standardized system for fire protection in glove boxes. A DP report describing this system is in preparation.

A. S. Jennings
Separations Engineering Division

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March 4, 1971

Mr. A. F. Westerdahl, Chief
Patent Branch
Savannah River Operations Office
U. S. Atomic Energy Commission
Aiken, SC 29801

Dear Mr. Westerdahl:

REQUEST FOR PATENT REVIEW

Please review for patent matter:

DP-1242, "Fire Prevention and Protection in Hot Cells and Canyons" by A. J. Hill.

If any technical clarification is needed please call H. S. Hilborn, whose Document Review is attached.

Please telephone your comments to the TIS office (ext. 3598) and notify me by signing and returning to TIS the original of this letter. A copy is provided for your file.

If you decide to pursue a patent on any development covered, I shall be happy to supply additional information required such as appropriate references and the names of persons responsible for the development.

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By: H S Hilborn
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SAVANNAH RIVER LABORATORY
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(TWX: 810-771-2670, TEL: 803-824-6331, WU: AUGUSTA, GA.)

CC: A. J. Hill, Jr.

August 25, 1970

Mr. Donald Kerlin
U. S. Coast Guard, MMT-4
400 7th Street, SW
Washington, D. C. 20591

Dear Mr. Kerlin:

Thank you for your telephone request of August 14, 1970 for a copy of report DP-1242 "Fire Protection and Ventilation in Hot Cells and Canyons" by A. J. Hill, Jr.

This report is in preparation and we shall send you a copy when it is issued in about three to four months.

Yours very truly,

S. W. O'Rear, Supervisor
Technical Information Service

SWO'R:sm

Geo. D.
This is the call I mentioned. Recall whether Ashley received the call in my absence.

Telephone request to A. J. Hill, Jr., 8/14/70 for copy of DP-1242(now in TIS Editing) FIRE PROTECTION AND VENTILATION IN HOT CELLS AND CANYONS by A. J. Hill, Jr.

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U. S. Coast Guard, MMT-4
400 7th Street, S. W.
Washington, D. C. 20591

OSR 24-A117
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SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA 29801
(TWX: 810-771-2670, TEL: 803-824-6331, WU: AUGUSTA, GA.)

January 11, 1971

Mrs. Mary T. McGuire
Refinery & Chemical Library
Bechtel Corporation
50 Beale Street, 15-C-1
San Francisco, CA 94119

Dear Mrs. McGuire:

Thank you for your letter of December 31, 1970, to Dr. A. J. Hill, in which you requested copies of Fenwal reports PSR-366 and PSR-368. These reports will be reproduced with two others in the appendix of Dr. Hill's report DP-1242 which will be issued in about two months. A copy of his report will be sent to you at that time.

Yours very truly,

S. W. O'Rear, Supervisor
Technical Information Service

SWO'R:sm

Bechtel Corporation
Engineers—Constructors

Fifty Beale Street
San Francisco, California 94119

December 31, 1970

Dr. Arthur J. Hill, Jr.
E. I. du Pont de Nemours Co. Inc.
Savanah River Laboratory
Aiken, South Carolina 29801

Dear Dr. Hill:

Fenwal incorporated suggested we contact you for the following reports:

PSR-366 "Thermal Fire Detector Evaluation"

PSR-368 "Smoke & Products of Combustion Detector Evaluation"

Our engineers are in need of these two reports. If you cannot supply us, could you give the name or names where they are available.

Thank you for your attention to our request.

Very truly yours,

BECHTEL CORPORATION

Mary T. McGuire

Mary T. McGuire

MTG:kw

Please address information to:

Bechtel Corporation
Mrs. M.T. McGuire
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50 Beale Street, 15-C-1
San Francisco, California 94119

663222

DP-1242

General, Miscellaneous,
and Progress Reports
(TID-4500, UC-2)

FIRE PREVENTION AND PROTECTION IN HOT CELLS AND CANYONS

by

Arthur J. Hill, Jr.

Approved by

A. S. Jennings, Research Manager
Separations Engineering Division

April 1971

E. I. DU PONT DE NEMOURS & COMPANY
SAVANNAH RIVER LABORATORY
AIKEN, S. C. 29801

CONTRACT AT(07-2)-1 WITH THE UNITED STATES ATOMIC ENERGY COMMISSION

ABSTRACT

In a comprehensive study of fires and explosions that have occurred in shielded facilities and glove boxes at atomic energy sites, the modes of initiation and propagation were identified. Some measures were defined to prevent fires and explosions in hot cells and canyons and to prevent propagation of fires into ventilation exhaust systems. To provide guides for selecting automatic fire extinguishing systems for hot cells, the characteristics and performance data of commercially available detectors and the suitability of various extinguishing agents were studied.

CONTENTS

INTRODUCTION

The protection of personnel, facilities, and environment is a necessary consideration in the design and operation of all production and research facilities at atomic energy sites. Despite precautions, some serious and costly fires and explosions have occurred. Fires in hot cells (or caves) of research facilities and of fuel reprocessing facilities could disperse large quantities of radioactive materials that are handled if the primary containment is destroyed or the protective ventilation and filter systems are breached.

Fire prevention and protection methods and ventilation in hot cells and canyons have been investigated. A study was also made of fires, explosions, and near-serious incidents that have occurred in these facilities and in glove boxes to determine the causes, and thus to develop improved preventive and protective measures to reduce the risk of serious fires and explosions. This report summarizes these studies.

SUMMARY

Although few fires or explosions have occurred in shielded facilities, there have been a few serious and many near-serious incidents.[1] The consequences of incidents have been reduced by the protective shielding, and serious fires and explosions have been averted by well trained personnel acting promptly following established procedures. Operating errors have caused fires and explosions, and several incidents have been due, at least in part, to continuing an operation when an important instrument was either inoperable or exhibiting abnormal behavior.

No fires or explosions have been reported that have destroyed the final filters in ventilation exhaust systems of shielded cells. However, because filters have been destroyed in glove box fires, and because of the potential for similar accidents in shielded cells, glove box fires and explosions were studied to establish measures to prevent the propagation of fires into exhaust ducts.

Preventive measures can significantly reduce the potential for fires and explosions and can minimize the consequences of those that may occur, but such measures cannot eliminate operating errors and unforeseen incidents. Protective systems must supplement preventive measures.

A study was made of the properties and applications of extinguishing agents suitable for use in the protection of shielded facilities. Halon 1301 (bromotrifluoromethane) can be used in place of carbon dioxide, dry powder, and foam to provide faster, more effective extinguishing capability. If Halon 1301 is used, most of the problems anticipated with the other agents are eliminated. Although Halon 1301 is not suitable for extinguishing metal fires, it can render the surroundings inert in the event of a metal fire and prevent the fire from propagating through exhaust ducts to absolute filters.

In a test program by Fenwal Incorporated, the response times of various types of detectors were determined under varied conditions to provide data for selecting detectors for shielded facilities. Thermal detectors are more reliable and suitable for remote locations where maintenance and testing is difficult or not feasible. The response rate of smoke detectors is similar to that of thermal devices, but significantly slower with solvent fires, especially low molecular-weight alcohols. Light detectors respond faster to fires, but they require more maintenance and are more prone to false alarms. Products-of-combustion detectors (ionization type) lose sensitivity in a high radiation field.

Detector and smoke tests showed that, for early detection, a detector should be located near the ceiling in the center of a small cell even with down-draft ventilation. In larger cells, additional detectors are desirable, particularly above principal equipment or areas where a fire could originate.

DISCUSSION

FIRE PREVENTION AND PROTECTION

Although precautions are taken in the design of facilities, materials of construction, and operational planning, operating errors and unforeseen problems do occur. Also, changes in process materials and operations make it difficult to anticipate all situations that may arise. However, good housekeeping, prompt removal of combustible waste materials, and limits on amounts of combustible materials, especially solvents, reduce the potential for fire.

Some combustible materials, such as plastics, elastomers, and laminates, are necessary in structural and operational applications and cannot be eliminated. Most of these organic materials, including those that are usually considered to be fire resistant, either pyrolyze or degrade in intense heat to produce gaseous products that are flammable, will propagate a fire, or will cause an explosion.[2] Thus, the use of these materials must be limited as far as possible, and precautions taken to prevent fires in which they can contribute to the fuel loading and thereby sustain or intensify a fire. Plastics and laminated hardboard for neutron and gamma shielding can be protected by metal sheathing except at viewing ports or windows. A vent must be provided for the escape of gases which could rupture the sheathing if the core material cannot be insulated from sources of heat, particularly fire. Exposure of plastics to intense alpha radiation degrades the exposed surfaces, and radiation damage may reduce the temperature at which thermal degradation may occur and may also increase the sensitivity to ox oxidation by nitric acid or to attack by solvents. Further study and experimental work are needed to establish safe limits of exposure.

Because of the serious potential of hot cell fires and the restrictions imposed by remote operations, most cells are now equipped with a manually operated extinguishing system or with means to introduce an extinguishing agent or inert gas promptly. Some cells are protected by automatic systems, but most of these are designed for manual control during normal operations. In many cells, detectors only alert personnel to abnormal conditions to be investigated. Except for metal fires, the extinguishing agents usually are carbon dioxide or dry powder. For metal fires, extinguishing agents such as magnesium oxide sand, graphite powder, or "Met-L-X"*

* Registered trademark of Ansul Chemical Co. for a dry powder fire extinguishing agent.

are used. In at least one installation, liquid nitrogen is provided to cool and extinguish sodium fires.

Most of the detection systems originally installed in the large cells or canyons for production operations, particularly the light detectors designed to detect the flickering light of flame, have been removed or inactivated because of their inaccessibility for maintenance, frequency of false alarms, and failure to respond to an actual fire. Where there is potential for fire in specific locations or areas, heat detectors have now been installed, or thermocouples have been placed at strategic locations adjacent to equipment or in exhaust ducts to indicate abnormal increases in temperature.

With the demand for larger and more concentrated isotopic power sources, the quantity and specific acitivity of radioisotopes handled in both production and research facilities is increasing rapidly. Furthermore, in the development and preparation of heat sources and other devices, large quantities of isotopic materials are handled as dry powders. Maintaining total containment while processing isotopes is more difficult with dry powders than with solutions or massive solid forms; nevertheless, total containment is mandatory.

CAUSES OF FIRES AND EXPLOSIONS[1]

Most of the incidents in hot cells, including those resulting in actual fires, can be attributed to the following: failure of electrical controls or of electrical equipment; ignition of combustibles from hot surfaces of equipment such as furnaces, heaters, hotplates, or overheated vessels, and from welding sparks and flames; improper handling of flammable solvents and other flammable materials; metal fires from reactions of reactive metals with air, moisture, or organic materials; and resin fires from exposure of irradiated anion exchange resins to air.

In the large production facilities for processing irradiated fuels, most of the process materials are totally enclosed in steel tanks and piping. Fires, explosions, and near-serious incidents have resulted from operating errors, leaks, spills during changes in piping and equipment, abnormal operating conditions (particularly in dissolvers and evaporators), and overheating of gases or reactors in off-gas systems.

In a few fires, costly delays have been attributed to the lack of carefully planned and practical procedures to be followed by personnel. For example, firemen and other specially trained personnel have been delayed because of security regulations and requirements for protective clothing for contamination control. Such restrictions should be evaluated realistically for emergency exceptions before an emergency arises.

Several incidents have been due, at least in part, to continuing an operation when an instrument or control was known to be inoperable or exhibiting abnormal conditions. If a control or instrument vital to the safety of an operation is faulty, the process should be shut down until the unit is replaced or the reason for the unusual behavior is determined. For example, incidents have been caused by overheating of electrical heaters, such as those in off-gas systems, because the controls fail in closed position. Where overheat can cause fires, explosions or excessive rates of reaction, a supplementary safeguard should be installed independent of the normal process controllers. Examples of critical controls are high or low liquid-level sensors in vessels, high or low flow-rate sensors in liquid or gas lines, and pressure sensors.

Common causes of fires and preventive measures are summarized in the following sections.

Failure of Electrical Controls or Electrical Equipment

Preventive measures for fires caused by electrical failures include the following:

- Mount electrical equipment (motors, switches, controls, etc.) outside of cells insofar as possible.
- Where external mounting is not feasible, install totally enclosed equipment, switches, contacts, etc.
- Within cells, enclose electrical cords and distribution wiring in conduit or metal sheathing or use fiberglass-insulated wiring.
- Insofar as possible, make all wire junctions in junction boxes outside primary containment and ground all junction boxes, cable trays, and conduits.
- In argon atmospheres, operate electrical installations at low voltage, or locate all junctions, switches, and other sources of arc-over outside the containment.
- Enclose heating elements of furnaces, ovens, hotplates, or other heating devices.
- Equip ovens, furnaces, heaters, reaction vessels, and similar equipment with a high temperature cutoff safety circuit in addition to, and independent of, normal controls.

Ignition of Combustibles by Hot Surfaces

Preventive measures for fires caused by ignition of combustibles by hot surfaces include the following:

- Stringently control housekeeping and make frequent inspections.
- Restrict quantity of combustible solvents and other process materials to the minimum necessary to accomplish the work.
- Remove combustible wastes promptly and do not permit them to accumulate.
- Where welding is unavoidable, remove combustible materials or shield them from sparks.

Improper Handling of Flammable Solvents and Gases

Preventive measures for fires caused by flammable solvents and gases include the following:

- Apply safeguards on all electrical installations as outlined above.
- Limit the temperature of heat sources such as steam, electrical equipment, lights, and chemical reactions to temperatures below the flash point of the solvents being handled.
- Design facilities so that major heat sources (e.g., evaporators) will be separated from large volumes of solvent.
- Provide a separate exhaust or purge system independent of the primary ventilation system for ovens and process vessels in which combustible fumes may be generated.
- Test the ventilation periodically to ascertain that flow is adequate and that solvent vapors are well below the explosive limit.
- Where gas or vapor concentrations cannot be maintained well below the explosive limit (for example in handling acetone or propane), conduct operations in an inert atmosphere or install an explosion suppression system.

Metal Fires

Although extinguishing agents and techniques for preventing and extinguishing such fires are known, improved methods are needed.

Current studies[3,4] to expand the knowledge of both ignition and burning characteristics of metals are also leading to improved methods of prevention and extinguishment.[5] Similar studies are continuing on the prevention and extinguishing of fires involving nonradioactive metals such as sodium, NaK, lithium, aluminum, and zirconium. Up-to-date information and references to development work are obtainable from most suppliers of special metals.

Preventive measures for metal fires include the following:

- Recognize conditions under which metal fire potential exists.
- Establish procedures and train personnel to reduce the potential for errors that could result from inadequate preparation or hasty decisions.
- Consider nonradioactive as well as radioactive metals in plans for preventing and extinguishing fires.

Resin Fires

The causes of fires with nitrated anion exchange resins have been investigated.[6]

Preventive measures for resin fires included the following:

- Equip facilities in which resin is handled with adequate spray and deluge systems.
- Monitor the temperature of the columns so that the appropriate cooling can be applied when required.
- Vent or provide the resin columns with an appropriate pressure relief system to avoid the possibility of explosion.

VENTILATION

No fires or explosions destroying the final HEPA* filters of shielded cells have been reported. However, final filters have been destroyed by fires originating in glove boxes and hoods. Two conclusions can be drawn from these fires that may prevent similar fires in shielded cells: 1) materials that are flammable, such as dust and metal powders, should be filtered from the exhaust

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* High Efficiency Particulate Air

air streams as close to the point of origin as possible, and at some distance ahead of the main filter system; 2) materials that usually are considered fire resistant may, when exposed to intense heat, decompose to produce gaseous products that are flammable and can propagate a fire through exhaust ducts or cause an explosion. Stainless steel screens in the exhaust duct behind the primary filter will stop burning debris from the primary filter before the embers ignite the secondary or main filters. Where this is not feasible or where there is real potential for fire, a suppression system should be installed in the ventilation exhaust ducts to prevent propagation of fire through the ducts to final filters. Fiberglass ducts do not protect as well as stainless steel. Fiberglass is not easily ignited, but once ignited, the fire is difficult to extinguish, and the dense smoke produced can clog absolute filters. Where fiberglass is required for corrosion resistance, an extinguishing system must be located within the duct or the means to introduce an extinguishing agent into the duct must be provided.

In the event of a fire in a shielded cell, the normal ventilation air flow should be reduced, preferably by damping the inlet air, unless the system already has a very low flow. With reduced flow the ventilation system can still remove combustion products that could contribute to the fire or cause an explosion. Ventilation reduces the overpressure caused by heat and combustion products from the fire. The limited air supply also reduces the burning rate and the rate at which a vaporizing extinguishing agent, such as CO_2, is diluted and removed from the cell. Conversely, increasing the air flow through a cell supplies more fresh air to a fire and increases both the intensity and the potential for propagation into the ventilation exhaust duct. If the air flow is completely stopped, the cell or containment box within a hot cell can rapidly become pressurized by the heat and combustion products generated in the fire. The release of an extinguishing agent, such as CO_2, at high pressure and in the large volume required to blanket a fire will result in even greater overpressure. If the vaporizing extinguishing agent is heavier than air, shutting off the ventilation flow can cause the vapors to settle and flow out through open service trenches or under the shielding wall and contaminate clean areas.

To maintain integrity of the exhaust ventilation system, a separation of at least 20 feet between filters in or near shielded cells and the final filters has been recommended.[7] The potential for propagating fires in filter systems can also be reduced by screens between filter banks with the screen downstream and close to the first filter and well upstream of the second. Deep bed sand filters have also been used for final filtration of exhaust air from large separations plants. These filters are fireproof and can withstand overpressure better than HEPA filters.

PROTECTION SYSTEMS

Although the need for automatic extinguishing systems has been generally recognized, the factors deterring the installation of these systems are: confusion in selecting appropriate extinguishing agents, the questionable reliability of detectors in remote environments, and the high cost of some of the proposed systems. In tests of protection systems, some guides for selecting detectors and extinguishing agents appropriate for various applications are given and criteria are provided for locating detectors with respect to the size of facilities, the ventilation, the materials processed, and the type of fire that can occur.

Extinguishing Agents

Carbon Dioxide

Carbon dioxide has been used more than other extinguishing agents to protect hot cells, except in metal fires. The installation of carbon dioxide systems has been deterred by concern about thermal shock to electronic components, plugging of filters by ice crystals when large amounts of CO_2 are required, how effectively CO_2 can extinguish fires where there is a high flow without provision for reducing the flow, and the effect of releasing large amounts of CO_2 into systems where negative pressure must be maintained for containment of radioactive materials. When large amounts of CO_2 are released, filters can become plugged and overpressures can occur. In some installations where CO_2 is used, plugging and overpressure have been counteracted by opening additional exhaust capacity when the agent is released. However, this may also increase the rate of removal of CO_2 and thus may increase the intensity of the fire.

Dry Chemicals

To avoid the risk of overpressure, dry chemical extinguishers have also been considered. In the first instant of discharge, dry chemicals approach total flooding similar to the discharge of CO_2. The powder settles rapidly, and the extinguishing capability diminishes with the settling. The major disadvantages of dry chemicals are the potential for plugging the exhaust ventilation filters in shielded cells and the residual fine powder which must be removed because it increases the potential for spreading contamination. Even equipment that is not directly involved in a fire may require disassembling, cleaning, and reassembling before reuse.

Water

Concern about nuclear criticality, spread of contamination, and wetting of electrical and electronic components has deterred the use of water. However, it has been necessary to extinguish large fires with water. In a large fire, chemical agents are not usually effective, and the consequences of a serious fire may outweigh the damage caused by water. Contamination may be spread, but the spreading is likely to be two-dimensional. Three-dimensional spreading occurs when contamination is airborne by hot smoke and gases. The possibility of criticality must be carefully considered, but where water can be tolerated, controlled amounts from spray nozzles can be applied effectively.

Foam, particularly high expansion foam, can be used to get water into shielded facilities to extinguish fires. A large volume of water is not required, and the resulting contamination potential is reduced. Usually foam is blown in with a large volume of air. In the contained volume of a shielded cell, usually operated at negative pressure, blowing the foam in can cause overpressure and spread of contamination. In-cell air can be used to generate the foam as an alternative to blowing in fresh air; however, experimental work[8] indicates that smoke generated in a fire, particularly with plastics, interferes with the formation and stability of foam.

Halon 1301

Halon 1301 (bromotrifluoromethane) can be used as a substitute for carbon dioxide in special applications because of the low concentration required to extinguish fires, the speed of extinguishment, the demonstrated effectiveness against plastic and cellulose fires, the low toxicity at the concentration required for most fires, and the concern about some aspects of CO_2 systems and the problems with the use of foam and dry powder systems. Halon 1301, like CO_2, is most effective in extinguishing fires in confined systems (such as shielded cells) and beginning fires.

Carbon dioxide extinguishes fire by blanketing to exclude oxygen. A concentration of at least 45 vol % CO_2 in air is required for most fires, and CO_2 cannot be used to extinguish metal fires because it may accelerate oxidation. Only 5 vol % of Halon 1301 is needed to extinguish fires because it reacts chemically with the intermediate products involved in the propagation of flame. The reaction is very fast, and the inhibiting and extinguishing action starts well before the effective concentration is attained.

Like CO_2, Halon 1301 is not effective against metal fires. However, it can be used in some metal fires, such as plutonium and magnesium fires, to render the surroundings inert when mixed with air, and thus to reduce the chance for propagation while the metal fire is extinguished with suitable agents for the specific metal involved. Because the reaction of Halon 1301 with other reactive metals is not known, more studies are needed before Halon 1301 systems are used in cells where fires involving reactive metals can be anticipated. However, the exhaust ducts and final filters can be protected by introducing Halon 1301 into the exhaust duct. Because the toxicity of Halon 1301 is low, the concentration required to extinguish a fire is breathable. There are no solid or liquid residues and no ice crystals to clog filters or reduce visibility during discharge. Tests showed that the slight increase in pressure during discharge and vaporization of the small quantity of agent required to extinguish a fire did not upset the control of ventilation.

Although both Halon 1301 and CO_2 are designated primarily for solvent and electrical fires, they are effective when paper cartons, tissues, and plastic sheets or bags are ignited. Halon 1301 is more effective than CO_2 in preventing rekindling of a fire.

In the extinguishing action of Halon 1301, some pyrolysis products formed are toxic and corrosive, but the amount formed usually is very small because the quenching action is fast and the amount of agent that actually takes part in the chemical reaction is small. The quantity of pyrolysis products is further reduced by early detection and prompt extinguishment of a fire. Fast action also blocks formation of flammable gases produced in a hot fire by burning organic materials, especially plastics.

Detectors

Early warning of beginning fires or of unusual conditions that can cause a fire reduces the frequency and severity of incidents. Detectors that are commercially available and most of those under development are primarily for normal domestic and industrial applications, except those for aircraft and special applications. The detectors installed in hot cells and canyons have caused many false alarms and have sometimes failed to respond to actual fires. With more reliable systems, automatic action would be preferable in most applications.

Detector characteristics important for operation in relatively inaccessible shielded facilities are reliability, sensitivity, durability, maintenance requirements, and cost. Because the information available was of little help in determining the suitability of detectors in the environments encountered in cell and canyon applications, Fenwal Incorporated was contracted to conduct a comprehensive survey.

Fenwal surveyed the available literature, including files at the library of the National Fire Protection Association, on commercially available detectors. Although Fenwal was able to characterize the detectors, much of the performance data, particularly that for thermal detectors, was directed toward approval by insurance rating associations and did not disclose performance data that would be useful in making selections for special applications. The performance of products-of-combustion detectors was even more difficult to analyze, particularly with the variables anticipated in hot cell and canyon applications. The survey report, *Fire Detector Characteristics* (PSR-356), is given in Appendix A.

Two basic functions of a detector are to sense combustion in the incipient stage and to initiate preplanned actions. The first function is inherent in the device, but the second function relates to the circumstances of specific applications. A detector that will not sense combustion makes an excellent alarm and shutdown system worthless. Conversely, an adequate detector is useless if the action it precipitates is not adequate to cope with the situation that develops. Thus, the selection of an appropriate detector is the first step in an overall system of protective action and an integral part of the total system.

Detectors currently available respond to one or more of the physical manifestations of combustion: heat, light, products of combustion, or pressure. The amount of each function depends upon the type of materials present, the quantity, and the area exposed. In selecting a detector, physical variables such as the volume to be protected, the configuration of the volume, the direction and rate of air flow, the range and rapidity of normal temperature fluctuations, corrosive atmospheres, and radiation effects should be considered. Because no single detector is suitable for all applications, adequate protection may require a combination of two or more types.

Unless a detector is located where it is readily accessible, it must be self-resetting or capable of being reset remotely after actuation. Provisions should be made to test the response of the detectors as well as the operation of the electrical and electronic components, and a procedure for periodic testing should be established. The action to be initiated by personnel should be clearly defined and periodically reviewed. The physical and environmental parameters established in the selection of a system must remain basically unchanged. Major alterations in the equipment, operating conditions, and process materials must be reviewed to determine the effect on the system. Periodic reevaluation also is necessary to be certain that a major change has not been effected in small increments.

General Characteristics of Fire Detectors

The general characteristics of thermal, products-of-combustion, and surveillance or light detectors are summarized in the following paragraphs.

Thermal Detectors:

- Detectors for aircraft applications are very reliable but usually have a high temperature rating (250°F and above), so that they are not suitable for applications where the ambient temperature is moderate. They are suitable, however, for sensing overheat in areas at elevated temperatures or adjacent to heated equipment.

- Detectors that are not resettable are not suitable for shielded environments unless they are readily accessible. For example, with line detectors made of conducting wires enclosed in thermoplastic, the burned-out section must be replaced, and with some combination detectors (rate-of-rise and fixed setting), a fusible link melts at the fixed temperature (set point).

- Line detectors with pneumatic tubing do not respond well to fires that develop slowly.

- Fixed temperature detectors with bimetallic strips, whether straight or curved, require only very light force to close the alarm contacts. Thus, they are very sensitive to mechanical shocks or vibration. Fixed temperature detectors with bimetallic disks that snap to close contacts require more force and are less sensitive to shock or vibration.

Products-of-Combustion Detectors:

- Some products-of-combustion detectors alarm and hold although the conditions causing the alarm are transient; they have to be reset electrically.

- Detectors with light sources (either direct beam or scattered light) are sensitive to dust.

- Ionization detectors are sensitive to dust and may also respond to high molecular weight vapors.

Light Detectors:

- Surveillance or optical devices are fast acting, but they are influenced by condensates, smoke, dust, and some vapors.

- Infrared detectors can respond to a broad spectral band. Signals from infrared sources other than flames must be avoided; therefore, optical filters are used that limit the response to a narrow band characteristic of flames, and the detectors are designed to respond only to a surge of varying amplitude and a frequency characteristic of flames.

- Interruption of infrared radiation from any external source such as lights or motors at the critical frequency will still cause an alarm.

- Because infrared has a low reflectance, equipment size and location will be an important factor to avoid loss of protection in "shadowed" areas.

- Ultraviolet detectors respond to only a narrow spectral range, so there is little latitude for adjustment.

- The ultraviolet detectors do not respond to solar radiation and, because ultraviolet radiation is not transmitted through glass, the detectors are not affected by normal electric lights. Windows to protect ultraviolet detectors from dust or corrosive atmospheres must be quartz.

- Ultraviolet detectors are very sensitive to small sparks such as those from switches or motors, and to welding. Ultraviolet radiation is reflected from metal surfaces. This characteristic can be a disadvantage in response to other ultraviolet sources.

Experimental Program

To compare the performance of various types of detectors, Fenwal was contracted for a three-part experimental program. The first part was a preliminary thermal study and subsequent evaluation of thermal detectors; the second part of the program, tests of smoke and products-of-combustion detectors; and the third part, surveillance or light (radiant energy) detectors. The tests in the first two programs were conducted in an environmental test chamber: a 32-ft-long by 12-ft-wide by 8-ft-high room having a movable partition and a variable exhaust rate. For these tests, the partition was positioned to simulate cells 6 ft long and 12 ft long. The effect of air flows was established by conducting tests in static air and with flows of one volume change in three minutes and of one volume change in one minute. In the third series of tests, the full length of the chamber was used to determine the limit of sensitivity of the light detectors to fires at greater distances.

A thermal study before the tests of detectors determined heat distribution and thermal gradients within the simulated cells as a function of fire location, magnitude of the fire, cell size, and ventilation. The thermal output of each fire was determined by measuring the weight loss of the fuel (n-heptane) as a function of time; smoke tests were conducted to supplement the thermal data and to show air currents and stagnant areas.

Five fire locations were selected (center of each cell and each corner), and two tests were run at each location. Location of the detectors was based on analysis of the thermal data. The in-cell temperatures near the ceiling rose faster than the temperature in the exhaust duct, even under cases of high ventilation flow, although the air flow patterns in the two sizes of cell (6 x 12 x 8 and 12 x 12 x 8 ft) were substantially different for equivalent fire sizes and locations. This was confirmed by the temperature profiles recorded from multiple thermocouples as well as by the detector response times. For a fixed size cell, the response time of a detector is influenced more by the location of the detector with respect to the fire than by the total cell ventilation flow.

Smoke release patterns in test cells with no fires could not predict the air flow pattern created by even a small fire and, thus, these patterns were of little value in locating detectors in cells. Combined smoke and thermal tests showed that the smoke was mostly entrained in heated air over the fire and was carried to the ceiling of the cell rather than directly into the exhaust duct even under test conditions simulating down-draft ventilation of the cell.

The complete report of the thermal studies and thermal detector studies, *Thermal Detector Evaluation* (PSR-366), is given in Appendix B. The tests of the thermal detectors are summarized in the following paragraphs.

Eight thermal detectors were tested with two sizes of fire (n-heptane fuel), to give different rates of rise in temperature, with static air and two rates of air flow. Of six resettable detectors, five were spot types and one was a line type. Three of the five spot devices were fixed temperature, bimetallic units (snap disks), one was rate compensating, and one was a combination fixed temperature/rate-of-rise device. The line detector was rate-of-rise only (pneumatic tubing).

Although nonresettable detectors are not practical for remote locations, two nonresettable spot detectors were included for comparison of response: one fixed temperature and one combination.

Only detectors approved by rating associations (Underwriter Laboratories, Factory Mutual, or Factory Insurance Associates) were used in the test program. The endurance demonstrated under the rigorous test conditions was noteworthy. The units were wiped to remove carbon between the small and large cell test series; no other maintenance was performed. Some results of the thermal detector tests are:

- Of the resettable devices, only one failure was encountered after exposure to 55 fires; one snap disk failed to reset.
- There were no electrical failures.
- In general, the line detector was the first to respond in most of the fires because the detector was strung around the ceiling so that a section was always relatively close to each of the five fire positions.
- The spot types of rate devices were usually somewhat slower as the fire was moved to positions farther from the detector.
- In most tests, the rate-of-rise detectors responded before the fixed temperature units. This was evident in the combination detectors.
- The three fixed temperature (snap disk) units were basically the same, but two with fins responded faster and reset earlier upon cooling than the equivalent detector without fins.
- The response times of the thermal detectors were consistent with the temperature rise records obtained in each of the two test cells. The results of these tests and the data obtained in the preliminary thermal studies verified the reproducibility of detecting fires and the air flow patterns.

The tests of smoke and products-of-combustion detectors are summarized in the following paragraphs. The full report, *Smoke and Product of Combustion Detector Evaluation* (PSR-368), is given in Appendix C.

Six products-of-combustion detectors (ionization devices) and four smoke detectors (photoelectric devices), were tested by Fenwal in static air and with two rates of air flow. In addition to the two sizes of n-heptane fires used in tests of thermal detectors, the smoke and products-of-combustion detectors were subjected to fires of isopropyl alcohol, and to smoke from polyvinylchloride (electrical insulation) on a preheated hot plate. One of the products-of-combustion detectors was a resistance bridge type that included a moisture sensitive membrane. To alarm, the detector must sense an increase in water vapor as well as smoke or other combustion products.

Some generalizations can be made from these tests:

- Sealed units or those with remote circuitry are more reliable in repeated exposure to fire conditions than those with open circuitry in the detector.

- With one exception, the products-of-combustion detectors responded earlier than the smoke detectors. With polyvinylchloride smoke, a smoke detector alarmed first. This detector operates when smoke reduces the light transmission between a source and photoelectric cell (obscuration type). The other smoke detectors were diffusion detectors in which the light from the source re reaches the photoelectric cell by diffusion or backscatter.

- n-heptane, isopropyl alcohol, and cellulose fires were hot enough to overcome any effect of air flow rate under the test conditions. The polyvinylchloride generated more smoke than the other materials, and more trouble was encountered with the detectors. Cleaning was necessary after each test.

- Fires with isopropyl alcohol were the most difficult to detect. A resistance bridge type detector that was predicted to be the best, did not respond to the alcohol fires under any of the test conditions.

- With fires of flammable liquids, none of the smoke detectors responded as fast as the thermal detectors. However, some of the products-of-combustion detectors approached the rapid response times of thermal detectors.

- In all tests, the first three detectors to respond were located in the center of the test cells near the ceiling, not in the ventilation exhaust duct.

The results of tests of light or surveillance detectors are summarized briefly. The full report, *Light Detector Evaluation* (PSR-373), is given in Appendix D.

Two infrared and two ultraviolet detectors were tested in the 32-ft chamber. Nine units were originally scheduled for testing, but four were not submitted by the manufacturers and one was not yet commercially available. In a series of tests, the response times of both the ultraviolet and infrared detectors were determined for fires of n-heptane, isopropyl alcohol, paper, and polyvinylchloride with a distance between the fires and the detectors of up to 32 ft. In a second series of tests at a fixed detector-to-fire distance with alcohol fuel, the area of the fire was reduced to determine the lower limit of detection for each detector. The time of response was also determined as the angle of the fire from the center line of the detector was increased. Finally, the increase in response time with obscuration of the fire was determined by generating smoke in the chamber before the test fire was ignited.

Some generalizations can be made from these tests:

- Light detectors respond in less than one second to most fires of significant size and at distances up to 32 ft unless they have a built-in time delay. One of the infrared detectors tested had a three-second delay to reduce the potential for false alarms.
- The ultraviolet detectors responded slightly faster than the infrared to fires of n-heptane, alcohol, and paper, but they were very slow with smoke from polyvinylchloride. The response time of the infrared detectors to polyvinylchloride was about the same as that for the other three fuels.
- The response time of all the detectors increased as the fire position was moved from directly in front of the detector to either side, with a sharp increase at angles greater than 60°.
- Mechanical design of a detector head, generally related to the intended use, has more effect on detector sensitivity at wide angles than does the sensitivity of the cell. For example, a detector with a recessed head has a much narrower angle of radiation acceptance than one with a sensor that protrudes.
- One of the infrared detectors tested had a focusing lens before the sensing cell to increase the sensitivity.
- Generation of smoke in the test chamber before ignition of a test fire significantly increased the response time of all of the detectors tested.

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APPENDIX A

FIRE DETECTOR CHARACTERISTICS

E. I. duPont deNemours and Company

Savannah River Laboratory

PSR-356

ABSTRACT

A survey of fire detectors was conducted to provide a guide in selecting detection devices for hot cell and canyon environments. The three general classifications of detectors investigated were thermal, smoke and products of combustion and surveillance.

The principle of operation of the various detectors is described and detector applicability to hot cell and canyon operation is discussed.

INTRODUCTION

The detection of fire can be accomplished in numerous ways depending on the specific physical characteristic of the combustion process utilized for detector actuation. An understanding of the principle of operation of fire detectors currently available is a prerequisite for the intelligent selection of a detector or combination of detectors for each specific application.

Fire detection in a hot cell (canyon) presents two rather unique problems not usually encountered in most applications. The first is the severe environment associated with nuclear radiation and the second is the relative inaccessibility of all devices and equipment in the cell.

At the request of E. I. duPont deNemours and Company, Fenwal Inc. has conducted a survey of the available types of fire detectors in order to facilitate detector selection for hot cell applications. The result of this survey is the subject of this report.

Dr. A. J. Hill, Jr. of the Savannah River Laboratory served as technical coordinator for this program.

RESULTS AND CONCLUSIONS

Fire detection in hot cell environments can be effectively accomplished provided that the variables peculiar to each installation are taken into consideration. These variables include the size of the protected volume, the type and amount of combustible materials, the configuration of the protected volume, the size and location of equipment in the protected volume, the direction and extent of air flow and the range and rapidity of normal temperature fluctuations.

The detection devices should be self-resetting or capable of being remotely reset after actuation.

Provisions for testing detection devices should be made at the time of detector installation and a periodic test procedure established.

The action to be initiated by the detector and/or by personnel at the time of detector operation should be clearly defined.

Protected volumes should be periodically inspected and evaluated to ensure that changes in equipment size or location or operating parameters have not compromised the effectiveness of the detection system.

A definitive program should be established to evaluate the effect of nuclear radiation on fire detection devices.

Most of the detector types discussed in the body of this report have been available for a number of years. Almost without exception, they are approved by Underwriters Laboratory with respect to electrical considerations and proper functioning as fire detectors. Operational history over the years substantially documents the reliability of these devices in performance and durability. However, when detector reliability is considered in the light of the severe environmental conditions encountered in hot cells, it becomes apparent that sufficient information is not available. Too little is known of the effects of nuclear radiation on the various materials of construction utilized in the manufacture of fire detectors. Thus, while the inherent reliability of these detectors is a proven fact in normal or standard environments, it is felt that an evaluation program is needed to establish detector effectiveness in applications such as hot cells.

The inaccessibility of the equipment used in hot cell applications make it advisable to select detection devices which can be functionally tested periodically and which do not require replacement after normal actuation. This approach would tend to eliminate from consideration detection devices which do not automatically reset themselves or which cannot be manually reset from a remote location. Thermal detectors can be tested by the application of heat from a coil or a heat gun. Smoke detector operation can be determined by energizing a small smoke-producing capsule in the hot cell. Surveillance detectors require only that the appropriate type of radiation be created within their field of vision.

GENERAL CONSIDERATIONS

The basic functions of a fire detector are to sense combustion in its incipient stage and to initiate a preconceived plan of action designed to minimize or eliminate potential destruction to personnel and property. The first function is inherent in the detection device itself while the second function relates to the circumstances peculiar to the application. It is essential that both functions be considered simultaneously if maximum overalll effectiveness is to be achieved. The selection of a detection device which, because of type, location or operating principle, will not sense combustion renders worthless an otherwise excellent alarm, extinguishing or shutdown system which is wholly dependent on proper operation of the detection device. Conversely, a perfectly adequate detection device is to no avail if, upon operation, it precipitates action which is inadequate to cope with the situation. An extreme example would be a detection device which, upon operation, caused an alarm light to glow in an unattended area.

It is clear that personnel and property protection considerations do not end with the selection of the detection device. An overall protection system and procedure must be formulated, the fire detector itself being an integral part of the total formulation. Each application must be examined in its own light to ensure the selection of the most effective detection and subsequent plan of action.

The physical manifestations of combustion may be broadly classified as light, heat, pressure and products of combustion, either visible or invisible. The quantitative output of each parameter is a function of the type of combustible, amount, and exposed surface area. Detector selection therefore depends to some degree on the nature of the combustible contained in the volume to be protected. Where the combustible is a fixed type, detector selection is simplified. If the combustible materials are varied the problem of detector selection becomes more complex and often results in the requirement for two or more different type detectors to provide adequate coverage. There is unfortunately no universal detector which provides sufficient coverage under all circumstances.

Environment plays an important role in the selection of a detector. The ambient temperature, temperature fluctuations, air flow rate and corrosiveness of the atmosphere should be considered. In hot cell applications, particular attention must be paid to detector materials of construction because of nuclear radiation activity.

Another important consideration in detector selection is the physical location of equipment in the volume requiring protection. In a location such as a hot cell where there is a continual flow of air through the cell, the placement of apparatus has an effect on the air path through the cell. This of course will determine the course subsequently followed by smoke and to a lesser degree will affect the distribution of heat throughout the cell. Bulky equipment such as tables and benches can create 'shadow areas' and greatly decrease the effectiveness of surveillance detectors.

The severe environment encountered in hot cells may be expected to cause a reduction in the life span of detection devices. It is advisable therefore to devise a method of testing the detection device(s) and to install the test circuit in the cell when the detector installation is made. This will facilitate periodic checks of the integrity of the detection devices(s) without the necessity of cell shutdown and decontamination.

The effectiveness of detection devices is maintained only as long as the physical and environmental parameters of the protected volume remain basically unchanged. Major alterations to the physical plant or operating conditions should be accompanied by a review of the effect on detection efficiency. A more common pitfall is the gradual occurrence of a number of minor modifications to equipment or procedures, none of which taken separately would seriously impair detector function but cumulatively serve to compromise detector effectiveness. This situation can be avoided by the establishment of periodic, systematic evaluation of protected volumes designed to establish detection requirements as if each protected volume were being considered for the first time.

THERMAL DETECTORS

Thermal detectors may be broadly classified by function as fixed temperature, rate of temperature rise or a combination of the two functions. Fixed temperature devices are designed to respond when a predetermined temperature is reached. Rate-of-rise devices respond to temperature increases above a predetermined rate and are not influenced by lower rates of temperature rise. The combination devices are designed to operate at either a predetermined temperature or a predetermined rate of temperature increase.

FIXED TEMPERATURE DETECTORS

The bimetallic strip is a common type of thermal fire detector. This device uses a strip composed of two metals having different thermal expansion coefficients. When the temperature of the strip is increased, it warps and the resulting motion is used to close a set of electrical contacts. The temperature setting of the device is controlled by the spacing between the bimetallic strip and the electrical contact. This device is available in a wide range of temperature settings and is self-resetting after operation. The one disadvantage of this type of device is its susceptibility to false alarms due to mechanical shock or vibration.

Another type of bimetallic detector utilizes a snap-action disc. The disc snaps through at a predetermined temperature closing a set of electrical contacts. This positive mechanical contact closure makes the device more reliable from the standpoint of shock and vibration. This type of device is available in a wide range of temperature settings and is self-resetting after operation.

Eutectic fuses are used in a number of fixed-temperature detectors. In one type of device the eutectic material serves to restrain a spring. When the eutectic melts the spring is released and its subsequent action is used to close a set of electrical contacts. Another type detector has a set of open contacts positioned below the eutectic fuse. When the eutectic melts, it drops between the contacts thus completing a circuit. The primary disadvantage of these devices is that they are not self-resetting.

A variation of the fixed-temperature detector is the 'line' detector. This device consists of two tensioned steel wires twisted together and electrically insulated from each other by a heat sensitive covering applied to each wire. When any segment of the covering melts the two bared wires come into contact with each other to complete an electrical circuit. This type of detector is normally strung back and forth along the ceiling of the protected volume. Once the device alarms, all sections of the detector with bare wire exposed must be replaced.

There are other types of 'line' detectors which were designed primarily for use in aircraft. One type uses small diameter tubing filled with gas and provides an alarm when heat causes the gas to expand and move a bellows. A second type utilizes a thermistor type material in a small diameter tube. In this device a change in resistance caused by an increase in temperature is utilized to provide an alarm. A third type of line detector consists of a small diamter tube containing a wire and a eutectic salt. When the salt reaches its melting point, its resistance drops sharply and current flows from the center wire to the tubing to provide an alarm. The first two types of line detectors are 'averaging' devices, that is the entire length of the device must be heated to the set point to provide an alarm or else a section must be heated well above the nominal set point. The third device is a 'discrete' detector in that it will provide an alarm when any six inch section of tubing is heated to the set-point temperature.

The aircraft line detectors are normally used in zones having elevated ambient temperature and are not available at the low temperature set-point values commonly associated with commercial fire detectors. They are used as overheat detectors and there is at least one application where line detection is used in a nuclear filter bank installation. These devices are self-resetting and are extremely rugged in their construction.

RATE-OF-RISE DETECTORS

Rate-of-rise detectors are designed to function when the rate of temperature increase at the detector exceeds a specified number of degrees per minute. These devices may be used over a wide range of ambient temperatures since they do not have a fixed temperature setting. Rate-of-rise detectors may be generally classified as pneumatic or thermoelectric.

The pneumatic devices operate on the principle of air expansion due to an increase of temperature. They are available in both 'spot' and 'line' configurations. Both types utilize a chamber equipped with a flexible diaphragm and a small relief vent. Line detectors use small diameter tubing connected to the chamber as the sensing element whereas with spot detectors the chamber itself is the sensing element. The pressure developed in the chamber due to air expansion caused by a temperature increase causes the flexible diaphragm to operate a set of electrical contacts. If the system were closed, contact closure would occur at a fixed temperature. It is the function of the chamber relief vent to bleed chamber pressure off until the rate of pressure rise exceeds a value corresponding to a predetermined rate of temperature rise (usually about 15°F/minute).

At lower rates the chamber pressure is effectively relieved by the chamber vent and the diaphragm remains motionless.

Thermoelectric devices use two sets of thermocouples, one exposed to convection and radiation and the other insulated. The thermocouples are wired so that their outputs are opposed or 'bucking' one another. When both sets of thermocouples sense the same temperature, the output voltages from each set are the same and the total output voltage is zero. Gradual temperature rises produce a small output voltage which drops to zero again as the insulated set of thermocouples eventaully reaches the temperature of the exposed set. A rapid rate of temperature rise causes a relatively large voltage output because of the differrnce in temperature between the insulated and exposed thermocouples. The output voltage is used to operate a sensitive relay preset to a specific value corresponding to a particular rate of temperature rise.

Rate-of-rise detectors are self-resetting. Their prime disadvantages are failure to react to a fire which propagates slowly and generates heat at a low rate and the possibility of false alarms due to a rapid increase in temperature not caused by combustion.

COMBINATION TEMPERATURE DETECTORS

Combination temperature detectors incorporate both a fixed temperature setting and a rate of temperature rise setting. The rate of rise feature is normally achieved by a spot type pneumatic detector. To provide a fixed temperature setting, a eutectic fuse is positioned in the sensing chamber so as to confine one end of a leaf spring. When the eutectic melts, the spring is released and exerts pressure on the flexible diaphragm thus causing contact closure.

Another type of combination detector is called a rate compensation device. This device employs a cylindrical shell with a high coefficient of expansion which contains two curved struts with a low expansion coefficient. Electrical contacts are affixed to the struts which are mounted under compression in the shell. When the temperature rises, the shell expands relieving the compression on the struts allowing the contacts to close. Rapid rates of temperature rise are sensed first by the outer shell and only gradually by the strut assembly. Where the rate of temperature increase is low (0 to 5^{O}F/minute), both shell and struts expand but because of the difference in thermal expansion coefficients, the shell expands more rapidly relieving the compression on the struts and allowing the contacts to close.

This type of device is self-resetting whereas the first type of combination detector is not because of the eutectic fuse used as the fixed temperature mode of detection.

One combination detector utilizes the pneumatic detection approach for the rate of rise setting and a bimetallic strip for the fixed temperature setting. This device is also self-resetting.

SMOKE DETECTORS

Smoke or product-of-combustion detectors are devices designed to sense visible or invisible particles generated by combustion. They operate on either the principle of photoelectricity or ionization.

Photoelectric smoke detectors employ a light source and a photoconductive sensor. In one type of detector the light beam is directed onto the sensor which may be in close proximity to the light source or some distance away. When smoke passes between the light source and the sensor, the amount of radiation impinging on the sensor surface is reduced. This causes a change in the sensor resistance and this circuit upset is used to electrically open or close contacts. Since this device alarms due to obscuration of the light beam, anything which can cause this obscuration will trigger the device. A cloud of dust or a solid object inserted between the light source and the sensor can cause a false alarm.

The second type of photoelectric smoke detector also uses a light source and a photoconductive sensor, but in this case the sensor is positioned so that the light beam does not shine directly on the sensor. When smoke passes into the light beam, the light is diffused and some light is reflected onto the sensor. This reflected light changes the sensor resistance and initiates the alarm process. A cloud of dust passing through the light beam will have the same effect as smoke and cause the unit to alarm.

Some photoelectric smoke detectors, in which light source and sensor are located in the same housing, are equipped with small fans to continually draw air through the light beam to improve the response time of the device.

Ionization detectors are designed to detect invisible products of combustion which are often generated before visible smoke. These devices utilize a radioactive source to ionize the air between the source and a collector plate and a small current flows across the ionized path. When smoke particles, larger than air molecules pass between the radioactive source and the collector plate, they absorb or interfere with the radiation produced by the source. This interference reduces the amount of ionization and subsequently reduces the current flow between source and collector. The reduction in current is utilized to provide operation of electrical contacts.

The presence of dust or vapors with molecules larger than air can result in inadvertent operation of the ionization detector. The effect of additional radiation sources in the vicinity of the detector has not been evaluated but it would appear that a reduction in sensitivity would result due to an increase in the amount of ionized air.

SURVEILLANCE DETECTORS

Surveillance detectors are designed to detect radiation emitted by the process of combustion. The two types commonly used are infrared detectors and ultraviolet detectors. These detectors are often used in boilers and furnaces to detect the absence of combustion. In recent years they have been utilized as fire and explosion detectors.

Infrared detectors, when used as fire detectors, are normally designed to detect infrared radiation modulated at a frequency of 13 cycles per second. This is the frequency of the flickering associated with flames. This frequency discrimination eliminates inadvertant detector operation due to the presence of infrared radiation from sources other than flames such as incandescent lights or motors. However, interruption of infrared radiation by an external device at the critical frequency can alarm the detector.

Ultraviolet detectors are being used in increasing numbers as fire and explosion detectors. Most types have the feature of being 'solar blind', which means that they do not respond to radiation emitted by the sun. Since ultraviolet radiation cannot be transmitted through glass, normal electric lights present no problem. Ultraviolet detectors are extremely sensitive to electric sparks and cannot be used in an area in which any welding operation is being conducted. Ultraviolet radiation is reflected very nicely by metal surfaces and thus can be detected around corners under certain circumstances.

Surveillance detectors are usually designed to remain in the alarmed condition once they operate. To reset the units usually involves merely the momentary interruption of the supply voltage. The selection of the proper quantity and location of detectors requires careful consideration to ensure that 'shadow' areas are not created by personnel and/or equipment in the protected volume.

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APPENDIX B

THERMAL FIRE DETECTOR EVALUATION

PSR-366

E. I. duPont de Nemours and Company
Savannah River Laboratory

November 25, 1969

ABSTRACT

A series of tests was conducted in a simulated hot cell in which temperature development was monitored at twenty-three cell locations after ignition of a liquid pan fire within the cell. A determination was made of the effect on temperature development produced by a variation in cell volume, fire location, fire magnitude, and cell ventilation rate.

With the cell equipped with several commercially available thermal fire detectors, a second similar series of tests was conducted and the response times of the various detectors were determined.

INTRODUCTION

The relative inaccessibility of hot cell and canyon internal instrumentation dictates the necessity for careful component selection from the standpoint of reliability of effectiveness. When the function of a component is the detection of combustion which could potentially endanger personnel and equipment, the selection assumes increasing importance. Early detection of a fire threat is desirable to minimize fire and/or smoke damage provided that the detection level is not compromised to the extent that inadvertent detector operation is caused by normal ambient temperature fluctuations.

At the request of the Savannah River Laboratory, Fenwal Inc. has commenced a three-phase study of the effectiveness of detection devices in responding to combustion in a simulated hot cell. Each phase involves a specific mode of detection, the first being thermal detection, the second smoke and products of combustion detection and the third light or surveillance detection.

Phase I of the program has been completed in which thermal detectors have been evaluated. The detector evaluation was preceded by a study of thermal patterns caused by combustion of n-heptane in the simulated hot cell. The procedures used and the results obtained in this Phase I effort are the subject of this report.

Dr. A. J. Hill, Jr. of the Savannah River Laboratory served as Technical Coordinator for this program.

SUMMARY AND CONCLUSIONS

1. The most effective location for spot type thermal detectors was found to be near the ceiling at the center of the simulated cells for all ventilation rates evaluated.

2. The air flow rates through the simulated cells had only a slight effect on the thermal patterns created by the test fires.

3. The cell exhaust vent duct temperature increased very little due to the test fires except when flames from a test fire located near the duct were drawn into the duct at the highest ventilation rate evaluated.

4. In the 8' x 12' x 6' simulated cell, ceiling temperatures were consistently lower for the high air flow condition than for the static or low air flow conditions.

5. In the 8' x 12' x 12' simulated cell, no consistent effect of ventilation rate on ceiling temperature was observed for all fire positions.

6. The rate of rise detector provided earliest response in all tests. This was predictable since the conditions selected for the program produced a temperature environment that favored this mode of detection.

7. The fires located in the center of the test cells were sensed most rapidly by the unit rate-of-rise detector while those off center were sensed most rapidly by either the line or unit rate-of-rise detectors.

8. The two bimetallic snap disc detectors equipped with vanes or fins consistently responded to fires more rapidly than a similar unit not so equipped.

9. Average detector response times ranged from 36 seconds to 193 seconds for the various fire conditions evaluated. A summary of response time data is shown in Table No. 1.

DISCUSSION

Thermal Study

The thermal study was conducted to determine the most effective locations for the detectors evaluated in this program. Tables No. 3 and 4 list the tests conducted in the 8' x 12' x 6' and the 8' x 12' x 12' test cells respectively. In the tables, the many combinations of the test variables of cell ventilation rate, fire size and fire position are shown. The thermocouple reaching the alarm temperature range of 135 to 140°F first varied from test to test mainly because of changes of fire position. In Appendix A, Figures No. 1, 2, 3 and 4 show that for fire position A, the order of thermocouple response to the fire was No. 1 and 6, 21, and 11 and 16. For the fire in position D (Figures No. 9, 10, 11 and 12), this order is reversed. The best average response time to the test fires was for thermocouple 21 at the center of the cell. This was so even with the fires at position C neglected. This result led to the decision to place the detectors in the center of the room.

The use of smoke generators proved to be very useful for showing ventilation flow patterns. However, the patterns of smoke flow for relatively cool smoke were very different from the patterns observed when the smoke was entrained in the convection currents which were much stronger than the ventilation currents. It must be concluded that heat flow patterns may be very different from smoke flow patterns and that the use of smoke flow alone to indicate thermal flow patterns is not meaningful.

Detector Evaluation

The result that rate-of-rise detectors alarmed first to all test fires must be interpreted with the following points kept in mind:

The thermal study indicated that the rate of temperature rise due to all but one of the test fires was greater than 15 F°/min, the rating of all rate-of-rise devices tested. Hence, it should be expected that these devices would respond earliest to the test fires. Slower developing fires would not cause alarm of the rate-of-rise devices so that fixed temperature response would be required to give an alarm.

The line type rate-of-rise detector which responded first to most of the test fires had the advantage of close proximity to most of the fire positions.

The settings of the fixed temperature devices varied from 135 to 140°F. This means that comparison of these units to each other should take into account the interval associated with raising the temperature of the air from the lower alarm level to the higher alarm level.

APPARATUS

Simulated Hot Cell

The test cell consisted of an 8' high by 12' wide by 12' long enclosure constructed of 3/4" plywood. The volume could be cut in half by reducing the cell length to 6' with a portable partition. A 12" diameter hole was cut into the portable partition, one foot above the floor and three feet in from one edge. A circular duct extended 12' from the partition and at that point was equipped with a variable speed fan to effect cell ventilation. An air inlet port, 12' in diameter, was cut into the wall opposite the portable partition. This port was diagonal to the exhaust hole and was one foot below the ceiling and three feet in from the side wall. An external 90° elbow, 12" in diameter was fitted to the inlet port with the opening facing downward. This elbow reduced the effect of prevailing wind on air flow through the port.

Test Fires

The source of heat in all of the tests was the combustion of liquid heptane. The heptane was floated on water in various size containers, circular in cross-section. Ignition was accomplished with an electric spark created just above the surface of the heptane.

Temperature Measurements

Temperature within the test cell was monitored with twenty-three iron-constantan thermocouples. Five thermocouples were mounted on each of four stands which consisted of 1/2" wide metal strips extending from floor to ceiling. The distances of these thermocouples from the ceiling were 4, 12, 36, 60 and 94 inches. Two additional thermocouples were positioned on a stand at distances of 4 inches and 12 inches from the ceiling. One thermocouple was placed in the center of the exhaust port in the plane of the cell wall. The specific locations of the thermocouple stands are shown in Figures No. 1 and 2. Table No. 2 indicates the numbering system for thermocouples on the stands.

The output of each thermocouple was fed to four positions of a pair of ganged, 24 position wafer switches. The rotating wipers of the switches were driven by a stepping relay. A pulse circuit was designed to energize the stepping relay at a rate of 2 pulses per second. In this manner, the output signal of each thermocouple was monitored for 1/2 second every three seconds. The thermocouple output signals were displayed on a recording oscillograph against an electronically superimposed time base. An instrumentation block diagram of the temperature measuring circuitry is shown in Figure No. 3.

Thermal Detectors

Thermal Detectors may be broadly classified by function as fixed temperature, rate of temperature rise or a combination of the two functions. All three types of detection devices were evaluated in this program. Each detector was assigned a letter designation for reference purposes in the remainder of the report. A brief description of the principle of operation of each detector is listed below:

Detector A

This is a combination type detector with a feature called rate compensation. It employs a cylindrical shell with a high coefficient of expansion which contains two curved struts with a low expansion coefficient. Electrical contacts are affixed to the struts which are mounted under compression in the shell. When the temperature rises, the shell expands relieving the compression on the struts allowing the contacts to close. Rapid rates of temperature rise are sensed first by the outer shell and only gradually by the strut assembly. When the rate of temperature rise is low (0 to 5°F/minute), both shell and struts expand but because of the difference in thermal expansion coefficients, the shell expands more rapidly, relieving the compression on the struts and allowing the contacts to close.

Detector B

This is a fixed temperature detector which utilizes a bi-metallic disc as the sensing element. The two metals used in the disc have different thermal expansion coefficients. At temperatures below the set point of the detector the disc surface is convex. As the disc temperature increases the two metals expand unevenly until, at the set point, the disc snaps through to a concave configuration. This motion is used to close a set of electrical contacts.

Detectors C and D

These detectors are fixed temperature devices which are identical in operating principle to Detector B. They incorporate a heat conducting vane or fin which is attached to the outer periphery of the bimetallic disc.

Detector E

This is a combination type detector. The rate detection function is accomplished with a herispherical chamber equipped with a flexible diaphragm and a small relief vent. The pressure developed in the chamber due to air expansion caused by a temperature increase causes the flexible diaphragm to operate a set of electrical contacts. If the chamber were sealed, contact closure would occur at a fixed temperature. It is the function of the chamber relief vent to bleed chamber pressure off until the rate of pressure rise exceeds a value corresponding to a predetermined rate of temperature rise.

The fixed temperature setting of this detector is accomplished with a bimetallic strip within the chamber which deflects as the temperature increases. This movement is used to close a set of electrical contacts when the chamber air reaches a predetermined temperature.

Detector F

This is a rate type line detector which incorporates as its sensing element an air-filled length of small diameter tubing, each end of which terminates in a chamber equipped with a flexible diaphragm and a relief vent. When the pressure in the tubing is increased due to a temperature increase, the chamber pressure also increases. If the rate of pressure rise in the chamber exceeds the venting capacity of the relief vent, the motion of the flexible diaphragm causes the closure of a set of electrical contacts.

Detector G

This is a combination detector and the rate function is accomplished pneumatically as previously described for Detector E. The fixed temperature setting is accomplished with a eutectic fuse positioned in the sensing chamber so as to confine one end of a leaf spring. When the eutectic melts, the spring is released and exerts pressure on the flexible diaphragm thus causing contact closure.

Detector H

This is a fixed temperature device only which incorporates a eutectic fuse in the sensing chamber which restricts one end of a leaf spring. When the eutectic melts the action of the released spring closes a set of electrical contacts.

A summary of the operating characteristics and the detector settings is given in Table No. 3.

Detector Instrumentation

All of the detectors tested were equipped with normally open electrical contacts which closed at detector function. Detector response time was recorded on a 20 channel event recorder. The recorder had a built-in 24 VDC power supply which was used to power each of 20 pairs of electrical contacts. When any pair of contacts was shorted, it caused deflection of the pen associated with the particular channel. For these tests, detector contact closure was used to provide the electrical short and cause the pen deflection.

PROCEDURE

Thermal Study

A total of 120 tests were conducted to evaluate the effect of several variables on the distribution of heat within the test cell. The variables evaluated were fire size, fire location, cell size and cell ventilation rate.

The first cell simulated was 8' high by 12' wide by 12' long. Two fire sizes were utilized, one of which was 13.5" in diameter and the second 7.25" in diameter. Fire tests were conducted under static conditions and with 0.33 and 0.91 cell air changes per minute. Five fire locations were evaluated. These locations are shown in the sketch in Figure No. 1.

The second simulated cell measured 8' x 12' x 6'. In these tests the fire sizes were 10" in diameter and 7.25" in diameter. Tests were conducted under static conditions and with 0.33 and 1.0 cell air changes per minute. As before, five fire locations were evaluated. These locations are shown in the sketch in Figure No. 2.

Detector Response Tests

These tests were basically the same as those described above except that the cells were equipped with thermal detectors and the response time of the detectors was determined as a function of cell size, cell ventilation rate, fire size and fire location. Spot or unit type detectors were mounted as a group at the center of the ceilings of both test cells. The line type detector was mounted in the 8'x12'x12' cell three feet in from the cell walls. In the 8'x12'x6' cell, it was mounted 3' from the 6' walls and 1.5' from the 12' walls. A brief experiment showed that placing the line type detector tubing at the junction of the wall and ceiling had no significant effect on response time. The duct type detector was mounted 25 inches from the intake of the exhaust vent duct.

Specific data obtained in this series of tests are shown in Tables No. 4 and 5.

Pan Fire Tests

These tests were conducted to determine the rate of heat production by the pan fires used in this program. Each size of standard fire was timed and observed closely from ignition to burn-out. From this data, the rates of fuel consumption and heat production were determined as indicated in Table No. 6.

Smoke Flow Tests

Tests were conducted to determine the flow patterns of ambient and heated air in the test cell. Initially, smoke from small smoke bombs was generated at floor level in the cells and observed through the windows of the cell for flow patterns. To illustrate the effect of thermal drafts, small heptane fires (7.25" diameter) were burned and smoke from a smoke bomb allowed to become entrained in the convection currents of the fire.

Figure No. 1

8'x12'x12' Test Cell

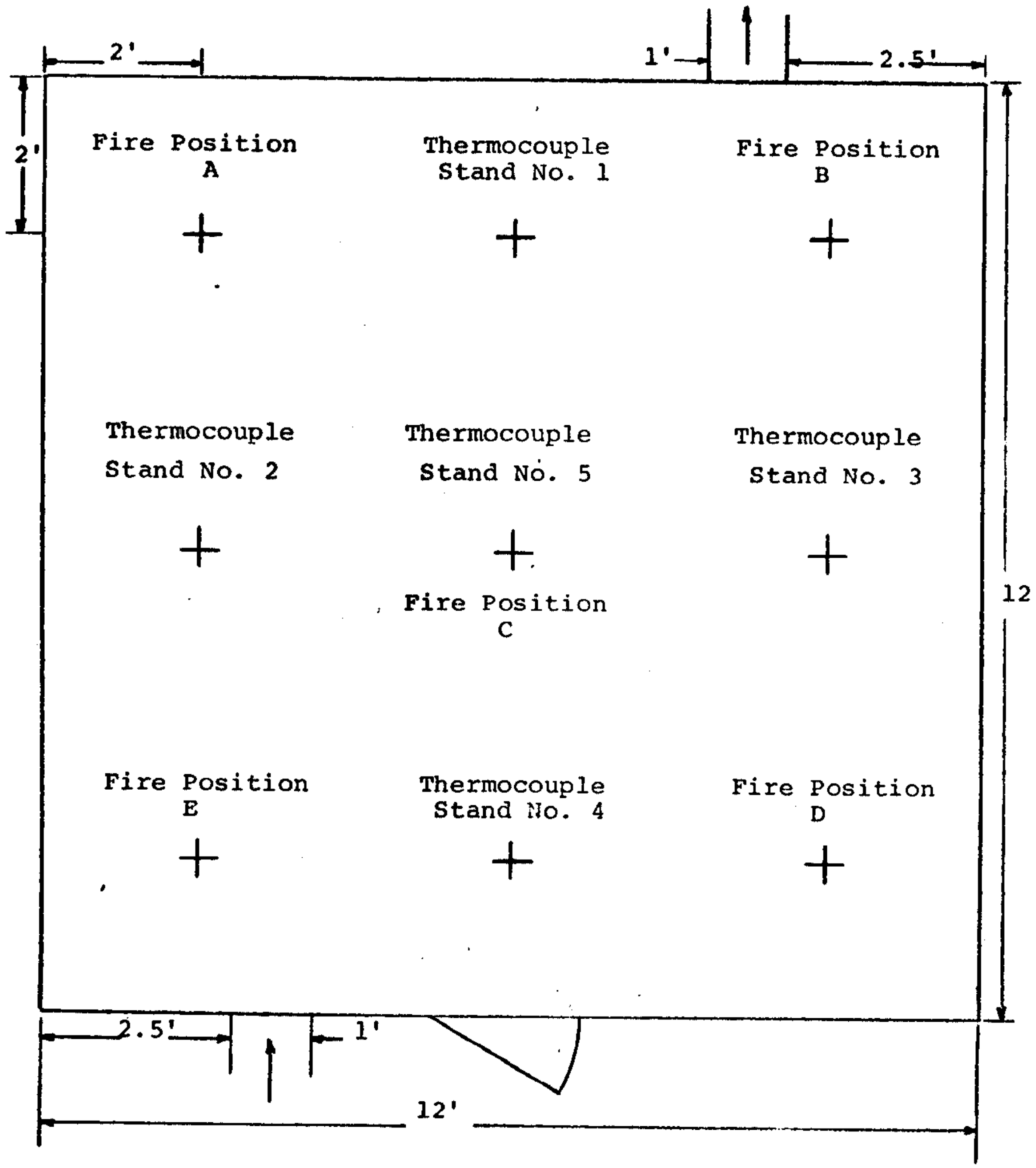


Figure No. 2

8'x12'x6' Test Cell

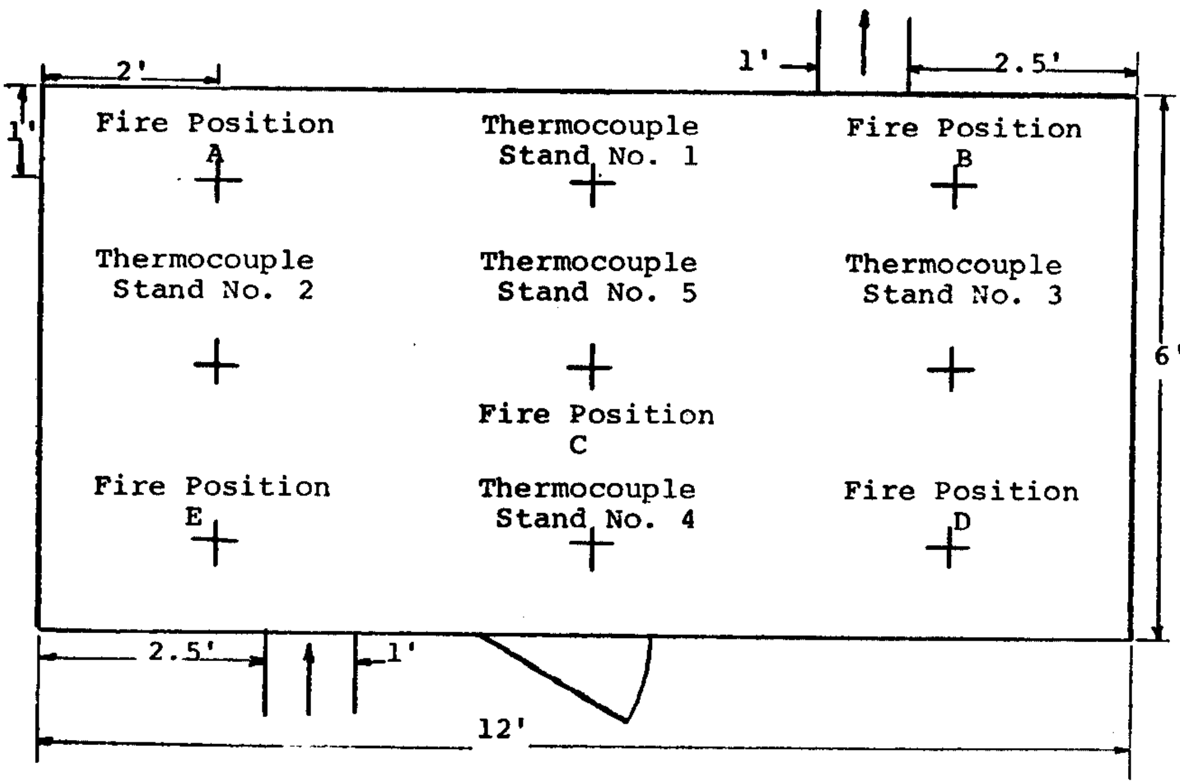


Figure No. 3

Instrumentation Block Diagram

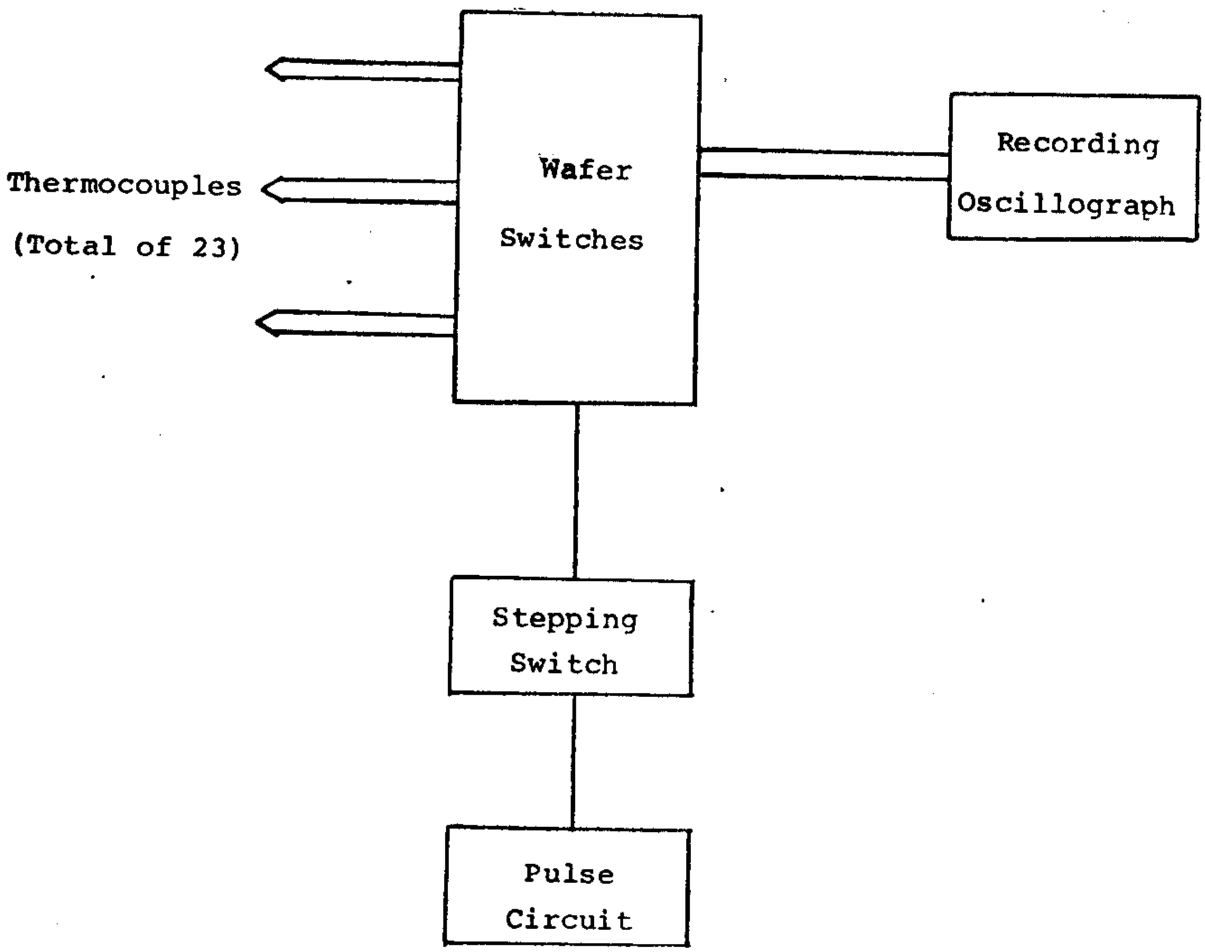


Table No. 1

Summary of Response Time Data

Cell Size	Total No. of Tests	Number of Tests Responded to/Average Response Time (Sec.) Detectors							
		A	B	C	D	E	F	G	H
8'/12'/12'	30	28/104	19/157*	25/129	29/96	29/73	30/36	9/62**	5/193**
8'x12'x6'	30	27/83	25/191	27/141	27/95	29/39	28/38	12/38**	9/185**

*Operable in 24 tests
**Operable in 12 tests

Table No. 2

Positions of Thermocouples

Distance Below Ceiling (in)	Thermocouple Stand No. 1	2	3	4	5
4	TC1	TC6	TC11	TC16	TC21
12	TC2	TC7	TC12	TC17	TC22
36	TC3	TC8	TC13	TC18	
60	TC4	TC9	TC14	TC19	
84	TC5	TC10	TC15	TC20	

TC23 at mouth of exhaust duct.

Table No. 3

Detector Types and Settings

Designation	Type	Principle of Operation	Setting
A	Fixed (Rate Anticipation)	Differential Expansion	$140^{o}F$
B	Fixed	Bimetallic Snap Disc	$135^{o}F$
C	Fixed	Bimetallic Snap Disc (w/vanes)	$135^{o}F$
D	Fixed	Bimetallic Snap Disc (w/vanes)	$133^{o}F$
E	Fixed/Rate Rise	Bimetallic Strip/ Pneumatic Chamber	$135^{o}F/15F^{o}/min$
F	Rate (Line Type)	Pneumatic Tube	$15F^{o}/min$
G	Fixed/Rate	Fusible Solder/ Pneumatic Chamber	$136^{o}F/15F^{o}/min$
H	Fixed	Fusible Solder	$136^{o}F$

Table No. 4

Detector Response Times

8'x12'x6' Cell

Test No.	Fire Size (in. dia.)	Fire Position	Flow Rate (CFM)	Response Time (Seconds) Detectors							
				A	B	C	D	E	F	G*	H*
1	10	C	0	34	57	44	33	17	22	24	79
2	10	C	172	27	47	39	28	6	11	7	NT
3	10	C	576	32	51	40	31	17	20	17	91
4	7.25	C	0	65	131	95	63	25	40	40	179
5	7.25	C	172	64	128	80	56	30	46	26	204
6	7.25	C	576	67	140	81	63	31	45	26	162
7	10	D	0	50	109	78	54	26	24	31	161
8	10	D	72	47	112	76	51	25	23	27	160
9	10	D	576	45	106	73	49	25	24	27	160
10	7.25	D	0	192	NR	445	225	75	56	91	NR
11	7.25	D	172	131	346	239	144	60	59	64	467
12	7.25	D	576	195	433	332	204	52	76	77	NR
13	10	B	0	43	68	60	43	23	26	NT	NT
14	10	B	172	52	105	80	52	25	25	NT	NT

Table No. 4 (Continued)

Detector Response Times

8'x12'x6' Cell

Test No.	Fire Size (in. dia.)	Fire Position	Flow Rate (CFM)	Response Time (Seconds) Detectors							
				A	B	C	D	E	F	G*	H*
15	10	B	576	NR	NR	NR	NR	84	52	NT	NT
16	7.25	B	0	98	262	190	94	41	46	NT	NT
17	7.25	B	172	107	260	177	109	44	43	NT	NT
18	7.25	B	576	NR	NR	NR	NR	NR	NR	NT	NT
19	7.25	A	0	149	NR	255	197	154	46	NT	NT
20	7.25	A	172	101	325	172	130	57	46	NT	NT
21	7.25	A	576	140	389	207	147	77	63	NT	NT
22	10	A	0	44	102	63	51	24	23	NT	NT
23	10	A	172	57	148	96	72	25	22	NT	NT
24	10	A	576	50	143	86	67	24	24	NT	NT
25	10	E	0	46	130	78	60	23	24	NT	NT
26	10	E	172	47	107	72	57	24	25	NT	NT
27	10	E	576	54	154	91	70	24	24	NT	NT

Table No. 4 (Continued)

Detector Response Times

8'x12'x6' Cell

Test No.	Fire Size (in. dia.)	Fire Position	Flow Rate (CFM)	Response Time (Seconds) Detectors							
				A	B	C	D	E	F	G*	H*
28	7.25	E	0	130	416	254	185	55	62	NT	NT
29	7.25	E	172	180	502	318	236	54	108	NT	NT
30	7.25	E	576	NR	NR	NR	NR	140	NR	NT	NT

NOTES

NR - No Response

NT - Not Tested

NO - Not Operable

*Non-ressettable

Detector Response Times

8'x12'x12' Cell

Test No.	Fire Size (in. dia.)	Fire Position	Flow Rate (CFM)	Response Time (Seconds) Detectors A	B	C	D	E	F	G*	H*
31	13.5	C	0	19	30	26	21	8	12	10	49
32	13.5	C	384	18	23	22	18	8	12	10	46
33	13.5	C	1050	23	31	28	23	11	14	13	50
34	7.25	C	0	118	255	128	107	34	60	348	346
35	7.25	C	384	126	316	175	113	27	46	43	475
36	7.25	C	1050	269	310	269	270	41	56	73	NR
37	7.25	D	0	391	NR	NR	305	141	45	NR	NR
38	7.25	D	384	NR	NR	NR	281	136	104	NR	NR
39	7.25	D	1050	NR	NR	NR	NR	NR	137	NR	NR
40	13.5	D	0	32	49	42	33	19	18	40	NT
41	13.5	D	384	32	57	46	33	18	16	23	NT
42	13.5	D	1050	32	82	50	32	19	16	19	NR
43	13.5	E	0	35	60	43	28	19	14	NT	NT
44	13.5	E	384	42	87	57	37	19	14	NT	NT

Table No. 5 (Continued)

Detector Response Times

8'x12'x12' Cell

Test No.	Fire Size (in. dia.)	Fire Position	Flow Rate (CFM)	Response Time (Seconds) Detectors A	B	C	D	E	F	G*	H*
45	13.5	E	1050	43	98	58	35	18	14	NT	NT
46	7.25	E	0	350	NR	412	220	207	71	NT	NT
47	7.25	E	384	243	538	306	157	440	50	NT	NT
48	7.25	E	1050	265	NR	277	143	407	66	NT	NT
49	7.25	A	0	135	295	174	138	73	32	NT	NT
50	7.25	A	384	108	270	152	105	63	28	NT	NT
51	7.25	A	1050	150	337	206	138	72	37	NT	NT
52	13.5	A	0	24	31	30	24	17	11	NT	NT
53	13.5	A	384	26	36	32	24	19	11	NT	NT
54	13.5	A	1050	24	84	44	28	24	12	NT	NT
55	13.5	B	0	32	NO	52	39	19	15	NT	NT
56	13.5	B	384	30	NO	43	34	19	14	NT	NT
57	13.5	B	1050	26	NO	34	29	17	15	NT	NT

Table No. 5 (Continued)

Detector Response Times

8'x12'x12' Cell

Test No.	Fire Size (in. dia.)	Fire Position	Flow Rate (CFM)	Response Time (Seconds) Detectors							
				A	B	C	D	E	F	G*	H*
58	7.25	B	0	129	NO	191	143	84	59	NT	NT
59	7.25	B	384	103	NO	187	125	68	43	NT	NT
60	7.25	B	1050	93	NO	142	97	57	40	NT	NT

NOTES

NR - No Response

NT - Not Tested

NO - Not Operable

* - Non-resettable

Table No. 6

Heptane Test Fire Characteristics

Fire Size (in. dia.)	Average Rate of Heat Production (kcal/sec.)
7.25	5.2
10.0	11.2
13.5	23.8

Table No. 1

Data Summary for

Figures 1 to 14

Figure No.*	Fire** Position	Fire Size (in diameter)	Ventillation Rate (cfm)
1	A	13.5	1050
2	A	13.5	0
3	A	7.25	1050
4	A	7.25	0
5	C	13.5	1050
6	C	13.5	0
7	C	7.25	1050
8	C	7.25	0
9	D	13.5	1050
10	D	13.5	0
11	D	7.25	1050
12	D	7.25	0
13	B	13.5	1050
14	B	13.5	0

*All figures of data for 8'x12'x12' cell.

**See Figure 1.

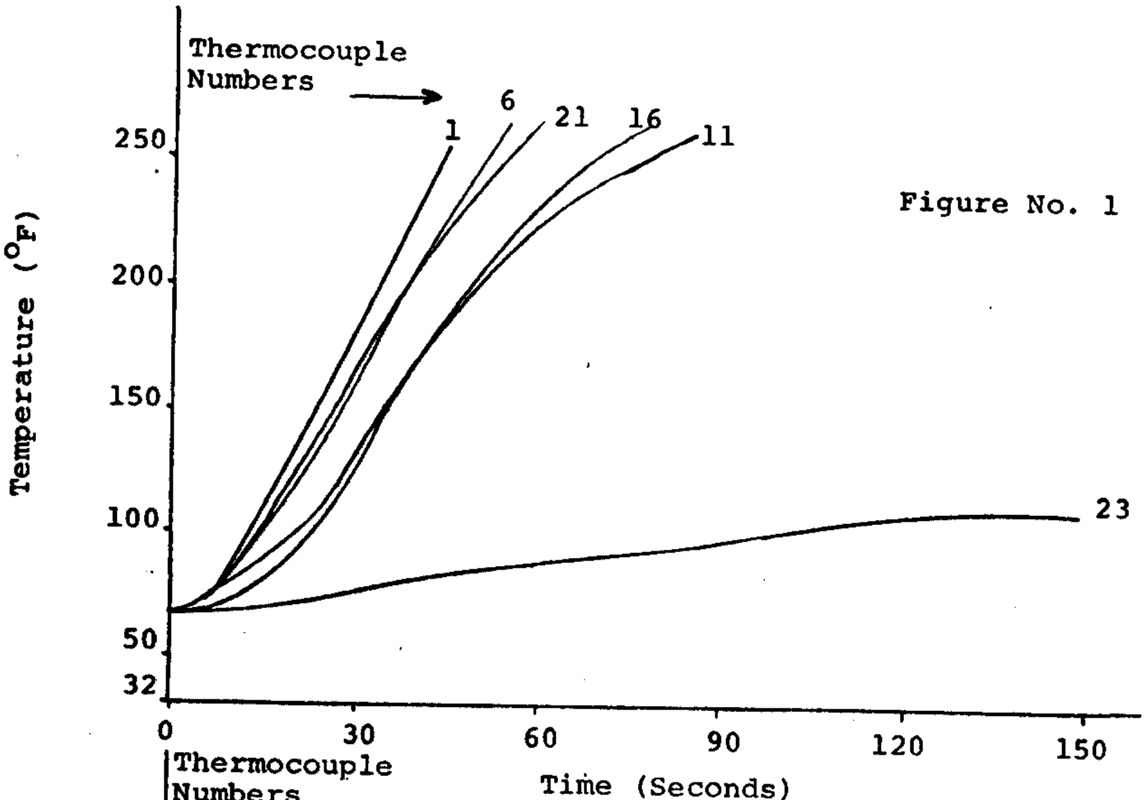


Figure No. 1

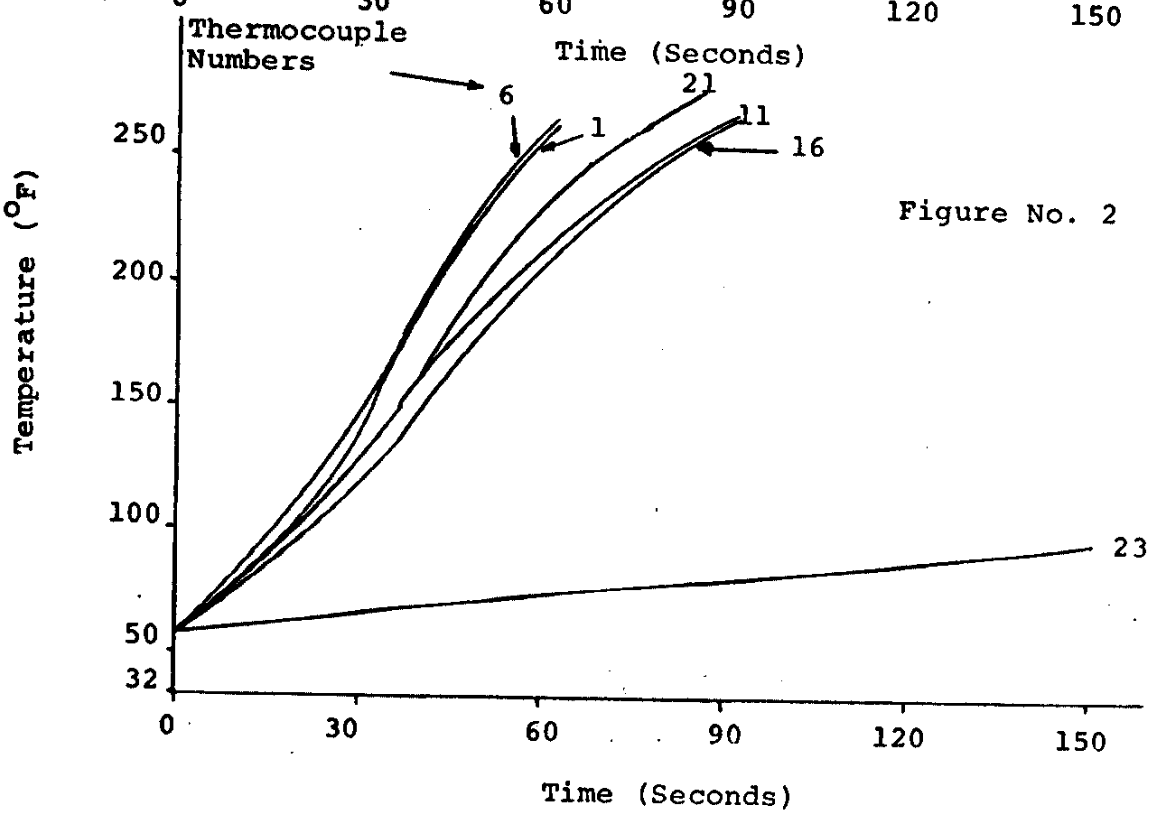


Figure No. 2

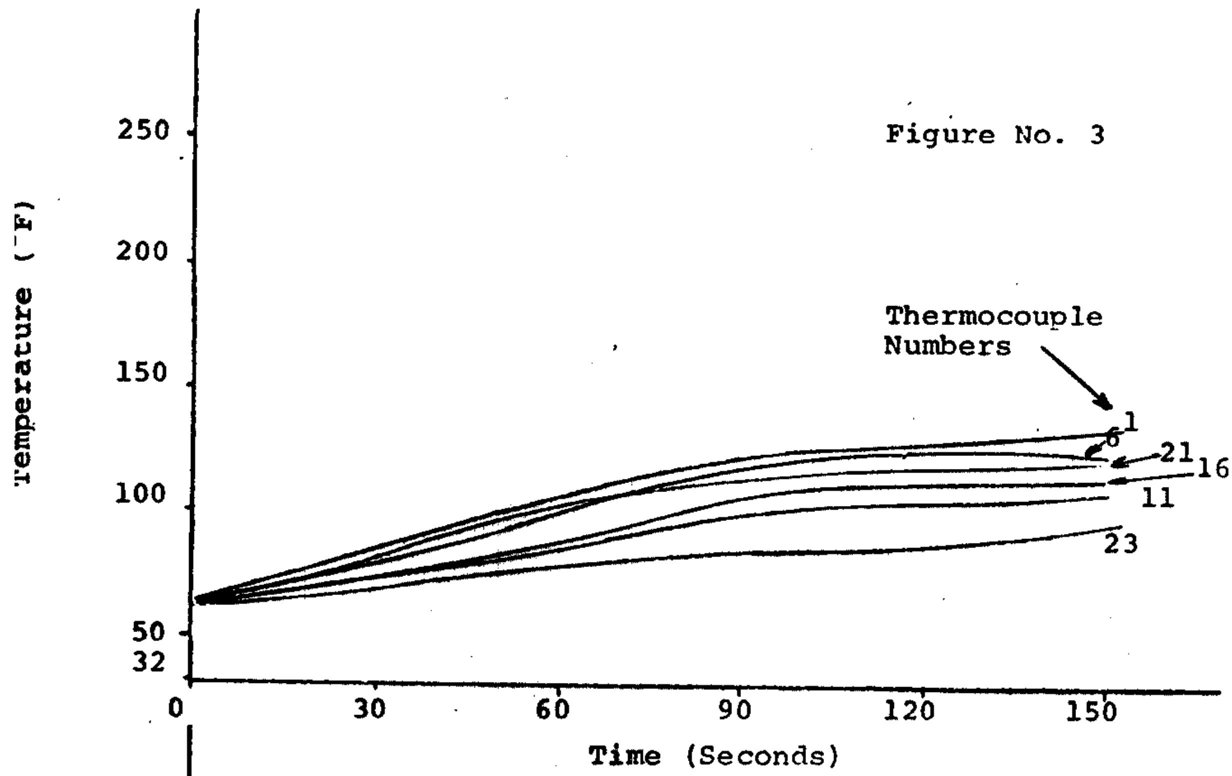


Figure No. 3
Temperature (°F)
250
200
150
100
50
32
Thermocouple
Numbers
1
6
21
16
11
23
0
30
60
90
120
150
Time (Seconds)

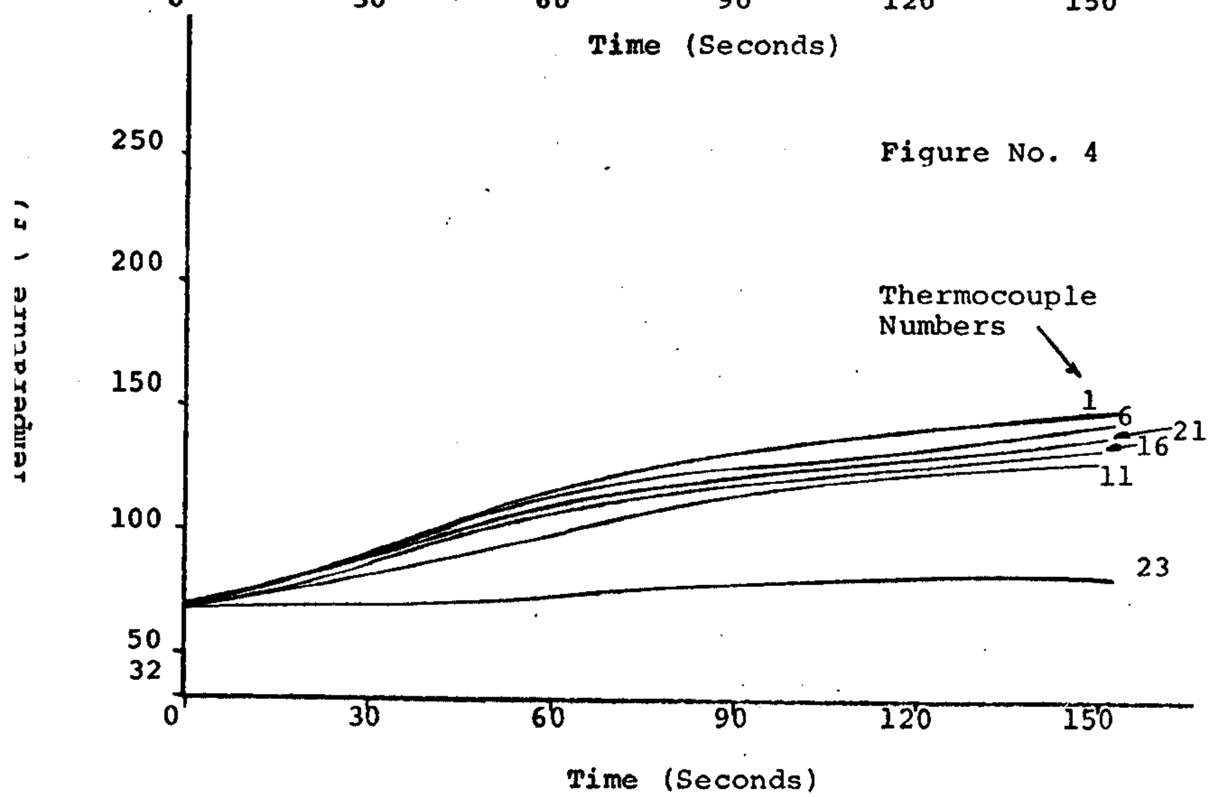


Figure No. 4
Temperature (°F)
250
200
150
100
50
32
Thermocouple
Numbers
1
6
21
16
11
23
0
30
60
90
120
150
Time (Seconds)

Figure No. 5

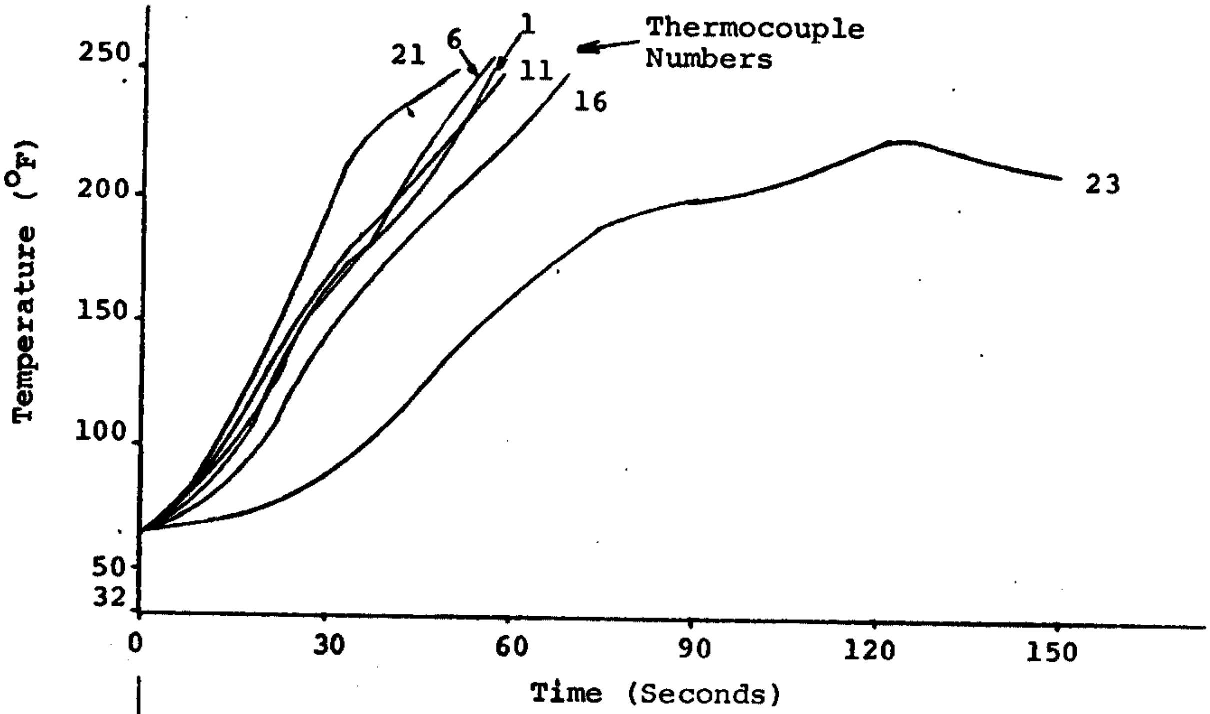
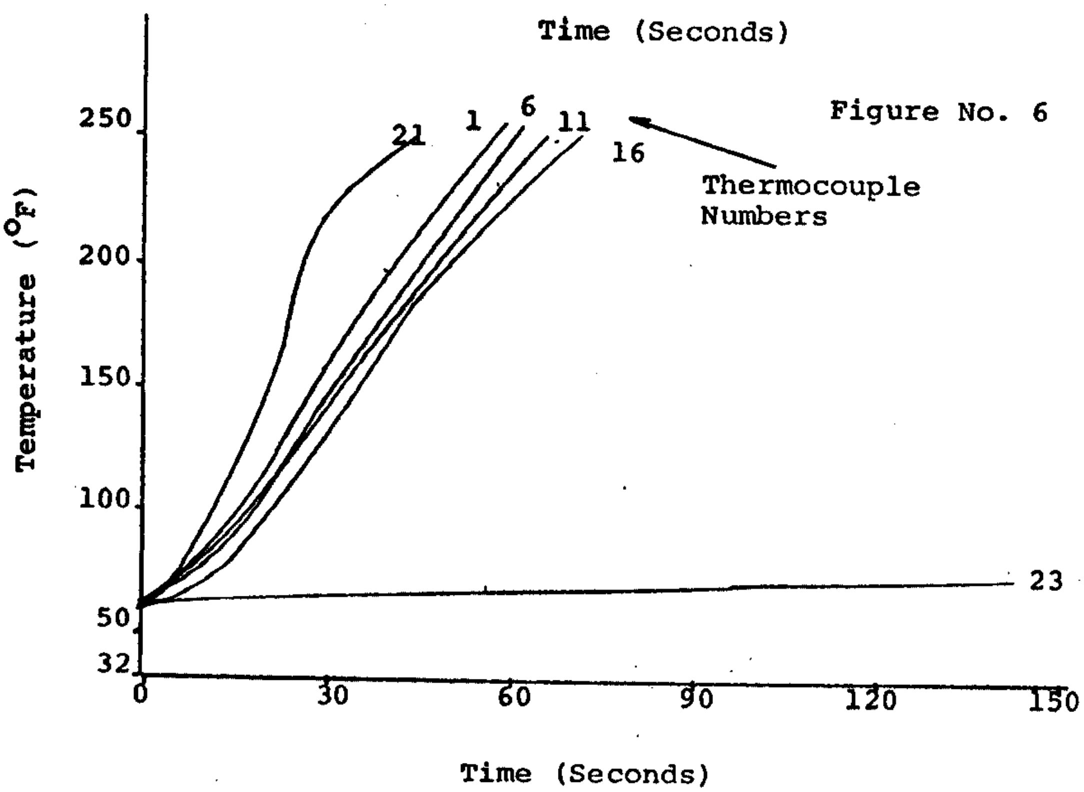


Figure No. 6



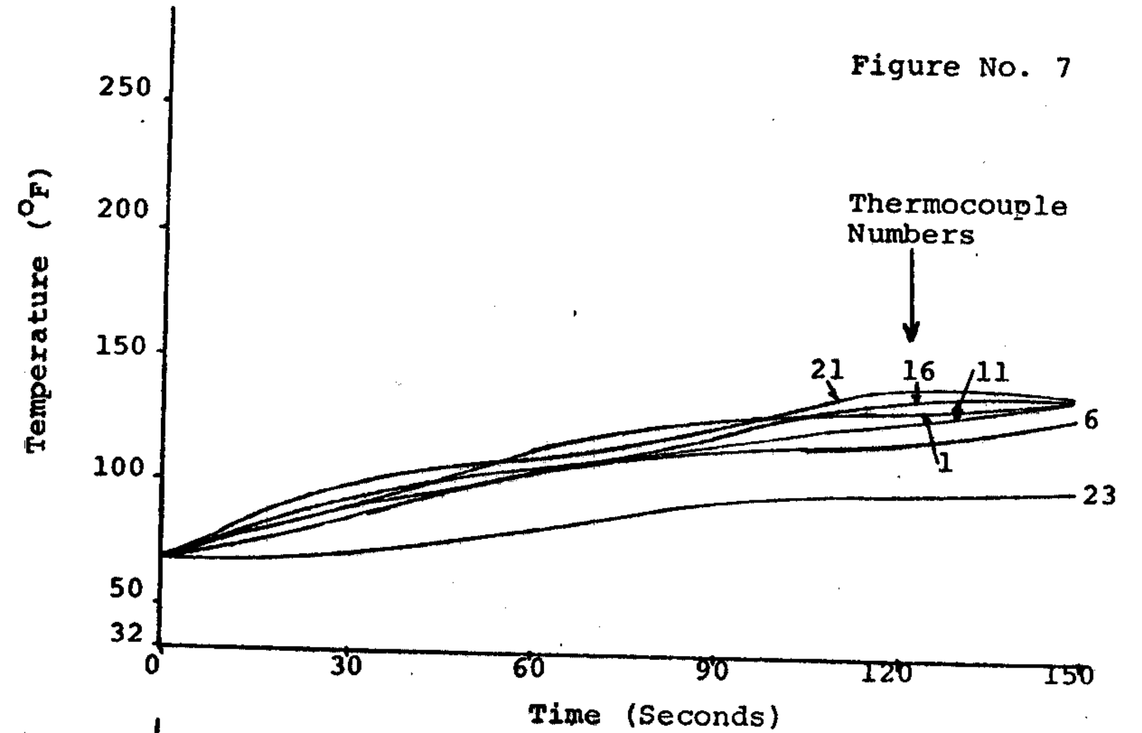


Figure No. 7
Thermocouple Numbers
21
16
11
6
1
23
250
200
150
100
50
32
Temperature (°F)
0
30
60
90
120
150
Time (Seconds)

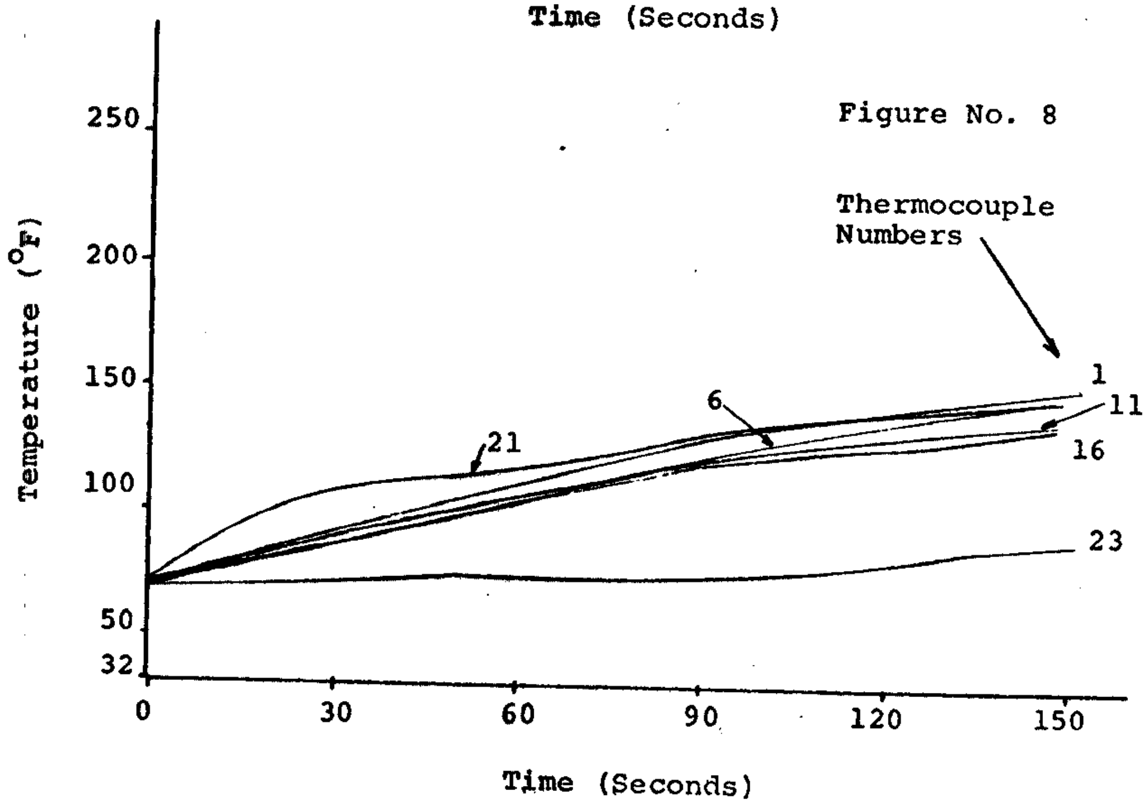


Figure No. 8
Thermocouple Numbers
1
11
16
6
21
23
250
200
150
100
50
32
Temperature (°F)
0
30
60
90
120
150
Time (Seconds)

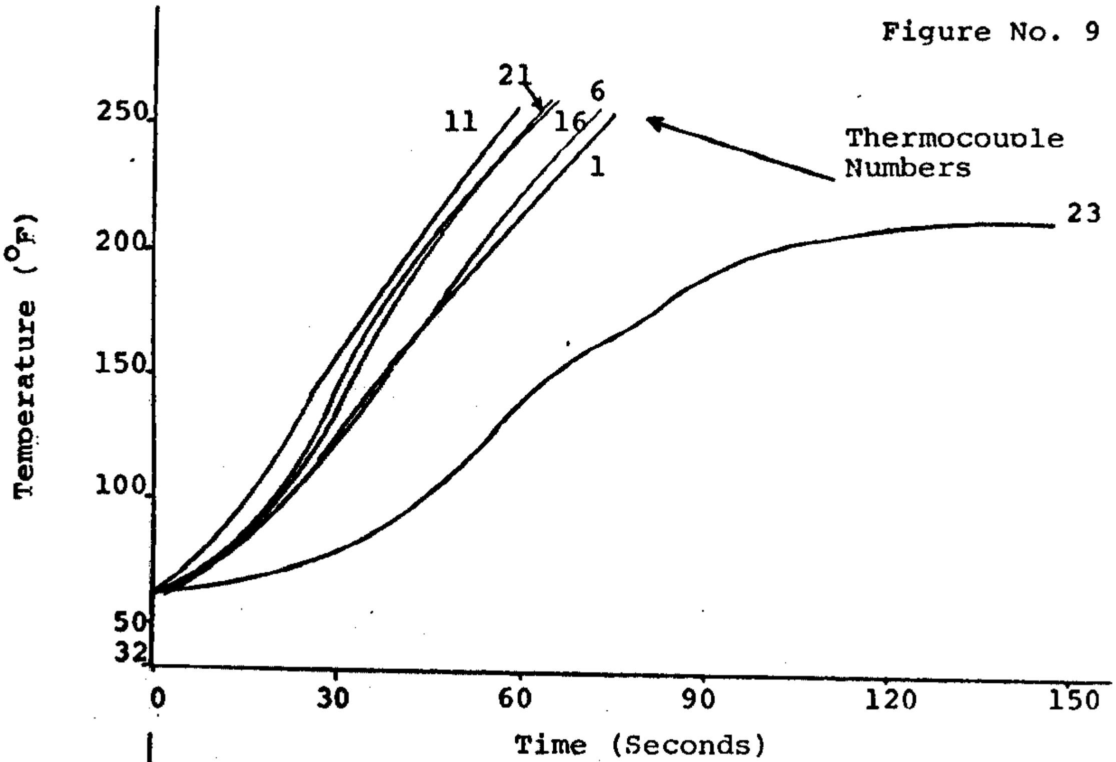


Figure No. 9
Thermocouple Numbers
21
11
6
16
1
23
250
200
150
100
50
32
0
30
60
90
120
150
Temperature (°F)
Time (Seconds)

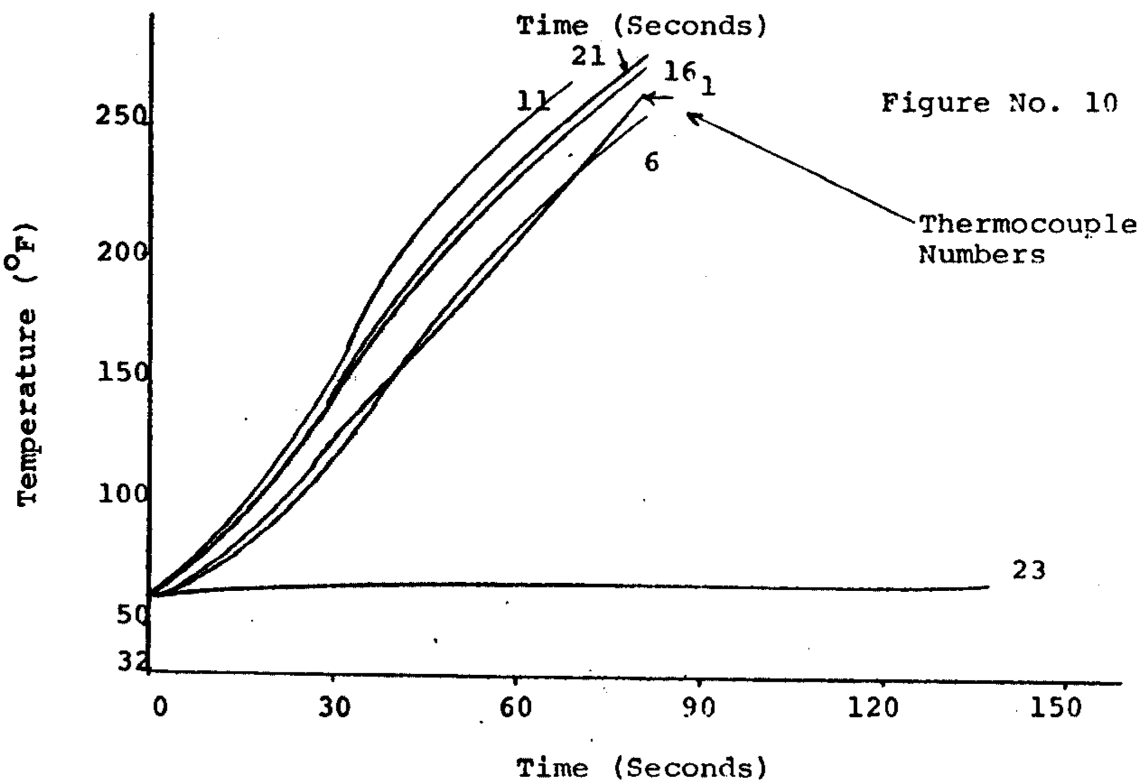


Figure No. 10
Thermocouple Numbers
21
11
16
1
6
23
250
200
150
100
50
32
0
30
60
90
120
150
Temperature (°F)
Time (Seconds)

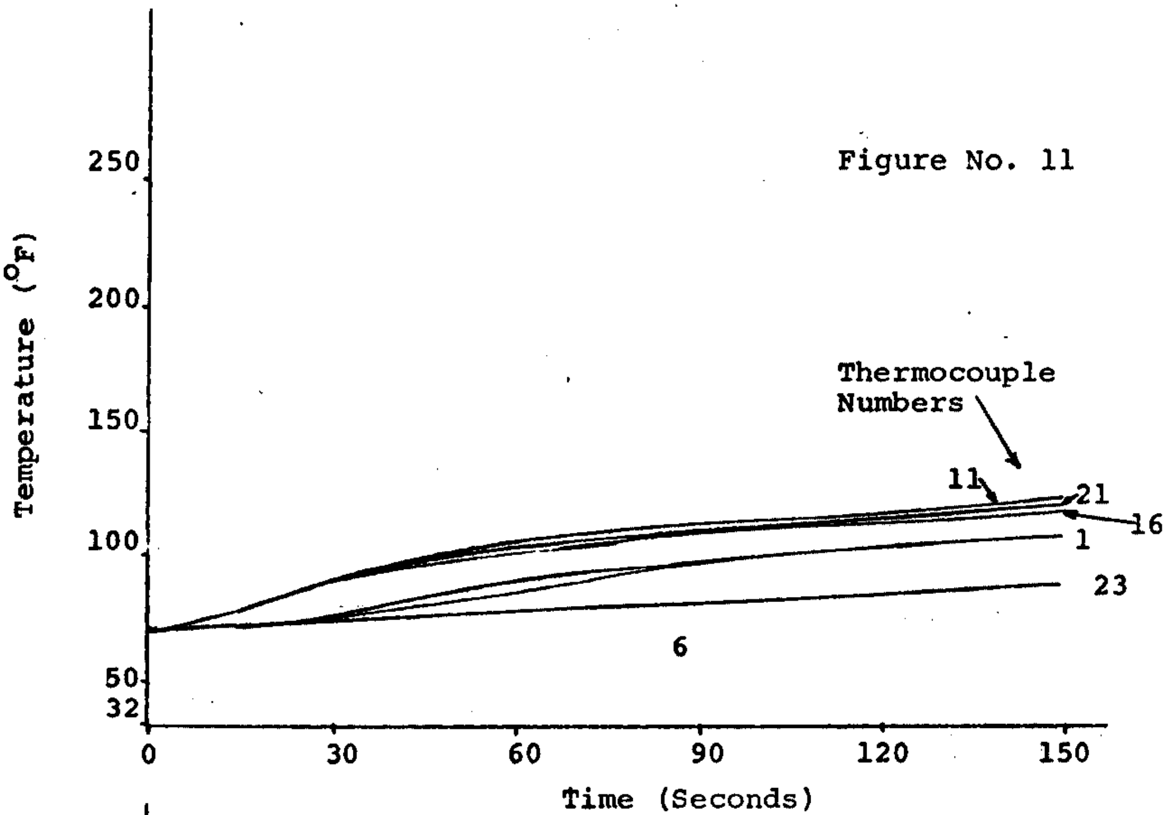


Figure No. 11
Temperature (°F)
250
200
150
100
50
32
Thermocouple Numbers
11
21
16
1
23
6
0
30
60
90
120
150
Time (Seconds)

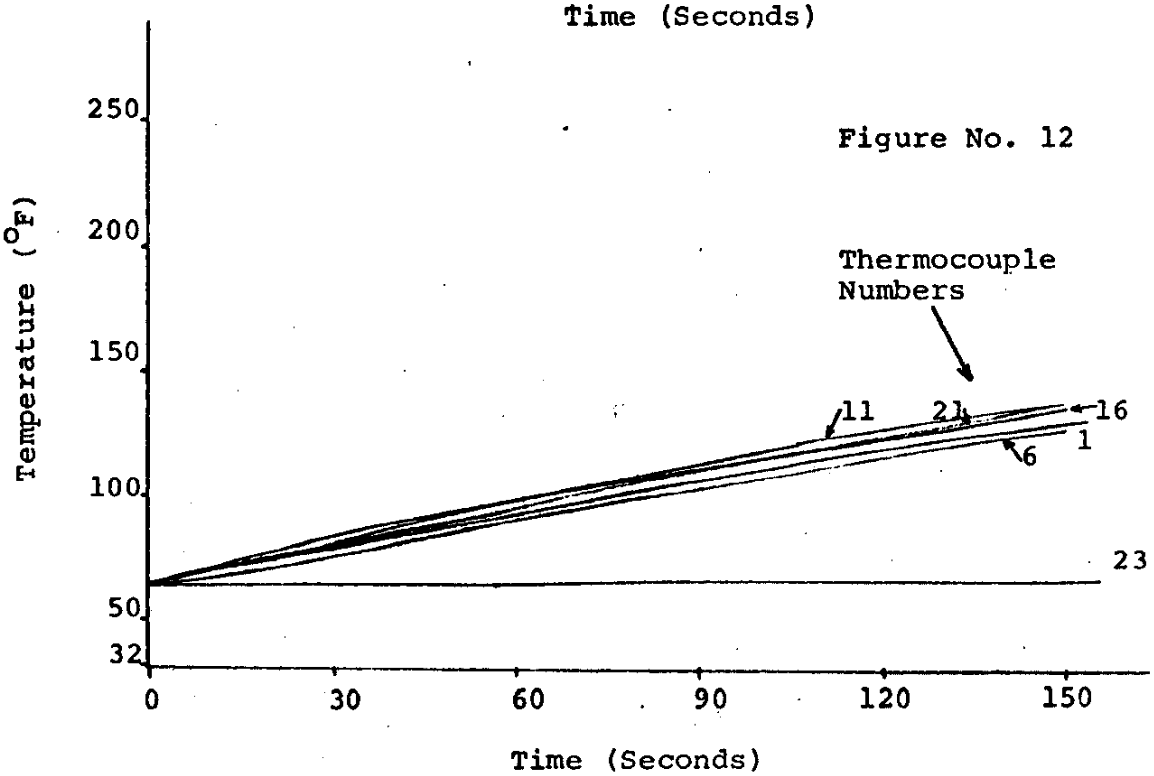


Figure No. 12
Temperature (°F)
250
200
150
100
50
32
Thermocouple Numbers
11
21
16
1
6
23
0
30
60
90
120
150
Time (Seconds)

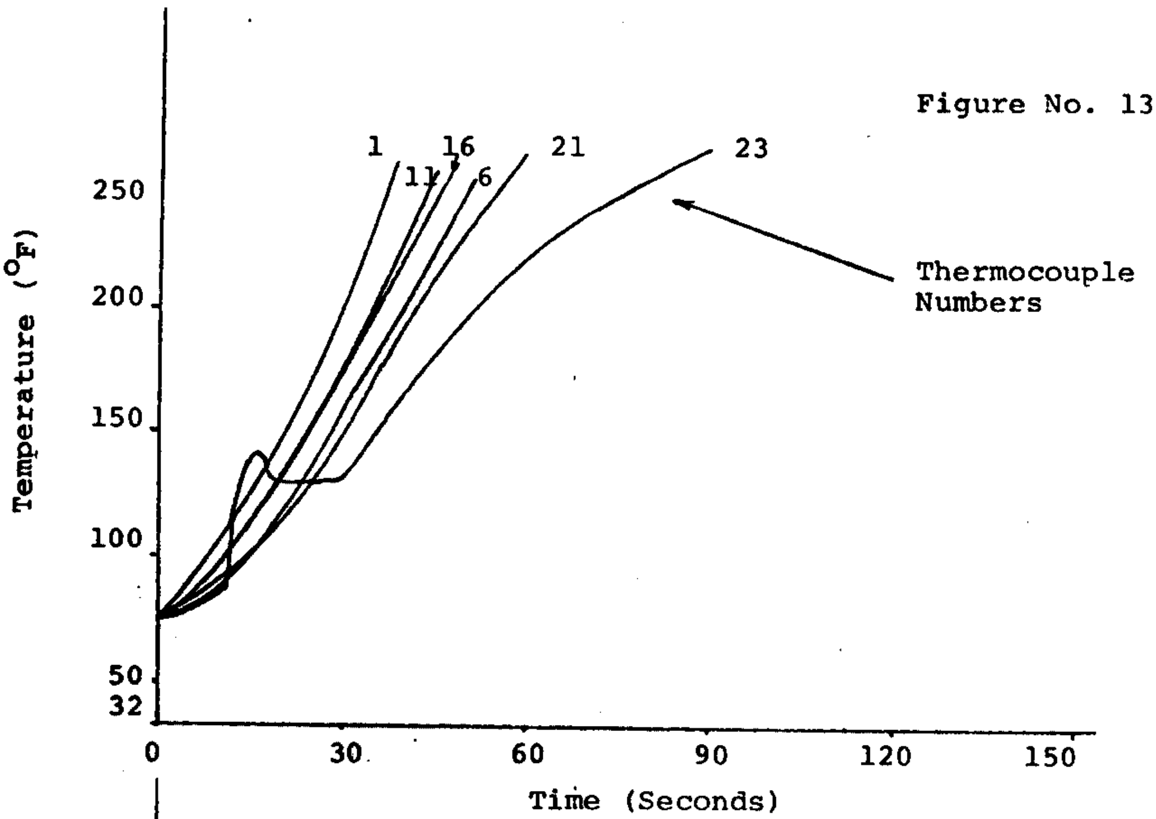


Figure No. 13
Temperature (°F)
250
200
150
100
50
32
0
30
60
90
120
150
Time (Seconds)
1
16
11
6
21
23
Thermocouple Numbers

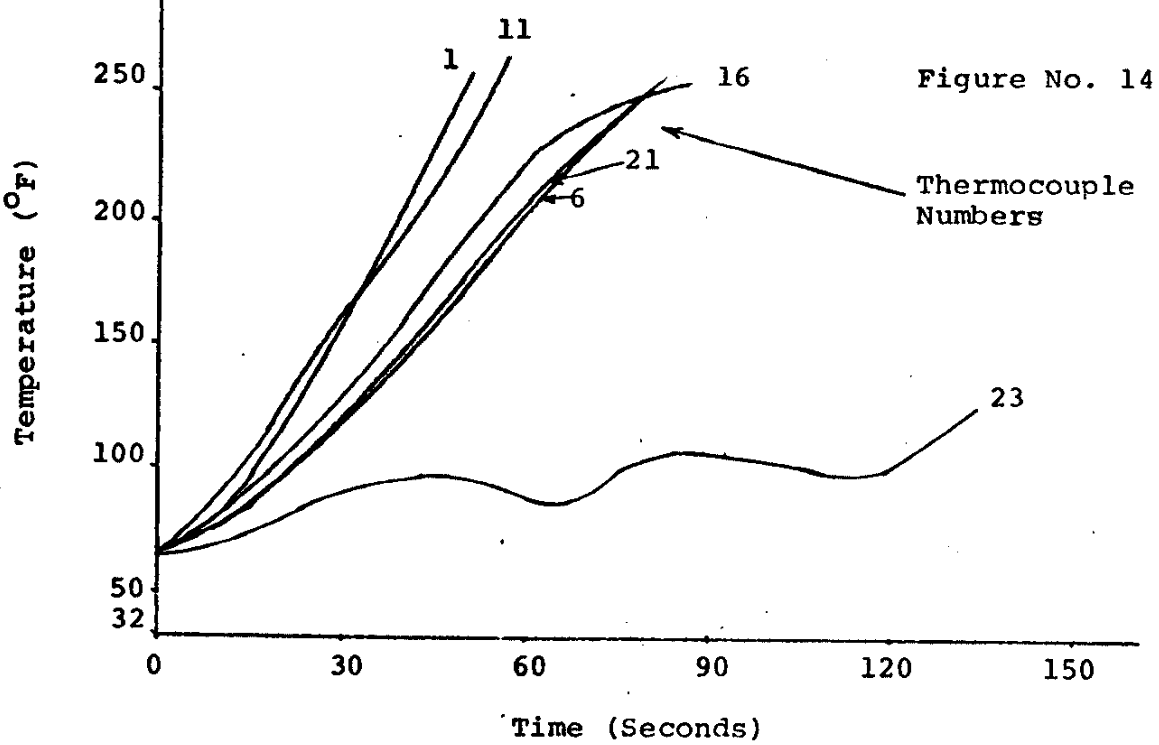


Figure No. 14
Temperature (°F)
250
200
150
100
50
32
0
30
60
90
120
150
Time (Seconds)
1
11
16
21
6
23
Thermocouple Numbers

APPENDIX C

SMOKE AND PRODUCTS OF COMBUSTION DETECTOR EVALUATION

PSR-368

E. I. duPont de Nemours and Company
Savannah River Laboratory

December 1969

ABSTRACT

A program was conducted in a simulated hot cell to evaluate the relative effectiveness of a number of commercially available Smoke and Products of Combustion Detectors. The fuels used to produce the visible and invisible products of combustion were heptane, isopropyl alcohol, paper and polyvinyl-chloride sheet. For each type of fuel, detector response was determined as a function of hot cell volume, position of the fuel within the cell and cell ventilation rate.

INTRODUCTION

At the request of the Savannah River Laboratory, Fenwal Incorporated has commenced a three-phase study of the effectiveness of detection devices in responding to combustion in a simulated hot cell. Each phase involves a specific mode of detection, the first being Thermal Detection, the second Smoke and Products of Combustion Detection and the third Light or Surveillance Detection.

Phase I of the program has been completed and the procedures and results are documented in Fenwal Incorporated Report No. PSR-366. The second phase has now been completed and is the subject of the report.

Dr. A. J. Hill, Jr. of the Savannah River Laboratory served as technical coordinator for this program.

SUMMARY AND CONCLUSIONS

1. The products of combustion detectors exhibited an average response time of 130 seconds for all test conditions as compared to 165 seconds for the smoke detectors.

2. The average percentage of fires responded to was 78.5% for the products of combustion detectors and 42% for the smoke detectors.

3. A summary of response time and frequency of response data for the individual detectors is given in Table No. 1.

4. The average response time of the smoke detectors increased 84.5% when the cell volume was doubled whereas the products of combustion detectors exhibited the same average response time for both cell volumes.

5. The average response of the products of combustion detector in the exhaust duct was 174 seconds as compared to 135 seconds average response time of all the other detectors evaluated.

6. The effect of increasing the cell ventilation rate is to decrease the response time of the exhaust duct detector.

7. The type of combustible had no effect on the ability of the products of combustion detectors to respond whereas the operation of the smoke detectors was severely impaired with the relatively clean burning isopropyl alcohol.

8. Detectors with exposed circuitry required more cleaning and maintenance than those units which had sealed or remote circuitry.

APPARATUS

Simulated Hot Cell

The test cell consisted of an 8' high by 12' wide by 12' long enclosure constructed of 3/4" plywood. The volume could be cut in half by reducing the cell length to 6' with a portable partition. A 12" diameter hole was cut into the portable partition, one foot above the floor and three feet in from one edge. A circular duct extended 12' from the partition and at that point was equipped with a variable speed fan to effect cell ventilation. An air inlet port, 12" in diameter, was cut into the wall opposite the portable partition. This port was diagonal to the exhaust hole and was one foot below the ceiling and three feet ir from the side wall. An external 90° elbow, 12" in diameter, was fitted to the inlet port with the opening facing downward. This elbow reduced the effect of prevailing wind on air flow through the port.

Smoke Sources

Four combustibles were used to produce smoke for the detector evaluation. Heptane and isopropyl alcohol liquid were burned in 7 1/4 and 8 inch diameter pans, respectively, with the fuel floating on a layer of water. The paper fires consisted of twenty paper towels which were wadded together and burned in a five gallon metal container. The fourth smoke source consisted of four 4" x 4" x 1/16" sheets of polyvinyl chloride (PVC) which were placed on a grill 1/2 inch above an electric coil.

Detectors

Two principles of operation are utilized by the sensing elements of smoke and products of combustion (POC) detectors. Smoke detector function is based on the use of optics to determine the presence of visible smoke. The POC detector monitors the electrical conductivity of air or a suitable sensing element and is activated by the presence of visible or invisible products of combustion. The following paragraphs give more complete descriptions of the sensing mechanisms of the various detectors evaluated.

Smoke Detectors

The operation of the smoke detectors tested is based on the reflection of light from an internal lamp to a sensing cell by visible smoke particles. Each detector has a light source and a sensing element (photocell or tube) enclosed within a black mesh or labyrinth which prevents ambient light from impinging on the sensing cell. Through the appropriate positioning of the components and/or through the use of baffles, light normally does not fall on the photo sensitive device from the light source. When visible smoke enters the beam of the light source, some light is reflected to the sensing cell. The resulting signal is monitored until it reaches a preset alarm level. At that time, the device acts to open, close or power electrical contacts.

Products of Combustion Detectors

The most common type of POC detector bases its operation on the change of electrical conductivity of ionized air when products of combustion are introduced into the air. These detectors contain a chamber exposed to ambient air and containing a cathode and anode across which a constant voltage is applied. A small source of radioactivity is positioned near the air gap between the anode and cathode such that the air is ionized. A very small current flows between the two electrodes using the ions of air molecules that are produced by the radioactive source. When relatively heavy products of combustion molecules enter the gap, they are ionized by the radioactive source. Because of their larger size, these particles move relatively slowly toward the electrodes of the chamber and thus reduce the current flow between the plates. In addition, their larger travel times expose these particles to a higher probability of being neutralized by combination with free electrons. This recombination has the effect of reducing the total number of charge carriers in the gap and therefore the total current. This reduction in current flow in the ionization chamber is monitored by the detector circuitry with an alarm transmitted when it drops to a specified level.

Some detectors of this type have a second ionization chamber which is almost isolated from ambient air. Gradual changes of atmospheric conditions that might otherwise alarm a single chamber detector are compensated for by this second chamber in a bridge circuit with the detecting chamber.

A second type of POC detector utilizes a conductive grid deposited on glass as the sensing element. The absorption of products of combustion onto the detector grid changes the conductivity of that grid with the result that an alarm is transmitted. A second grid which is isolated from rapid ambient air change is used in a bridge circuit to compensate for normal fluctuations of barometric pressure, temperature and humidity.

Table No. 1 lists the principles of operation and other characteristics of the various detectors used in this program.

Detector Instrumentation

All of the detectors tested were equipped with normally open electrical contacts which closed at detector function. Detector response time was recorded on a 20 channel event recorder. The recorder had a built-in 24 VDC power supply which was used to power each of 20 pairs of electrical contacts. When any pair of contacts was shorted, it caused deflection of the pen associated with the particular channel. For these tests, detector contact closure was used to provide the electrical short and cause the pen deflection.

PROCEDURE

Detector Response Tests

Detector response tests were conducted to evaluate the relative capabilities of the various detectors to respond to a variety of fire situations. The program variables were cell size, cell ventilation rate, smoke source location, and type of combustible.

The first cell simulated was 8' high by 12' wide by 12' long. Smoke sources were those described in the apparatus section. Ventilation rates were 0,0.33 and 0.90 cell air changes per minute. Five smoke source positions were utilized. These locations are shown in the sketch of Figure No. 1.

The second simulated cell measured 8' x 12' x 6'. Test variables were the same as those above except that cell ventilation was at rates of 0,0.33 and 1.0 cell air changes per minute. The smoke source positions are indicated in Figure No. 2.

For the tests in both cells, the spot type detectors were mounted as a group at the center of the ceiling of the test cell. The sampling tubes of the duct type detector entered the exhaust vent duct 25 inches from the intake at the wall of the cell.

Complete listings of the data of these tests are given by cell size and type of combustible in Tables No. 3 to 10.

DISCUSSION

The most meaningful analysis of the data generated in this program is through the use of statistical averages of response times and frequency of response of the detectors in situations where one of the test variables of ventilation rate, cell size, combustible and fire position is held constant while the rest are varied. Further averaging of all data for smoke detectors and POC detectors separately leads to the conclusion that POC detectors will, in general, respond faster than smoke detectors to fire situations. Under the test conditions of this program, the frequency of response for POC detectors was appreciably higher than for smoke detectors. This was particularly noticeal when a clean burning fuel such as isopropyl alcohol was used. Other data concerning the various tests can be reduced to the type of statistics presented in the summary and conclusions section of the report.

All detectors utilized in this evaluation are listed by Underwriters' Laboratories, Incorporated in its Fire Protection Equipment List of January, 1969. Detectors were tested as received or, where the sensitivity was variable, were set to the manufacturers or U. L. recommended sensitivity prior to testing.

Figure No. 1

8'x12'x12' Test Cell

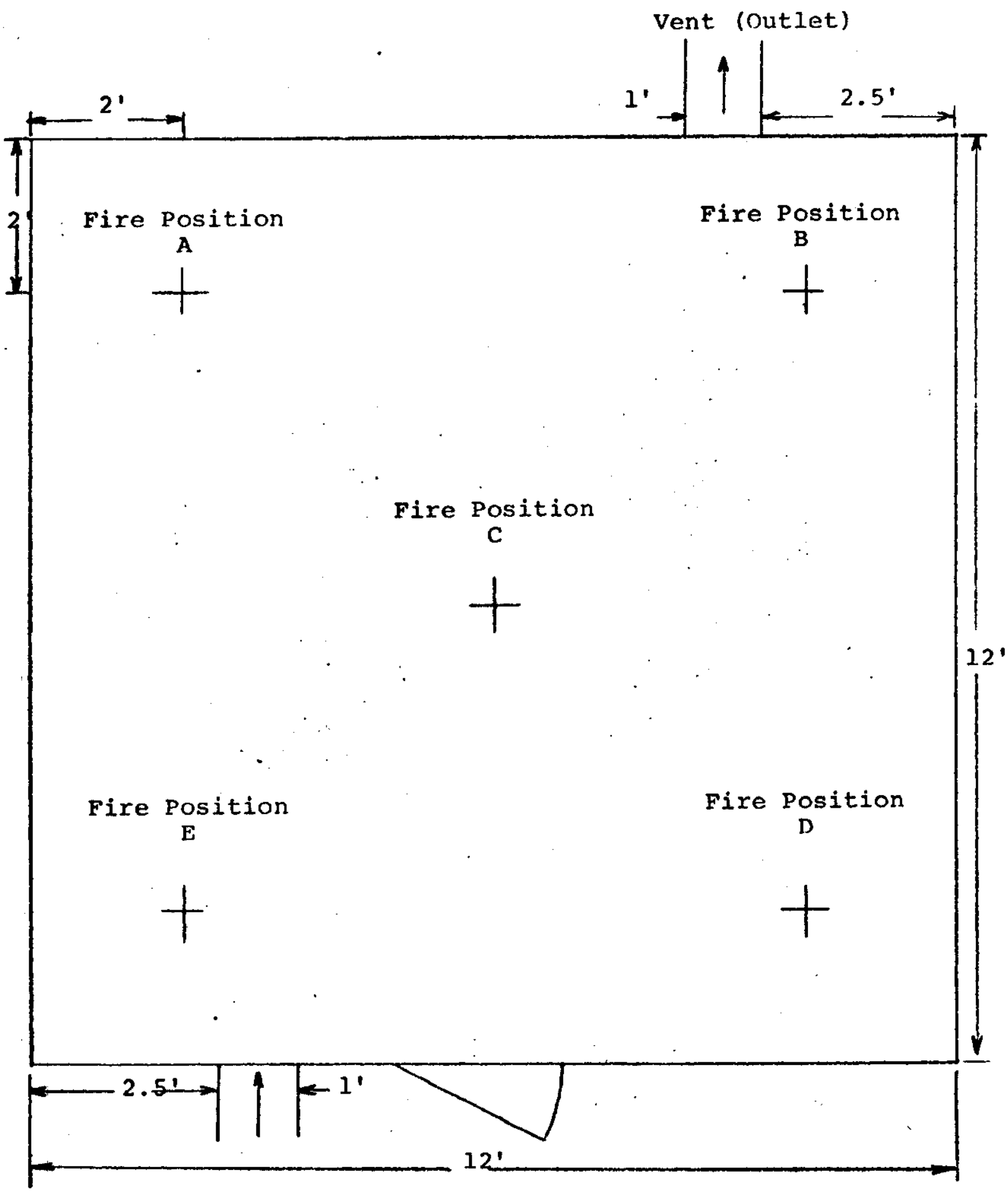


Figure No. 2

8'x12'x6' Test Cell

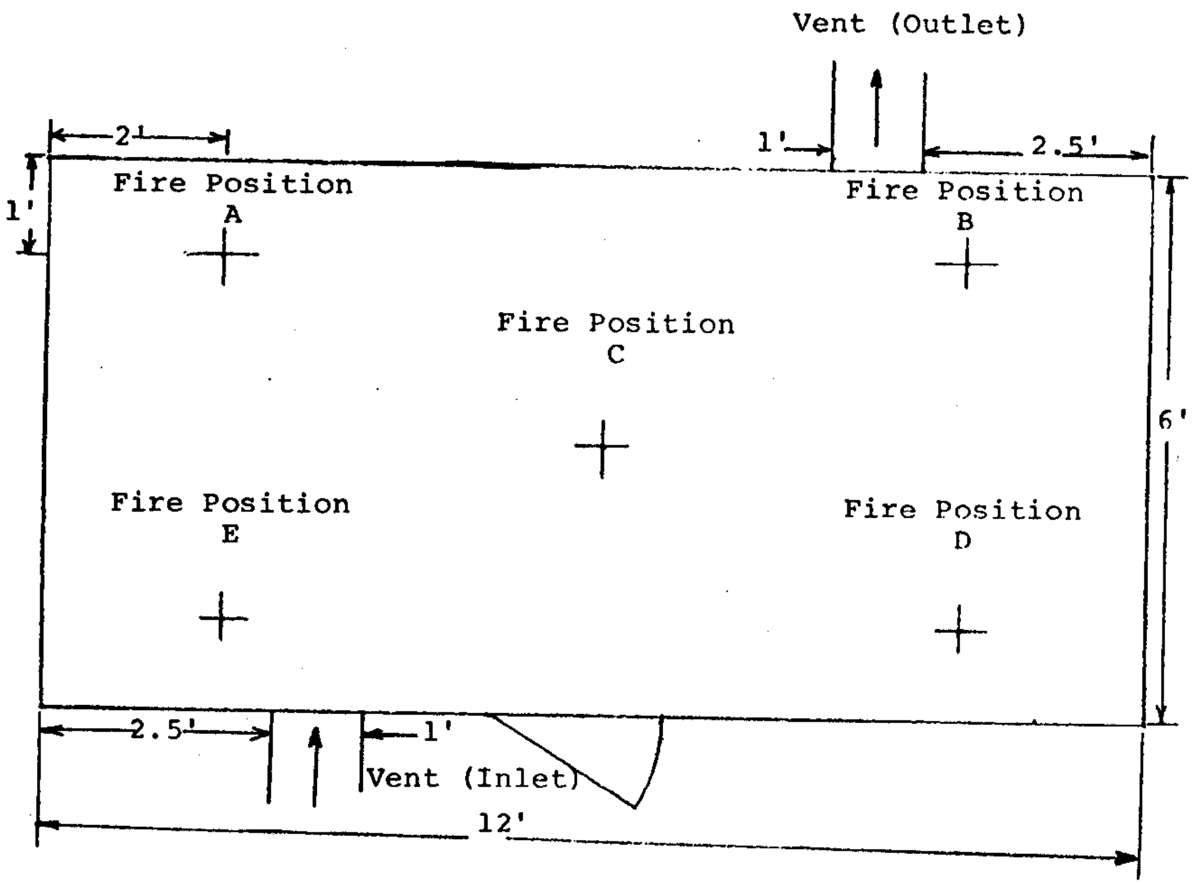


Table No. 1

Summary of Response Time Data

Cell Size	Percentage of Tests Responded to/Average Response Time (Sec.) Detectors									
	A	B	C	D	E	F	G	H	I	J
8'x12'x12'	52/207	43/218	NT	62/219	98/57	91/80	94/118	92/129	66/207	86/190
8'x12'x6'	6/103	25/121	64/125	NO	94/73	81/140	96/124	23/95	57/184	64/158

Notes: NT: Not Tested

NO: Not Operable

TABLE NO. 2

DETECTOR CHARACTERISTICS

DETECTOR	TYPE	ELECTRONIC COMPONENTS	COMPENSATING CHAMBER/GRID
A	Smoke	Exposed	NA
B	Smoke	Exposed	NA
C	Smoke	Remote	NA
D	Smoke	Exposed	NA
E	POC/IC	Remote	Yes
F	POC/IC	Exposed	No
G	POC/IC	Sealed	No
H	POC/IC	Exposed	No
I	POC/GRID	Exposed	Yes
J *	POC/IC	Remote	Yes

Table No. [illegible]

Detector Response Times
8'x12'x12' Cell
Heptane Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
1	C	0	62	47	NT	38	7	8	45	20	NT	NA
4	C	0	125	142	NT	77	9	7	46	14	NT	NA
5	A	0	133	155	NT	D	11	17	75	19	NT	NA
6	A	0	110	132	NT	D	15	17	50	40	NT	NA
7	A	0	155	151	NT	D	11	22	65	39	NT	NA
27	E	0	196	D	NT	207	13	16	62	26	NT	NA
28	D	0	140	D	NT	D	14	15	79	69	NT	NA
33	B	0	220	D	NT	139	16	14	62	43	NT	NA
3	C	384	82	80	NT	62	9	11	46	22	NT	129
8	A	384	132	126	NT	121	19	19	70	20	NT	D
26	E	384	173	243	NT	177	14	19	73	16	NT	166
29	D	384	132	192	NT	302	D	29	72	83	NT	D

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 3 (Continued)

Detector Response Times
8'x12'x12' Cell
Heptane Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
30	D	384	124	420	NT	343	15	21	74	46	NT	142
34	B	384	184	154	NT	113	15	23	54	D	NT	D
2	C	1050	75	71	NT	74	10	11	61	22	NT	71
9	A	1050	98	145	NT	152	14	16	62	40	NT	D
10	E	1050	D	D	NT	176	18	19	63	35	NT	625
31	D	1050	135	D	NT	D	13	16	82	97	NT	D
32	D	1050	121	D	NT	289	12	23	67	76	NT	63
35	B	1050	214	D	NT	113	24	23	54	58	NT	45
60	E	1050	D	D	NT	154	18	52	54	372	NT	50

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 4

Detector Response Times
8'x12'x12' Cell
Paper Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
11	A	0	226	420	NT	145	14	D	61	99	NT	NA
13	C	0	34	74	NT	39	10	15	64	27	NT	NA
16	D	0	118	128	NT	120	22	45	179	60	NT	NA
19	E	0	239	100	NT	106	15	D	119	95	NT	NA
22	B	0	83	190	NT	125	18	163	64	83	NT	NA
12	A	384	72	D	NT	D	23	107	107	72	NT	269
14	C	384	41	109	NT	73	16	18	59	41	NT	269
17	D	384	232	96	NT	96	17	D	99	232	NT	137
20	E	384	126	147	NT	D	22	185	121	126	NT	192
23	B	384	D	183	NT	117	19	NO	110	D	NT	197
15	C	1050	27	40	NT	40	8	11	50	27	NT	54
18	D	1050	66	95	NT	129	28	66	109	66	NT	80

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 4 (Continued)

Detector Response Times
8'x12'x12' Cell
Paper Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors									
			A	B	C	D	E	F	G	H	I	J
21	E	1050	133	170	NT	D	17	21	94	133	NT	60
24	B	1050	NO	D	NT	D	33	155	102	NO	NT	52
25	A	1050	39	150	NT	46	10	23	44	39	NT	78

Notes: NT: Not Tested
NO: Not Operable

Table No. [illegible]

Detector Response Times
8'x12'x12' Cell
Alcohol Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
36	C	0	D	D	NT	296	22	13	66	159	NT	NA
37	C	0	D	D	NT	67	9	7	46	44	NT	NA
38	C	0	D	D	NT	D	42	27	87	84	NT	NA
41	A	0	D	D	NT	D	40	189	80	D	NT	NA
44	E	0	D	D	NT	D	43	52	115	86	NT	NA
47	D	0	D	D	NT	D	36	236	119	D	NT	NA
48	D	0	D	D	NT	D	31	96	94	360	NT	NA
51	B	0	D	D	NT	D	26	38	104	68	NT	NA
39	C	384	D	NO	NT	NO	35	17	D	D	NT	233
42	A	384	D	D	NT	224	38	78	94	286	NT	170
45	E	384	D	D	NT	D	50	35	112	40	NT	D
49	D	384	D	D	NT	D	66	53	107	63	NT	189

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 5 (Continued)

Detector Response Times
8'x12'x12' Cell
Alcohol Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
52	B	384	D	D	NT	D	89	31	121	82	NT	406
40	C	1050	D	NO	NT	NO	42	21	NO	157	NT	143
43	A	1050	D	D	NT	D	43	48	102	122	NT	160
46	E	1050	D	D	NT	D	44	34	121	200	NT	146
50	D	1050	D	D	NT	472	32	50	114	30	NT	140
53	B	1050	D	D	NT	D	83	38	132	60	NT	114

Notes: NT: Not Tested
NO: Not Operable

Table No. 6

Detector Response Times
8'x12'x12' Cell
PVC Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
57	C	0	680	760	NT	360	200	160	355	385	NT	NA
66	D	0	D	481	NT	173	48	51	135	52	NT	NA
68	E	0	D	D	NT	375	159	300	444	168	304	NA
71	A	0	D	D	NT	827	93	D	171	197	162	NA
74	C	0	960	687	NT	240	117	144	171	177	143	NA
77	E	0	D	NO	NT	D	155	462	448	454	174	NA
78	A	0	D	D	NT	NO	66	D	164	535	D	NA
58	C	384	865	705	NT	280	110	NO	300	490	NT	360
67	D	384	D	D	NT	288	60	77	212.	NO	84	258
70	E	384	D	D	NT	620	120	228	270	274	198	264
72	A	384	D	D	NT	D	156	434	274	280	NO	314
75	C	384	511	D	NT	277	126	163	196	203	154	348

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 6 (Continued)

Detector Response Times
8'x12'x12' Cell
PVC Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
59	C	1050	D	D	NT	920	500	500	D	505	NT	490
65	D	1050	D	D	NT	297	123	111	229	88	NT	153
69	E	1050	D	D	NT	D	144	24	D	126	D	196
73	A	1050	D	D	NT	D	320	D	D	D	D	228
76	C	1050	D	D	NT	D	177	214	271	306	446	228

Notes: NT: Not Tested
NO: Not Operable

Table No. 7

Detector Response Times
8'x12'x6' Cell
Heptane Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
80	C	0	D	63	NT	NO	264	137	NO	38	NO	NA
82	C	0	172	58	NT	NO	8	78	55	106	D	NA
96	C	0	D	NO	NT	NO	13	27	62	NO	24	NA
97	E	0	D	D	71	NO	16	184	56	NO	D	NA
113	A	0	D	80	96	NO	13	13	55	NO	242	NA
119	D	0	D	D	70	NO	D	NO	D	NO	D	NA
120	B	0	D	D	97	NO	13	220	47	NO	464	NA
83	C	172	D	D	NT	NO	5	384	39	193	D	D
98	E	172	D	D	119	NO	12	303	46	NO	D	D
114	A	172	D	D	176	NO	D	13	56	NO	D	106
118	D	172	D	D	146	NO	13	112	55	NO	D	D
121	B	172	D	D	126	NO	NO	148	45	NO	NO	NO

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 7 (Continued)

Detector Response Times
8'x12'x6' Cell
Heptane Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors									
			A	B	C	D	E	F	G	H	I	J
123	B	172	D	D	139	NO	14	NO	58	NO	79	105
127	A	172	D	D	119	NO	11	13	48	NO	D	D
84	C	576	D	D	NT	NO	D	270	39	54	312	D
99	E	576	D	D	182	NO	18	D	59	NO	D	59
115	A	576	D	D	214	NO	11	44	56	NO	D	D
117	D	576	D	D	312	NO	13	221	61	NO	224	61
122	B	576	D	D	144	NO	18	NO	63	NO	55	44

Notes: NT: Not Tested
NO: Not Operable

Table No. 8

Detector Response Times
8'x12'x6' Cell
Paper Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
81	C	0	80	24	NT	NO	8	NO	50	NO	NT	NA
102	D	0	D	116	43	NO	19	D	44	NO	9.5	NA
108	B	0	D	133	32	NO	26	36	NO	NO	D	NA
88	C	172	D	44	NT	NO	7.5	14	40	NO	D	152
103	D	172	D	122	20	NO	11	12	48	NO	66	117
109	B	172	D	242	36	NO	23	34	NO	NO	D	186
128	C	172	D	54	28	NO	8	15	45	NO	NO	D
92	C	576	D	166	NT	NO	7	NO	42	NO	NO	78
104	D	576	D	194	30	NO	16	17	51	NO	NO	65
110	B	576	D	258	29	NO	20	25	38	NO	NO	87
116	A	576	D	D	56	NO	36	D	54	NO	D	70
129	C	576	D	155	20	NO	10	D	52	NO	17	107

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 9

Detector Response Times
8'x12'x6' Cell
Alcohol Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
85	C	0	D	D	NO	NO	32	228	72	79	NO	
89	A	0	D	D	NO	NO	22	313	82	NO	D	
95	E	0	D	NO	NO	NO	34	36	78	NO	26	
100	E	0	D	D	D	NO	42	394	90	NO	37	
105	D	0	D	D	D	NO	39	22	29	NO	D	
111	B	0	D	D	D	NO	22	35	54	NO	91	
126	B	172	D	D	D	NO	30	50	78	NO	NO	
124	B	172	D	D	D	NO	26	NO	83	NO	NO	
86	C	172	D	D	NO	NO	26	258	72	138	NO	
90	A	172	D	D	NO	NO	23	202	66	NO	NO	
93	E	172	D	D	NO	NO	36	13	82	NO	D	
101	E	172	D	D	D	NO	37	D	82	NO	D	

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 9 (Continued)

Detector Response Times
8'x12'x6' Cell
Alcohol Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
106	D	172	D	D	D	NO	35	19	20	NO	330	
112	B	172	D	D	D	NO	45	42	58	NO	377	
87	C	576	D	D	NO	NO	30	230	73	58	D	
94	E	576	D	D	NO	NO	63	38	78	NO	104	
107	D	576	D	D	D	NO	63	46	472	NO	190	
125	B	576	D	D	D	NO	29	38	97	NO	278	

Notes: NT: Not Tested
NO: Not Operable
D: Did Not Function

Table No. 10

Detector Response Times
8'x12'x6' Cell
PVC Smoke

Test No.	Fire Position	Flow Rate (CFM)	Response Times (Seconds) Detectors A	B	C	D	E	F	G	H	I	J
130	A	0	D	D	419	NO	206	D	288	NO	225	NA
133	E	0	D	D	433	NO	200	332	385	NO	264	NA
136	D	0	D	D	168	NO	216	NO	344	NO	195	NA
139	B	0	D	D	237	NO	309	NO	400	NO	234	NA
131	A	172	D	D	D	NO	188	244	300	NO	228	322
134	E	172	D	D	138	NO	262	NO	225	NO	145	217
137	D	172	D	D	190	NO	360	466	416	NO	NO	390
140	B	172	D	D	254	NO	428	454	607	NO	D	D
132	A	576	D	D	D	NO	249	263	538	NO	271	337
138	E	576	D	D	88	NO	178	D	219	NO	D	135
135	D	576	D	D	116	NO	176	D	255	NO	D	185

Notes: NT: Not Tested
NO: Not Operable

APPENDIX D

LIGHT DETECTOR EVALUATION

PSR-373

E. I. duPont de Nemours and Company
Savannah River Laboratory

February 1970

ABSTRACT

A program was conducted to determine the relative effectiveness of four commercially available optical light detectors designed for use as fire detectors. Response times of the detectors to flames produced by burning heptane, alcohol, paper and polyvinyl chloride were measured. Other test variables were chosen to allow evaluation of the detectors' field of vision, effectiveness of response to small fires and ability to detect flames through a smoke cloud.

INTRODUCTION

At the request of the Savannah River Laboratory, an AEC facility operated by the duPont Company, Fenwal Incorporated has conducted a three-phase study of the effectiveness of detection devices in responding to combustion in a simulated hot cell. The initial phase of the program involved a study of thermal detection, the second phase smoke and products-of-combustion detection and the final phase light ~~of~~ or surveillance detection.

The first two phases of this study have been completed and the procedures and results obtained are documented in Fenwal Incorporated Report Nos. PSR-366 and PSR-368. The third and final phase of the program has now been completed and is the subject of this report.

Dr. A. J. Hill, Jr., of the Savannah River Laboratory served as technical coordinator for this program.

SUMMARY AND CONCLUSIONS

1. The ability of light detectors to respond to the burning of a specific combustible depends upon the emission spectra of the combustion reaction. The ultraviolet light detectors detected alcohol, heptane and paper fires more rapidly than the infrared detectors. Detection of polyvinylchloride fires was faster with an IR detector than a UV detector.

2. The use of light collecting lenses improved the field of view of one IR detector. This detector also showed the ability to detect smaller alcohol fires at a fixed distance than were detected by the other IR and both UV detectors.

3. The specific mounting configuration of the sensing element within or on the detector housing does effect the cone of vision of the detector.

4. The presence of heavy smoke prior to open flaming will impair the performance of all light detectors. The smoke density and absorption spectra will influence the degree of impairment for a specific detector.

5. The average response times for the fire size and position tests varied from a low of .03 seconds for one UV detector observing heptane fires to a high of 71 seconds for the same detector viewing the PVC fires. Table No. 1 lists averages for all detectors in the fire size and position tests.

APPARATUS

Flame Sources

Two liquid and two solid combustibles were utilized as flame sources in this program. Heptane and isopropyl alcohol were burned in various diameter pans with the heptane floating on a layer of water and the alcohol burning in an otherwise dry pan. Paper fires consisted of paper towels wadded together and burned in a cylindrical wire mesh basket. Polyvinyl chloride (PVC) sheets four inches square and 1/16 inch thick were burned by placing four squares in a vertical position parallel to each other and 1/2 inch apart above a Bunsen burner flame that was shielded from the view of the detectors.

Light Detectors

The sensing elements of the detectors tested respond to electromagnetic radiation in the infrared, visible and/or ultraviolet region of the spectrum. Through the use of optical filters and/or electronic sensing circuitry, the IR detection systems are sensitive only to specific optical phenomenon associated with flames. The UV detectors, by virtue of their sensitivity to ultraviolet radiation only, will respond to open flames, sparks or other sources of ultraviolet light. Discussions of the specific detectors tested are given below.

Infrared Detectors

Both IR detectors tested in this program utilized broad-band photocells as their sensing elements. Two factors in the design of these detectors make them blind to all light except that of open flames. The first was to cover the sensing cell with an optical filter passing almost exclusively IR radiation. This feature minimizes alarms from exposure of the cell to ambient sunlight and artificial light sources such as incandescent and fluorescent light bulbs.

The second feature designed to help the detector discriminate between open flames and other light sources is based on the flickering phenomenon associated with open flames. The intensity of light produced by most open flame sources pulses with a frequency of from four to twenty-two cycles per second. Through the use of electronic filtering of the signal from the photocell, the detector has the ability to selectively respond to flames flickering at a frequency within the range chosen by the manufacturer of the detector. Coupled with the optical filter, this selective filtering of signals allows the detector to distinguish open flames from other light sources. The two IR detectors are designated A and B in the Data Tables.

Ultraviolet Detectors

The use of a sensing element that is blind to all except ultraviolet radiation is the basis of the two UV detectors tested in this program. The sensing element is a gas discharge tube containing a gas which is ionized by electromagnetic radiation in the ultraviolet region of the spectrum. The ionized gas becomes a conductor of electrical current between two high voltage electrodes in the gas discharge tube. This current flow is sensed by the electronic circuitry of the detector. A counting circuit in the detector then removes the voltage from the electrodes so that the current flow is interrupted. When the voltage is reapplied to the device, it is again sensitive to ultraviolet radiation and will conduct in its presence. If this cycle of alarm, shutdown and alarm again is repeated often enough, the detector will act to close, open or power contacts. The sensitivity of the instrument is based on the number of cycles required to be observed within a specific time. This counting feature eliminates false alarms due to the occasional triggering of the discharge tube by backbround radiation. The two UV detectors are designated C and D in the Data Tables.

Dectector Instrumentation

Figure No. 1 illustrates the connection of the typical detector to its power supply and the channels of a recording oscillograph used to make a record of the time of detector functioning. This circuitry serves to indicate on the oscillograph chart the time at which power was applied to a specific detector and then to record the time at which the detector indicated an alarm condition.

PROCEDURE

Fire Size and Distance Tests

A group of tests was conducted in which fires of four types of combustibles were burned at each of three positions, A, B and C, which were 3', 6.5' and 10' respectively from the detectors along the normal to the mounting plane of the detectors as illustrated in Figure No. 2. For these tests, alcohol and heptane were burned in pans of 7, 5 and 3 inches diameter at all positions. Paper fires that were built at each location consisted of 20, 25 and 40 paper towels wadded together and placed in wire mesh baskets 6", 6" and 12" in diameter and 6", 10" and 6" in height respectively. The one size of PVC fire tested at each position was made of four 4" x 4" x 1/16" sections of PVC sheet that were mounted vertically and parallel to each other 1/2" apart in a metal holder above a Bunsen burner. The Bunsen burner flame was necessary to ignite and sustain flaming of the PVC although the burner flame itself was shielded from the view of the detectors.

The results of these tests are listed in Table No. 2.

Limiting Fire Size Tests

In this series of tests the diameter of an alcohol pan fire placed 6.5 feet from the detectors was gradually reduced until all detectors failed to respond to the fire. The initial pan diameter was seven inches. The fire size was reduced in steps to a minimum of 0.5" diameter. The results of these tests are given in Table No. 3.

Cone of Vision Tests

This group of tests evaluated the limitations of the detectors with respect to the angular and distance relationship between the sensing element and the fire source. The fire source, a 5" diameter alcohol fire, was moved through a variety of angles with respect to the normal to the mounting plane at fixed distances from the detectors. The resulting pattern within which the fire was detected is the cone of vision. Test results are given in Table No. 4.

Smoke Obscuration Tests

Two tests were conducted in which a cloud of smoke was introduced into the test cell which the detectors were observing and activated by three inch diameter alcohol fires at positions A and B. As the smoke cloud developed from a commercially available smoke bomb*, each detector was monitored for the time at which it ceased to be

*Superior Signal Company, Inc., Spotswood, New Jersey alarmed by the fire. The resultant data indicates the relative ability of the detectors to "see" through an obscuring smoke cloud and is listed in Table No. 5.

DISCUSSION

To determine the response times of the IR and UV detectors, the fires were ignited before power was applied to the detectors. This was necessary to eliminate errors that would occur by detectors sensing the igniter used to start the fires. The warm-up time for the detectors varies from unit to unit but for an individual unit it was assumed to be constant. The warm-up time for each detector was determined by exposing the unit to a strong source of radiant light, switching on the power to the detector and measuring the time for the detector to alarm. In subsequent fire tests, the time for the detectors to respond was calculated by measuring the period from the time power was applied to the detectors until each detector alarmed and subtracting from these times the appropriate warm-up time for each detector. The response times reported for IR detector B also include a three-second delay built in by the manufacturer.

To detect a fire, IR and UV detectors must receive radiant energy of sufficient intensity as well as of the proper wavelengths. The fuel, fire size, and fire position (distance and angle) with respect to the sensing element determine the intensity of the radiant energy falling on the sensing cell. A detector may be very slow to respond, or may fail to respond if (1) the radiant energy from a fire is not strong enough, (2) the radiation does not contain enough energy of the appropriate wavelengths, (3) the sensing cell is partially shielded by the design of the detector housing, or (4) objects or smoke within the protected area shield the detector from the IR or UV radiation.

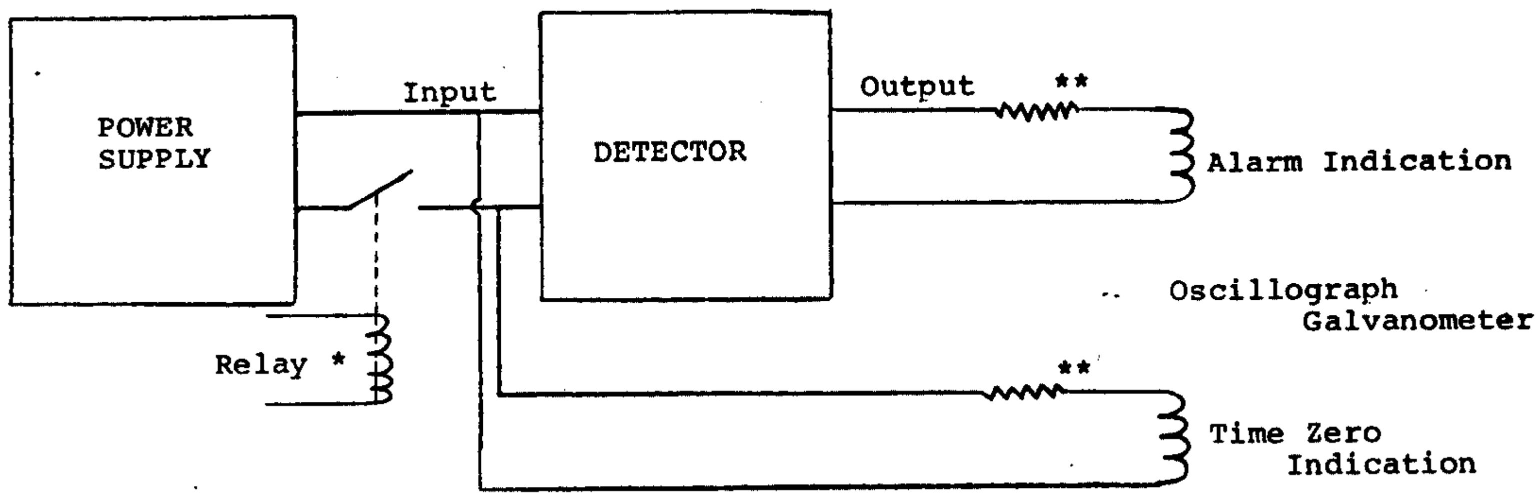
Each of the test series conducted in this program illustrates the effect of one or more of the factors discussed above. The data of Table No. 1 indicates that the infrared radiation content of paper flames is lower than that of alcohol, heptane or PVC fires. Similarly the long response times of the UV detectors to the PVC fires indicate that the PVC fire is a poor source of UV radiation.

The effect of fire size is clearly indicated by Table No. 3. The data in Table No. 4 shows that detector housing design does influence the field of view of the detector. The IR detector A and the UV detector D both had recessed sensing elements and are noted to have narrower fields of vision than their companion detectors which had similar sensing elements. The difference in IR detectors is the use of the light collecting lens on the unit with the wider cone of vision.

For the UV detectors, the improved exposure given to the non-recessed gas tube electrodes results in the improved field of vision for that unit compared to the slightly recessed unit.

FIGURE NO. 1

TYPICAL INSTRUMENTATION SCHEMATIC FOR LIGHT DETECTOR TESTS



Notes: *Applies power to all detectors simultaneously

**Dropping resistors for protection of galvanometers

FIGURE NO. 2

DETECTOR AND FIRE LOCATIONS

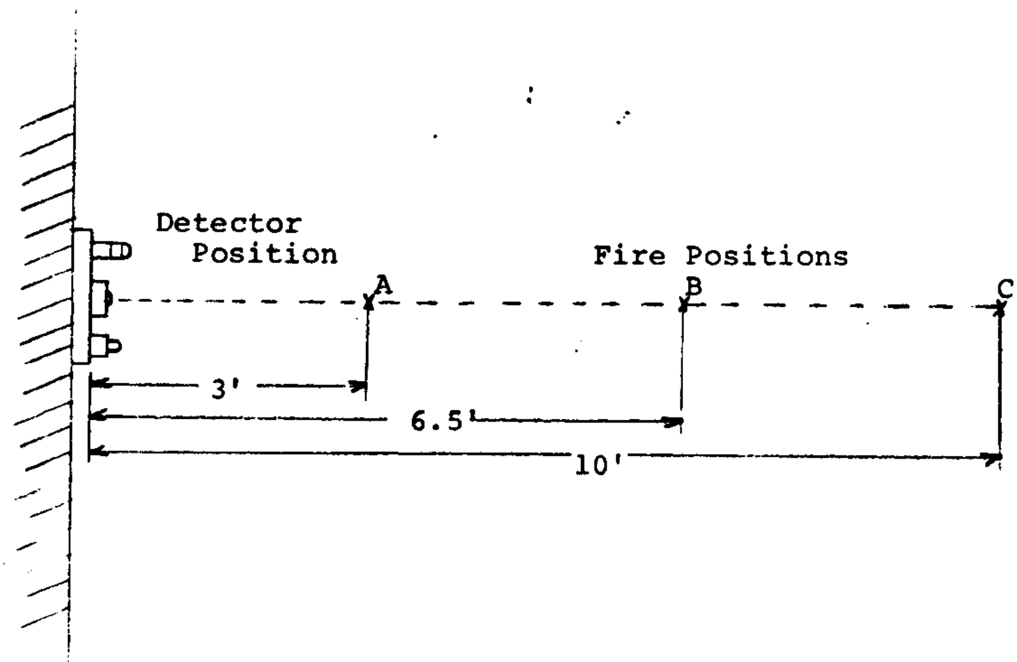


TABLE NO. 1

SUMMARY OF RESPONSE TIME DATA

FUEL	DETECTOR AVERAGE RESPONSE TIME (SEC.)			
	A	B	C	D
Alcohol	.303[1]	3.2381	.305	.304
Heptane	1.393[2]	3.3347	.0324	.098
Paper	.089[3]	36.825	.1858	.515
PVC	D	3.133	70.875	50.476

Notes: [1] Responded in 3 out of 9 tests

[2] Responded in 6 out of 10 tests

[3] Responded in 1 out of 9 tests

D Did not respond

A and B are IR Detectors

C and D are UV Detectors

TABLE NO. 2

DETECTOR RESPONSE TIMES

TEST NO.	TYPE OF FIRE	FIRE POSITION	FIRE SIZE (in. dia)	DETECTOR RESPONSE TIME (sec) A	B	C	D
2	Alcohol	A	7	.090	3.078	.025	.023
6	"	A	5	.728	3.072	.045	.036
5	"	A	3	D	3.039	.085	.078
3	"	B	7	.090	3.183	.040	.038
8	"	B	5	D	3.207	.100	.256
7	"	B	3	D	3.292	.575	.513
4	"	C	7	D	3.183	.075	.161
10	"	C	5	D	3.484	.185	.713
9	"	C	3	D	3.605	1.618	.926
12	Heptane	A	7	1.310	3.117	.005	.003
11	"	A	5	1.682	3.286	.015	.000
15	"	A	5	.900	3.242	.025	.023
18	"	A	3	2.555	3.242	.028	.036
13	"	B	7	1.910	3.832	.015	.022
16	"	B	5	D	3.539	.038	.143
19	"	B	3	D	3.272	.055	.093
14	"	C	7	.000	3.492	.039	.055
17	"	C	5	D	3.000	.045	.333
20	"	C	3	D	3.446	.059	.276

TABLE NO. 2
(continued)

DETECTOR RESPONSE TIME

TEST NO.	TYPE OF FIRE	FIRE POSITION	FIRE SIZE (in.dia)	DETECTOR RESPONSE TIME (sec) A	B	C	D
21	Paper	A	6" x 6" H	D	40.572	.070	.508
27	"	A	6" x10" H	D	56.792	.023	.320
25	"	A	12" x 6" H	.089	3.202	.000	.033
22	"	B	6" x 6" H	D	63.222	.475	.483
28	"	B	6" x10" H	D	78.987	.157	.856
24	"	B	12" x 6" H	D	3.065	.015	.093
23	"	C	6" x 6" H	D	3.485	.755	1.703
29	"	C	6" x 6" H	D	78.952	.170	.538
26	"	C	12" x 6" H	D	3.149	.008	.103
40	PVC	A		D	3.242	56.575	45.143
41	"	B		D	3.000	57.475	5.543
42	"	C		D	3.058	98.575	100.743

Notes: D - Did not function

A and B are IR Detectors

C and D are UV Detectors

TABLE NO. 3

DETECTION LIMIT FOR ALCOHOL FIRE
(Fire Position B (6.5 ft.)

TEST NO.	FIRE SIZE (in. dia)	DETECTOR RESPONSE TIME (sec) A	B	C	D
3	7.0	.090	3.183	.040	.038
33	6.5	D	3.000	.055	.138
32	5.5	D	3.380	.039	.218
34	2.5	D	3.034	.325	.853
35	1.5	D	3.202	.265	.933
36	1.0	D	3.275	5.328*	1.246*
38	0.75	D	3.782	61.425*	2.483*
37	0.50	D	D	D	D

Notes: *Intermittent Operation

D - Did not function

A and B are IR Detectors

C and D are UV Detectors

TABLE NO. 4

CONE OF VISION OF DETECTORS
5" diameter Alcohol Fire

TEST NO.	L (ft.)	Angle (°)	DETECTOR RESPONSE TIME (sec) A	B	C	D
109	3	60	3.550	3.217	.072*	3.053
132	3	72	D	3.117	.040	.093
117	3	73	6.640	3.357	.105	.943
118	3	75	D	3.537	.050	27.358*
110	3	75	D	3.002	.165	10.013
108	3	88	D	3.312	.033	17.418
119	3	88	D	3.612	.035	4.308*
112	6.6	60	D	3.139	.065*	21.274*
122	6.5	63	D	3.422	.270	20.393
123	6.5	66	D	3.567	.475	27.543
120	6.5	68	D	3.372	.375*	D
121	6.5	74	D	3.487	.450*	D
113	6.5	75	D	3.139	5.315*	D
114	6.5	83	D	3.435	3.075*	D
115	6.5	88	D	3.152	.490*	D

TABLE NO. 4 (Cont.)

CONE OF VISION OF DETECTORS
5" diameter Alcohol Fire

TEST NO.	L (ft.)	Angle (°)	DETECTOR RESPONSE TIME (sec) A	B	C	D
116	10	88	D	3.355	10.725	D
126	11	83	D	3,387	69.205*	D
127	11	88	D	3.376	8.605*	D
125	13	83	D	3.342	D	D
124	15	83	D	3.376	D	D
128	20	88	D	11.542	D	D
129	25	88	D	18.662	D	D
130	30	88	D	72.622	D	D
131	32	88	D	52.242	D	D

Notes: D - Did not respond

* - Intermittent operation

A and B are IR Detectors

C and D are UV Detectors