NBSIR 82-2521

Full-Scale Study of the Effect of Pendent and Sidewall Location on the Activation Time of an Automatic Sprinkler

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

July 1982

Sponsored in part by:
U.S. Fire Administration
Federal Emergency Management Agency
Washington, DC 20472

Department of Health and Human Services
Washington, DC 20201

NBSIR 82-2521

FULL-SCALE STUDY OF THE EFFECT OF PENDENT AND SIDEWALL LOCATION ON THE ACTIVATION TIME OF AN AUTOMATIC SPRINKLER

Warren D. Hayes, Jr. and Richard H. Zile

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

July 1982

Sponsored in part by:
U.S. Fire Administration
Federal Emergency Management Agency
Washington, DC 20472

Department of Health and Human Services
Washington, DC 20201

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FULL-SCALE STUDY OF THE EFFECT OF PENDENT AND SIDEWALL LOCATION ON THE ACTIVATION TIME OF AN AUTOMATIC SPRINKLER

Warren D. Hayes, Jr. and Richard H. Zile

Abstract

A series of 17 full-scale tests was conducted to obtain measurements of the thermal response behavior of simulated and actual sprinklers positioned in the pendent and two separate sidewall locations. Exposure fires were simulated by a propane burner, and replicated the approximate temperature rises of several different burning furniture items typically found in residential and board-and-care type occupancies.

The results indicate that for this test arrangement the response time of a sprinkler is influenced by the location of the sprinkler, the growth rate of the fire, and the response characteristics of the sprinkler itself. In addition, for the fire growth rates studied, differences between the activation times of a pendent positioned sprinkler and those of two sidewall locations appeared significant. In some cases, it appears that equivalent response time at the sidewall location to that of a pendent location cannot be achieved for the configurations tested. The implications of these results require further investigation.

Key Words: Automatic sprinklers; compartment fires; fire safety; life safety; room fires; sidewall sprinkler systems; thermal response.

1. INTRODUCTION

1.1 General

This study is part of a multiyear sprinkler research program ongoing at the National Bureau of Standards (NBS). The overall goal of the program is to develop a quantitative basis for engineering guidelines for automatic sprinkler system design, with a focus on life safety. This portion of the study is sponsored in part by the Federal Emergency Management Agency's (FEMA) U.S. Fire Administration (USFA), and the Department of Health and Human Services (HHS).

The work reported here resulted from a series of full-scale experiments designed to examine the differences in response time for sprinklers in a bedroom-sized compartment, depending on the type of fire and the location of the sprinkler head. This represents an initial step towards characterizing the response time requirements for sprinklers positioned in sidewall locations. A range of fire exposures was selected to simulate typical fires occurring in 1) residences and 2) health care and board-and-care type facilities.

It is intended that this work contribute to an effort to develop engineering guidelines for the use of sprinkler systems in board-and-care facilities, and especially for the use of sidewall sprinklers in retrofit situations. Further, it is intended that this work will lead to a better technical basis for sprinkler design which will permit expansion of the current scope of NFPA 13D, Standard for Installation of Residential Sprinkler Systems, [1][1] to include other occupancies, and provide the basis for increased cost effectiveness in sprinkler system design for life safety.

1.2 Background

Historically, the principle role of automatic sprinkler systems has been that of property protection, and the success of such systems in controlling fires in commercial and industrial applications is well documented. However, one of the key recommendations in the National Commission on Fire Prevention and Control's report "America Burning" involved the pursuit of sprinkler technology targeted toward life safety [2]. This recommendation has influenced much of the recent research on automatic sprinkler behavior which has been directed toward assessing the life safety benefits of conventional sprinkler technology, augmenting the conventional technology as well as exploring new concepts, and providing the technical basis for the evolution of standards which address design and installation requirements to enhance the life safety impact of sprinklers.

The initial candidates under the new life safety mandate were the residential, health care, and board-and-care occupancies for both new and retrofit construction. These applications brought with them in addition to the life safety issue, limitations on 1) design requirements such as the available water supply and 2) system costs. In order to properly address these factors, a more complete engineering basis for sprinkler system design was necessary.

Ideally, a performance based approach to sprinkler system design is desirable because it would enable a design engineer to optimize performance in terms of extinguishment effectiveness and life safety. Flexibility in design is inherent in such an approach, [i.e., sprinkler head location (sidewall vs pendent) and water supply piping sized to meet a specific set of hazards and construction geometries].

---

[1]Numbers in brackets indicate the literature references at the end of this paper.

Such design must include consideration of 1) hazard identification, 2) sprinkler response characteristics, 3) water spray distribution, and 4) control or extinguishment effectiveness. The effect of each of these parameters in compartment fire situations requires better understanding, and characterization by itself and in combination before performance based guidelines can be developed. For the present, more prescriptive guidelines must suffice.

The National Fire Protection Association (NFPA) published in 1975 the first edition of NFPA 13D, Standard for Installation of Sprinklers in One and Two Family Dwellings and Mobile Homes. As the title implies, the scope of this standard included one and two family residences and mobile homes, and for the most part dealt with the application of conventional sprinkler technology. While this was the best the state-of-the-art could provide, it was recognized that the installation and hardware requirements had limited feasibility for such applications, and that there was an absence of any technical data regarding the likely benefits and limitations of such a system in terms of life safety.

The desire to respond to these difficulties, and in turn improve upon the technical guidance provided in the initial edition of NFPA 13D served as a focus for recent sprinkler research. For example, a major research program sponsored by USFA at Factory Mutual Research Corporation (FMRC) since 1976 has been directed at examining key sprinkler performance parameters in terms of life safety in typical residences. In addition, work conducted at NBS under the sponsorship of HHS has been concentrated on the use of sprinklers in patient rooms in health care facilities, again with the attention toward life safety considerations.

While the program objectives of these studies varied somewhat, the technical results led to similar observations which will influence much of the research directed toward advancement of sprinkler technology in the immediate future. Test results indicated that conventional sprinkler technology had limited application in terms of life safety. Hardware characteristics and installation requirements did not in some cases provide the desired level of life safety or the design flexibility suitable for broad application. However, it was also recognized that carefully planned advancements in technology could provide the technical feasibility for improved performance and less demanding design requirements.

A key design parameter, initially identified in the FMRC program as potentially having a substantial impact on sprinkler performance, was the response characteristics of the sprinkler head (i.e., the time required for the sprinkler to activate under a fire condition). FMRC determined that in order to achieve a level of performance necessary to provide adequate life safety, a sprinkler head would have to respond 4 to 5 times faster to a typical fire than conventional sprinklers respond [3]. The importance of this parameter was later demonstrated in the NBS work where substantial reductions in smoke concentration and carbon monoxide were observed when the activation time of the sprinkler head was reduced below that of conventional hardware [4].

The results of the work on sprinkler response characteristics have been translated into design requirements in the November, 1980 revision to the NFPA 13D Standard [1]. This has produced increased confidence regarding the life safety benefits of sprinkler systems designed in accordance with the NFPA 13D-1980 ed., and some modest relaxation in requirements such as the water supply. However, further research is necessary to extend the application of this technology beyond one and two family dwellings and mobile homes, to relate the design of the sprinkler system to the type of hazard to be considered, and to provide the technical basis for cost saving system design - particularly for retrofit. An assessment of the performance of sidewall sprinkler systems in terms of life safety and of improvements necessary to insure their viability is a logical extension of current work and provides an opportunity to enhance the potential for retrofitting of sprinkler systems to improve life safety in existing occupancies.

1.3 Recent Studies of Sidewall Sprinklers

A portion of the full-scale fire test program recently conducted under sponsorship of USFA was directed at evaluating the performance of a commercially available sidewall sprinkler head when exposed to a flaming upholstered furniture fire in a typically arranged living room [5]. In these tests, the sidewall sprinkler was found not to respond as effectively as a pendent sprinkler when exposed to this type of fire growth, and did not adequately control the fire. The exact nature of the decreased effectiveness has not yet been reported.

Tests in the patient room sprinkler series sponsored by HHS at NBS have also included some with a sprinkler located at a sidewall position. In these tests, those with the sprinkler located at the sidewall position have demonstrated longer times to activation than those at the pendent position, but upon activation were significantly more effective at extinguishment. This was judged by their demonstration of one fourth the weight loss of the combustible wardrobe. The reason for this difference is not yet understood [6]. In the Builders Hardware Manufacturers Association (BHMA) patient room tests at Illinois Institute of Technology Research Institute (IITRI), the sidewall sprinkler actually activated faster than the pendent sprinklers in one of three similar tests [7].

These results raise questions as to whether sprinklers located at sidewall positions have slower response times than those located at pendent positions, and whether the difference will affect the performance of the sprinkler system in terms of life safety. The answers to these questions are important because cost svaings may be achieved with the use of sidewall sprinklers in several situations, the most notable of which is the retrofitting of existing occupancies where accompanying piping installations would be simplified considerably. Examples of possible designs are 1) horizontal supply lines down corridors with a branch to a sprinkler head in each adjacent space, and 2) a vertical supply line in or near a wall with branches to sprinkler heads in two or more adjacent spaces on each floor. The second of these might be most useful in new residential construction.

1.4 Project Scope

The scope of this study is limited to providing a quantitative measure of sprinkler response time as a function of sprinkler location in a typical bedroom arrangement. It is further limited to placement specifications applicable to pendent sprinklers given in NFPA 13 [8] and a horizontal sidewall location recommended in the product catalog. It does not encompass any response optimization by minor changes in placement with respect to the walls and ceiling. Other aspects of performance differences between sidewall and pendent locations, such as spray distribution and extinguishment effectiveness, are not addressed.

1.5 Objective

The objective of this study was to compare measurements of response times of sidewall and pendent sprinkler locations in a small bedroom size compartment under conditions produced by moderately sized fires of several growth rates. These fires were designed to simulate the growth rates of incidental fires found to occur in residences, in board-and-care facilities, and similar occupancies.

2. EXPERIMENTAL DETAILS

2.1 Approach

2.1.1 General

The full-scale tests conducted in this study were arranged to expose commercially available sprinkler heads of a type and temperature rating appropriate for light hazard occupancies to a range of exposure fires. The sprinklers were positioned in the center of the room in a pendent arrangement, as well as on two different sidewalls. The exposure fires in a room with an open doorway were simulated through the use of a propane burner, and replicated the approximate temperature rise of several actual burning furniture items from previous full-scale testing.

The activation times of identical sprinkler heads positioned at the several locations within the room were recorded. Additionally, air temperature and thermal response measurements were taken at the same locations for the purposes of 1) characterizing the temperature history at the different locations, and 2) predicting activation of sprinklers having different response characteristics.

2.1.2 Selection of Thermal Exposure Conditions

<u>Review of Selected Test Data from Previous Work</u>

Selection of the exposure fires involved review of previous test fires conducted by NBS [4,9], FMRC [3], and IITRI [10] involving mattresses, upholstered chairs and combustible wardrobes. This range of fires provided a reasonable variation in exposures typical of the occupancy types in which we were interested.

A review of these test results revealed a wide variation in the temperature histories reported for fires with similar combustibles at the different test facilities. Some of the variation probably was the result of different methods of initiating the fires. Some tests were initiated with methenamine tablets, and others with wastebasket fires. This, combined with other variables such as room size, ventilation, location of fire within the room and points of measurement, resulted in a variation of between 2 and 19 minutes in the duration of the initial stage of the fire, (i.e., the time from ignition of the tablet or the trash can to the time when the major item became involved). An example of this is shown in figure 1 which presents upper room temperature plots for mattress fire tests conducted by FMRC, IITRI, and NBS. The IITRI and NBS tests were initiated with a wastebasket and the FMRC test was initiated with a methenamine tablet.

The rate of temperature rise after the major item became involved also varied considerably. In the case of mattress fires, one minute after the mattress become involved, different rates of temperature rise, namely 74°C and 333°C per minute, were reported by two of the laboratories. This is illustrated by plots IITRI-(AHCA)-6 and NBS-N39 in figure 1. Both were for hospital mattress fires ignited by exposure to a trash can fire.

Even with use of duplicate mattresses, bedding, trash can, and trash load, different rates of temperature rise one minute after the mattress became involved namely from 141°C and 333°C per minute were reported for tests conducted in two different burn rooms at NBS (plots NBS-N39 and NBS-205-09), and the peak temperature achieved in the mattress fires ranged from about 153°C (FMRC) to 600°C (NBS).

Comparison of these data demonstrates that it is inappropriate to attempt to replicate a single fire. Difference in room size, location of the major item of fuel within the room, conditioning of the fuel, ventilation factors, and location and type of the temperature sensor have produced wide variation in the thermal histories reported for different room fires involving the same combustible item. Therefore, the selection of source fires for this study was made to approximate several fire growth rates in the range of those produced by typical items of furniture rather than precisely replicating any previous test fires.

Simulation of Selected Fire Exposures

The upholstered furniture or bedding fires initiated with a small trash can fire were observed to include two distinct burn stages which will be referred to as initial burning and involvement of the major item. Of course, there is a transition stage, but test results indicate that it is rarely predominent. The initial stage consists of successive involvement of the combustible items contained in the trash can. As the fuel in the trash can is consumed by the incipient fire, the covering of the furniture or the bedding becomes involved. This progressive burning results in somewhat of a plateau in the temperature rise until the interior of the major item, most commonly polyurethane, becomes involved. After the interior becomes involved, the fire grows much more rapidly. This latter period of fire growth is the most distinguishing feature of the fire.

The selection of fire simulations for this study was influenced by the design of the propane burner, concern for maintaining the integrity of the burn room and desired expediency in analysis of the data. (For details of the burner see section 2.2.2 of this report.) It was found by preliminary experimentation using the pilot group of burner jets that to simulate the temperature plateau (initial 50°C stage) characteristic of trash can ignitions, the input gas pressure to the burner had to be reduced to a gage pressure of 68.9 kPa (10 psi). The result of this was to limit the maximum rate of temperature increase that could be obtained.

To reduce the complexity of analysing results it was desirable to insure that all of the tell-tale sprinklers reached activation temperature while the ceiling air temperature was continuing to rise in a linear fashion, and that symmetry of the flame should be maintained as closely as possible. To maintain symmetry, and avoid any effects of moving the center of the fire plume, the burner was programmed for the first three series to include only the first five groups of burner jets. The inclusion of the sixth group would have added large asymmetry to the flame.

Rates of temperature rise of 60, 90, and 190°C per minute, measured 25 mm (1 in) below the ceiling in the center of the room, were selected to simulate small to moderate fires. Schedules for sequence of operation of the burner groups for these different rates are given in table 1. In addition, a rate of 2600°C per minute was selected to represent a severe fire such as that resulting from the involvement of a combustible wardrobe. This rate was achieved by adding burner zones 2 through 7 at one second intervals. The addition of the seventh zone almost immediately after the sixth reduced the effects of the flame asymmetry caused by zone 6 which was excluded in the first three series to avoid such an effect.

The selection of a linear rate of temperature rise simplifies the analysis considerably. A device such as a sprinkler link placed in an environment which is increasing in temperature in a linear manner will change in temperature as shown in figure 2 until any part of the device starts to change phase (e.g., the fusible link begins to melt). It will take a time period greater than four times the measured response time constant of the device to adopt the same rate of temperature increase as the environment. The expression relating "compliance" of the link temperature rise to a step change in the environmental temperature is the same as that for a capacitive electrical circuit [11]:

$$C = 1 - e^{-t/\tau} \qquad (1)$$

where C = compliance

t = time elapsed after step change of environmental temperature

τ = time constant of link

e = base of natural log

The time lag of the sprinkler link temperature behind the linear ramp increase in the environmental temperature once compliance has been attained is the time constant of the link.

2.1.3 Measurement of Thermal Response

Tell-Tale Sprinkler Heads

A single make and model sprinkler head was used at all three sprinkler locations in each of the tests to indicate the time at which a "typical" commercial sprinkler head activated. These heads did not apply water or otherwise have any affect on the fire, and are referred to as "tell-tale" sprinkler heads throughout this report. These sprinkler heads had a 74°C (165°F) temperature rating and a link and lever design, and were characterized by a time constant (τ) of 114 s at an air velocity of 2.4 m/s (8 ft/s) as determined by the FMRC "plunge test" [12] (see appendix A). Details of the means for remotely indicating activation of the tell-tales are given in section 2.3.

Time Constant Discs

The concept of using a metal disc attached to a thermocouple for measuring thermal response was developed by Dr. G. Heskestad at FMRC [12]. Those used in this test series were made from brass sheet with diameter and thickness dimensions selected to exhibit a surface area to mass relationship that provided a specific thermal response to the temperature change of air moving past them at a given velocity. The thermal responses (time constants) selected were 5, 21.5, 80, and 160 s, at a reference velocity of 1.5 m/s (5 ft/s). Dimensions of these discs are given in table 2.

The 5, 80, and 160 s time constant discs were fabricated based on an extrapolation from a 21.5 s disc calibrated and supplied to NBS by FMRC. The extrapolation was based on the relationship:

$$\tau = \frac{mC}{hA} \qquad (2)$$

substituting for m (mass of disc) and A (area of disc):

$$\tau = \frac{\frac{\pi D^2}{4} \quad t\rho C}{h \ [2(\frac{\pi D^2}{4}) + \pi D t]}$$

solving for D:

$$D = \frac{4\tau ht}{\rho Ct - 2\tau h} \qquad (3)$$

where: D = diameter of disc

τ = time constant of disc

ρ = density of brass

C = specific heat of brass

t = thickness of disc based on available stock thicknesses

h = surface heat transfer coefficient (calculated from data on disc with time constant (τ = 21.5 s) measured in a 1.5 m/s (5 ft/s) air stream.

2.2 Test Facility

2.2.1 Room/Corridor/Lobby Test Facility

The test facility used for this study was a room/corridor/lobby used previously for patient room sprinkler fire tests. The burn test area of this facility consists of a 2.35 x 4.22 m (11 x 14 ft) burn room opening into the middle of a 2.44 x 18.82 m (8 x 62 ft) corridor which is terminated at one end with a 2.90 x 9.91 m (9 x 32 ft) lobby. The overall layout of the facility is shown in figure 3. The interior partitions are nominal 2 x 4 steel studs faced with 12.7 mm (1/2 in) gypsum board. The suspended ceiling is nominal 1-1/2 x 1 inch steel channels wired to the roof rafters and faced with 12.7 mm (1/2 in) gypsum board. The walls and the ceilings of the burn room and the burn corridor are surfaced with 12.7 mm (1/2 in) thick cement-asbestos board over the gypsum board.

2.2.2 Propane Burner

The propane burner was located in the burn room as shown in figures 4 and 5. The burner assembly consists of a 914 mm (36 in) square by 25 mm (1 in) thick aluminum plate with 39 gas nozzles in a hexagonal array. The nozzles are divided into seven groups or zones shown schematically in figure 6, each controlled by an electrical on/off valve. The valve for each zone can be operated by a separate switch on a control console connected to the burner with an umbilical cord. A flow control orifice immediately follows in line to the manifold for each zone and therefore establishes the output relationship of each zone to the total output of the burner, independently of the number of nozzles distributing the gas for each zone. The selection of the nozzles incorporated in each zone was done with emphasis on obtaining a smooth transfer of combustion rather than symmetry of fire growth. When operated at a gage pressure of 206.8 kPa (30 psi), the burner is capable of producing 3.98×10^6 W (13.6×10^6 BTU/hr). The control console and the propane tanks were located in an observation room at the east end of the burn corridor.

2.3 Instrumentation

2.3.1 General

Instrumentation included three tell-tale sprinklers, 12 time constant discs, 22 thermocouples, 1 air velocity probe, 1 heat flux meter, a video camera and monitor, and an automatic data acquisition system. The instrument list is given in table 3. Plan and elevation views of the room instrumentation are given in figures 4 and 5.

2.3.2 Tell-Tale Sprinkler System

The tell-tale sprinklers were located in the center of the ceiling, on the wall over the door, and on the wall opposite the burner. The size of the room used for this study permitted examination of only a single pendent sprinkler location. The room is approximately 3.4 by 4.2 m (12 x 14 ft) which provides an area of 14.3 m^2 (168 ft^2). Therefore, the pendent location was at the center of the ceiling. Its deflector was positioned 63 mm (2-1/2 in) down from the ceiling. The doorway sidewall head was centered over the door and the opposite sidewall sprinkler head was located midway between the front and back wall. The deflectors of the sidewall heads were positioned 152 mm (6 in) from the ceiling and 64 mm (2-1/2 in) from the wall in accordance with the manufacturer's instructions. Photographs of the three tell-tale positions are shown in figures 7, 8, and 9. The tell-tale sprinkler timing system, illustrated in figure 10, consisted of a tank of pressurized air, a pressure regulator, throttle valve, pressure, switch and pressure gage for each tell-tale sprinkler. The pressure regulator was set at a gage pressure of 48.3 kPa (7 psi), and the throttle valve was opened only enough to compensate for leaks in the system. The valve, gage and switch are connected to each tell-tale sprinkler with nominal 3/8 inch OD copper tubing. When a sprinkler head opened, the air pressure was released and the switch was activated. Each switch was connected by an electrical cable to a timer in instrument room no. 2.

2.3.3 Thermocouples

Two 0.51 mm (0.020 in) thermocouples were located in the center of the ceiling, 64 mm (2-1/2 in) down from the ceiling surface, to measure the air temperature along the ceiling. One of these was connected to the data acquisition system and the other to a strip chart recorder at the burner control console location.

A group of four thermocouples, including one of 0.05 mm (0.002 in) diameter wire, one of 0.13 mm (0.005 in) diameter wire, one of 0.25 mm (0.010 in) diameter wire[2], and one of 0.51 mm (0.020 in) diameter wire was located beside each tell-tale sprinkler. The thermocouple junctions were at the same level as the thermal link of the sprinkler and in the case of the sidewall tell-tales, the same distance from the wall as the link. They were made from chromel-alumel wire with beads approximately three times the diameter of the wire.

---

[2]The 0.25 mm (0.010 in) diameter thermocouples were replaced with 5 s time constant discs after test 11.

The junctions of the 0.05 mm (0.002 in) and 0.13 mm (0.005 in) diameter thermocouples were fabricated by a commercial supplier of thermocouple materials. These junctions with about 25 mm (1 in) of lead wire were connected to 0.5 mm (0.020 in) diameter thermocouple wire by wrapping the finer wire arcund the thicker wire and crimping approximately 64 mm (1/4 in) of copper capillory tubing over the wrap. The junctions of the 0.25 mm (0.010 in) diameter wire were welded with a portable spot welder and subsequently were spot welded to 0.51 mm (0.020 in) diameter lead wire. The junctions of the 0.51 mm (0.020 in) diameter wire were formed in place with a portable spot welder by just crossing the wires and welding. Therefore, except for the junctions, most of the thermocouple wire was 0.51 mm (0.020 in) diameter solid, duplex, insulated with asbestos and covered with woven glass.

The eight thermocouple array 51 mm (2 in) down from the ceiling and the tree consisting of seven TC's were part of the instrumentation for a previous test program and were included in this study for later comparisons.

2.3.4 Time Constant Discs

A group of four time constant discs was also located adjacent to the tell-tale sprinklers at each of the three locations. Included in each group was one disc with a time constant of 160 s, one with a time constant of 80 s, and two discs with a 21.5 s time constant. One of the latter had a shiny finish and one was painted black with a coating used for heat flux meters in order to obtain an indication of whether or not radiative heat transfer between the link and the environment was significant. As with the thermocouple arrays, the discs were located at the same level and distance from the wall as the links of the tell-tale sprinklers and oriented in the same direction as the links in the sprinklers.

Thermocouple attachments to the discs represented a compromise between having the least effect on the heat exchange with the environment and the need to physically support the discs. Attachments to the 21.5 and 80 s discs were made by crossing the thermocouple wires at the center of the disc and spot welding them to the disc. Although these junctions could be pulled off fairly easily, they all survived the test series. In the case of the 21.5 s disc, 0.25 mm (0.010 in) wire was used, and for the 80 s disc, 0.81 mm (0.032 in) wire was used. The 1.02 mm (0.032 in) thick wire was used for the 160 s discs and attachment was made by drilling a shallow hole for each wire, inserting the wire into the hcle, and peening about three places in the disc around the hole.

2.3.5 Video Monitoring

A video camera was mounted in a viewpoint in the side of the room opposite the burner to observe burner operation. This was connected to a monitor in the observation room beside the burner control console.

2.3.6 Data Acquisition

The data was recorded on magnetic tape by a digital data acquisition system located in instrument room no. 2.

3. TEST PROCEDURE

3.1 Test Schedule

Three tests were run on each of three days following the schedule given in table 4. To partially compensate for the potential affect of slight variation in initial temperature due to elevation of ambient temperature from previous tests, tests were repeated at each rate of rise so as to have a given test performed first, second, and third on different days.

3.2 Experimental Procedure

Before each test, a new tell-tale sprinkler head was installed at each location, pressurized to a gage pressure of 48.3 kPa (7 psi), and the timers reset to zero. The only instrument requiring pre-test adjustment was the velocity probe which was always balanced to output a small positive voltage.

The cooling water for the heat flux meters was turned on. Just prior to the initiation of the test, a zero scan was put on the magnetic tape. At time zero, the burner program was begun simultaneously with the activation of the timers and data acquisition equipment which was set to repeatedly scan through all the channels, each scan immediately following its predecessor. The resulting scanning interval was 2.5 s.

In all 17 tests, the initial burner rate was set to provide a temperature plateau of 50°C for 180 s, to simulate the initial fire from a small trash can fire. The burner rate was then increased to provide one of four selected linear increases in temperature. The burner was extinguished as soon as the temperature curve on the strip chart recorder at the burner control leveled off at its high point. Data recording was terminated 10 minutes after the burner was extinguished.

4. RESULTS

The results of 17 tests, three each with rates of temperature increase of 60, 90, and 180°C per minute, and eight with a rate of temperature increase of 2600°C per minute are reported. Table 5 summarizes the following: 1) activation times (i.e., from beginning of test, and including the 180 s time period for the initial temperature plateau) of the tell-tale sprinkler head, tested simultaneously at the pendent and two sidewall positions, 2) the average activation time, 3) the standard deviation among repeated tests, 4) the initial ambient temperature, and 5) the extrapolated time for the ceiling air temperature to reach 600°C for each rate of temperature rise. The thermal histories of the 160, 80, 21.5 and 5 s time constant discs, also exposed simultanteously at each of the three positions, are presented as plots in appendix B. The plots are grouped by location and by time constant (τ) for each rate of temperature rise. Appendix C provides illustrations (i.e., plotted standard deviation) of the variance in measured temperature values at corresponding times among repeated tests.

4.1 Tell-Tale Sprinklers

The results tabulated in table 5 demonstrate the variation in response time of a typical commercial sprinkler head positioned in three different locations in the room. The activation time lags of the door sidewall position and the opposite wall sidewall position behind the activation time of the center ceiling pendent position averaged 47.2 and 68.2 s respectively for the 60°C/min temperature rise, 32.9 and 58.3 s respectively for the 90°C/min temperature rise, and 25.8 and 41.8 s respectively for the 180°C/min temperature rise. In the case of the 2600°C/min temperature rise, the lag times were substantially shorter at 8.6 and 16.1 s respectively. It should be noted that the activation times recorded in table 5 were measured from the beginning of the test, but the temperature ramp itself was delayed 180 s in order to simulate the incipient burning stage described in section 2.

As would be expected, lag times were decreased for both sidewall locations when the rate of temperature rise was increased. This was especially noticeable when comparing the lag times associated with the substantially higher 2600°C/min rise to those of the other three simulations.

4.2 Time Constant Discs

At the pendent location (see figures B1, B7, B13, and B19), the 160 s disc did not adopt the slope of any of the temperature ramps of the simulated fire exposure as measured with the center ceiling thermocouple which had a calculated time constant of 13.5 s[3]. This is expected since it takes an exposure period of more than four time constants of the thermal device, (e.g., 640 s in this case) to do so, and the longest burner program incorporated its last fire zone at 459 s. Very shortly after the last burner zone was added, the slope of the ramp began to fall off, and the test was terminated. The 80 s disc did not reach compliance with the 180 or 2600°C/min ramp for the same reason.

---

[3]The time constant of the 0.51 mm (0.020 in) diameter chromel-alumel wire thermocouple was calculated to be 13.5 s, corresponding to a bead thickness of three times the wire diameter, and with an air velocity of 1.5 m/s (5 ft/s). The calculation was made based on a relationship for thermal time constants reported by Dils [13].

None of the discs in either of the sidewall positions (see figures B2, B3, B8, B9, B14, B15, B20, and B21) attained compliance with even the lowest temperature ramp. Furthermore, the ramps adopted by the 21.5 s sidewall discs demonstrated a break from linearity part way up the ramp. Although there were insufficient temperature and velocity measurements to form firm conclusions regarding the cause, a possible reason might be the loss of heat from the air stream to the ceiling in the course of the extended travel distance. It might also result from a changing flow pattern in the room occurring after the space above the door soffit has been filled and hot air begins to spill through the door into the corridor. It is possible that the 80 and 160 s discs respond too slowly to make the break conspicuous. It should be noted that the 5 s disc, included only in the 2600°C/min ramp exposure, responded faster than the 13.5 s thermocouple, lending some support to the validity of the slightly different convective heat balance equations used to calculate the disc and the thermocouple time constants.

Results of the second test with the 2600°C/min ramp revealed that the 5 s disc did not respond as it did in the first test. Subsequently, it was observed that due to their low mass and the higher velocities attributed to the 2600°C/min growth rate the discs were pushed against the walls or rotated and not aligned as would be the link of a sprinkler at the respective positions. The thermocouple wire supporting these discs apparently was not stiff enough to maintain them in the appropriate position. Attempts in subsequent tests to support them without interferring with their response appeared only partially successful. The discs with additional support were in the correct position after the tests but it is likely that the high velocity air currents of the fire plume continued to deflect them enough during the tests to effect their response. Their misalignment probably occurred simultaneously with the activation of the seventh zone of the burner which was approximately 6 s into the 2600°C ramp program. This would appear to explain the large variance observed with the 5 sec discs for the 2600°C/min temperature rise (see figures C14, C15, and C16).

Taking advantage of the use of ramp increases in temperature, the reductions in time constants needed to provide the sidewall sprinklers with the same response as the pendent sprinklers under identical conditions can be determined from the plotted data.

If a line is drawn at a selected activation temperature on the temperature plots in appendix B for any disc located at the pendent and sidewall positions, the time separation of the sidewall discs from the pendent disc on that line represents the time lag that must be substracted from the time constant of the sidewall disc. An example of this is given in figure 11. Based on such an approach, the values of the time constants required in sidewall locations to provide the same response as a 21.5 s disc at the pendent position are tabulated in table 6. A similar comparison could be made for other time constants.

4.3 Comparison of Tell-Tales and Time Constant Discs

The time-temperature curves of the time constant discs can be used to estimate when a sprinkler of identical time constant at the same location as the disc would activate.

An interesting comparison of the activation times was made using 74°C (165°F) as the sprinkler temperature rating. Plots of time to activation temperature versus rate of temperature rise are given in figures 12 thru 17 for each time constant at each location. These plots also include average activation times of the tell-tale sprinkler with a time constant of 114 s and estimated time to reach an arbitrarily selected critical temperature of 600°C in the upper room. For the comparisons in figures 12 thru 17, the initial 180 s period simulating a constant temperature level of approximately 50°C has been subtracted out. Predictably, the curve for the 114 S tell-tale sprinkler lies between those for the 80 and 160 s discs. Of course, more experimentation is needed to fill in data between the 180 and 2600°C rate of temperature rise. Without further data at these higher rates of temperature rise, it is difficult to assure the activation of a 74°C rated sprinkler head before attainment of a critical temperature of 600°C in the upper room, regardless of which of the three sprinkler locations was selected.

4.4 Prediction of Disc Temperatures

One of the purposes for including time constant discs in this study was to obtain data that would permit the prediction of the response of a sprinkler of any time constant to selected fire exposures. An attempt was made to do this by first correcting the measured gas temperatures from data from a thermocouple of known time constant and then predicting the temperature of one of the discs included in the same test. Correction of the thermocouple temperature data was accomplished by solving the following heat balance equation for the thermocouple.

$$hA\ (T_G - T) = mc\ \frac{dT}{dt} \tag{4}$$

where:

- h = convective heat transfer coefficient of the thermocouple
- A = surface area of the thermocouple
- T_G = temperature of the gas
- T = temperature of the thermocouple
- m = mass of the thermocouple
- c = specific heat of the thermocouple

but: $\tau = \frac{mc}{hA}$

where:

- τ = time constant of the thermocouple so: $$T_G - T = \tau \frac{dT}{dt} \tag{5}$$

approximating the derivative:

$$T_{G_1} = \tau \left(\frac{T_2 - T_1}{t_2 - t_1} \right) + T_1 \tag{6}$$

where:

T_{G_1} = corrected gas temperature

T = temperature of the disc or thermocouple

t = time

τ = time constant

The time constant of the thermocouple was measured in an improvised plunge tester constructed at NBS [14] and was adjusted through use of the following relationship:

$$\frac{\tau_R}{\tau} = \left(\frac{V}{V_R} \right)^{1/2} \tag{7}$$

where:

τ = time constant at selected time in a test

τ_R = time constant measured at a reference air velocity

V = air velocity at selected time in test

V_R = reference velocity of air during plunge test measurement of disc

The prediction of the disc temperature was accomplished by use of the Runge-Kutta [15] method for solving equation 5.

Comparison was then made of the predicted and the measured disc temperature for the pendent location. Plots of the corrected gas and predicted disc temperatures along with the measured gas and disc temperatures are given in figures 18 thru 21. The predicted and measured temperature plots for the 21.5 s disc are in good agreement. While the plots for the 80 s and 160 s discs indicate that these time constants are slightly longer than the estimates obtained from correction of the gas temperatures, the accuracy of the prediction is still fair. An estimate of the error may be obtained by the method illustrated in figure 11.

5. DISCUSSION

The results demonstrated that the response time of a sprinkler link (simulated or actual) can be substantially influenced by 1) the growth rate of the fire, 2) the location of the sprinkler in the room with respect to the fire, and 3) the response properties of the device itself. In addition, if the growth rate of the fire, and the resulting temperature rise at different locations at the ceiling in a room can be ascertained, then the time at which a device of a given time constant will activate can be approximated.

The value of these results, in terms of development of an engineering basis for sprinkler design, can best be described in terms of an example. A design engineer may desire that the sprinklers for a particular design activate prior to the attainment of 600°C in the upper room of a compartment (a temperature level that has been observed [16, 17] to approximate conditions at the onset of flashover). If it is assumed that the individual rates of temperature rise selected for this study (i.e., 60, 90, 180 and 2600°C/min) are representative of the range of hazards associated with the occupancy of concern to the designer, then the time to reach 600°C in the upper room can be extrapolated from the data in table 5, and compared to the activation times for devices of different time constants and different locations obtained from figures 11 thru 16.

The results indicate that a device characterized by a time constant ranging from 21.5 to 160 s would be satisfactory for fires producing temperature increase rates of 60, 90 or 180°C/min - regardless of sidewall or pendent location. However, at a temperature rise of 2600°C/min, a sprinkler positioned in the pendent location having a time constant of 160 s would not activate prior to the attainment of 600°C, and the tell-tale sprinkler (τ = 114 s) would be only marginally acceptable. Similar screening can also be performed by examination of figures 16 and 17 for the two sidewall positions.

It should be emphasized that this example represents a simple case, based on a conservative criterion, primarily for illustrative purposes. Continued research is contemplated that will permit the evolution of a performance based engineering approach to sprinkler design which encompasses a more universal application of this concept. This initial work does not include any specific considerations for other potential hazards such as smoke concentration or toxic gas production. Inclusion of these parameters, beyond simple correlations, would be difficult at this time. In addition, other system parameters such as water supply availability and spray distribution, and their resulting effects on extinguishment effectiveness, require examination.

An alternative design consideration involves determining the response characteristics for sidewall sprinkler locations that will provide similar response times to that of a specific pendent sprinkler. For example, a pendent sprinkler having a particular water flow and spray distribution may require a time constant of 21.5 s. Recent full-scale studies at FMRC support this for "typical" residential fires [3]. Assuming no substantial difference in water flow and spray effectiveness, table 6 illustrates the required decrease in time constant for the two sidewall positions that would provide similar response to the pendent location for the 60, 90 and 180°C/min temperature rates. The data in table 6 suggest that the designer would have to avoid locating a sprinkler at an opposite sidewall location if comparable response to a 21.5 s time constant sprinkler at the pendent position was desirable. While adjustment of the water supply and spray effectiveness might compensate, that is beyond the scope of this paper.

6. SUMMARY AND CONCLUSIONS

The following conclusions regarding sprinkler response characteristics are based on results from a limited number of full-scale tests. These tests were conducted in a room size compartment typical of a residential or health care occupancy with a single door opening, opposite the location of the fire source. The location of the fire source was not varied.

1. The response time of a sprinkler head is influenced by the design location of the sprinkler, the growth rate of the fire, and the response characteristics of the sprinkler itself.

2. For the configuration tested and regardless of the fire growth rate, the pendent location (closest to the fire source) always provided the earliest response, for devices of similar time constants (tell-tale sprinkler or time constant disc). The opposite sidewall location (greatest distance from the source) consistently provided the slowest response.

3. The magnitude of the lag times for the sidewall locations was greatest for the lower fire growth rates. Although expected, this may be quite significant in designing sprinklers for residential and health care occupancies where early response to moderate fire growth rates has been demonstrated to be significant in maintaining conditions acceptable for life safety.

4. The predicted thermal response of a device having a known (laboratory measured) time constant compared favorably with its measured response in the full-scale tests. However, additional refinement is considered necessary.

5. The use of time constant discs in lieu of actual sprinklers to evaluate response times at different locations under full-scale conditions was found to be satisfactory.

7. FUTURE WORK

Work is continuing at NBS to determine the applicability of existing analytical models in predicting sprinkler response time. In addition, research should be directed at interrelating the primary sprinkler characteristics in terms of life safety. While thermal response has been identified as a key parameter, others including water spray characteristics are also important in determining extinguishment effectiveness and the impact on life safety. Research in these areas will lead to a performance basis for sprinkler system design.

8. REFERENCES

[1] Standard for the Installation of Sprinkler Systems in Residential Occupancies, NFPA 13D, National Fire Protection Assn., Quincy, MA (1980 ed).

[2] America Burning, The Report of the National Commission on Fire Prevention and Control, Washington, D.C., May 1973.

[3] Kung, Hsiang-Cheng, Sprinkler Performance in Residential Fire Tests Study, Factory Mutual Research Corp., Report No. 22574, July 1980.

[4] O'Neill, J. G. and Hayes, Jr., W. D., Full-Scale Fire Tests with Automatic Sprinklers in a Patient Room, Natl. Bur. of Stand. (U.S.), NBSIR 79-1749, June 1979.

[5] Cote, A. E. and Moore, D. A., Field Test and Evaluation of Residential Sprinkler Systems: Los Angeles Test Series (draft), Presented to the NFPA 13D Subcommittee on April 7, 1980, National Fire Protection Assn., Quincy, MA, April 1980.

[6] O'Neill, J. G., Hayes, Jr., W. D., and Zile, R. H., Full-Scale Fire Tests with Automatic Sprinklers in a Patient Room: Phase II, Natl. Bur. Stand. (U.S.), NBSIR 80-2097, July 1980.

[7] Mniszewski, K. and Waterman, T., Effects of Open Doors on Sprinkler Effectiveness in a Patient Room, for Builders Hardware Manufacturing Assn. by Illinois Institute of Technology Research Institute, IITRI Project J8299-1, Final Report, June 1978.

[8] Installation of Sprinkler Systems, Standard No. 13-76, National Fire Protection Assn., Quincy, MA, (1976 ed).

[9] Babrauskas, V., Combustion of Mattresses exposed to Flaming Ignition Sources, Part 1 Full-Scale Tests and Hazard Analysis, Natl. Bur. Stand. (U.S.), NBSIR 77-1290, September 1977.

[10] American Health Care Assn., Fire Test is a Nursing Home Patient Room, Report 7463, Washington, D.C., June 1975.

[11] Benedict, R., Fundamentals of Temperature, Pressure, and Flow Measurement, John Wiley & Sons, Inc., New York, 1969.

[12] Heskestad, G. and Smith, F., Investigation of a New Sprinkler Sensitivity Approval Test: Plunge Test, Factory Mutual Research Corp., FMRC Serial No. 22485, December 1976.

[13] Dils, R. and Follansbee, P., Wide Bandwidth Gas Temperature Measurements in Combustor and Combustor Exhaust Gases, Pratt and Whitney Report 76-01, East Hartford, CT, 1976.

[14] Evans, D. D. and Madryzkowski, D., Characterizing the Thermal Response of Fusible-Link Sprinklers, Nat. Bur. Stand. (U.S.), NBSIR 81-2329, August 1981.

[15] Young, D. and Gregory, R., A Survey of Numerical Mathematics, Vol. I, page 473, Addison-Wesley Publishing Company, Reading, MA, 1972.

[16] Fang, J. B., Fire Buildup in a Room and the Role of Interior Finish Materials, Nat. Bur. Stand. (U.S.), Tech Note 879, June 1975.

[17] Budnick, E. K. and Klein, D. P., Mobile Home Fire Studies: Summary and Recommendations, Nat. Bur. Stand. (U.S.), NBSIR 79-1720, March 1979.

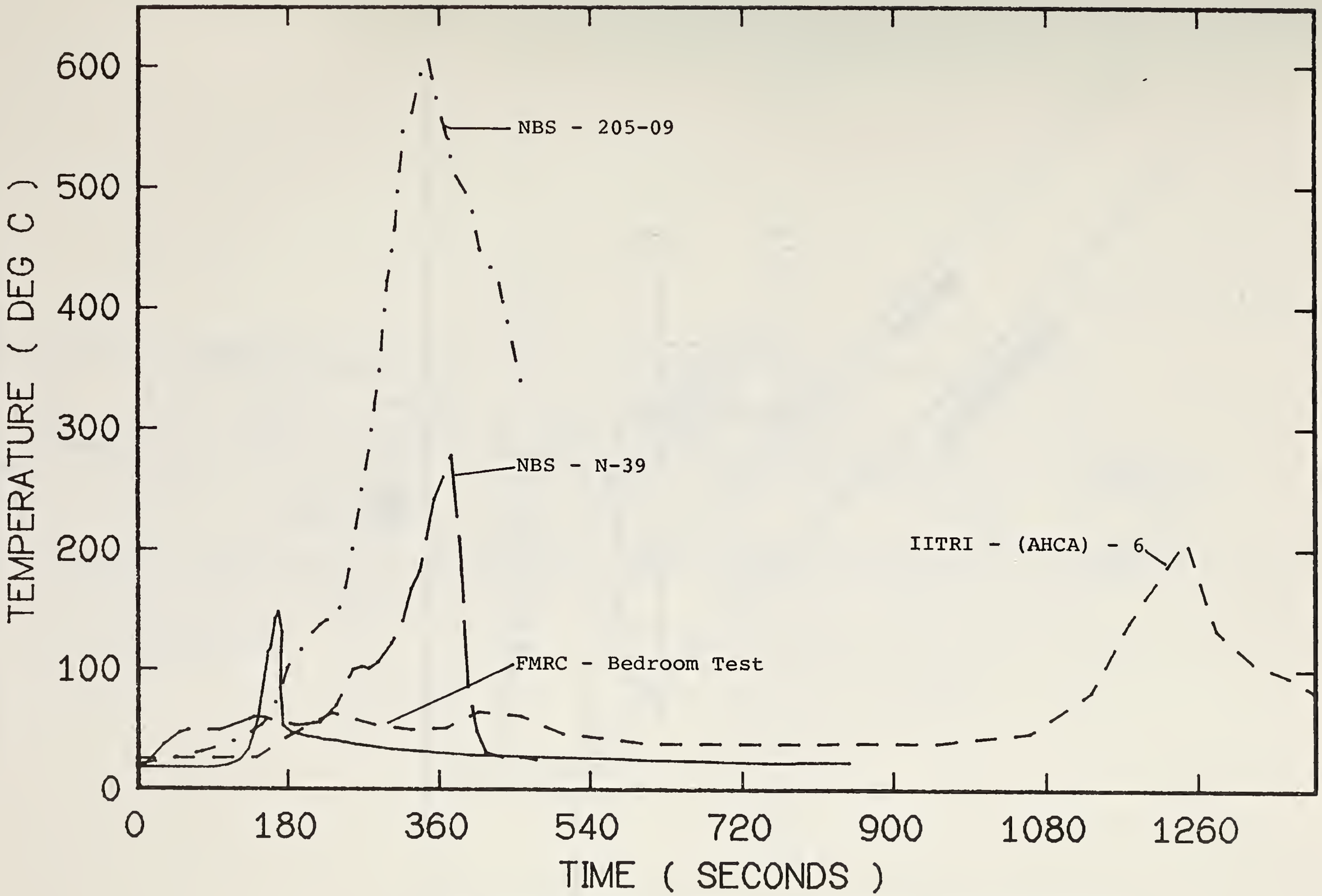

Figure 1. Room Gas Temperatures during Bedding Fires

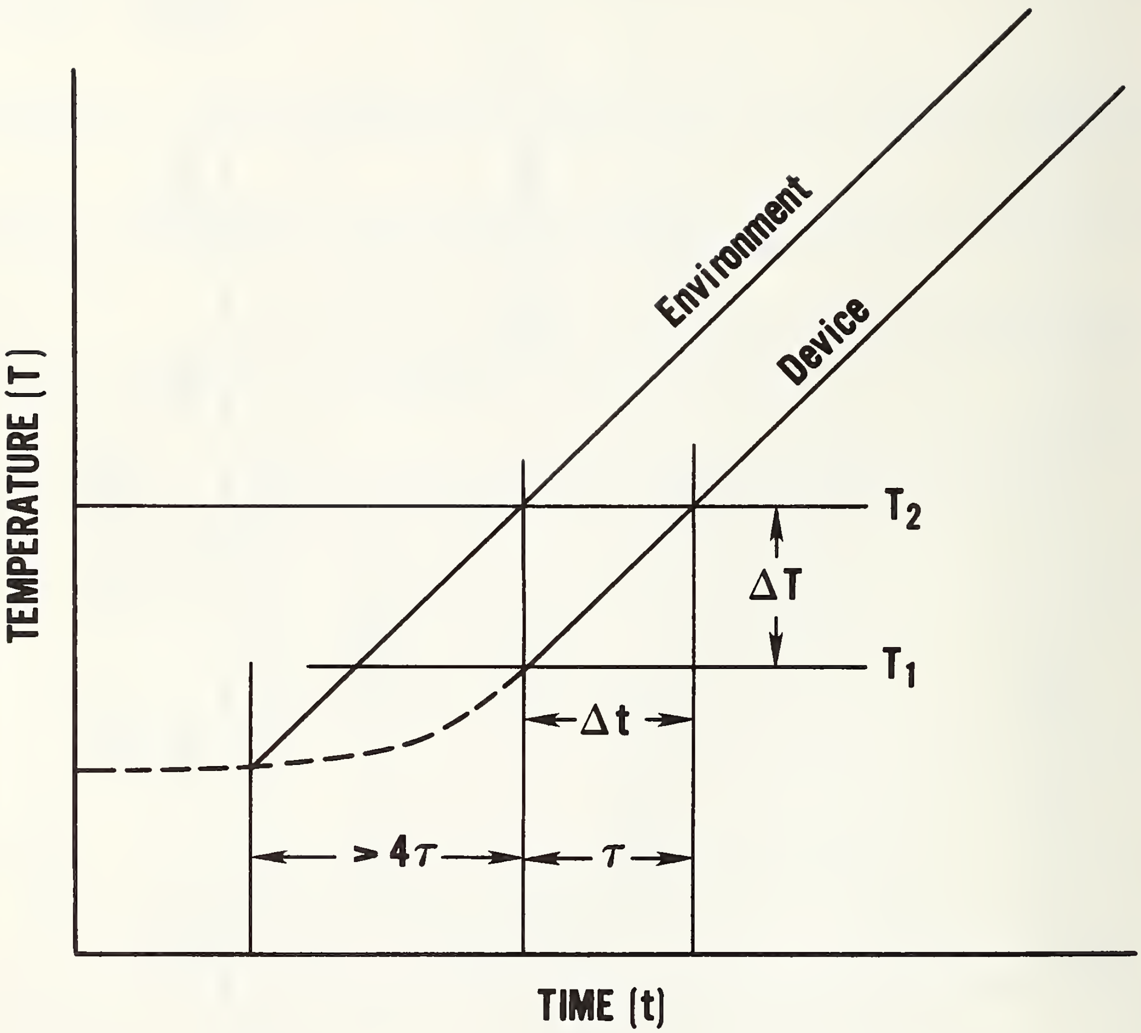

Figure 2. Ramp Temperature Change [11]

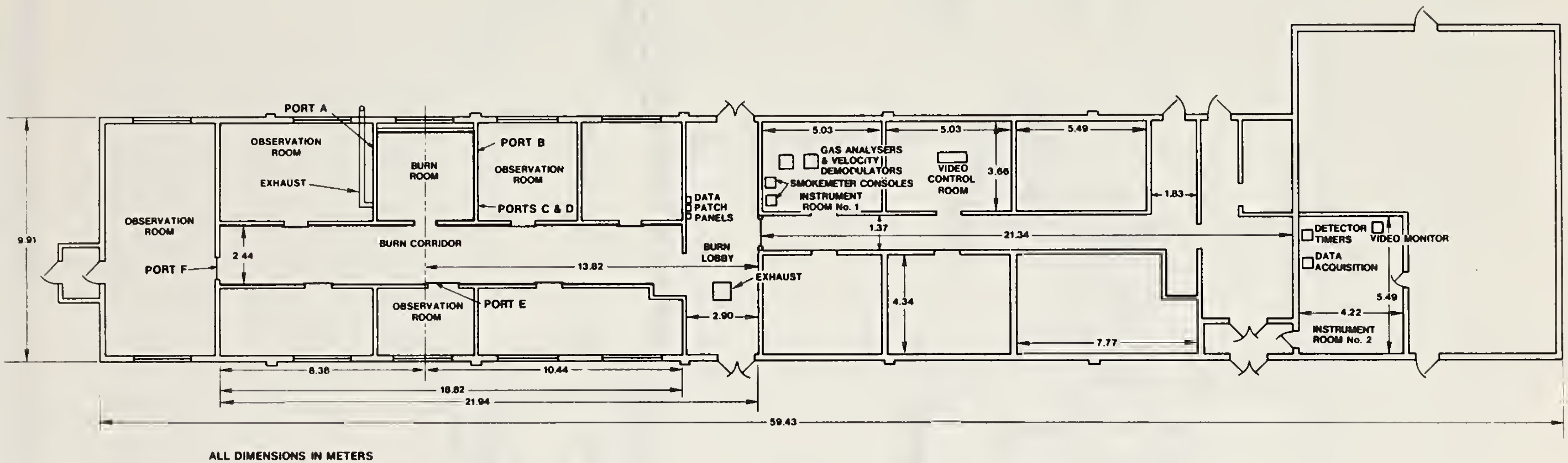

Figure 3. NBS Room/Corridor/Lobby Fire Test Facility

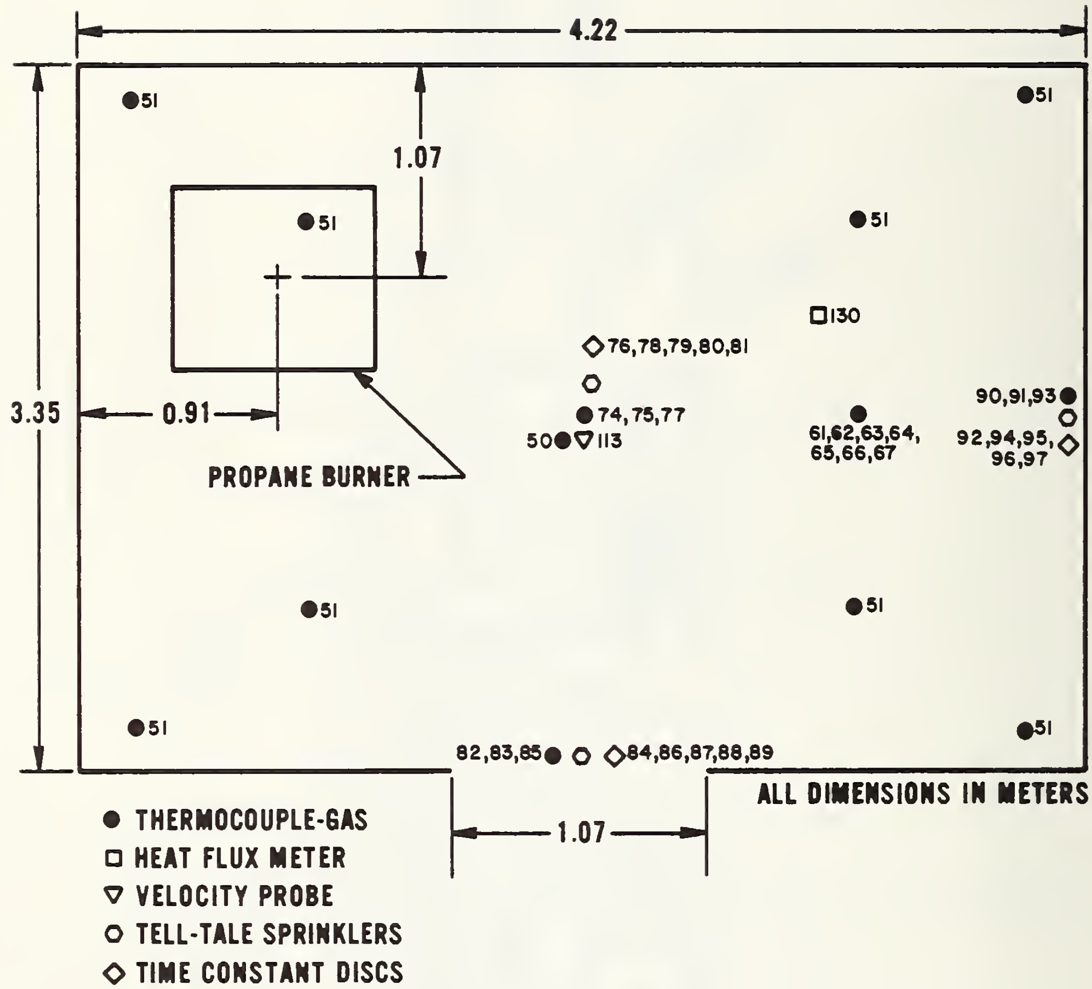

Figure 4. Plan View of the Fire Test Compartment

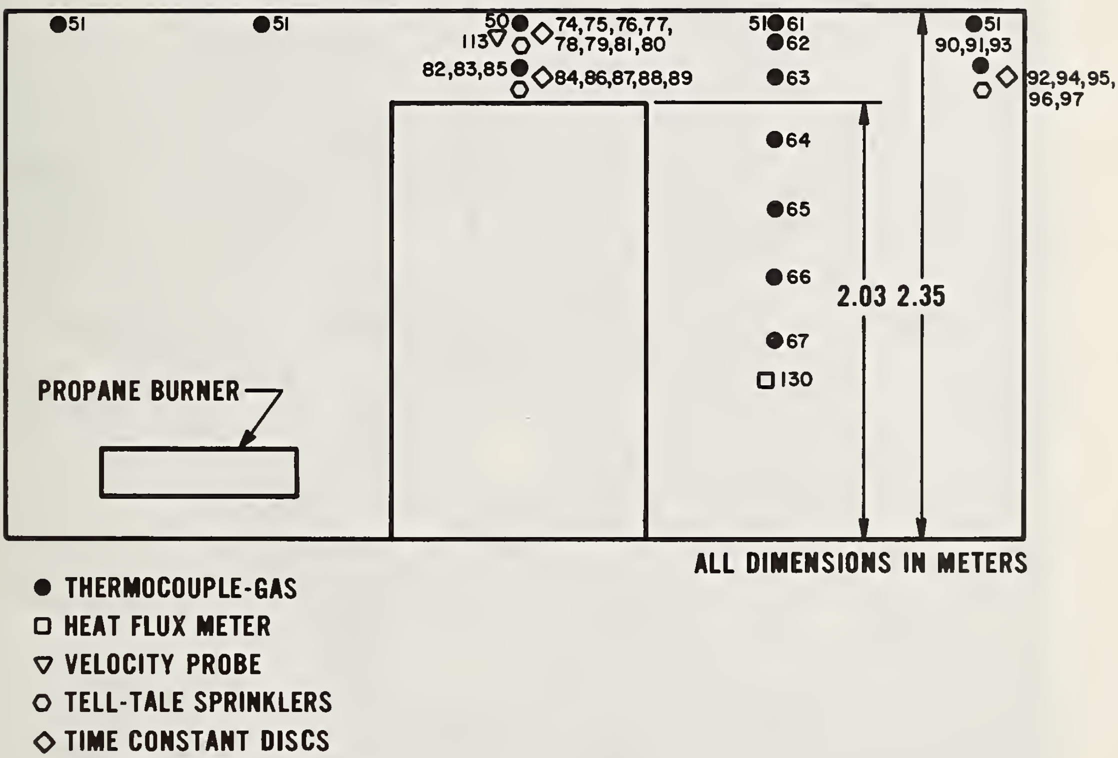

Figure 5. Elevation View of the Fire Test Compartment

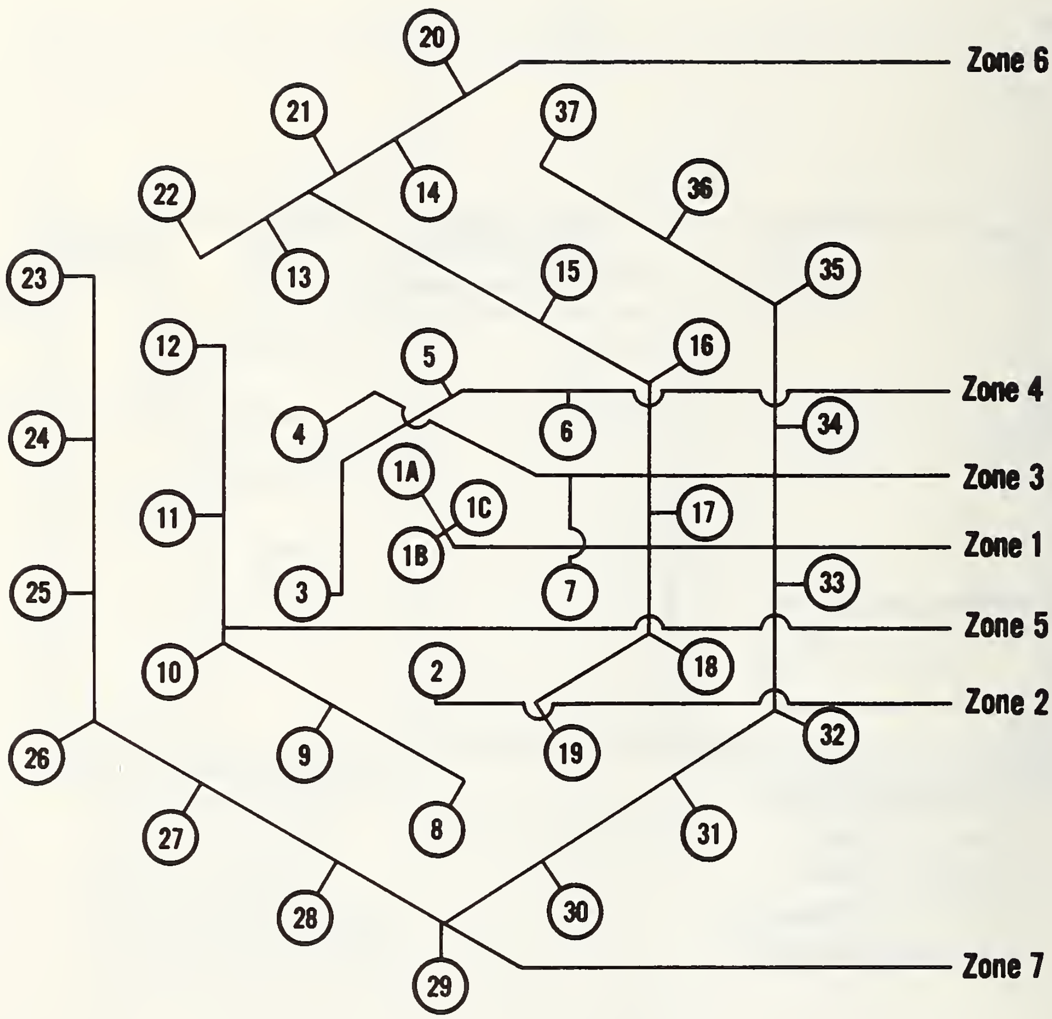

Figure 6. Schematic Diagram of the Burner

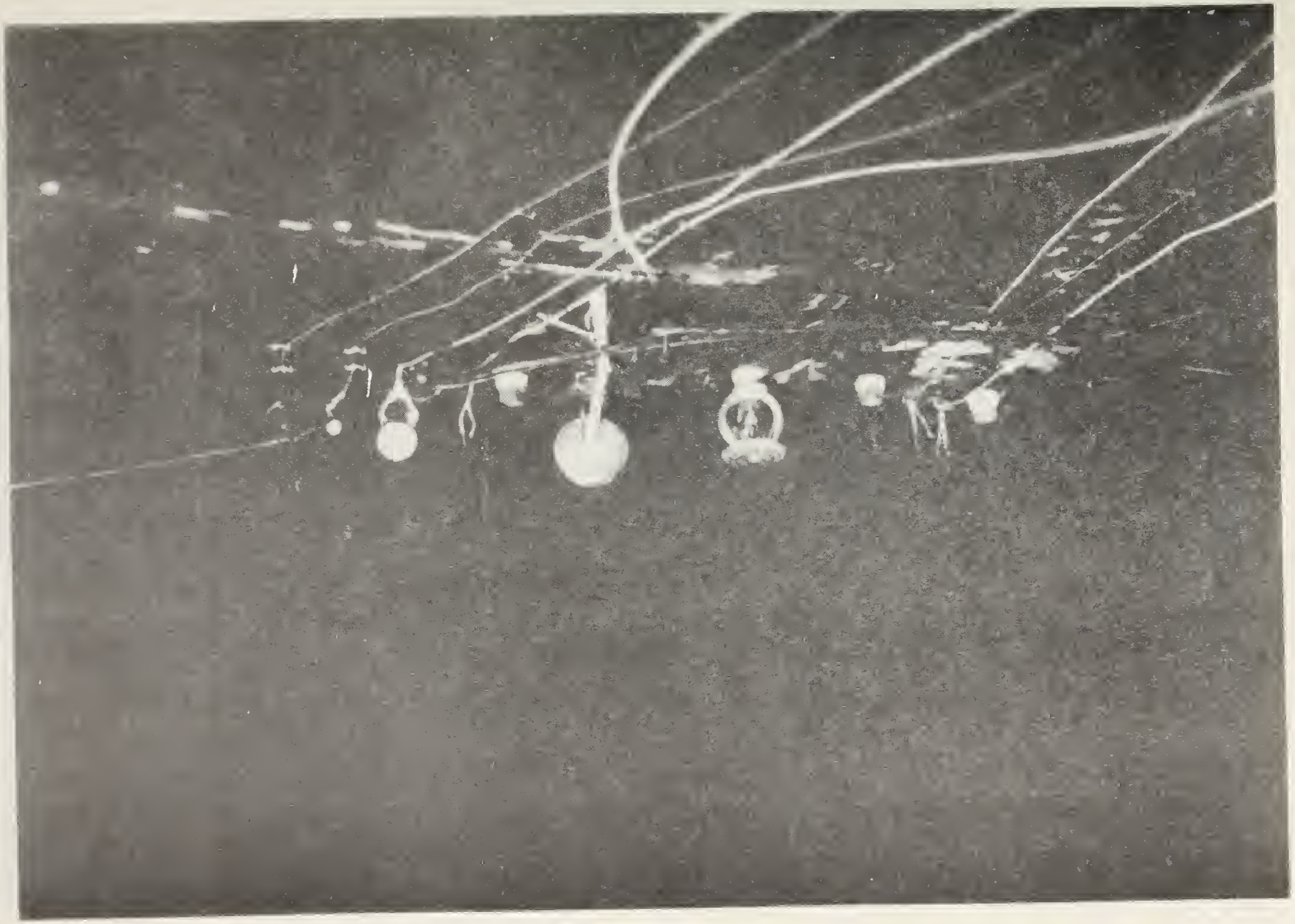

Figure 7. Photograph of Ceiling Instrumentation

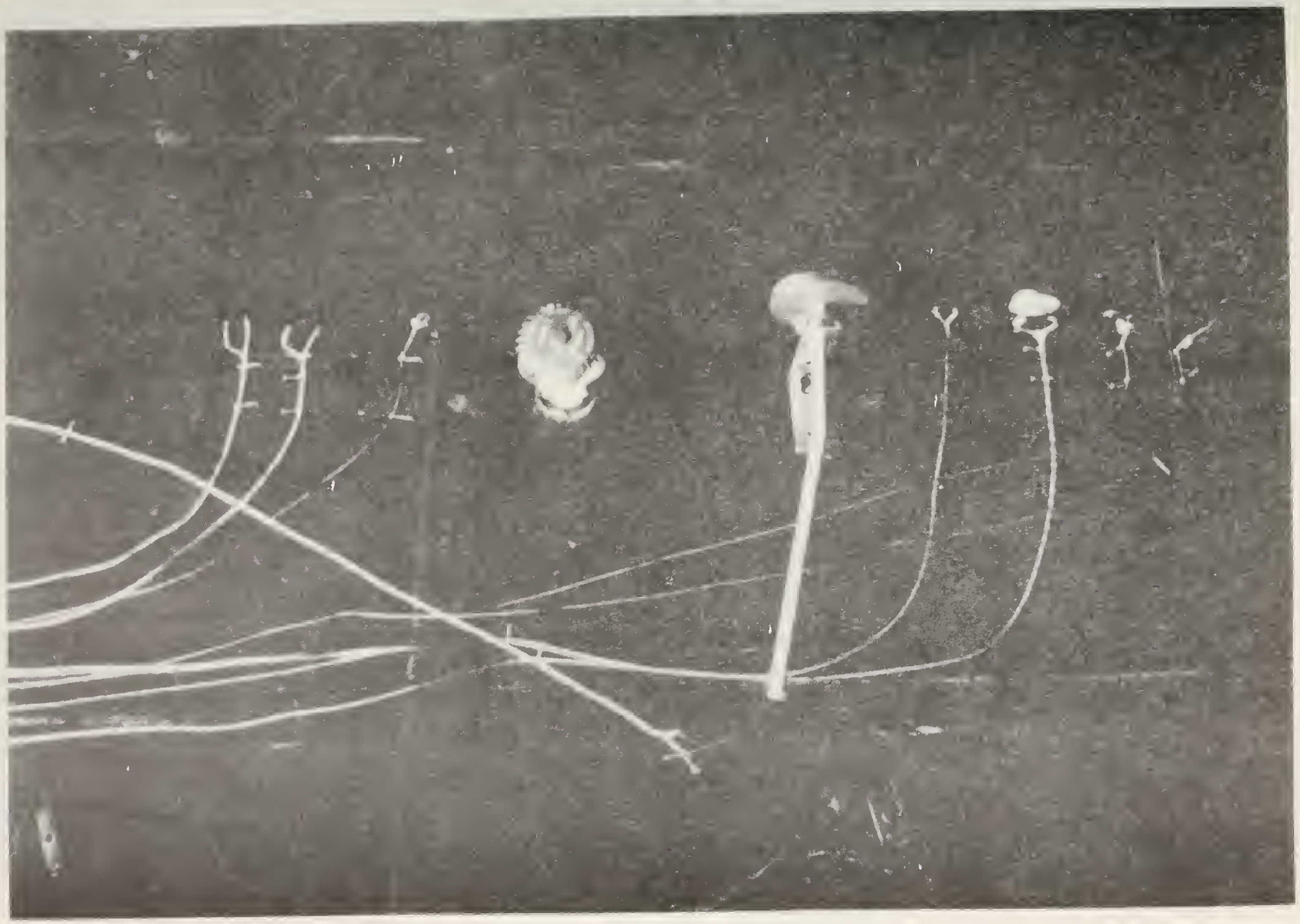

Figure 8. Photograph of Door Sidewall Instrumentation

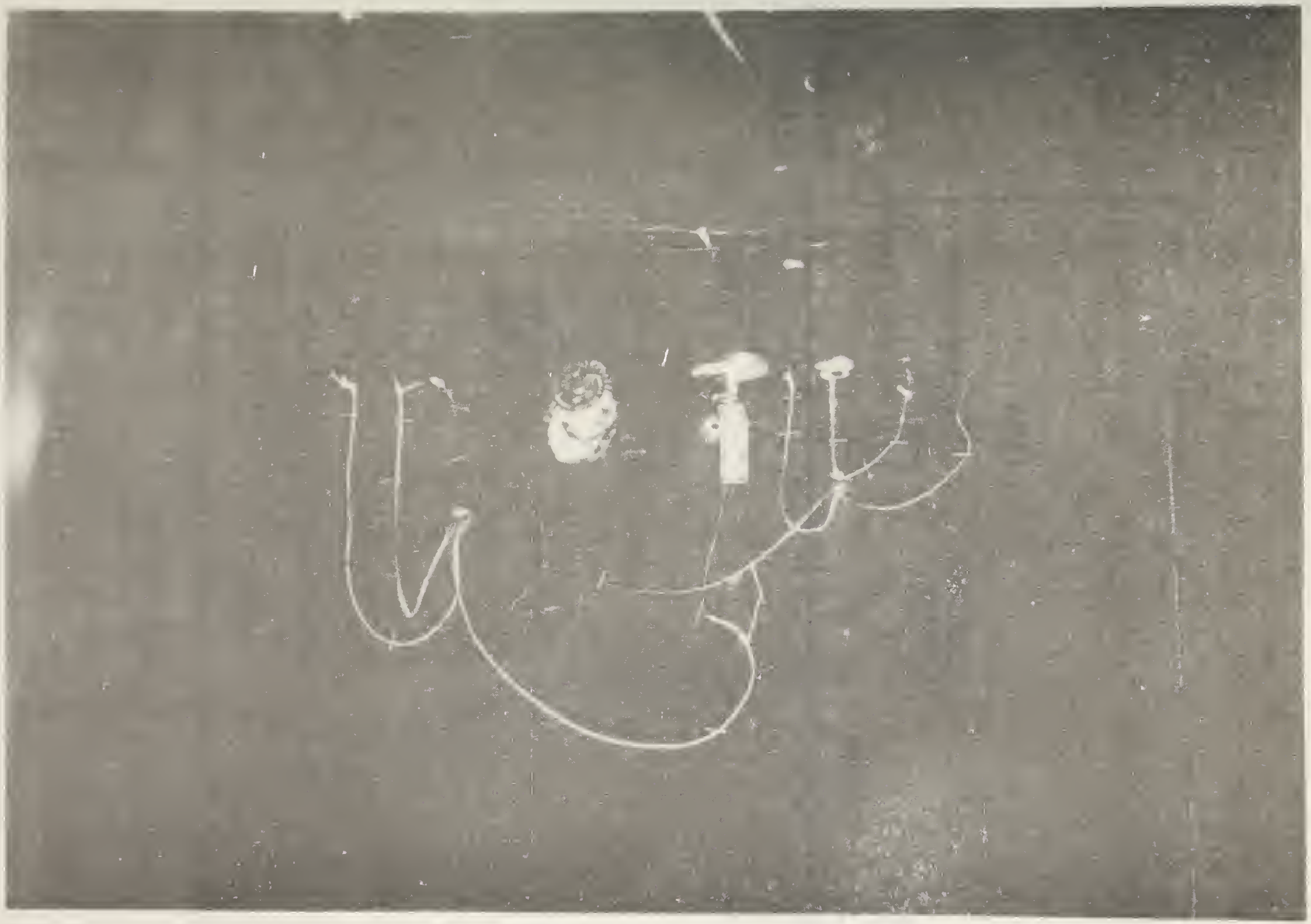

Figure 9. Photograph of Opposite Sidewall Instrumentation

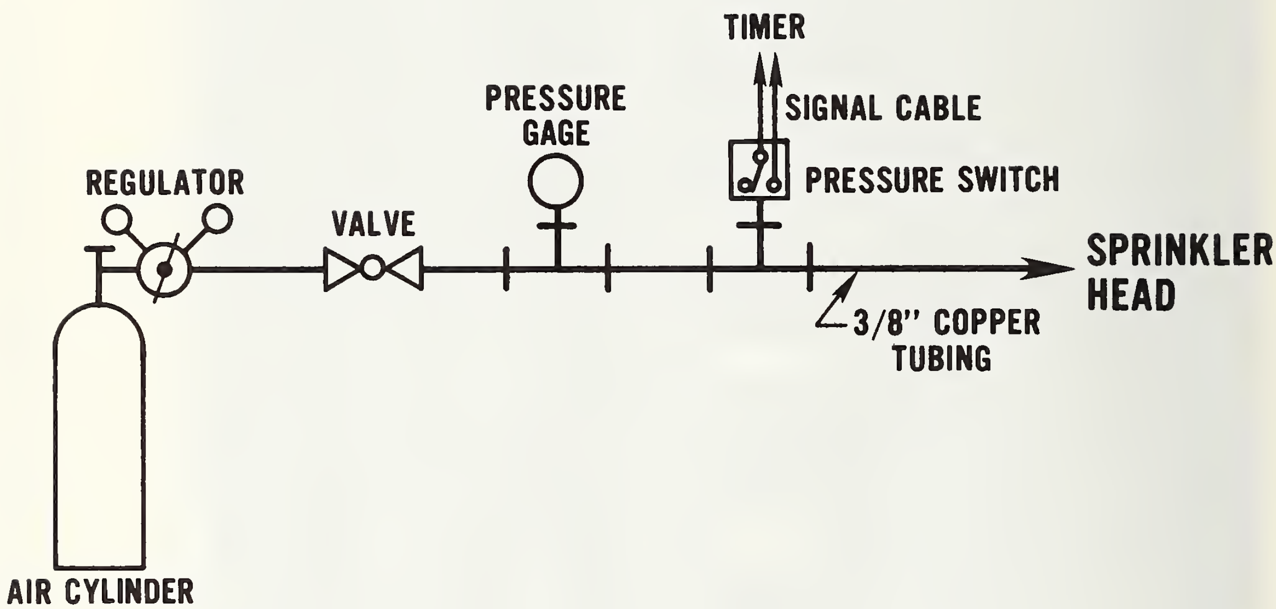

Figure 10. Tell-Tale Sprinkler Timer System Schematic

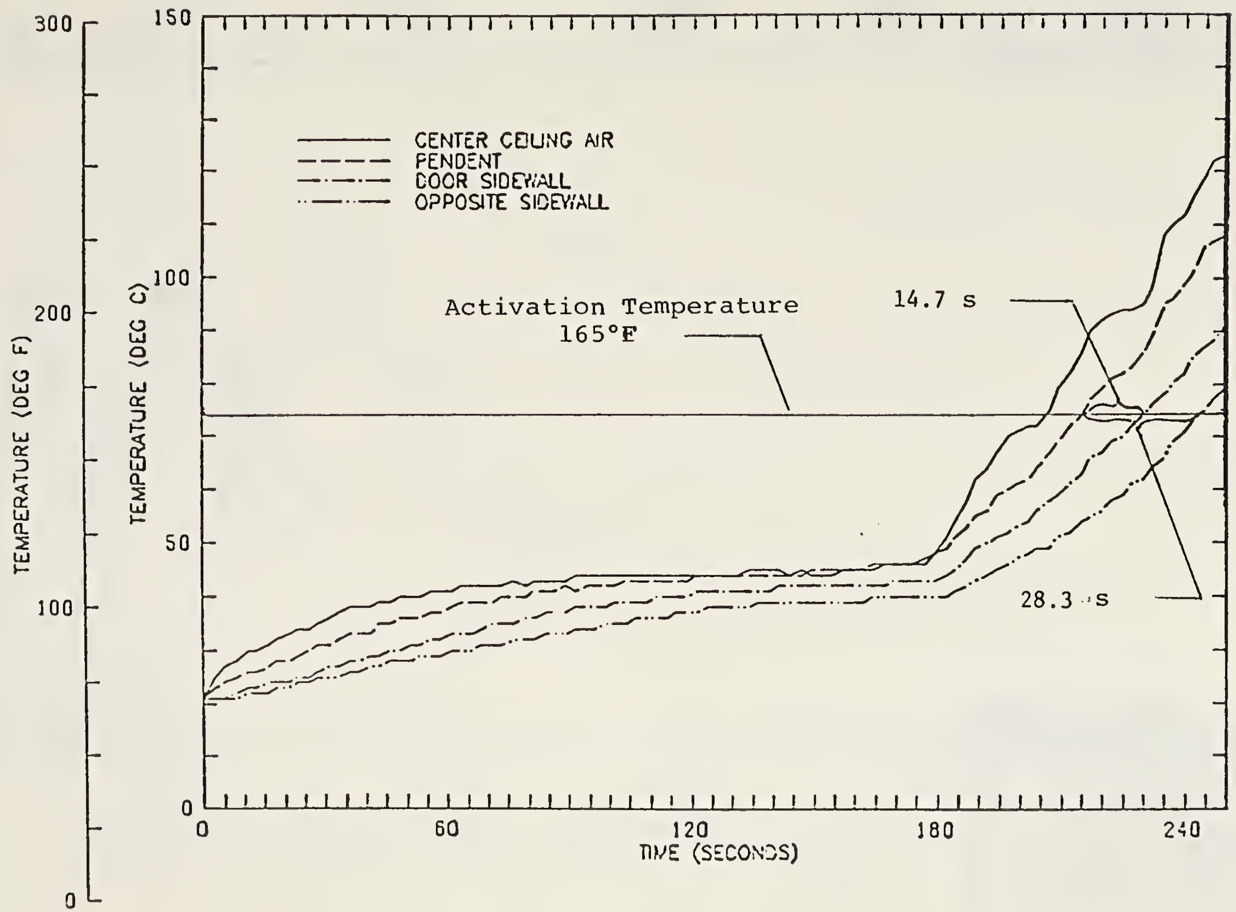

Figure 11. Sidewall (21.5 s) disc temperature lags, 60°C/min temperature rise

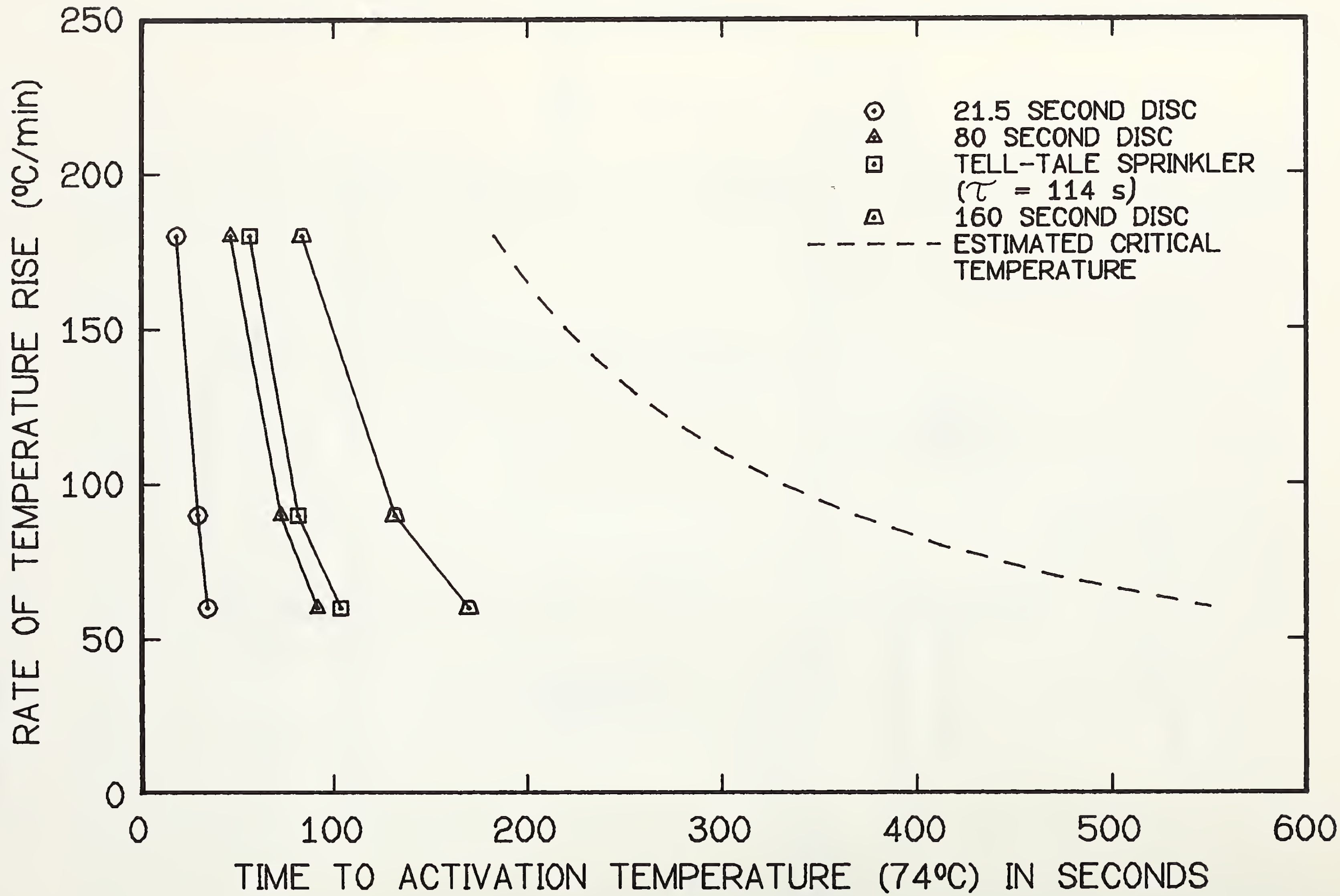

Figure 12. Rate of Temperature Rise vs Time from Beginning of Linear Temperature Increase to Activation Temperature, Pendent Position, 60 to 180°C/min Temperature Rise

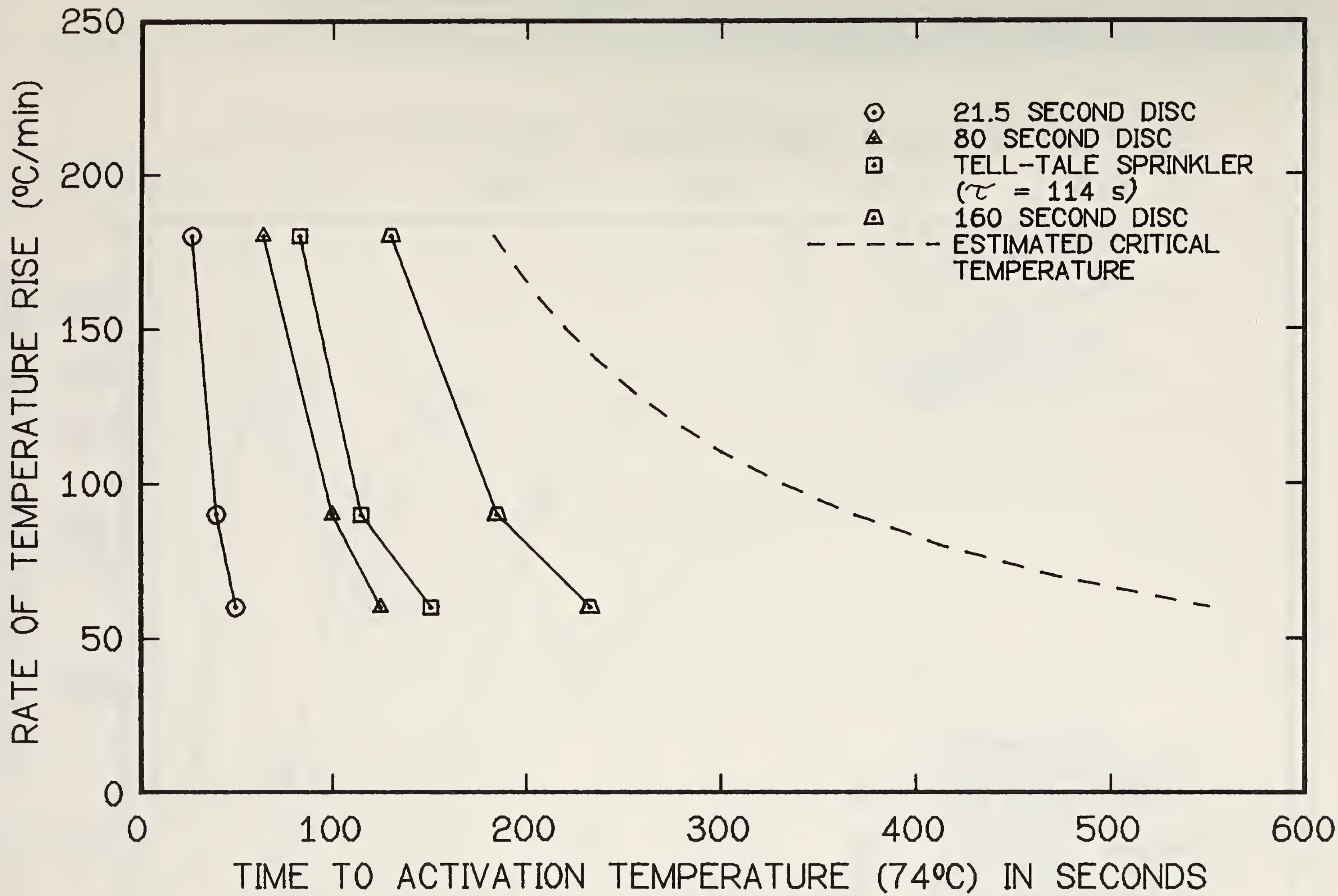

Figure 13. Rate of Temperature Rise vs Time from Beginning of Linear Temperature Increase to Activation Temperature, Door Sidewall Position, 60 to 180°C/min Temperature Rise

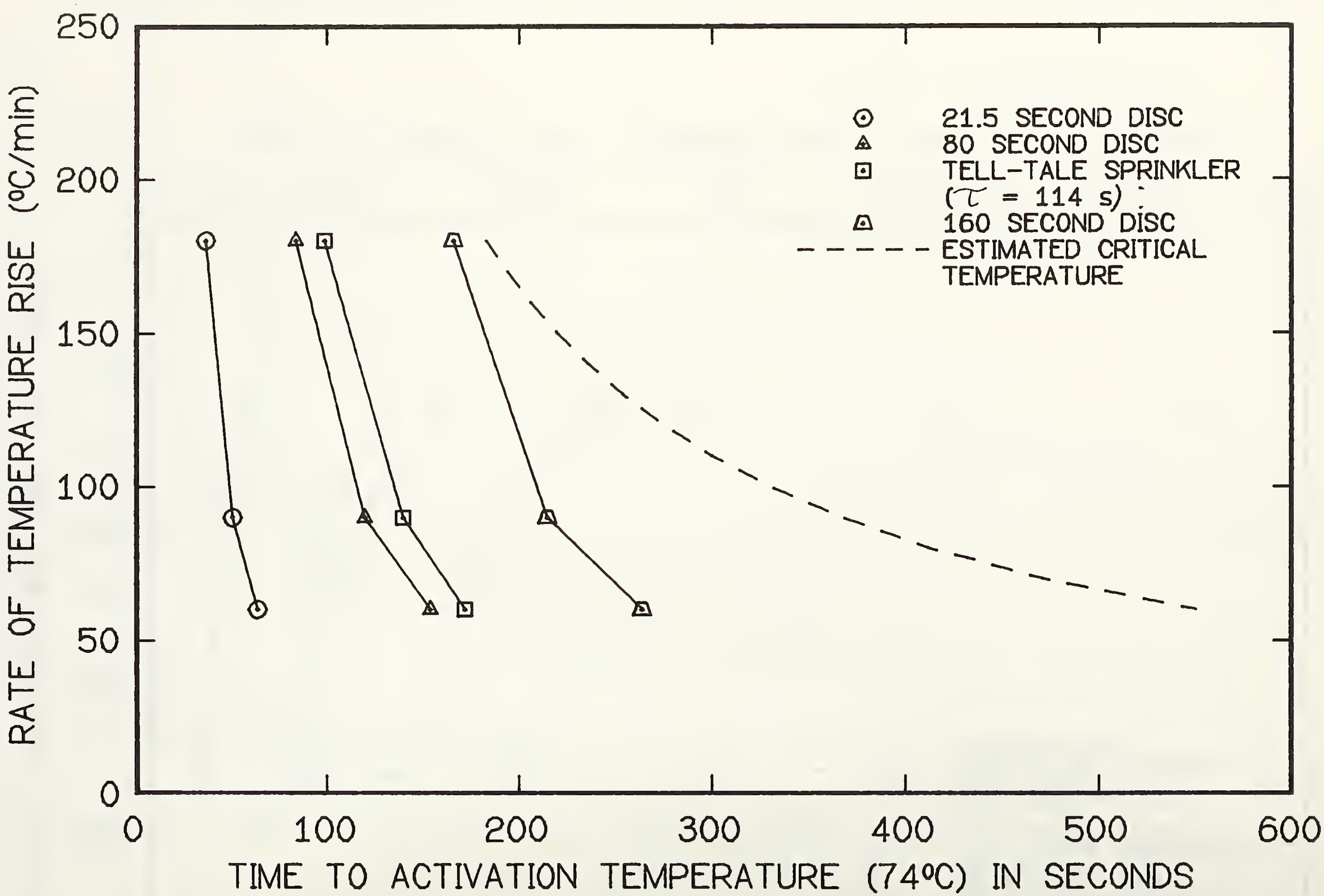

Figure 14. Rate of Temperature Rise vs Time from Beginning of Linear Temperature Increase to Activation Temperature, Opposte Sidewall Position, 60 to 180°C/min Temperature Rise

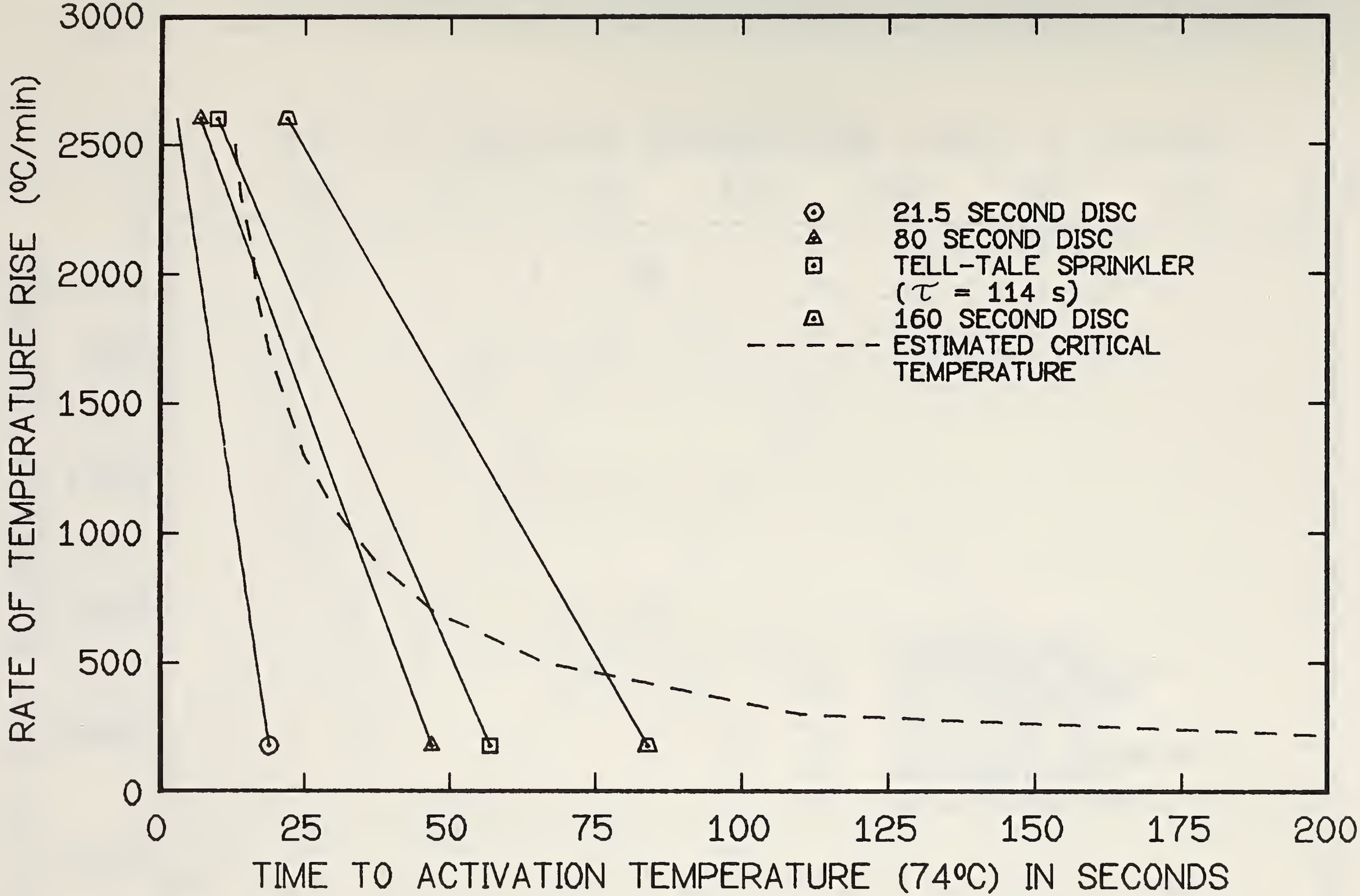

Figure 15. Rate of Temperature Rise vs Time from Beginning of Linear Temperature Increase to Activation Temperature, Pendent Position, 180 to 2600°C/min Temperature Rise

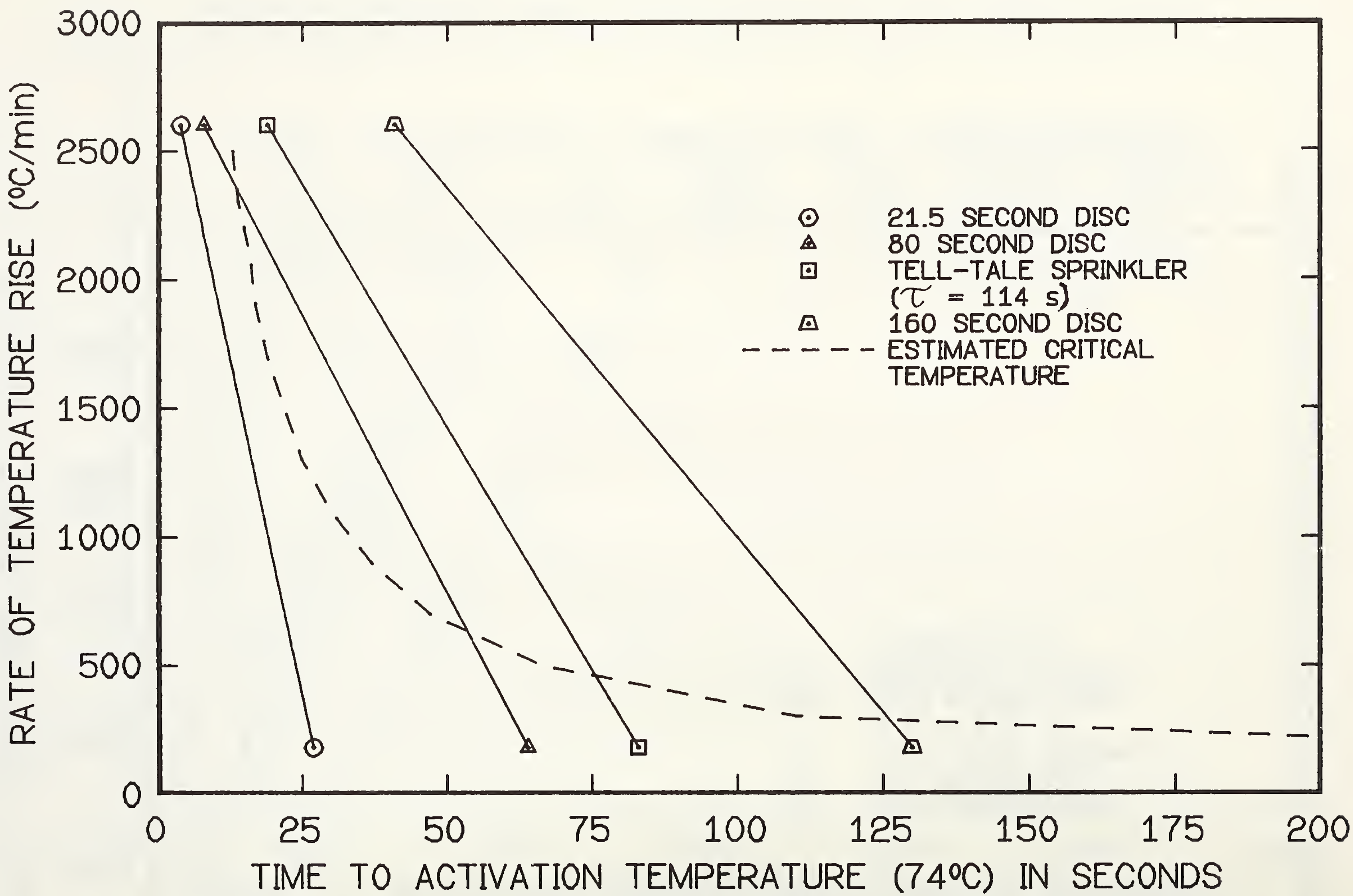

Figure 16. Rate of Temperature Rise vs Time from Beginning of Linear Temperature Increase to Activation Temperature, Door Sidewall Position, 180 to 2600°C/min Temperature Rise

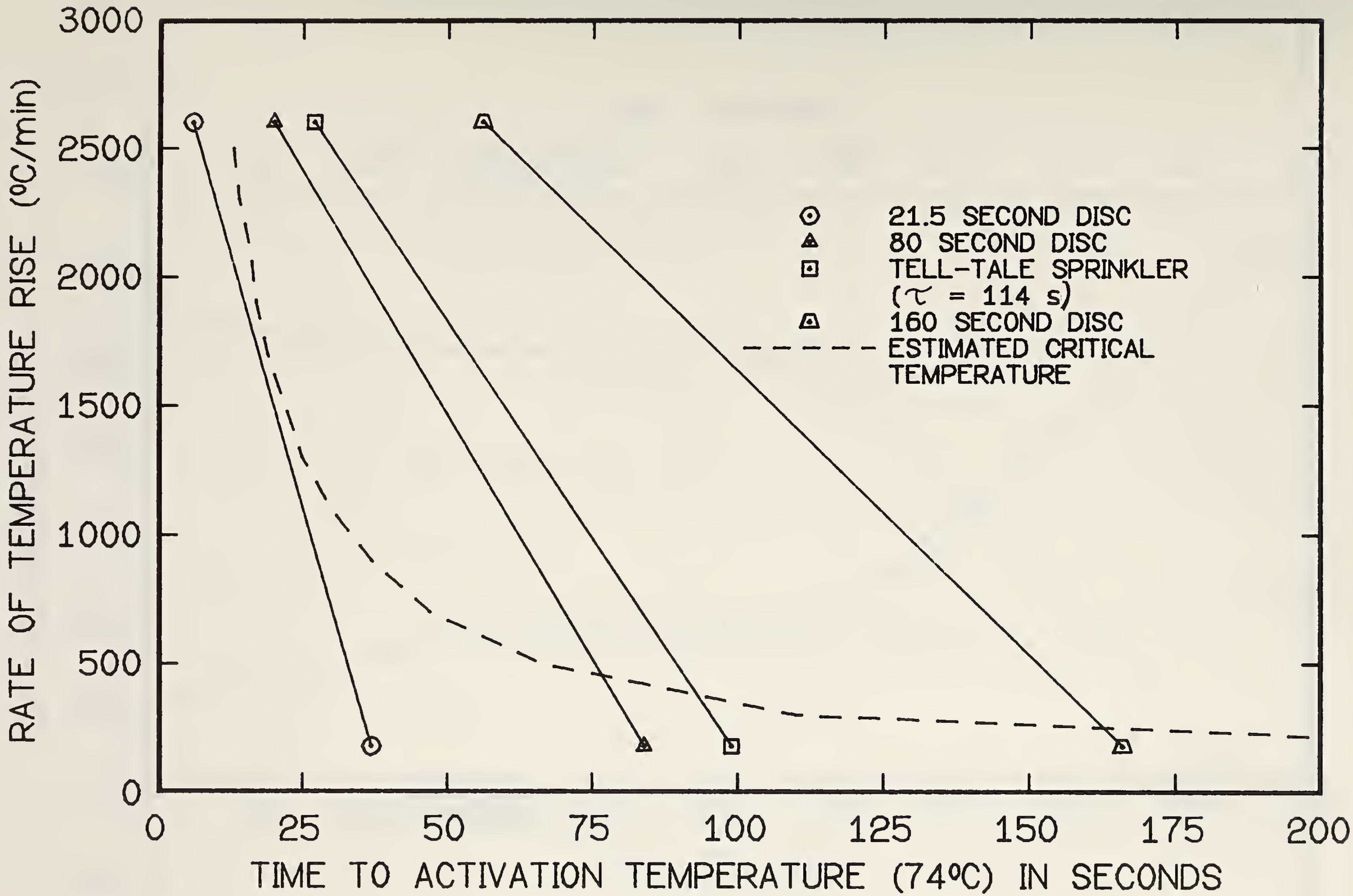

Figure 17. Rate of Temperature Rise vs Time from Beginning of Linear Temperature Increase to Activation Temperature, Opposite Sidewall Position, 180 to 2600°C/min Temperature Rise

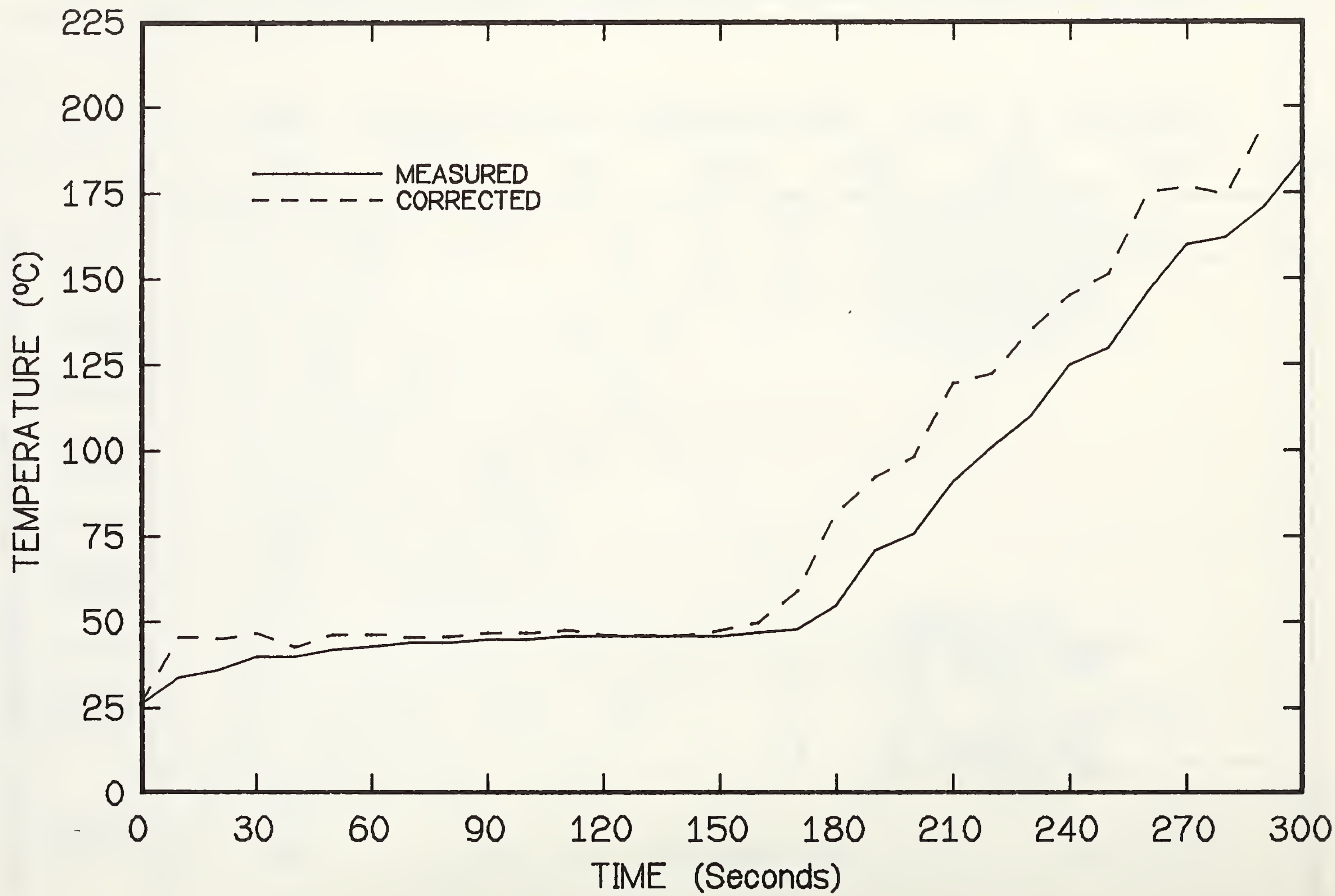

Figure 18. Temperature vs Time Curves - Measured and Corrected for 5.1 mm Thermocouple

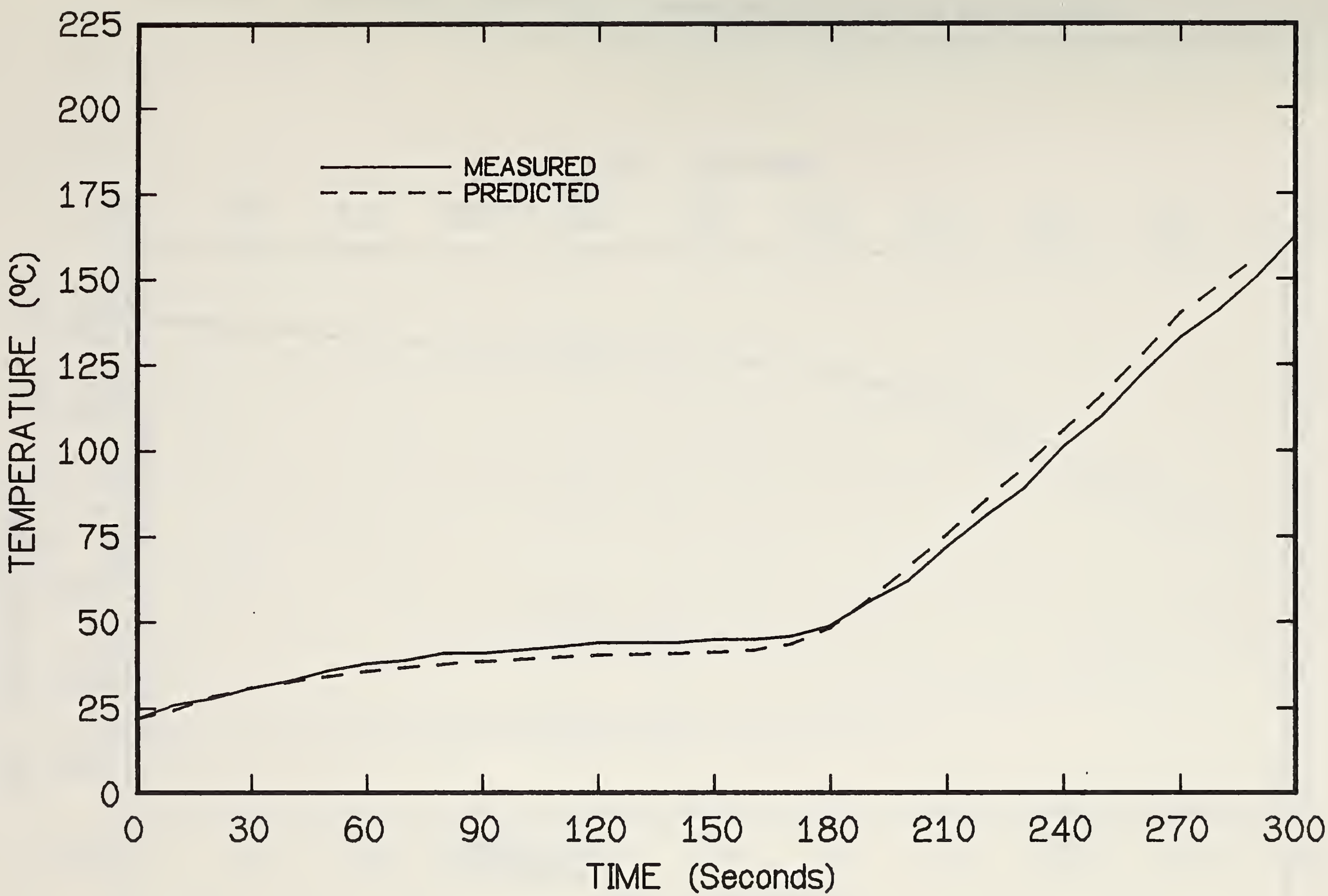

Figure 19. Temperature vs Time Curve - Measured and Predicted for 21.5 s Disc

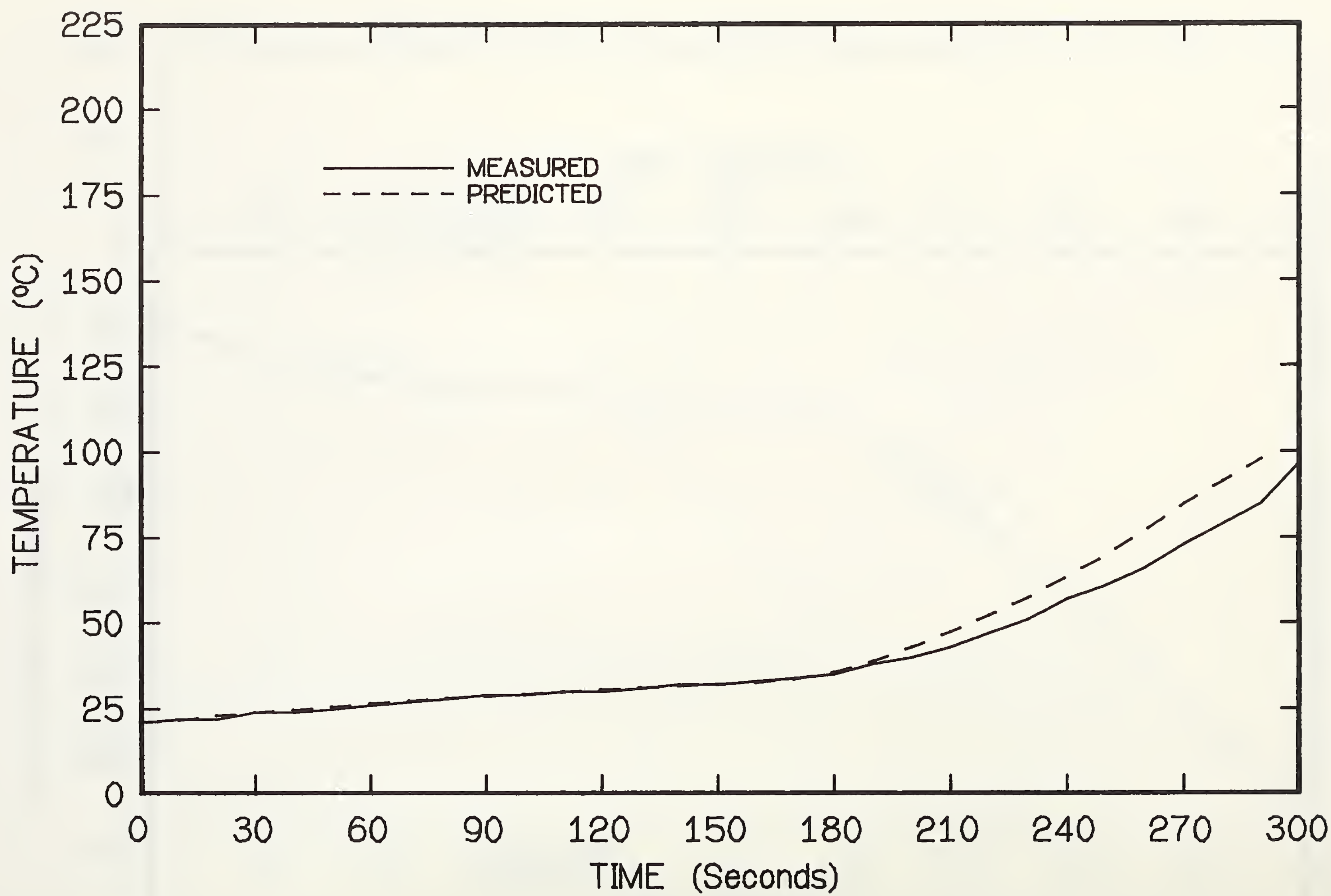

Figure 20. Temperature vs Time Curve - Measured and Predicted for 80 s Disc

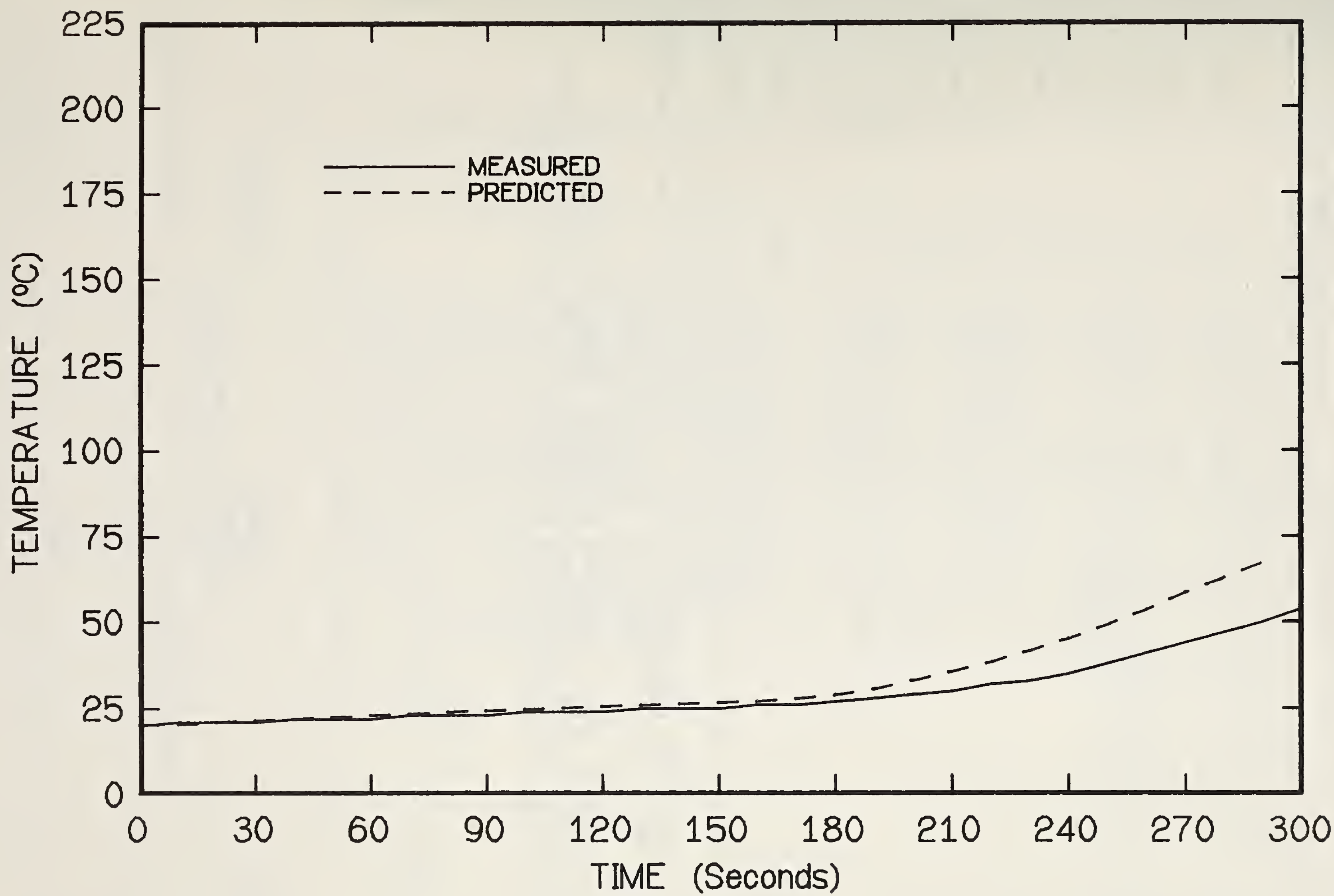

Figure 21. Temperature vs Time Curve - Measured and Predicted for 160 s Disc

Table 1. Burner Programs[a]

Burner Groups Activated	Activation Times (sec) 60°C/min	90°C/min	180°C/min
1[b]	0	0	0
1,2	180	180	180
1,3	207	196	187
1,4	234	212	194
1,2,4	261	229	201
1,3,4	288	247	208
1,2,3,4	315	264	216
1,2,5	340	282	224
1,3,5	365	299	233
1,4,5	390	316	241
1,2,4,5	414	331	249
1,3,4,5	437	346	256
1,2,3,4,5	459	361	262

[a]The burner program for the 2600°C/min rate of temperature rise was accomplished by adding burner groups 2 through 7 at one second intervals.

[b]Activation of burner group 1 provided an initial temperature plateau at approximately 50°C. This plateau was maintained for 180 s to simulate the burning of a small trash container as an exposure fire before the linear temperature increase ramp was initiated.

Table 2. Calculated Dimensions of Time Constant Discs

Time Constant (s)	Diameter (mm)	Thickness (mm)
5	6.4	0.2
21.5	9.8	0.8
80	27.6	3.1
160	55.1	6.3

Table 3. Instrument List

Channel	Type	I.D.	Instrument Description
50	TC	1	Center of room ceiling air, 0.05 M Dwn
51	TC	2	Ceiling air average, 8 TC on diagonals, 0.05 M Dwn
61	TC	3	Room tree, 0.97 M-W wall, 1.68 M-S wall, 0.05 M Dwn
62	TC	4	Room tree, 0.97 M-W wall, 1.68 M-S wall, 0.15 M Dwn
63	TC	5	Room tree, 0.97 M-W wall, 1.68 M-S wall, 0.31 M Dwn
64	TC	6	Room tree, 0.97 M-W wall, 1.68 M-S wall, 0.61 M Dwn
65	TC	7	Room tree, 0.97 M-W wall, 1.68 M-S wall, 0.91 M Dwn
66	TC	8	Room tree, 0.97 M-W wall, 1.68 M-S wall, 1.22 M Dwn
67	TC	9	Room tree, 0.97 M-W wall, 1.68 M-S wall, 1.53 M Dwn
68	TC	10	Center ceiling velocity probe
74	TC	11	Pendent loc., 2 mil TC
75	TC	12	Pendent loc., 5 mil TC
76	TC	13	Pendent loc., 10 mil TC
77	TC	14	Pendent loc., 20 mil TC
78	TC	15	Pendent loc., 160 s disc
79	TC	16	Pendent loc., 80 s disc
80	TC	17	Pendent loc., 21 s disc
81	TC	18	Pendent loc., 21 s disc blackened
82	TC	19	Door sidewall, 2 mil TC
83	TC	20	Door sidewall, 5 mil TC
84	TC	21	Door sidewall, 10 mil TC
85	TC	22	Door sidewall, 20 mil TC
86	TC	23	Door sidewall, 160 s disc
87	TC	24	Door sidewall, 80 s disc
88	TC	25	Door sidewall, 21 s disc
89	TC	26	Door sidewall, 21 s disc blackened
90	TC	27	Opposite sidewall, 2 mil TC
91	TC	28	Opposite sidewall, 5 mil TC
92	TC	29	Opposite sidewall, 10 mil TC
93	TC	30	Opposite sidewall, 20 mil TC
94	TC	31	Opposite sidewall, 160 s disc
95	TC	32	Opposite sidewall, 80 s disc
96	TC	33	Opposite sidewall, 21 s disc
97	TC	34	Opposite sidewall, 21 s disc blackened
113	VEL	14	Air velocity probe, ceiling center, 0.05 M Dwn
130	FLX	1	Total flux meter, (20 BTU/sq ft/s), 0.74 M level
999	TIME		Elapsed time in seconds

Table 4. Test Schedule

Temperature Rise	Order of Testing		
	1st day	2nd day	3rd day
60°C/min	1	3	2
120°C/min	2	1	3
180°C/min	3	2	1

Table 5. Tell-Tale Sprinkler Activation Time Summary

Test No.	Initial Test Temp. (°C)	Rate of Temp. Rise (°C/min)	Extrapolated Time to Critical Temp. (s)		Activation Times (s) Pendent	Door Sidewall	Opposite Sidewall	Plateau Temp. (°C)
3	21	60	730		285.3 (105.3)[1]	332.6 (152.6)	354.7 (174.7)	50
7	25	60	730		287.2 (107.2)	329.6 (149.6)	348.8 (168.8)	52
11	26	60	730		278.9 (98.9)	330.8 (150.8)	352.6 (172.6)	53
				AVG	283.8 (103.8)	331.0 (151.0)	352.0 (172.0)	
				Std. Dev.	4.35	1.51	2.99	
4	25	90	547		265.1 (85.1)	298.4 (118.4)	326.2 (146.2)	51
8	32	90	547		258.0 (78.0)	285.1 (105.1)	311.8 (131.8)	55
9	23	90	547		263.3 (83.3)	301.5 (121.5)	323.1 (143.1)	50
				AVG	262.1 (82.1)	295.0 (115.0)	320.4 (140.4)	
				Std. Dev.	3.69	8.71	7.58	
5	30	180	363		235.0 (55.0)	257.7 (77.7)	278.1 (98.1)	55
6	22	180	363		238.1 (58.1)	270.5 (90.5)	281.7 (101.7)	50
10	31	180	363		237.5 (57.5)	259.8 (79.8)	276.2 (96.2)	54
				AVG	236.9 (56.9)	262.7 (82.7)	278.7 (98.7)	
				Std. Dev.	1.64	6.86	2.79	
12	23	2600	192		190.2 (10.2)	199.6 (19.6)	209.2 (29.2)	*
13	25	2600	191		189.8 (9.8)	193.3 (13.6)	189.8 (9.8)	51
14	27	2600	191		189.4 (9.4)	198.1 (18.6)	208.6 (28.6)	55
15	26	2600	191		190.6 (10.6)	199.8 (19.8)	209.7 (29.7)	54
16	28	2600	191		189.1 (9.1)	198.1 (18.1)	206.8 (26.8)	53
17	25	2600	191		190.1 (10.1)	199.8 (19.8)	209.8 (29.8)	53
18	27	2600	191		189.2 (9.2)	198.6 (18.6)	207.9 (27.9)	53
19	24	2600	191		190.5 (10.5)	200.3 (20.3)	210.0 (30.0)	54
				AVG	189.9 (9.9)	198.5 (18.5)	206.5 (26.5)	
				Std. Dev.	0.58	2.2	6.8	

Tell-tale time constant = 114 seconds

[1]Values in parentheses are times from initiation of temperature ramp to link activation.
*No data

Table 6. Time Constant Disc Required at Sidewall Positions to Equal a 21.5 Second Disc at the Pendent Position

Rate of Temp. Rise (°C/min)	Time Constant: Door Sidewall Location (s)	Time Constant: Opposite Sidewall Location (s)
60	6.8	-6.8
90	11.4	0.3
180	13.4	4.4

APPENDIX A

PLUNGE TEST

The plunge test is a method of evaluating the responsiveness of thermally reactive devices, and was developed at FMRC by Dr. G. Heskestad [12]. Essentially it is a recirculating air tunnel provided with electrical heating coils to heat the air, maintained at a selected velocity, to a selected temperature above the activation temperature of the device to be tested. The thermally activated device to be tested is plunged from room air into the recirculated air and the time interval from plunge to activation is measured. The time constant of the device is then calculated using the following relationship.

$$\tau = -t/\ell n \left[1 - \frac{\Delta T_L}{\Delta T_g}\right]$$

where:

τ = the time constant of the device (seconds)

t = time interval between plunge and activation (seconds)

ΔT_L = the difference between ambient air temperature and the temperature rating of the device

ΔT_g = difference in temperature of the hot air stream and the device immediately before plunging.

APPENDIX B

TIME-TEMPERATURE PLOTS FOR TIME CONSTANT DISCS

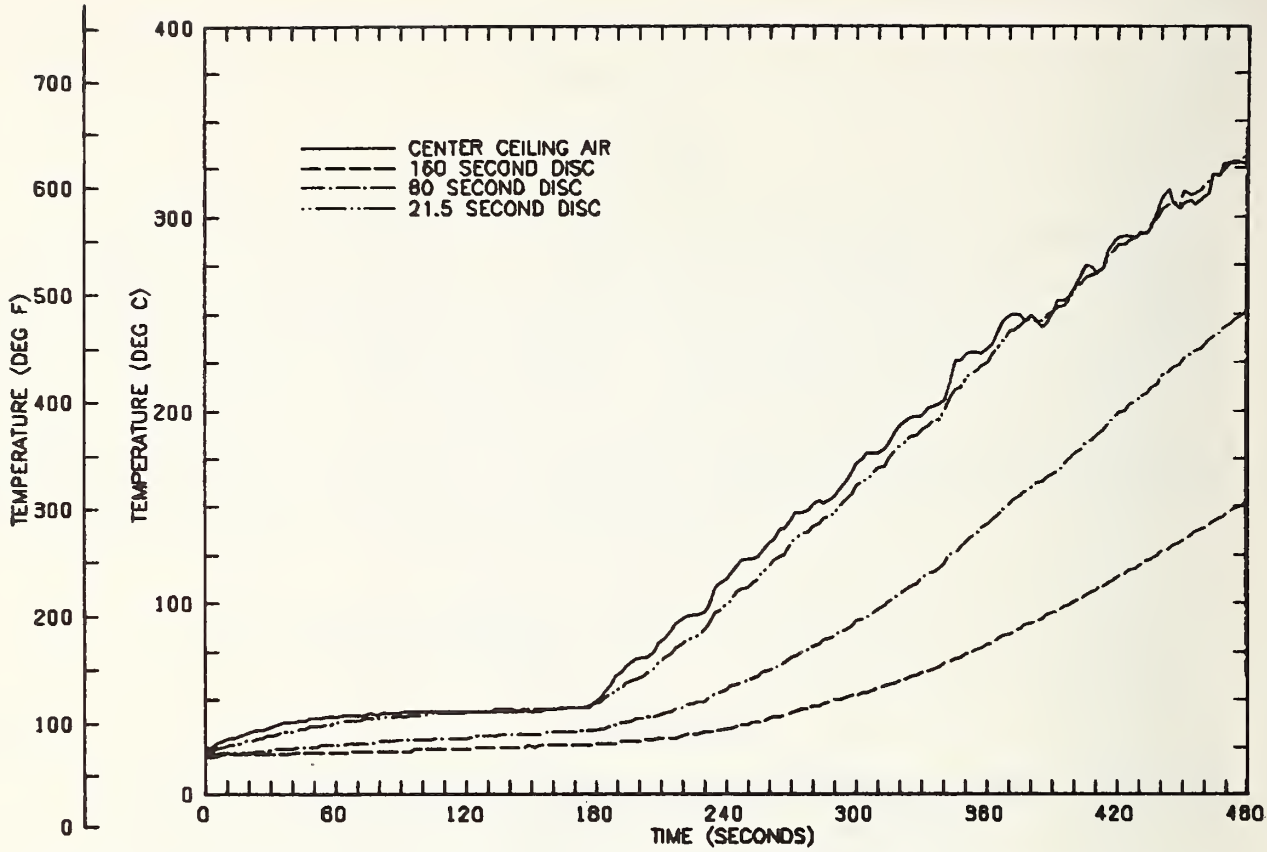

Figure B1. Pendent disc array time-temperature curves/60°C per minute rise

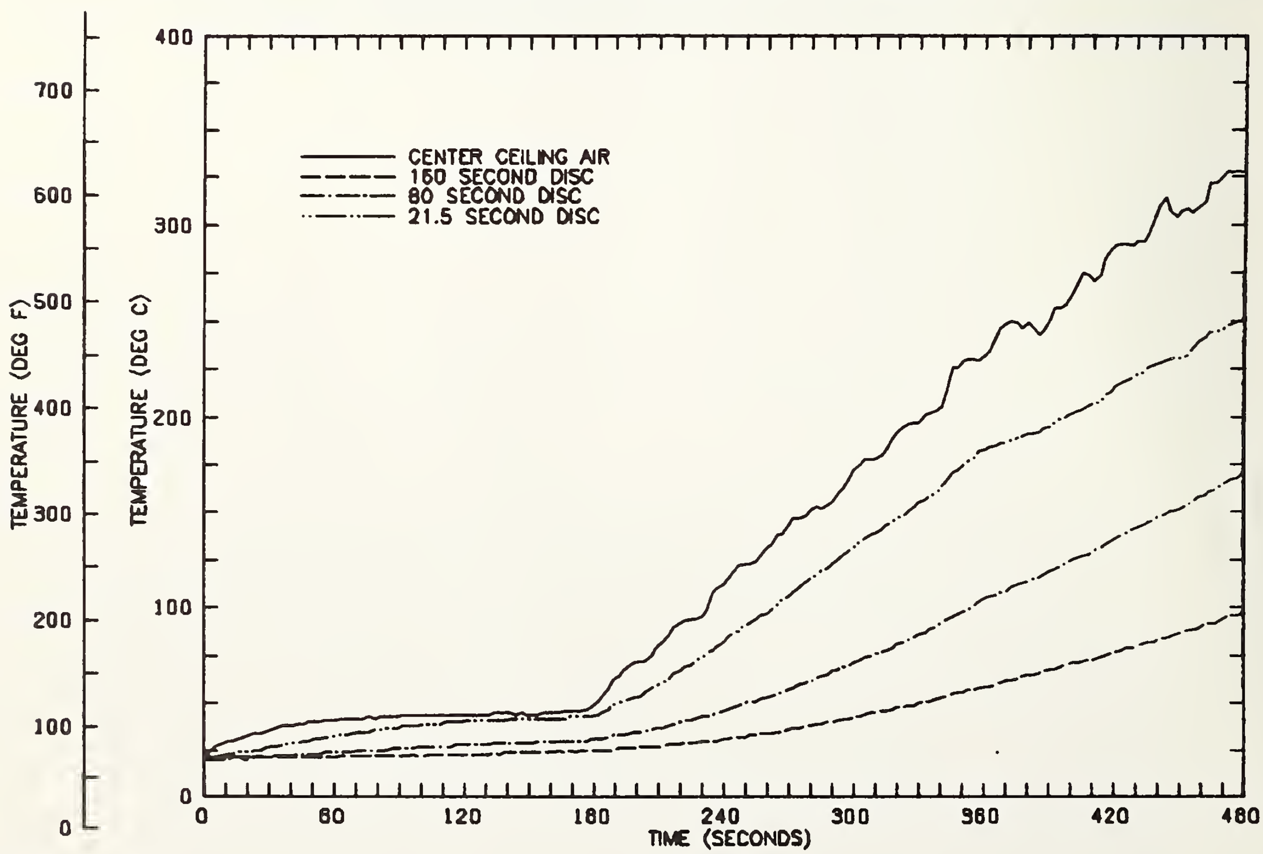

Figure B2. Door sidewall disc array time-temperature curves/60°C per minute rise

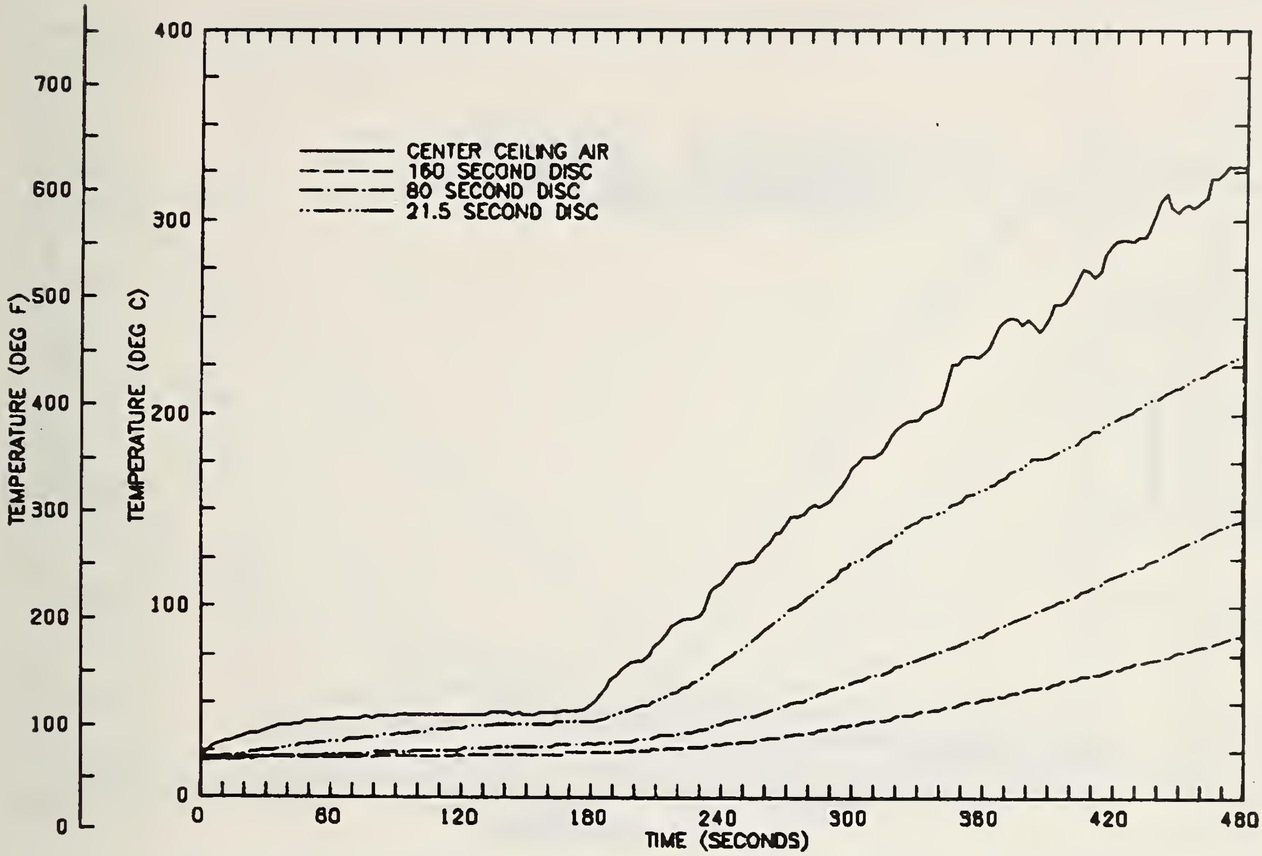

Figure B3. Opposite sidewall disc array time-temperature curves/60°C per minute rise

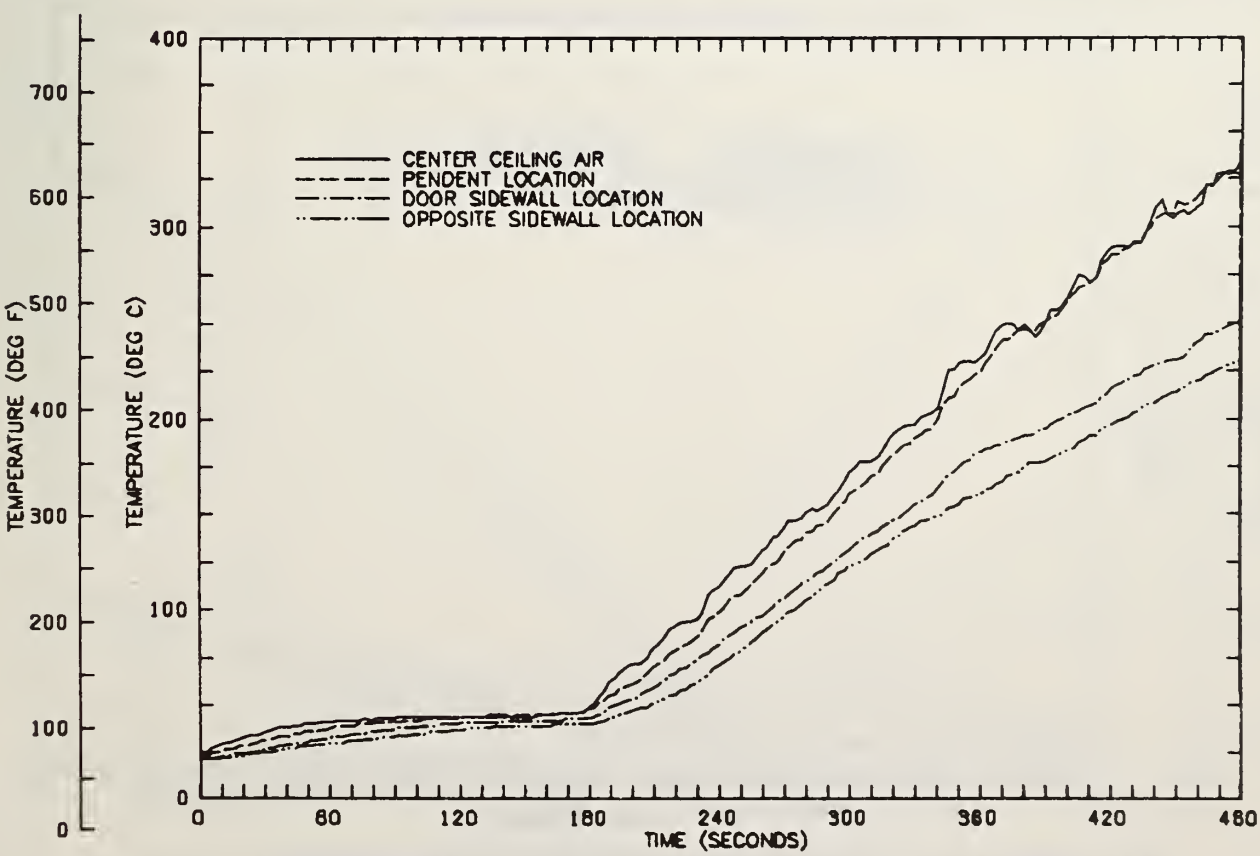

Figure B4. A 21.5 second disc temperatures/60°C per minute rise

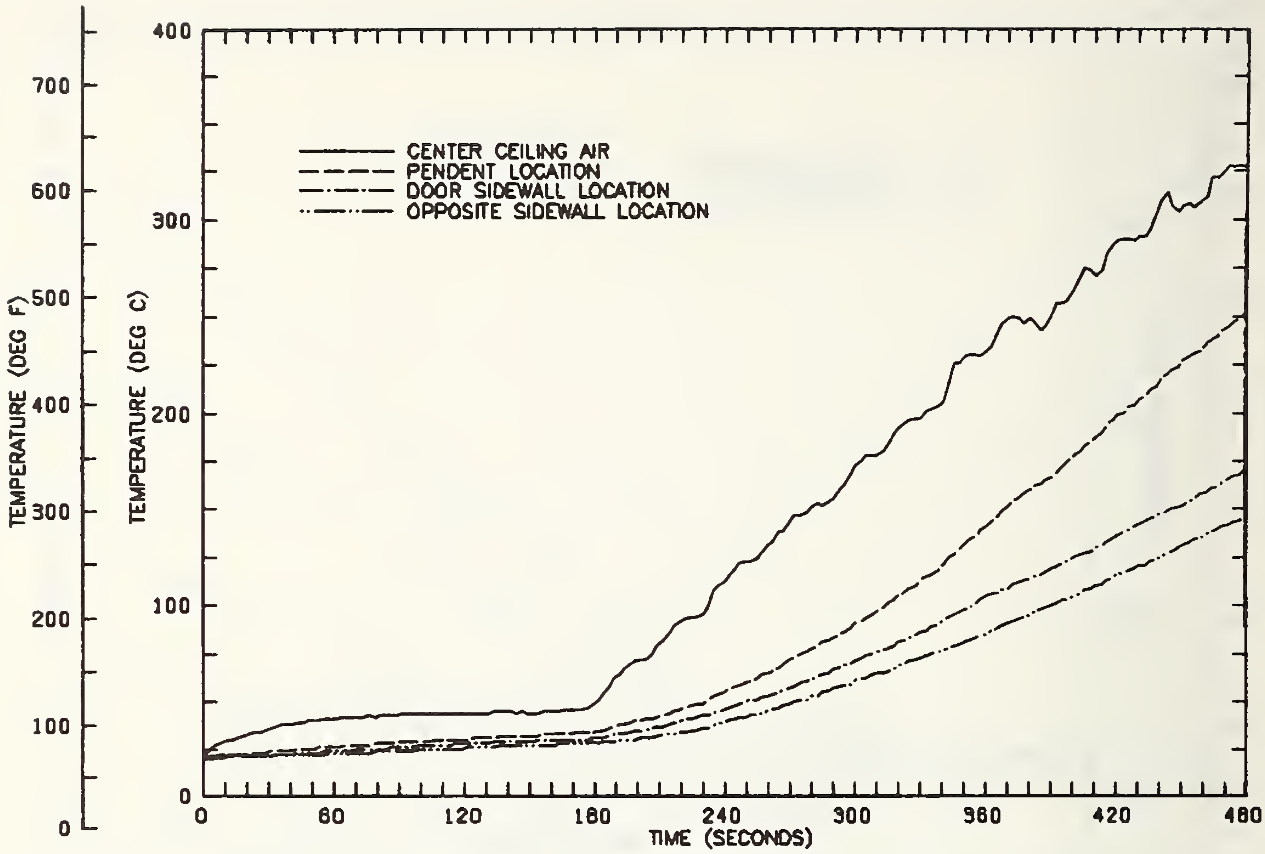

Figure B5. A 80 second disc temperatures/60°C per minute rise

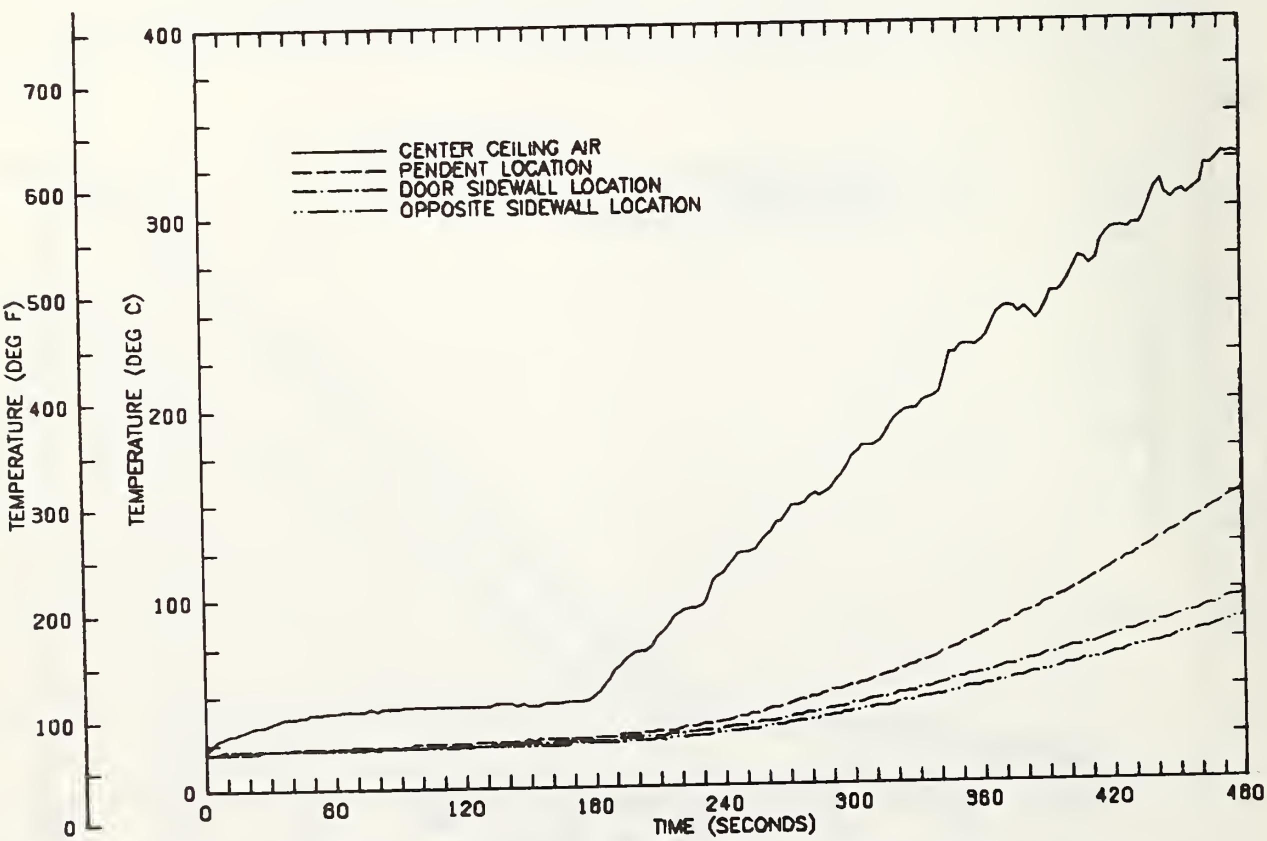

Figure B6. A 160 second disc temperatures/60°C per minute rise

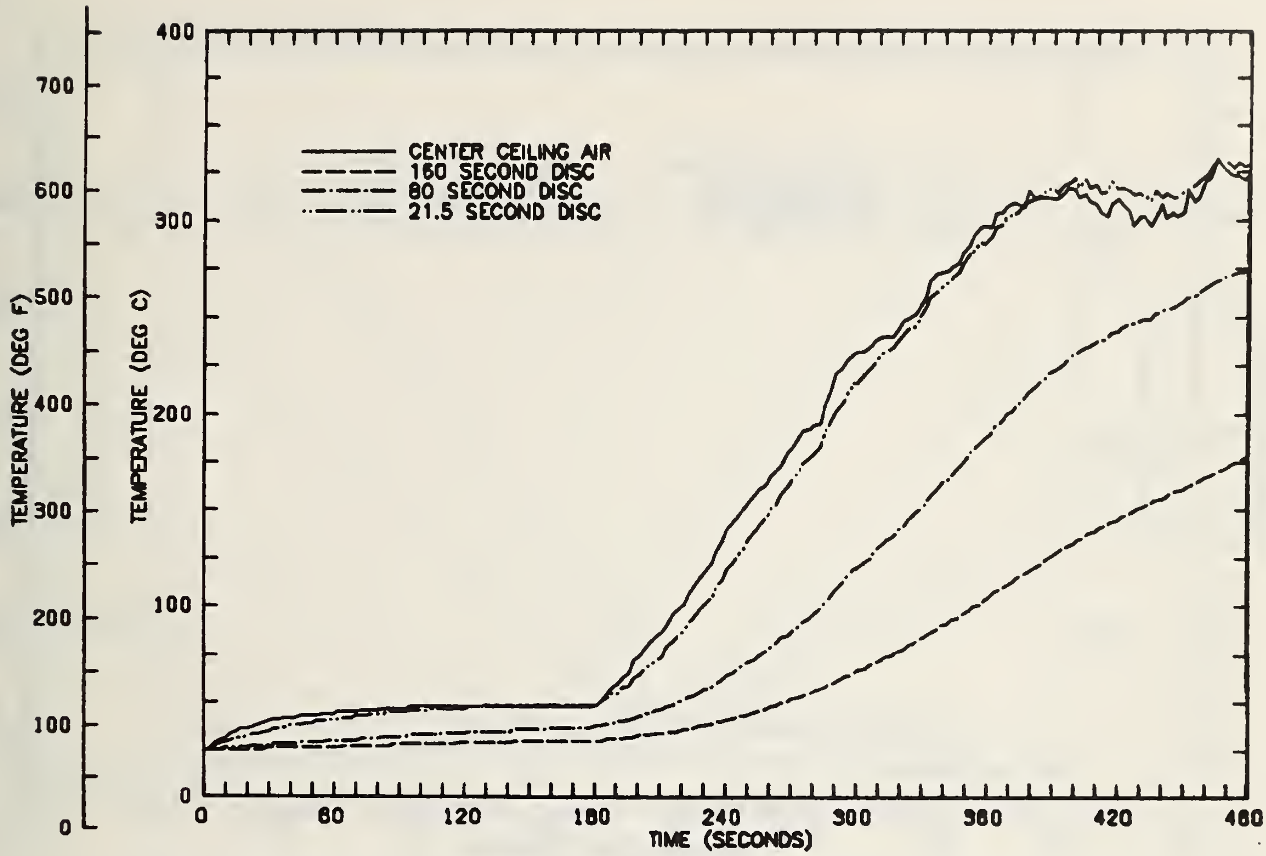

Figure B7. Pendent disc array temperatures/90°C per minute rise

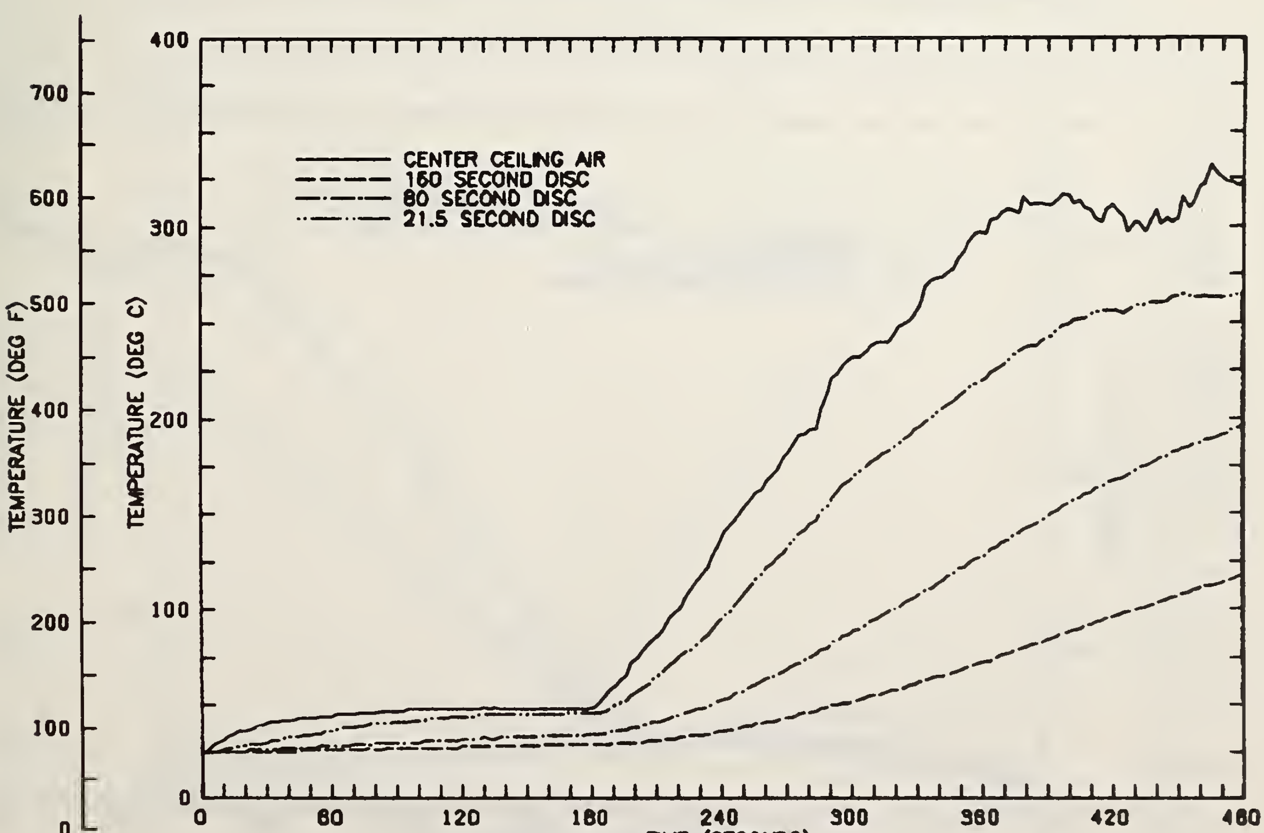

Figure B8. Door sidewall disc array/90°C per minute rise

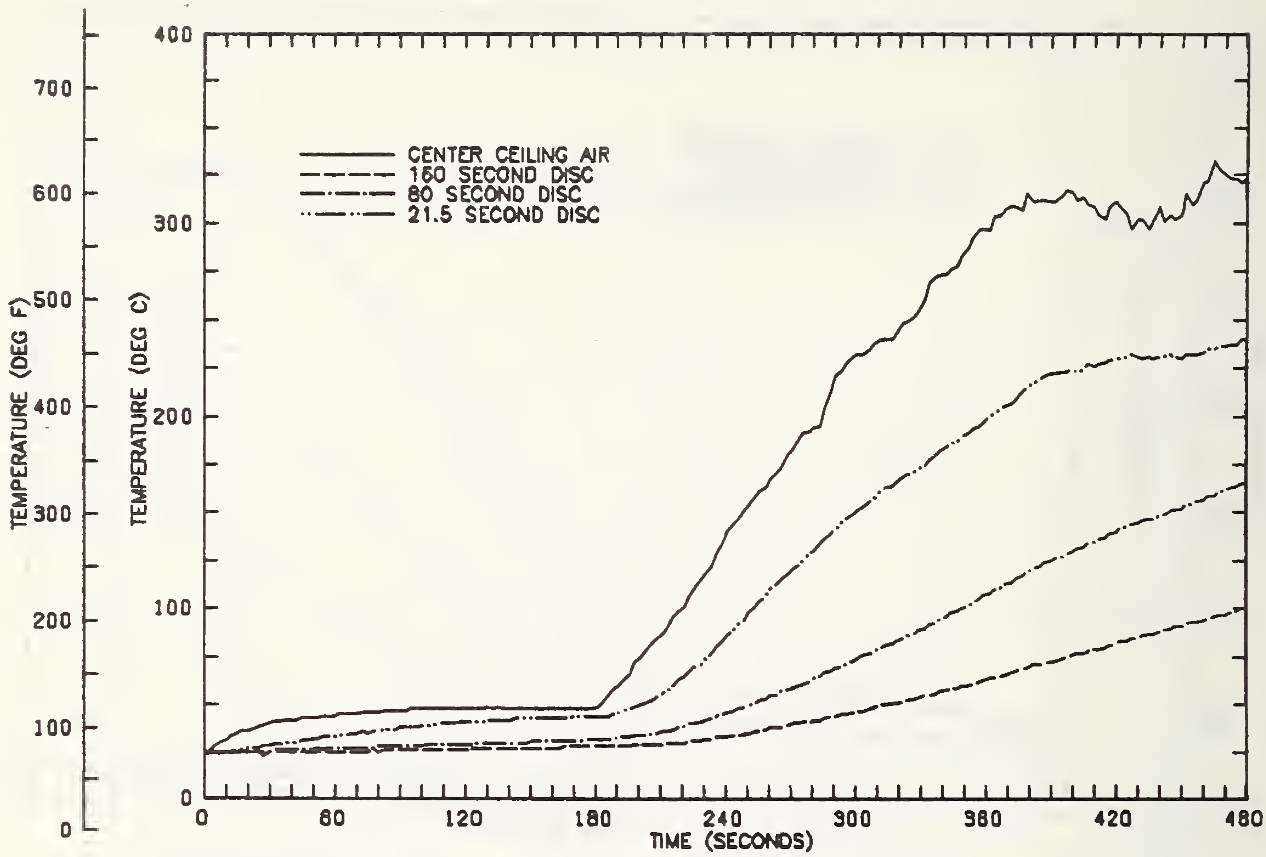

Figure B9. Opposite sidewall disc array/90°C per minute rise

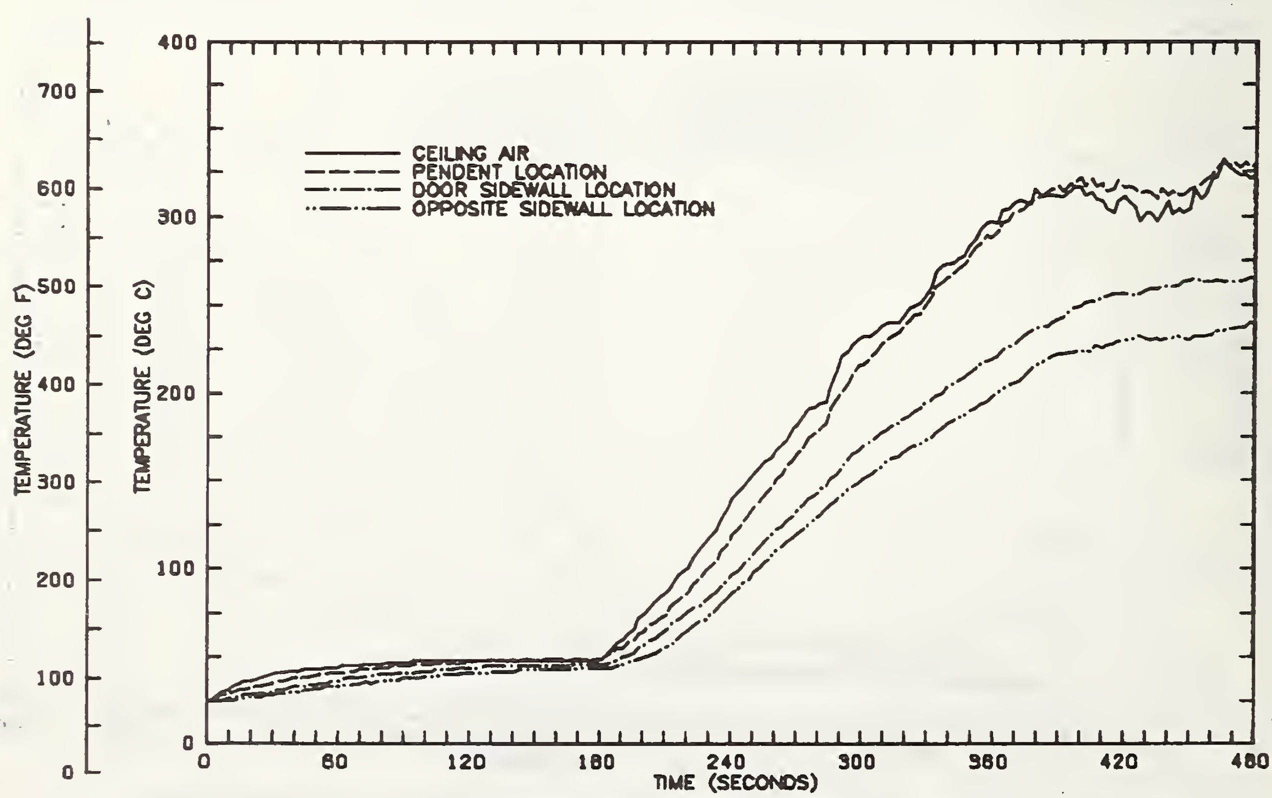

Figure B10. A 21.5 second disc temperatures/90°C per minute rise

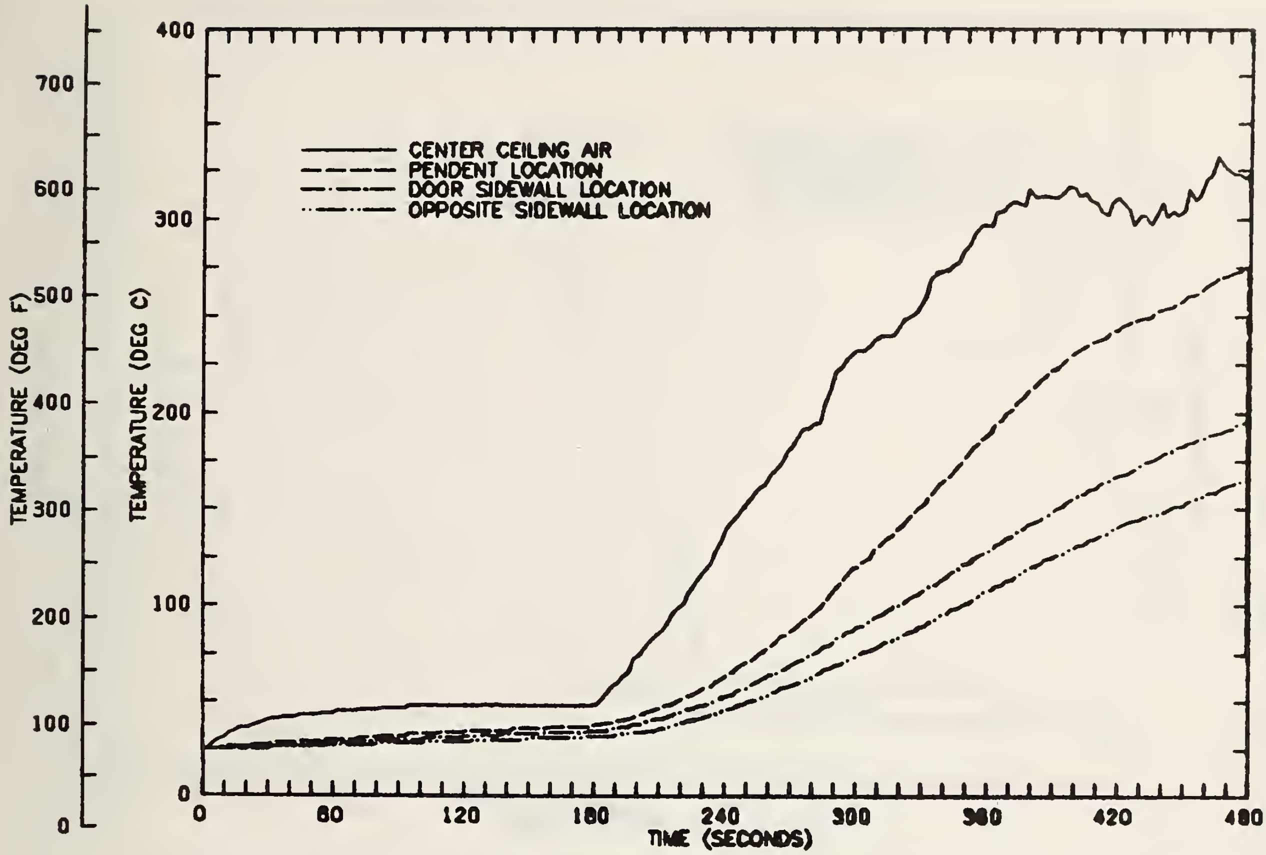

Figure B11. A 80 second disc temperatures/90°C per minute rise

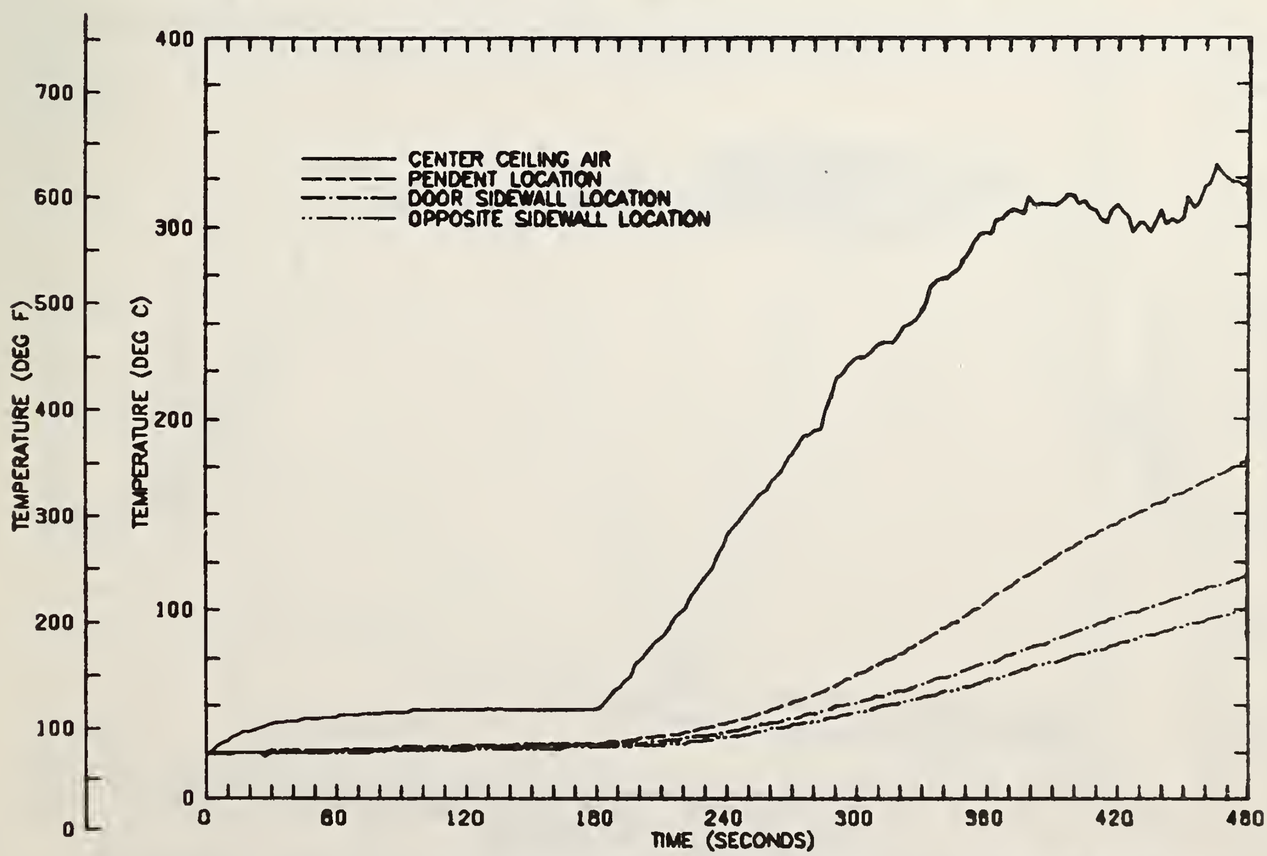

Figure B12. A 160 second disc temperatures/90°C per minute rise

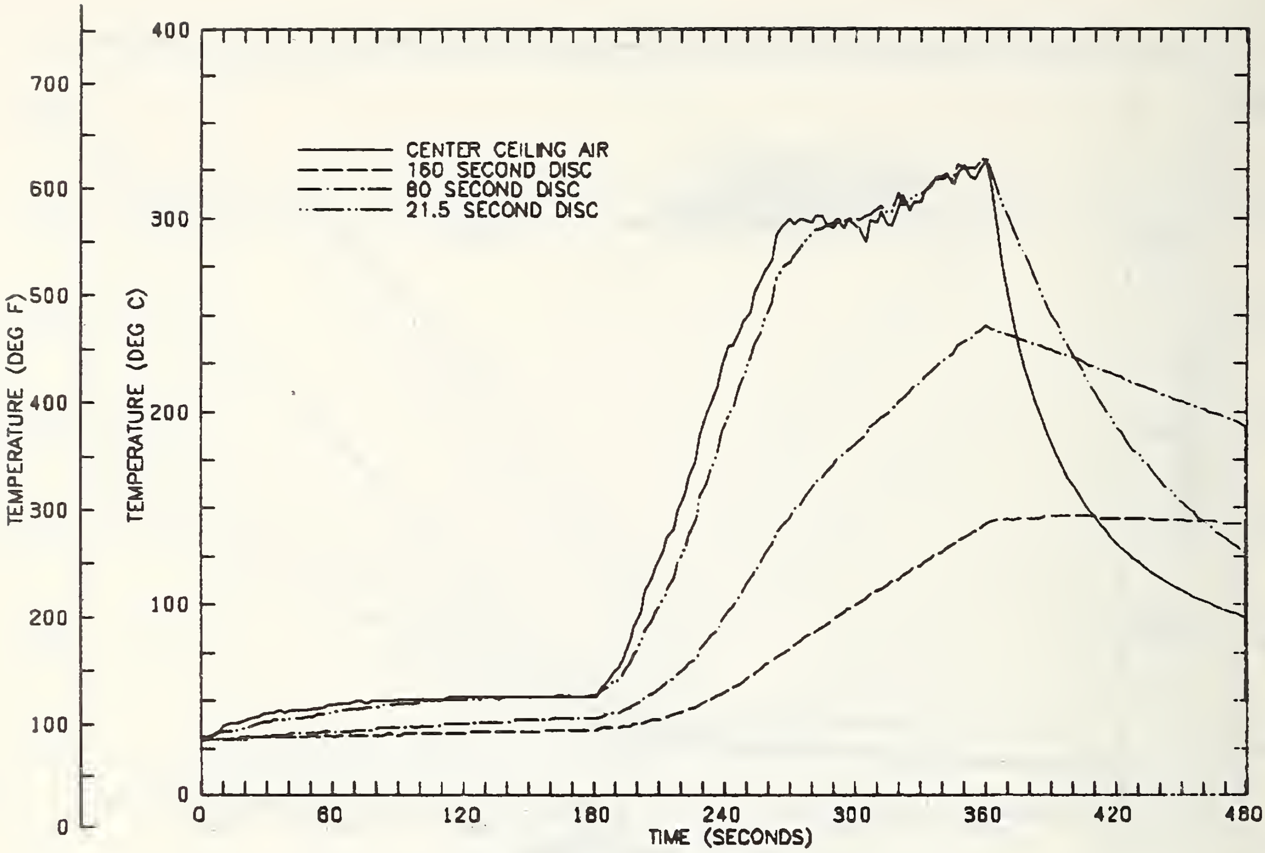

Figure B13. Pendent disc array temperatures/180°C per minute rise

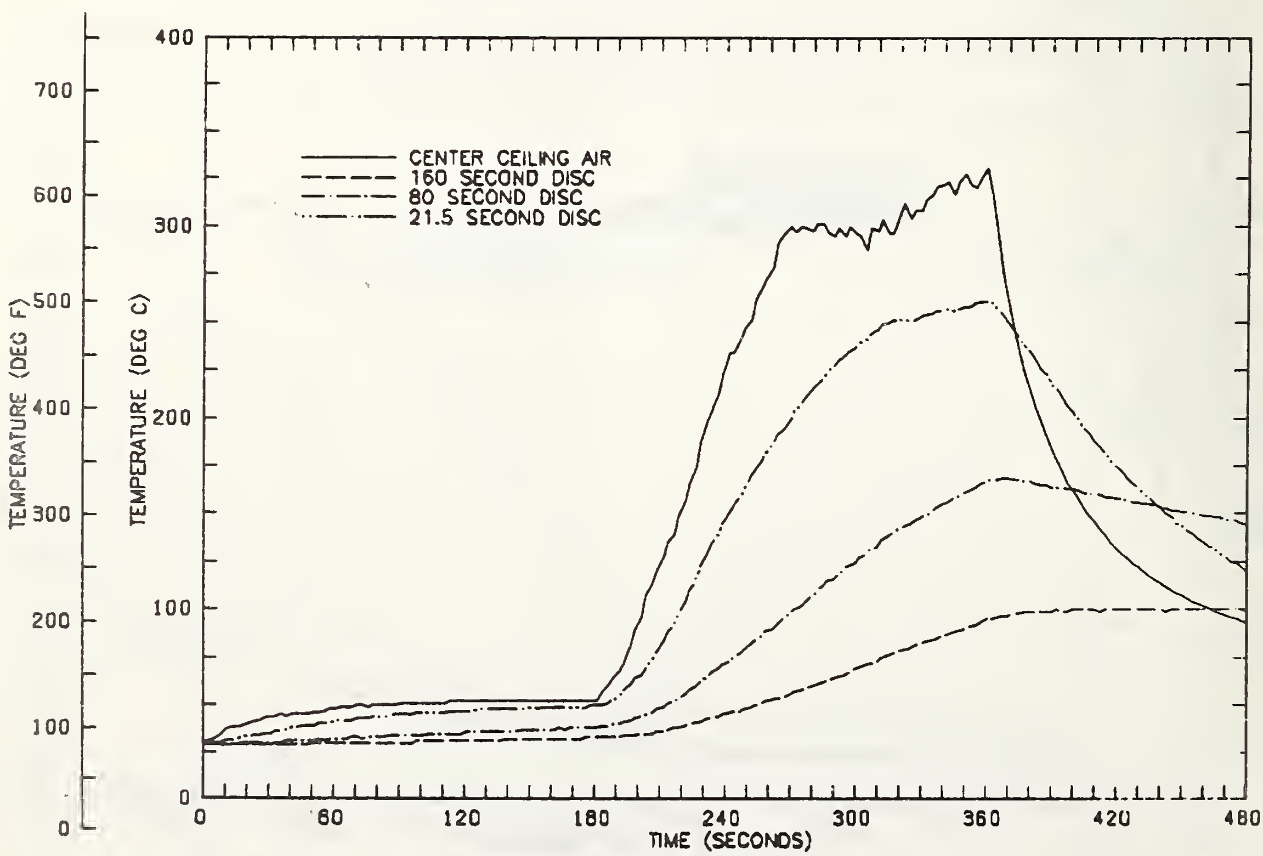

Figure B14. Door sidewall disc array temperatures/180°C per minute rise

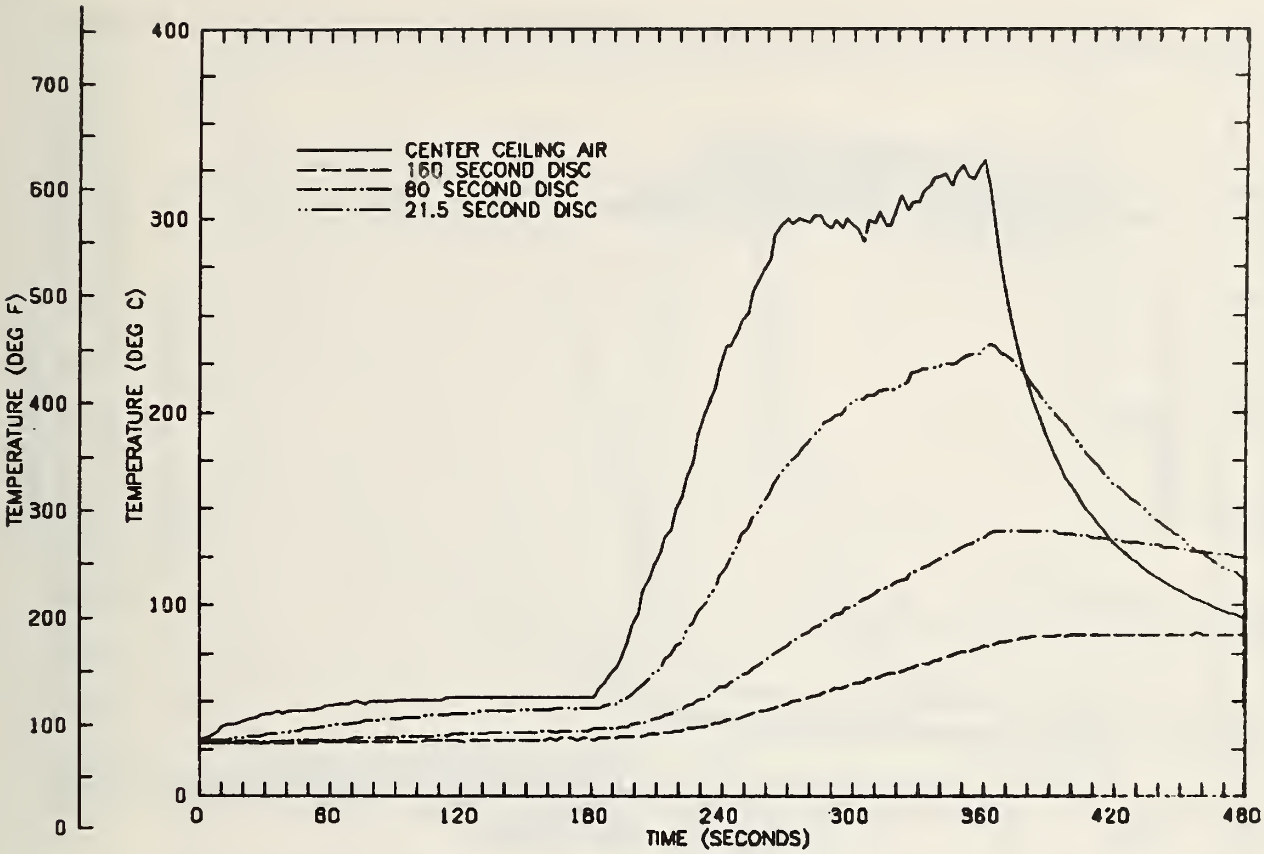

Figure B15. Opposite sidewall disc array/180°C per minute rise

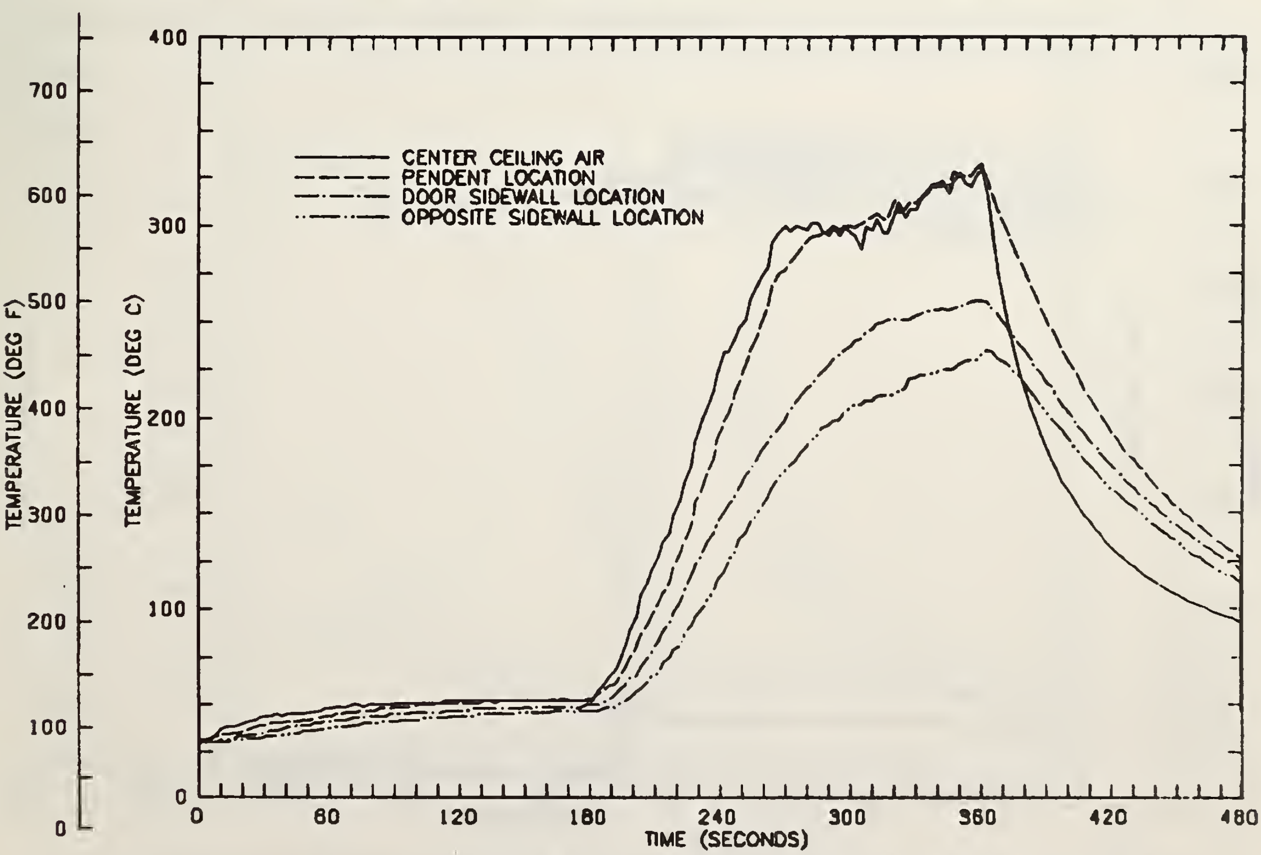

Figure B16. A 21.5 second disc temperatures/180°C per minute rise

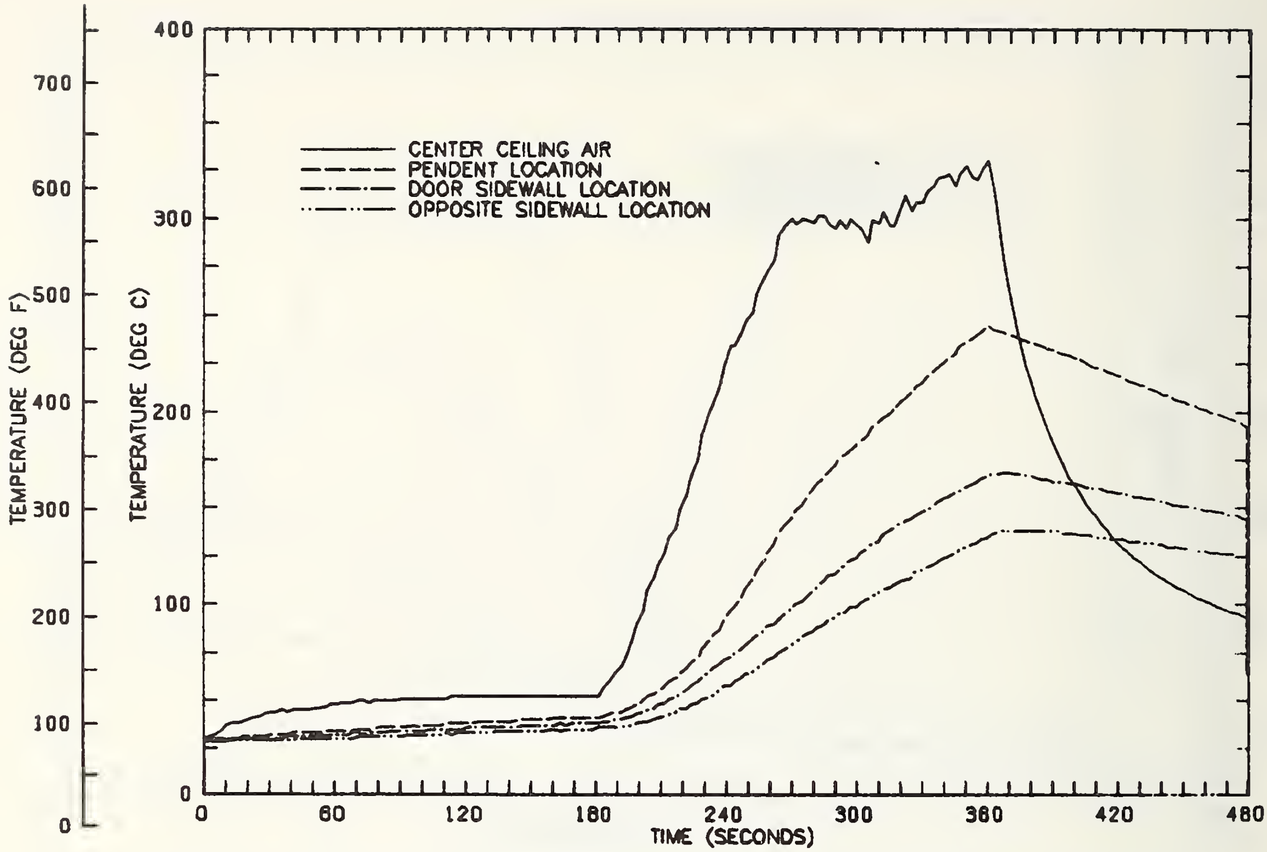

Figure B17. A 80 second disc temperatures/180°C per minute rise

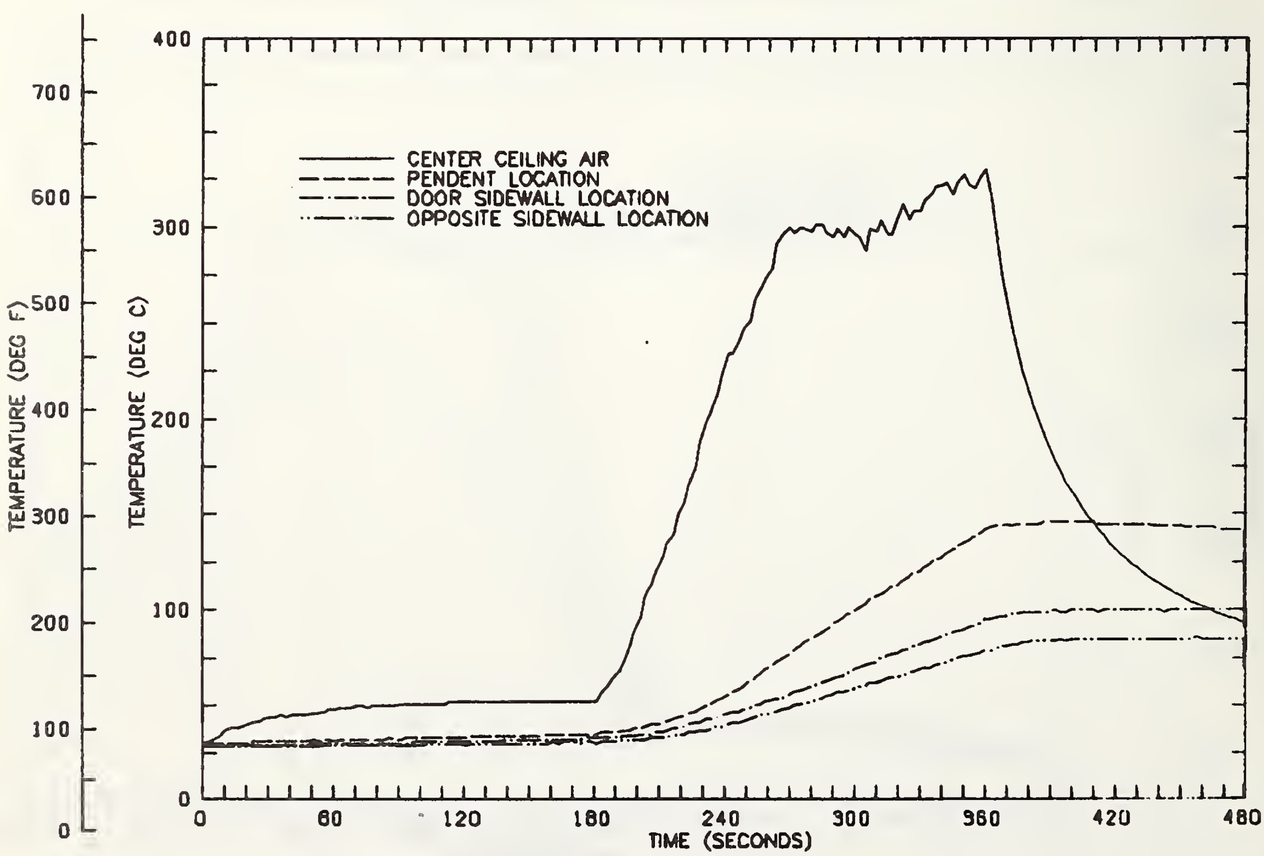

Figure B18. A 160 second disc temperatures/180°C per minute rise

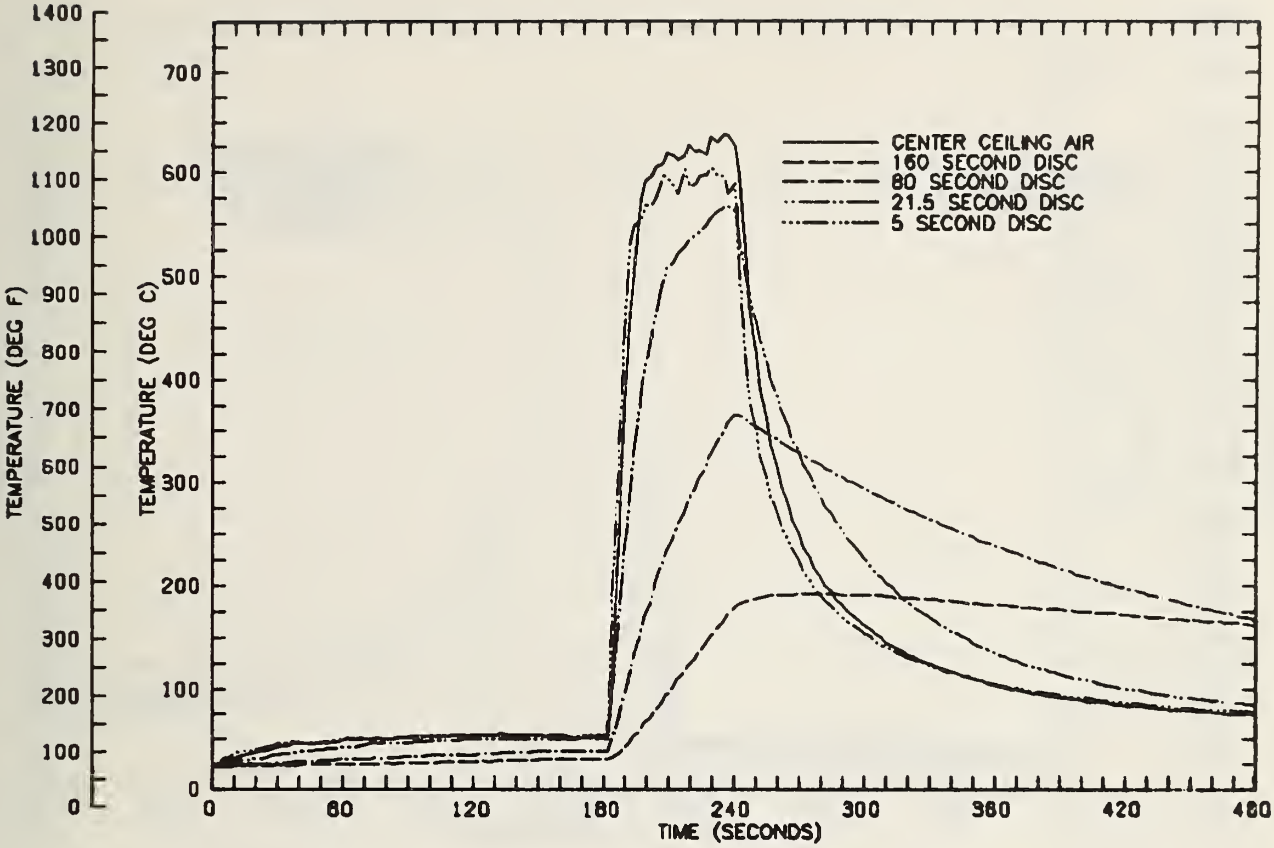

Figure B19. Pendent disc array temperatures/2600°C per minute rise

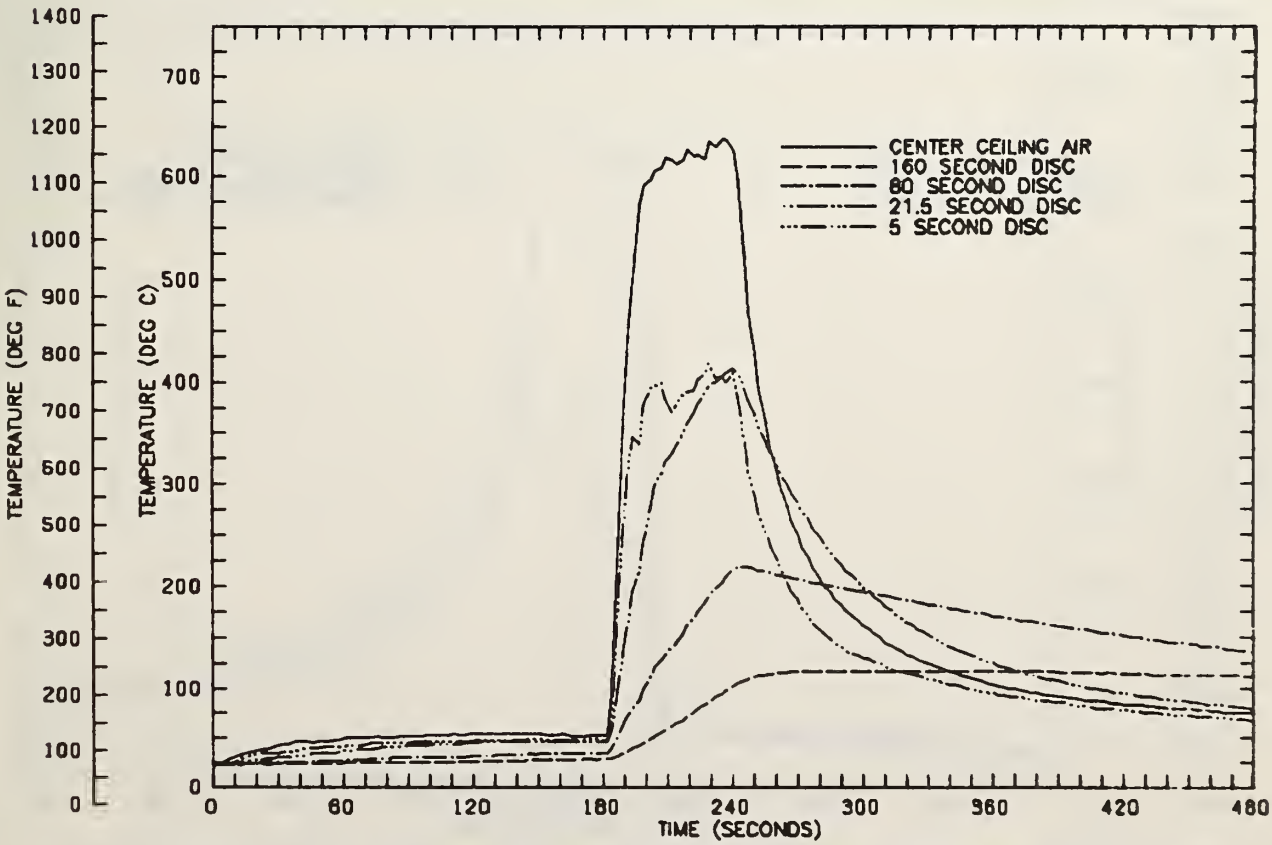

Figure B20. Door sidewall disc array temperatures/2600°C per minute rise

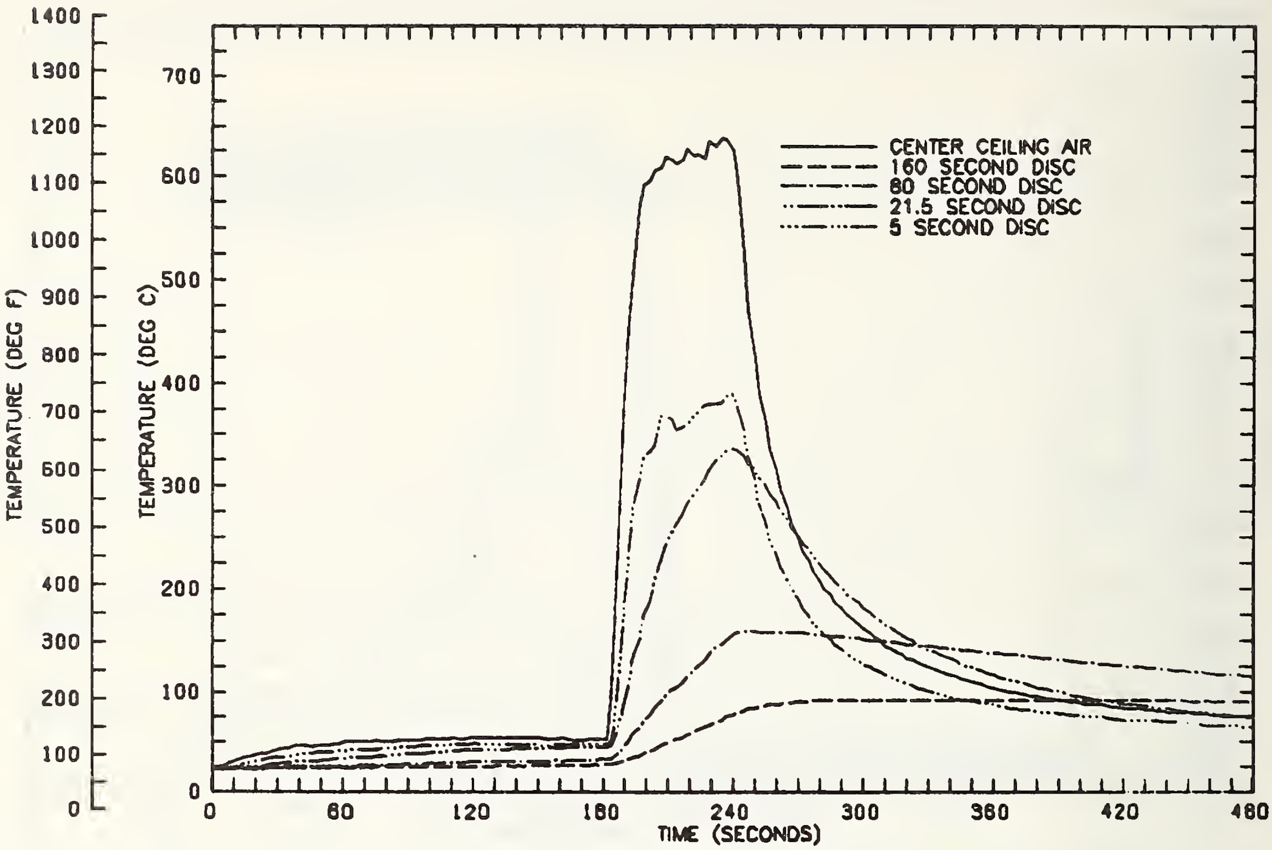

Figure B21. Opposite sidewall disc array temperatures/2600°C per minute rise

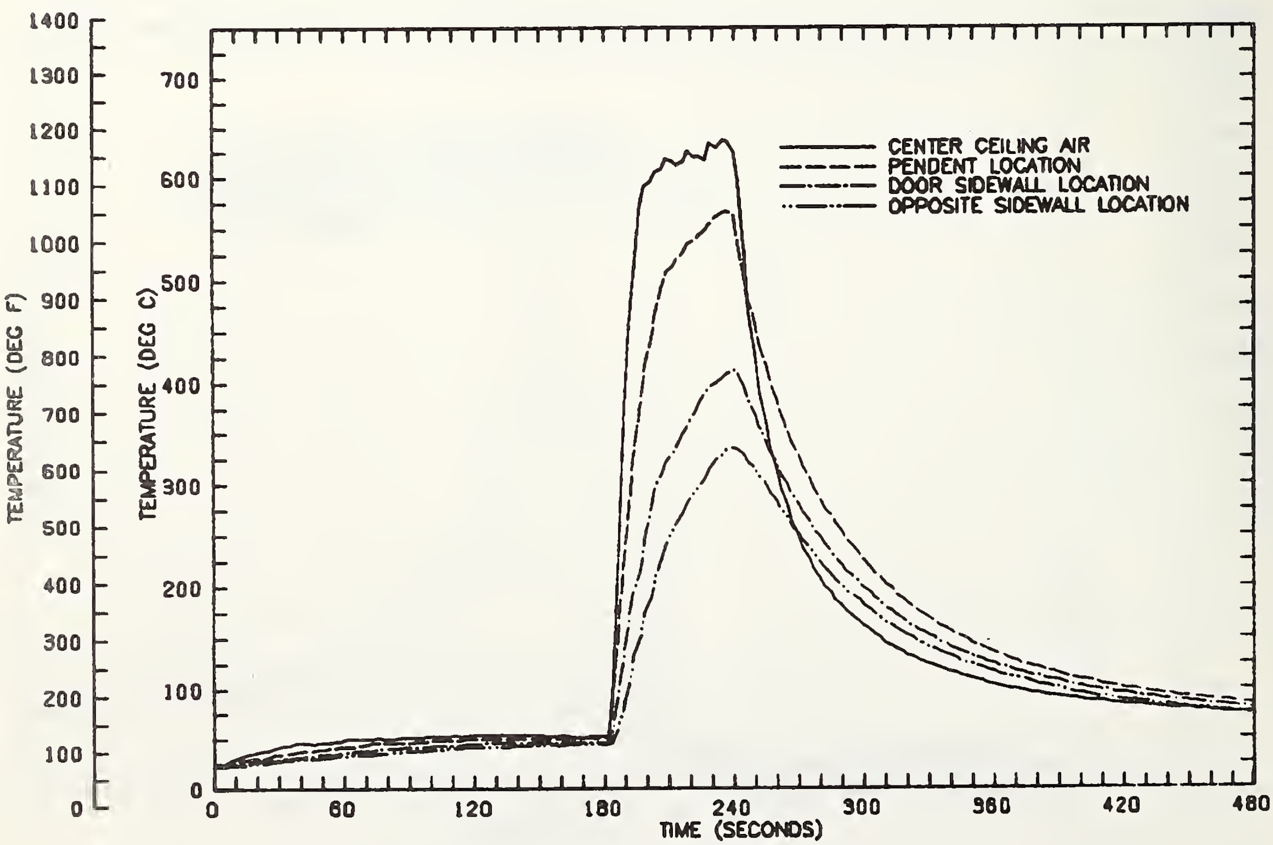

Figure B22. A 21.5 second disc temperatures/2600°C per minute rise

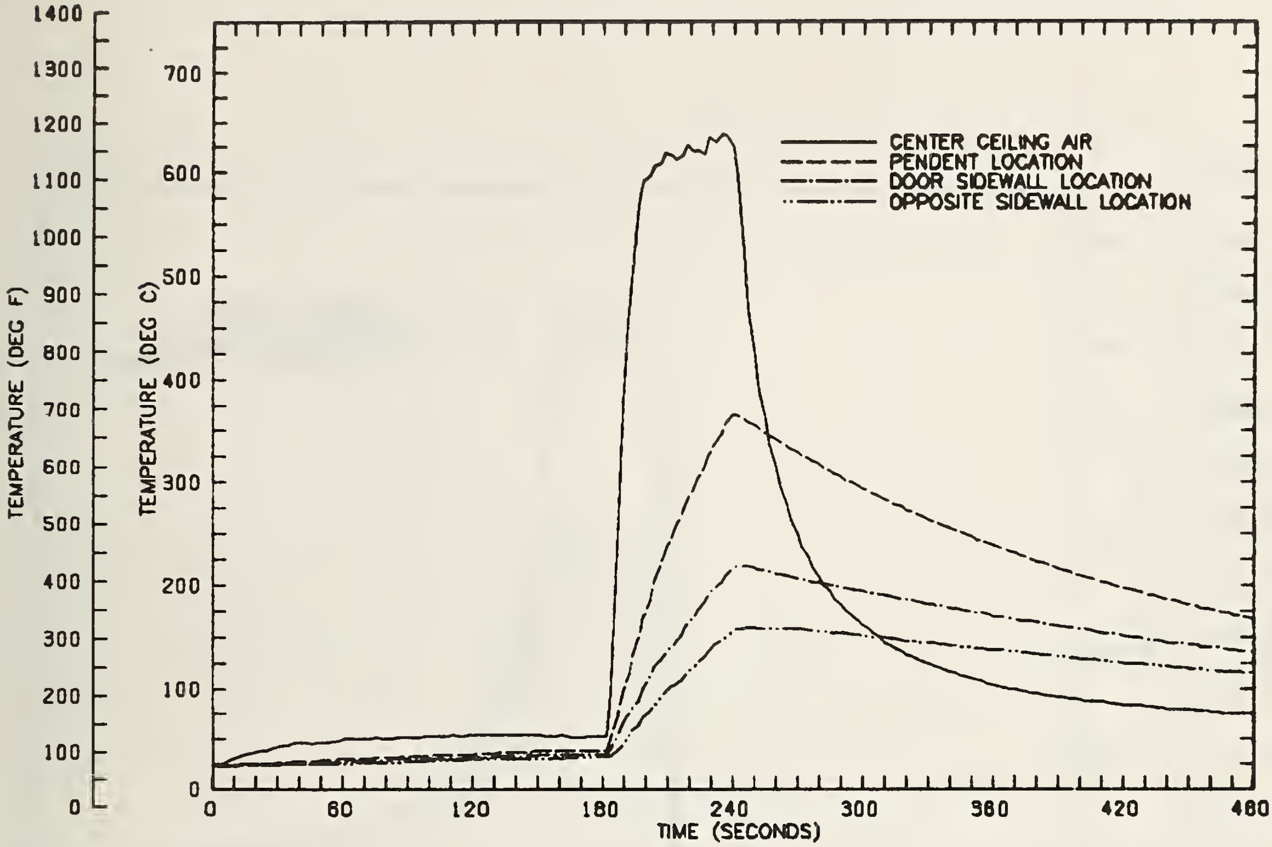

Figure B23. A 80 second disc temperatures/2600°C per minute rise

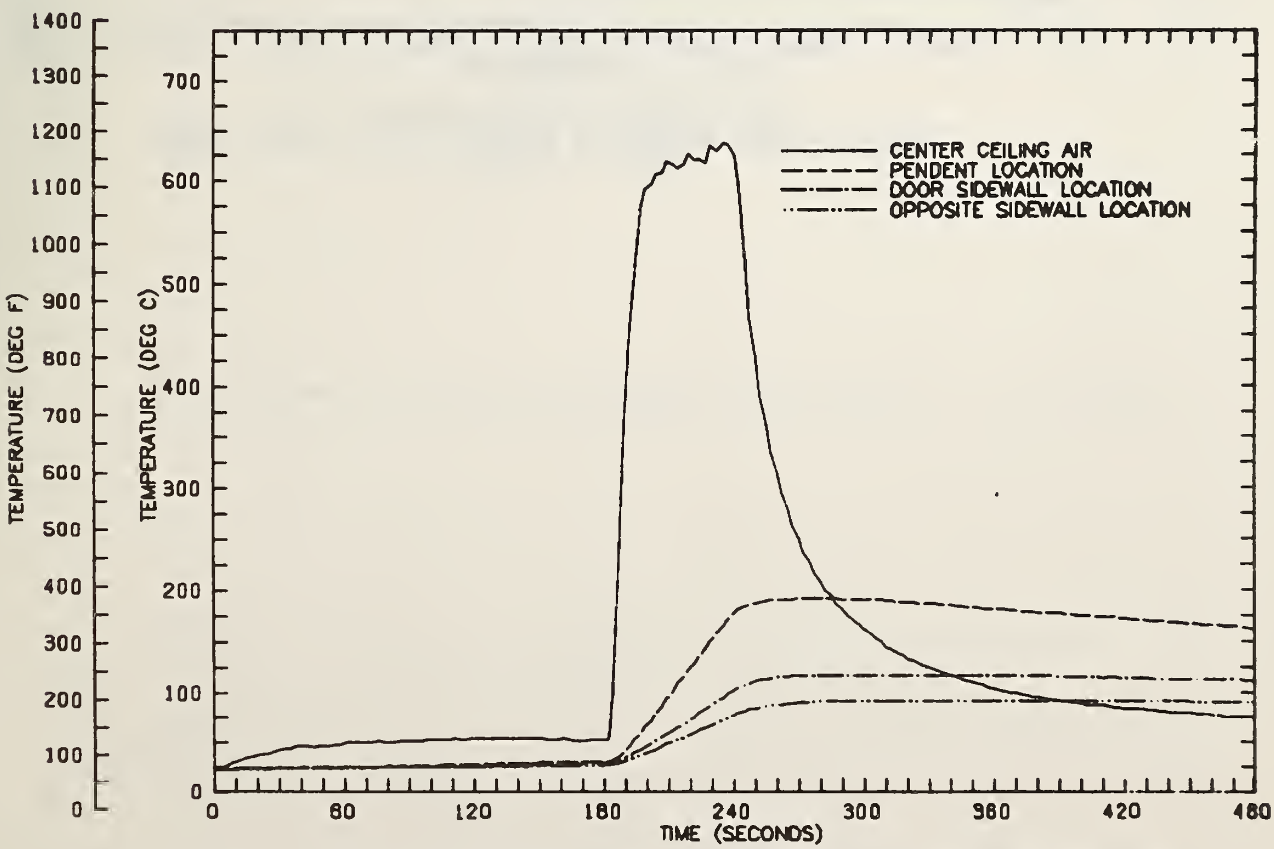

Figure B24. A 160 second disc temperatures/2600°C per minute rise

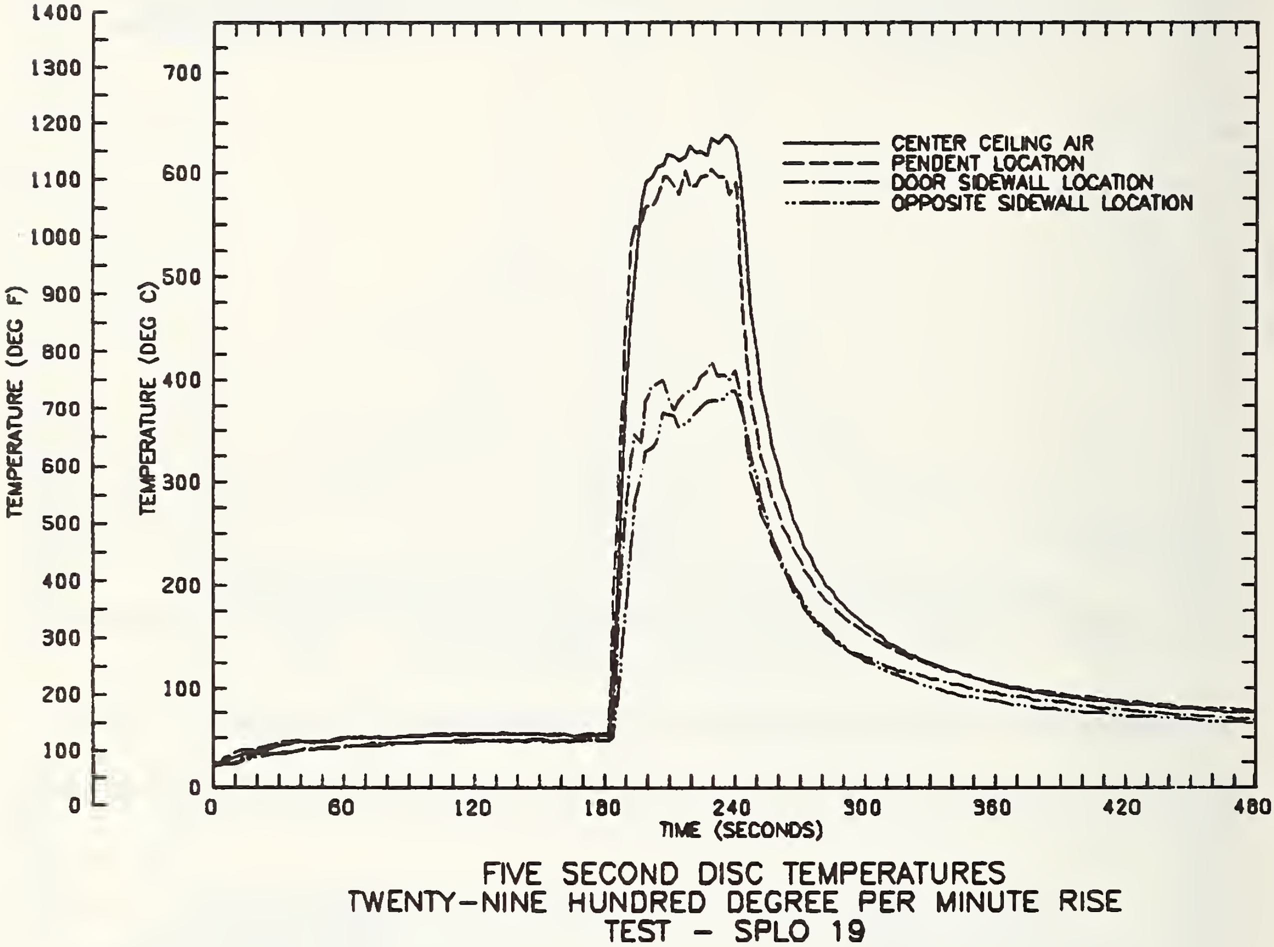

Figure B25. A 5 second disc temperatures/2600°C per minute rise

APPENDIX C

STATISTICAL VARIANCE AMONG REPEATED TESTS
(STANDARD DEVIATION)

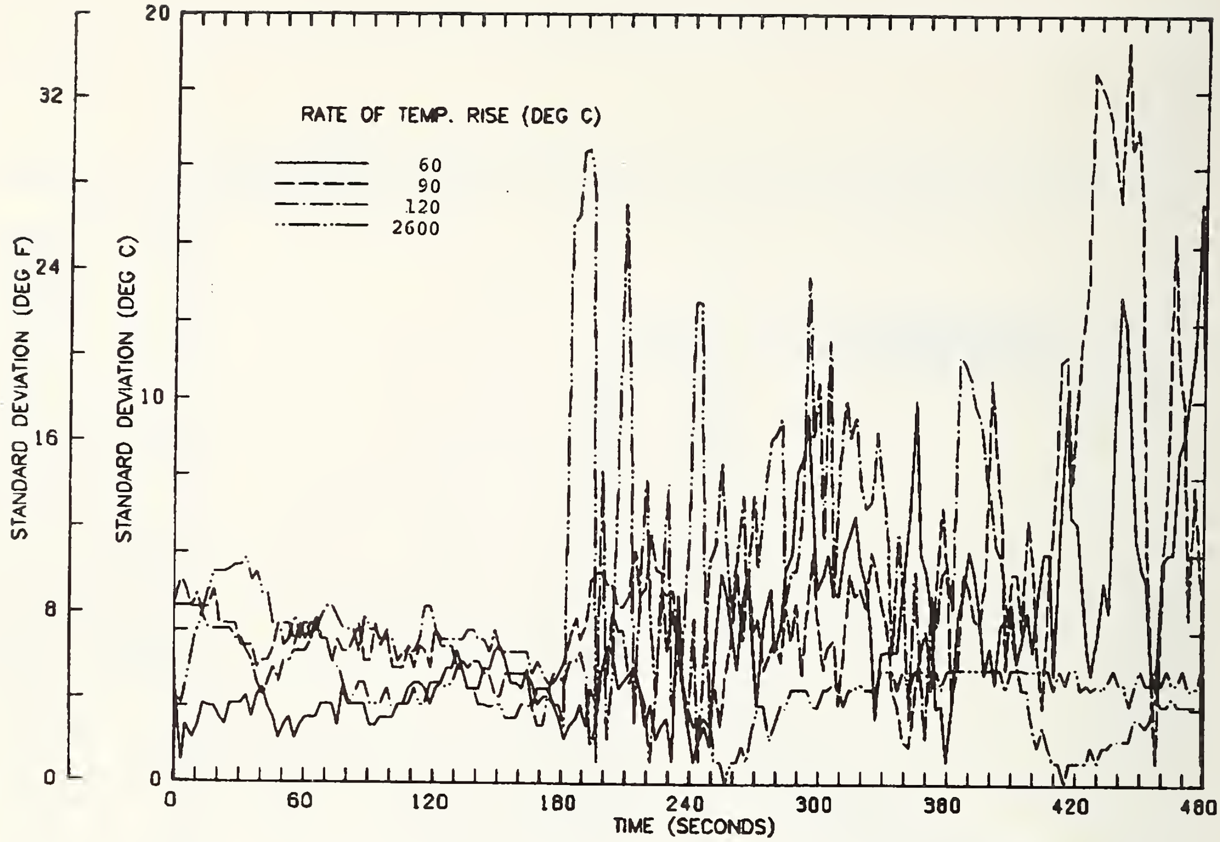

Figure C1. Standard deviation of ceiling air temperature

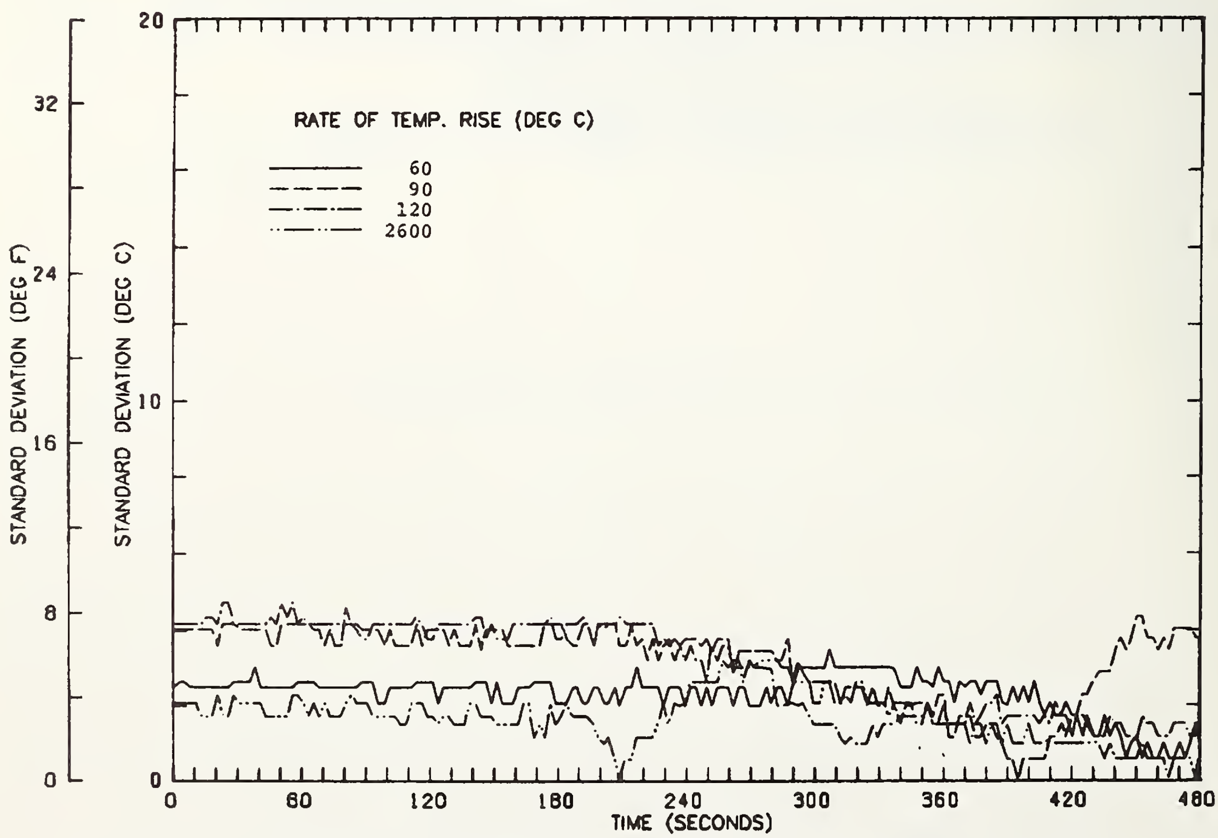

Figure C2. Standard deviation of 160 second disc/pendent position

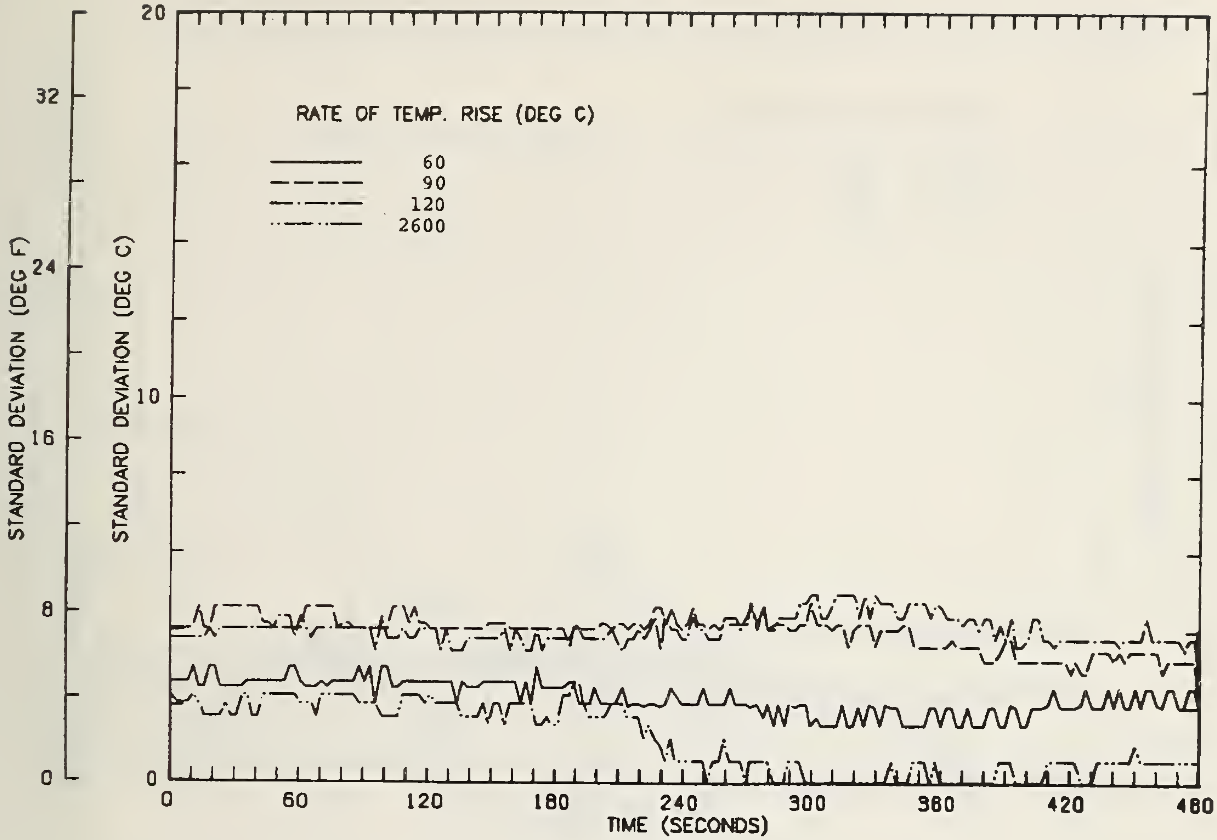

Figure C3. Standard deviation of 160 second disc/door sidewall position

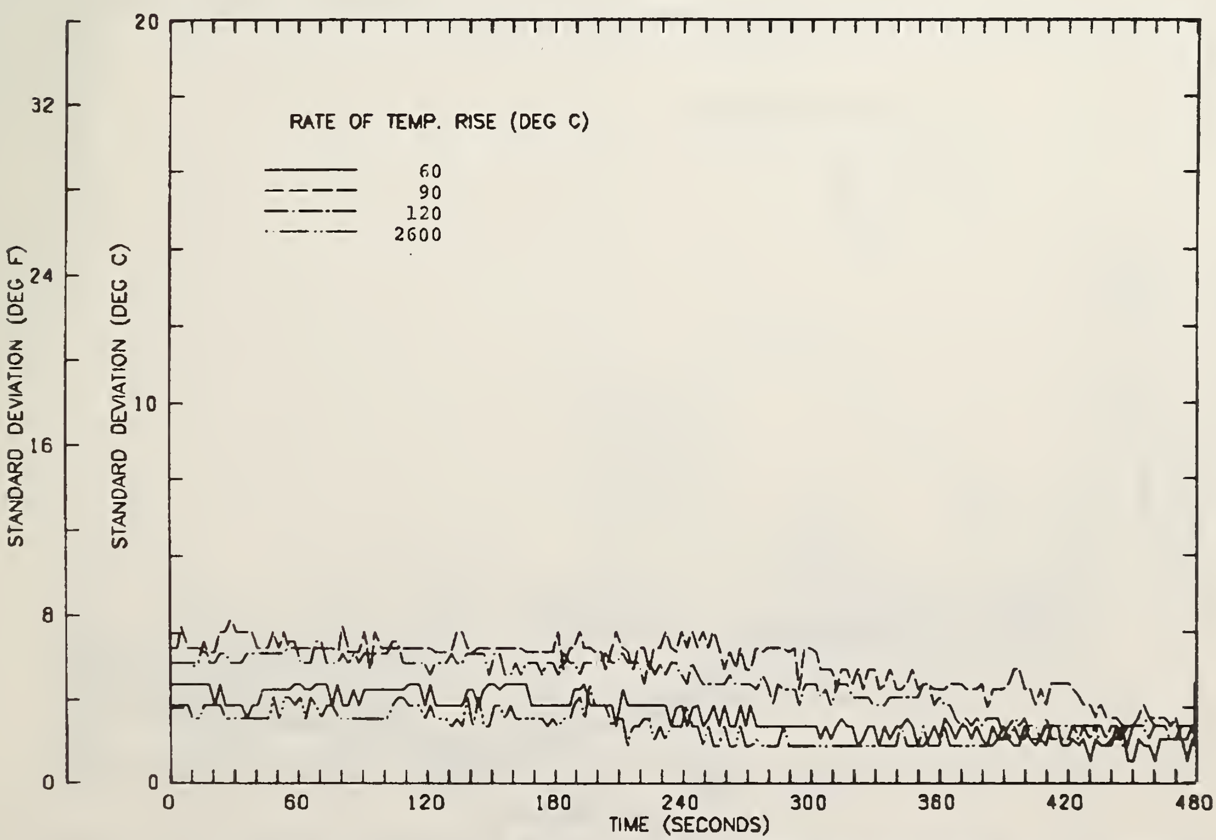

Figure C4. Standard deviation of 160 second disc/opposite sidewall position

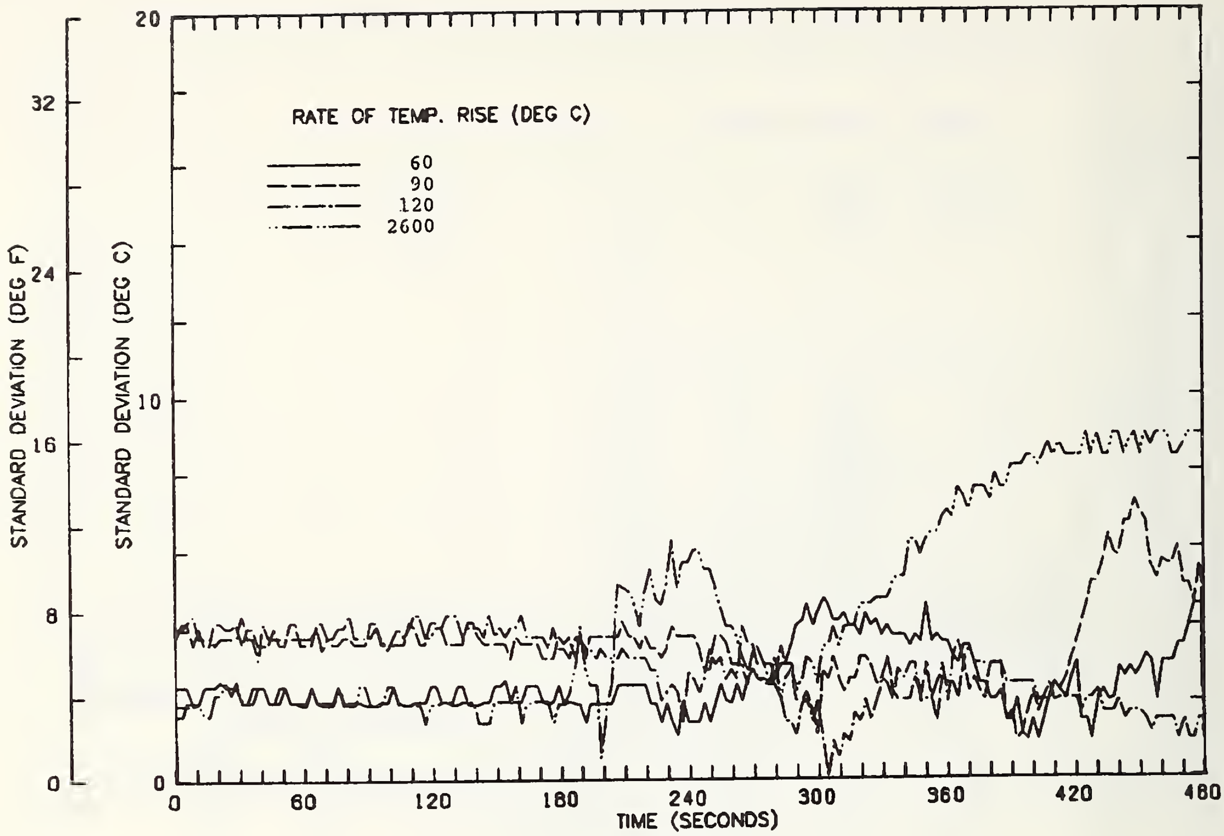

Figure C5. Standard deviation of 80 second disc/pendent positon

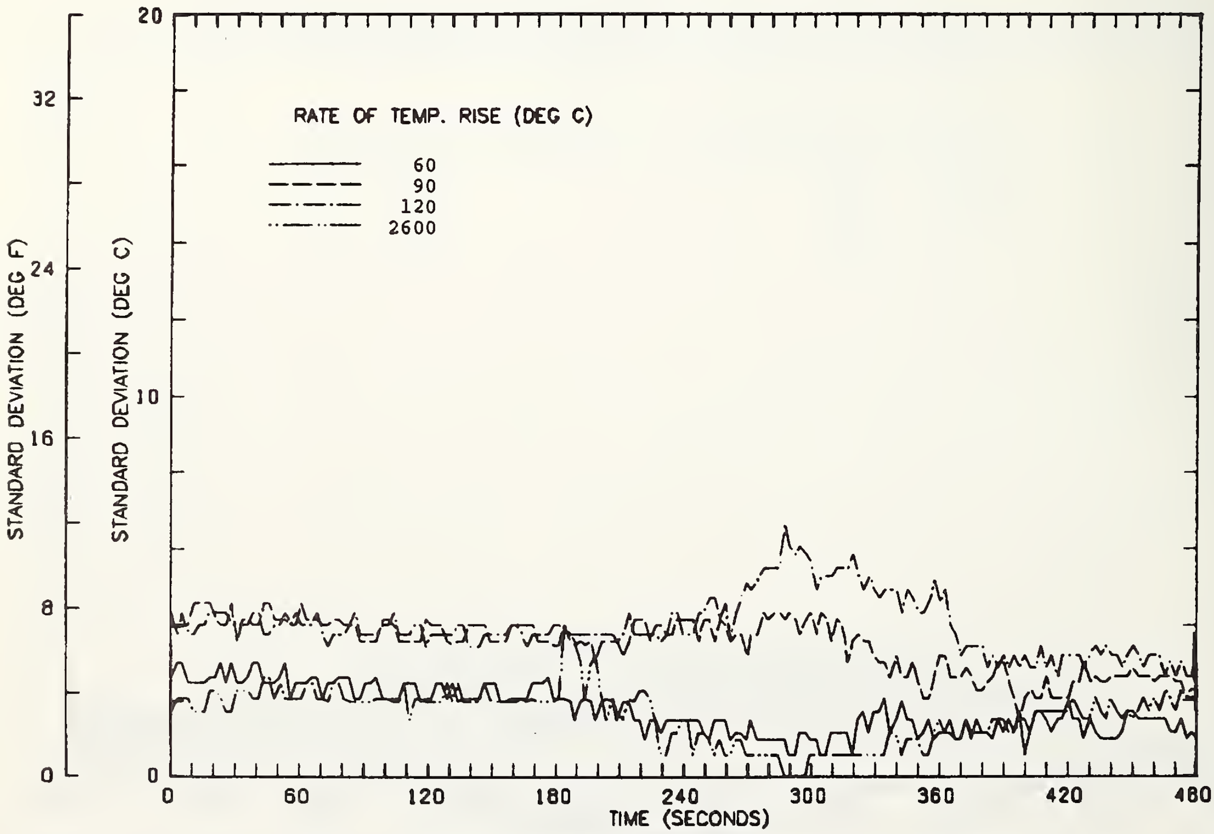

Figure C6. Standard deviation of 80 second disc/door sidewall position

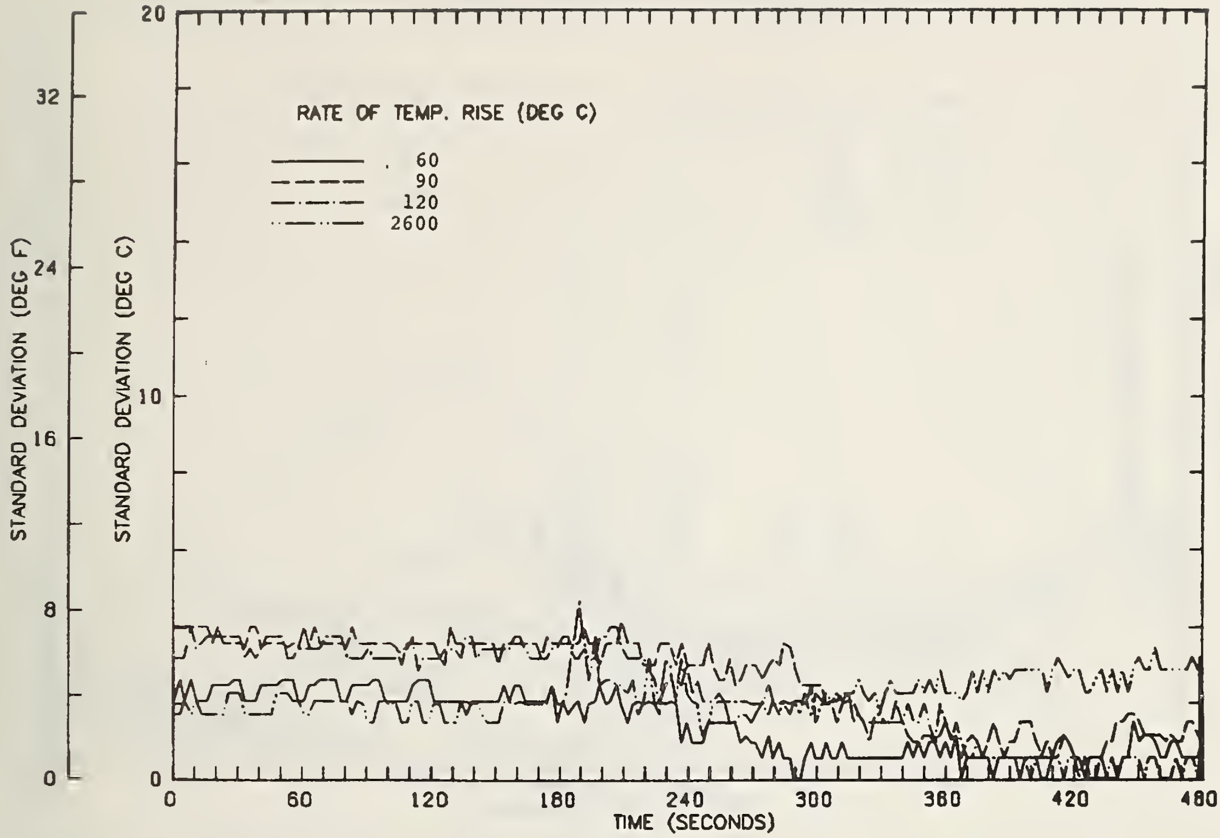

Figure C7. Standard deviation of 80 second disc/opposite sidewall position

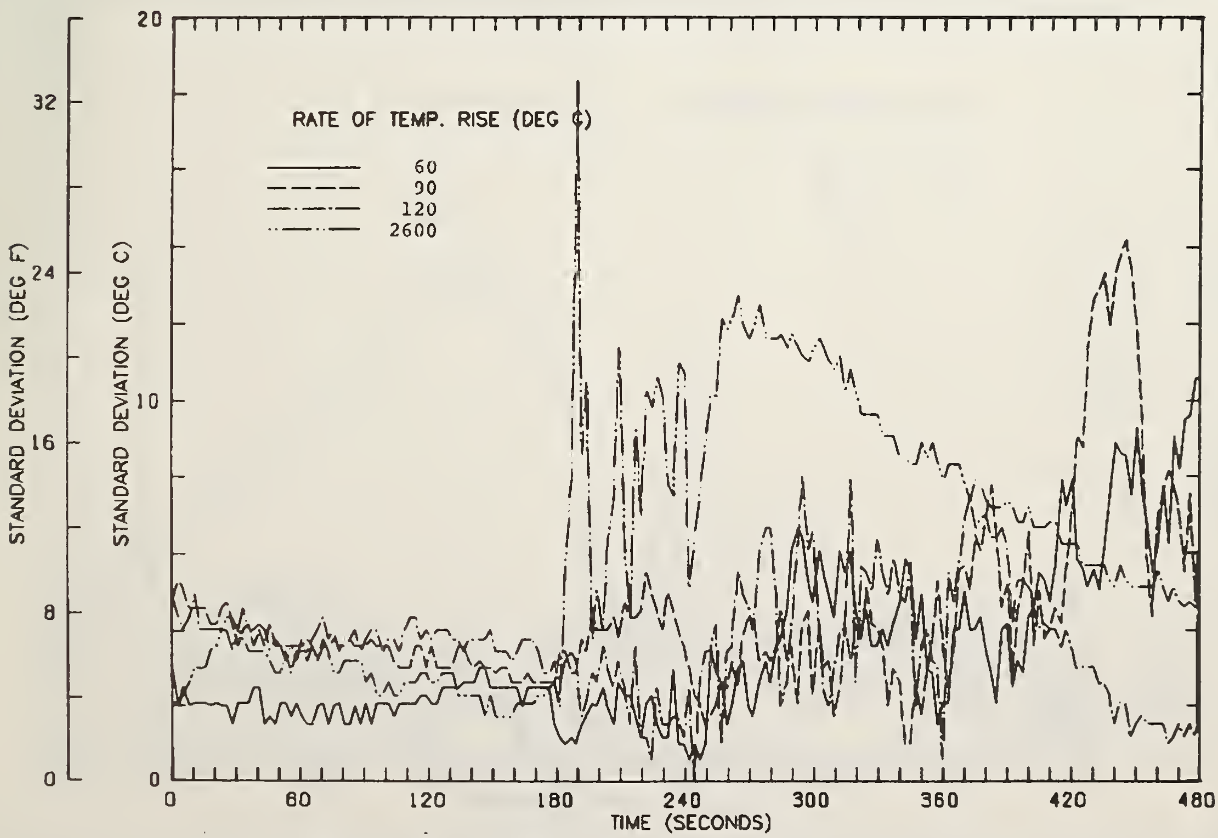

Figure C8. Standard deviation of 21.5 second disc/pendent position

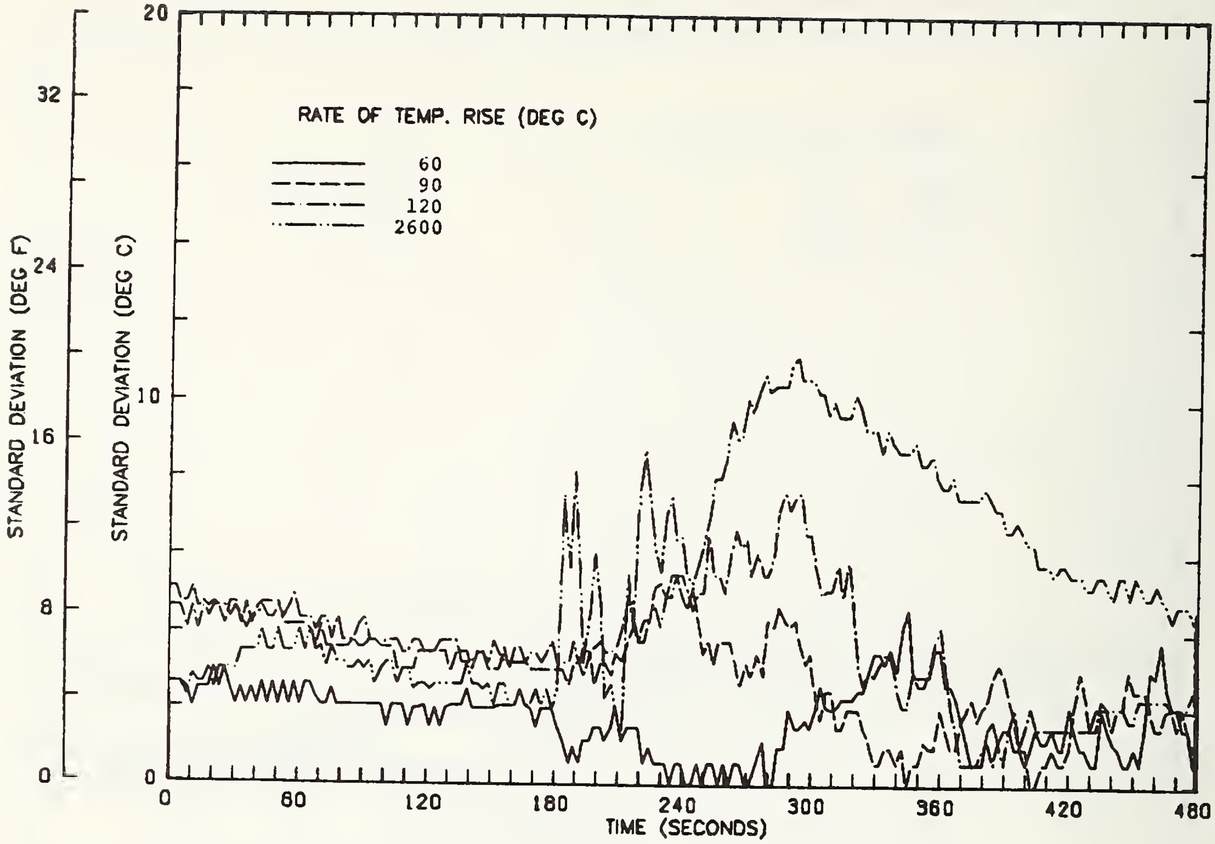

Figure C9. Standard deviation of 21.5 second disc/door sidewall position

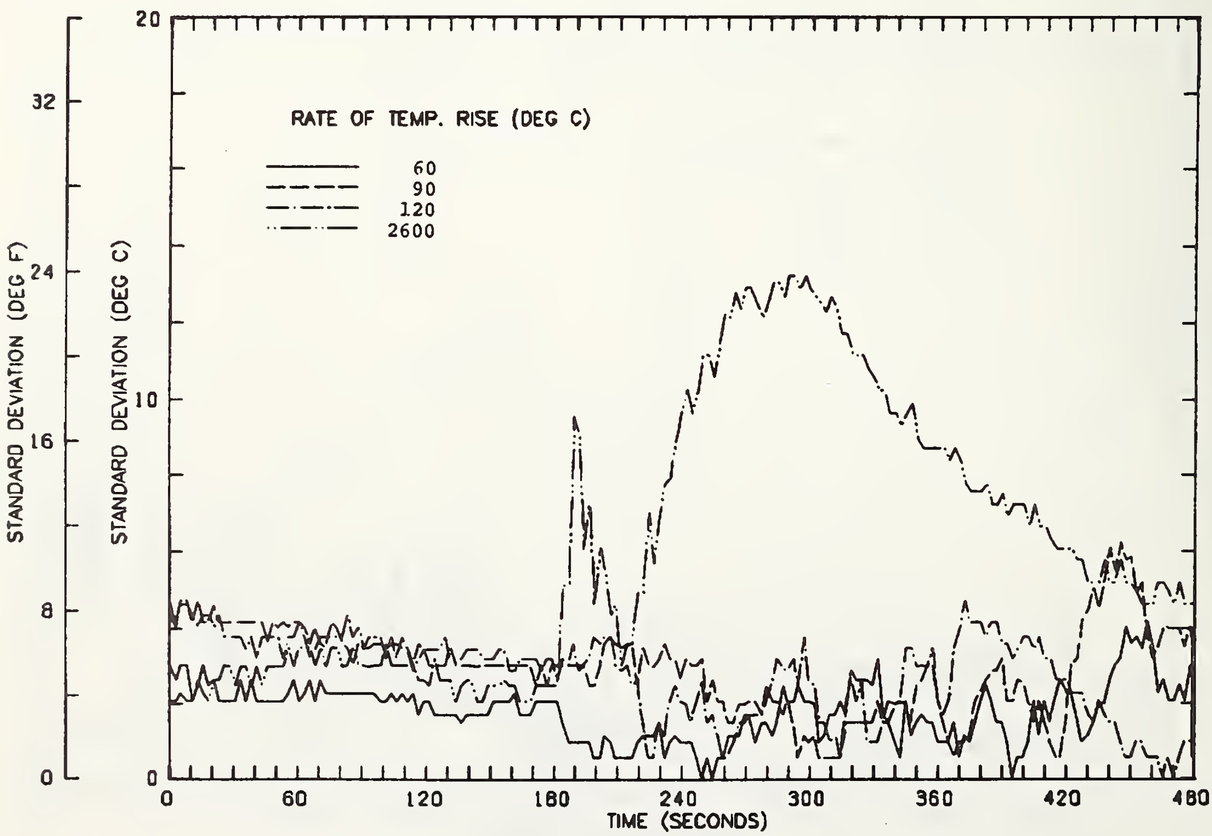

Figure C10. Standard deviation of 21.5 second disc/opposite sidewall position

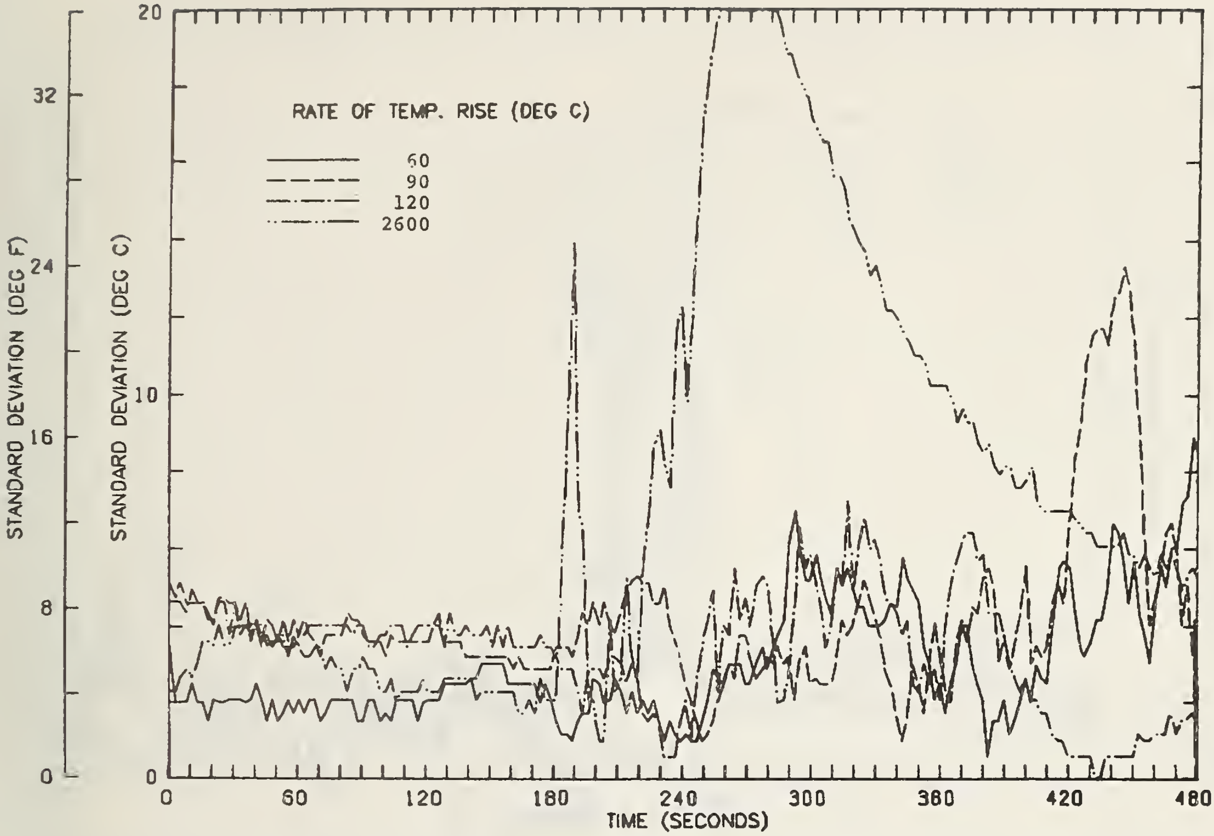

Figure C11. Standard deviation of a blackened 21.5 seond disc/pendent position

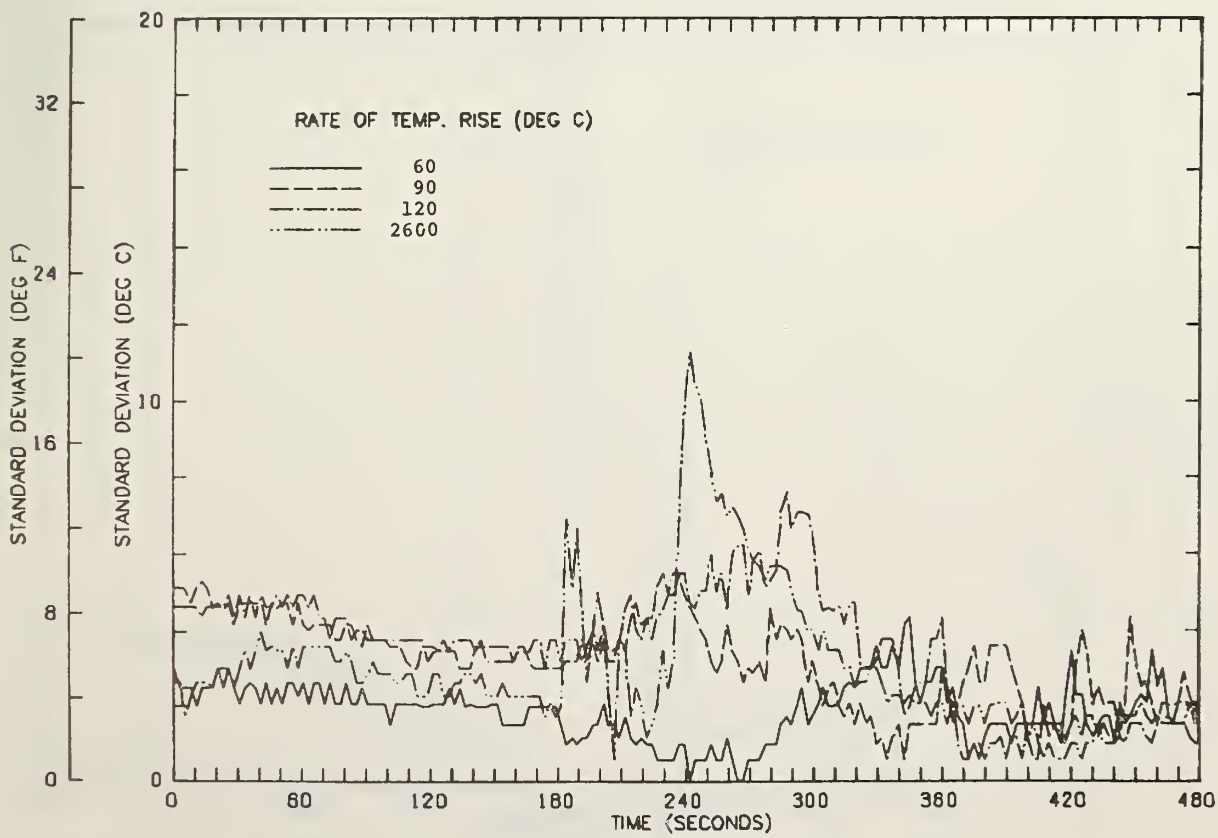

Figure C12. Standard deviation of a blackened 21.5 second disc/door sidewall position

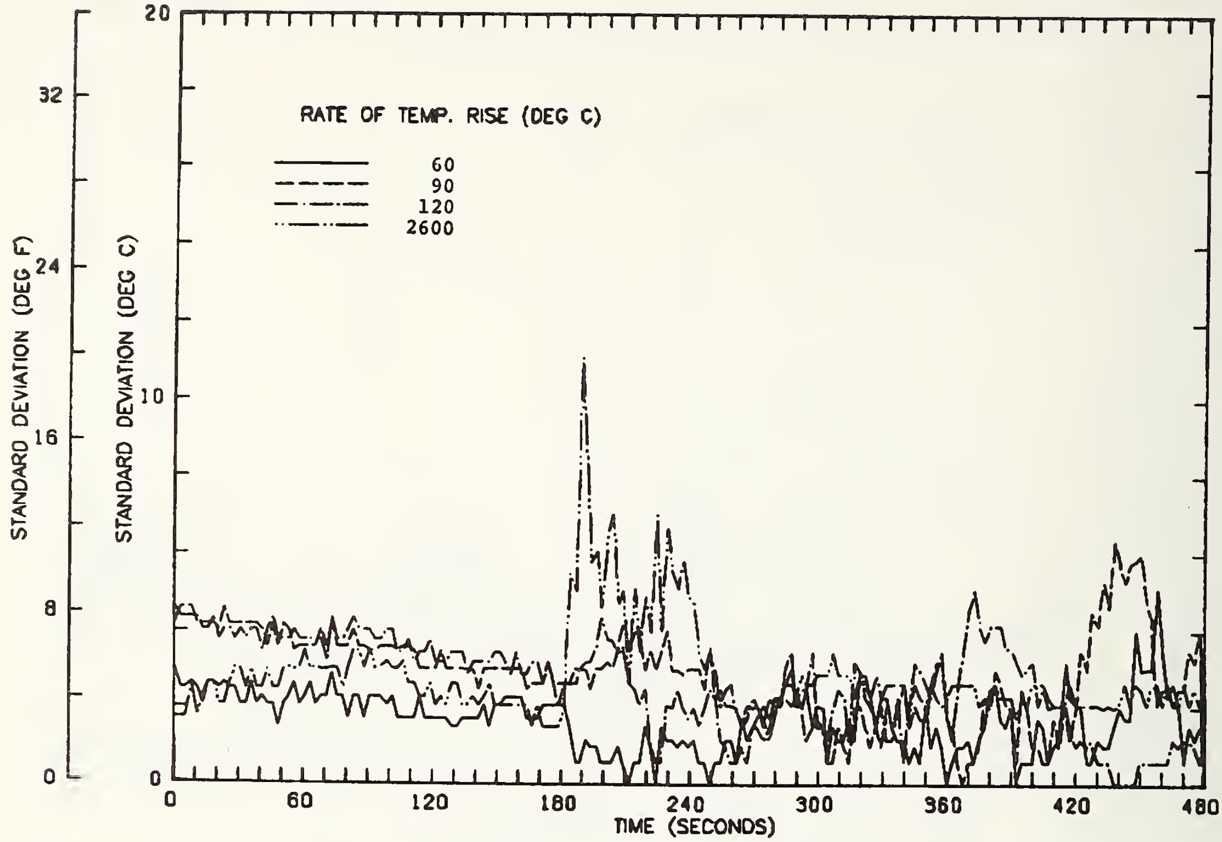

Figure C13. Standard deviation of a blackened 21.5 second disc/opposite sidewall position

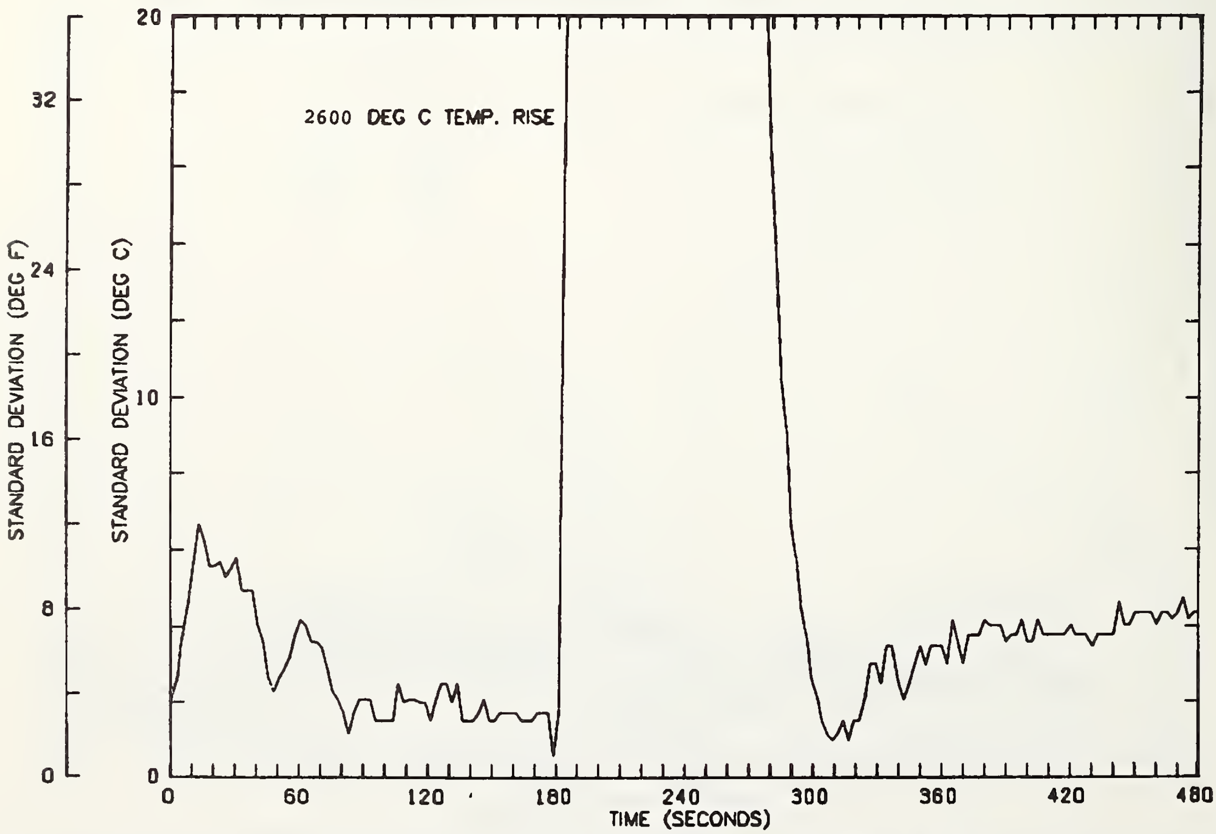

Figure C14. Standard deviation of 5 second disc/pendent position

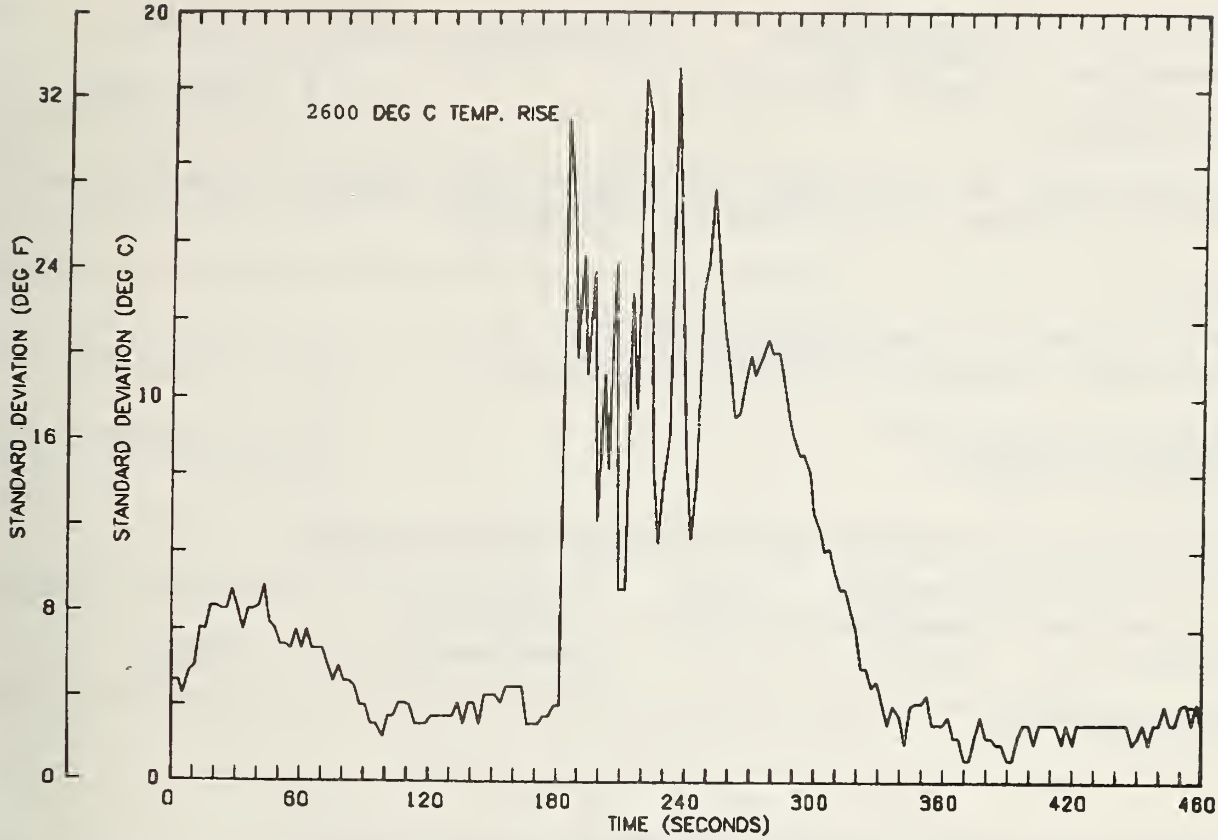

Figure C15. Standard deviation of 5 second disc/door sidewall position

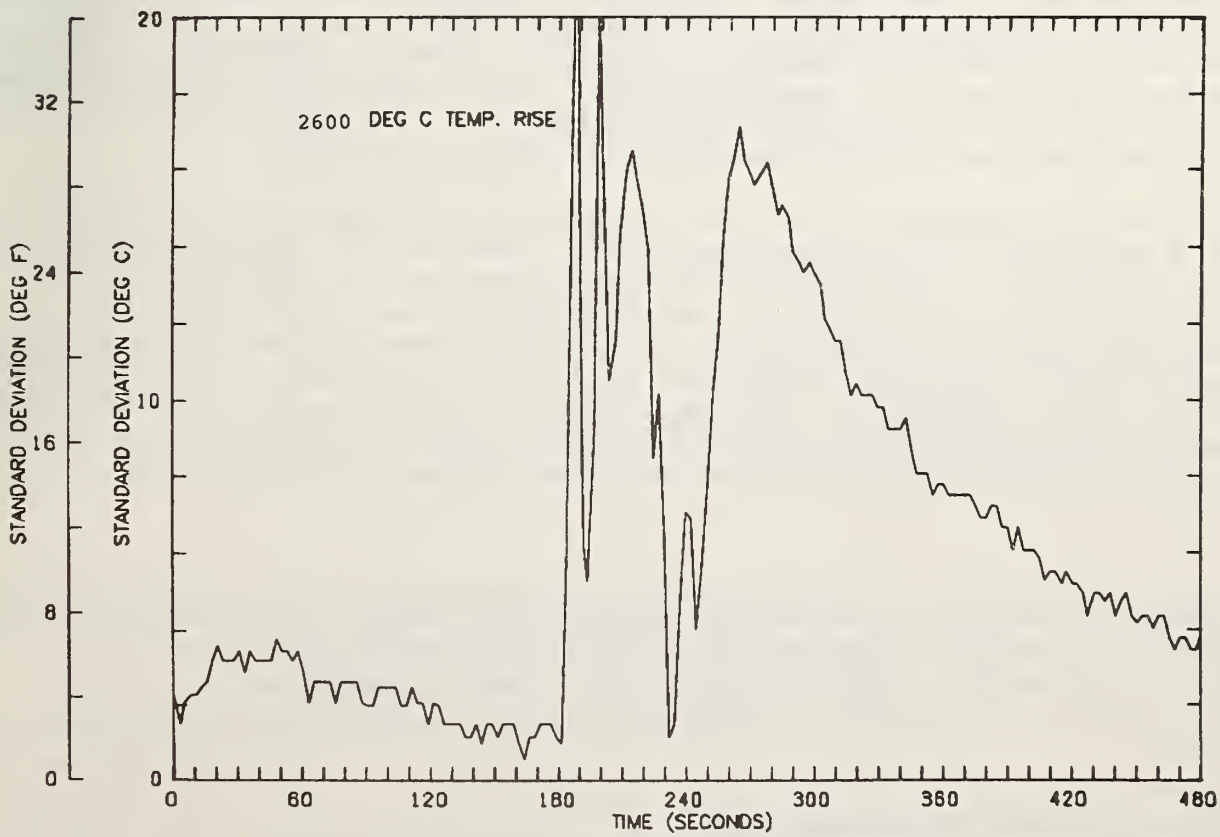

Figure C16. Standard deviation of 5 second disc/opposite sidewall position

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 82-2521	2. Performing Organ. Report No.	3. Publication Date July 1982

4. TITLE AND SUBTITLE

FULL-SCALE STUDY OF THE EFFECT OF PENDENT AND SIDEWALL LOCATION ON THE ACTIVATION TIME OF AN AUTOMATIC SPRINKLER

5. AUTHOR(S)

Warren D. Hayes, Jr. and Richard H. Zile

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

U.S. Fire Administration and Department of Health and Human Services
Federal Emergency Management Agency
Washington, D.C. 20472

Department of Health and Human Services
Washington, D.C. 20201

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A series of 17 full-scale tests was conducted to obtain measurements of the thermal response behavior of simulated and actual sprinklers positioned in the pendent and two separate sidewall locations. Exposure fires were simulated by a propane burner, and replicated the approximate temperature rises of several different burning furniture items typically found in residential and board-and-care type occupancies.

The results indicate that for this test arrangement the response time of a sprinkler is influenced by the location of the sprinkler, the growth rate of the fire, and the response characteristics of the sprinkler itself. In addition, for the fire growth rates studied, differences between the activation times of a pendent positioned sprinkler and those of two sidewall locations appeared significant. In some cases, it appears that equivalent response time at the sidewall location to that of a pendent location cannot be achieved for the configurations tested. The implications of these results require further investigation.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Automatic sprinklers; compartment fires; fire safety; life safety; room fires; sidewall sprinkler systems; thermal response.

13. AVAILABILITY

[XX] Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

74

15. Price

$9.00