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# USFA FIRE BURN PATTERN TESTS

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# REPORT OF

# THE UNITED STATES FIRE ADMINISTRATION

# PROGRAM FOR THE STUDY OF FIRE PATTERNS

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## ***ABSTRACT***

Fire patterns are the visible or measurable physical effects that remain after a fire. These include thermal effects on materials, such as charring, oxidation, consumption of combustibles, smoke and soot deposits, distortion, melting, color changes, changes in character of materials, structural collapse, and other effects.

The first scientifically controlled and recorded research into the formation, growth, nature, and investigative analysis of post-fire patterns was conducted in 1994-1995, by the United States Fire Administration under the direction of a specially appointed research committee of fire investigation experts. To provide data for the research, the United States National Institute of Science and Technology, Building and Fire Research Laboratory (NIST- BFRL) facilitated ten full-scale room fire tests. The purpose of the testing was to provide basic research into the true nature of fire patterns used by fire investigators to make determinations of fire origins and fuels.

The results indicated that generally, fire patterns provide definitive data useful for the determination of the origin of fires. It was found that fire patterns are influenced by a

## ***SUMMARY OF RESULTS***

Many of the concepts, investigative systems, dynamics of pattern production, and patterns analysis concepts put forward in the current, peer reviewed, standard text for fire pattern analysis in the profession, NFPA 921-1995, *The Guide for Fire and Explosion Investigations*, [1][1] were confirmed by the program's testing. These various confirmed fire patterns concepts include the following:

- Formation dynamics of truncated cone patterns
- Intensity patterns
- Movement patterns
- Calcination (dehydration) of gypsum wallboard
- Pattern persistence through flashover
- Pointer/arrow patterns
- Hourglass patterns
- Saddle burns
- Clean burn
- Heat shadowing
- Protected areas
- Beading of electrical conductors

[redacted]

- "V" patterns
- "U" Patterns
- Melting of materials
- Truncated cone patterns

Several of the "old wives' tales" and fire investigation misconceptions which are repudiated in NFPA 921 were also shown to be unsubstantiated by the program testing. Some of these theories include the following:

- Wide "Vs" vs. narrow "Vs"
- Crazing of window glass
- Nature of charring
- Window spotting/staining

Whether patterns are persistent through the room flashover transition is a commonly questioned issue. It had been opined by some, without appropriate testing or research, that flashover would destroy the patterns produced by early plume development. In the program testing, in every case in which the test rooms transited through flashover, the truncated cone (plume and upper layer) produced patterns persisted and were readily identifiable on the wall and ceiling surfaces of the post-flashover compartment.

An enduring "wives' tale" about "V" patterns has been that the angle of the lines of demarcation forming the legs of the "V" patterns were in some way indicative of the rate of burning of the fuel. The adage was *"Wide 'Vs' indicate slow fires, narrow 'Vs' indicate fast fires."* Because this concept of analysis of "V" angles flies in the face of conventional fire science logic, the program directly addressed this issue, in an attempt to put this point to rest. This was done by testing fuel packages with widely different rates of heat release on exactly the same test rooms and producing similarly angled "V" patterns. Other than those aspects which deal with the total plume length and therefore the production of ceiling jets, rates of heat release have little bearing on the angled shape of the patterns produced. In that regard, it could even be argued that the larger the size of the ceiling jets[2], the more downward radiation exists to widen the top of the plume. From this argument it would appear more logical that the "faster" the fire, the wider the "V," but this reversal of the "wives' tale" theory was not displayed in the test results either.

The width of the angles of lines of demarcation of a pattern is largely a function of the rate of heat release and the total time of burning [1].

As a supplementary part of the testing, the production and persistence through flashover of ignitable liquid patterns on floors were explored. Though burned "liquid pour" patterns were evident on floor coverings pre-flashover, the persistence of such patterns through the flashover environment was much less identifiable. A need for more research is indicated in this area.

[2] A ceiling jet is the flow of hot gases below and parallel to a ceiling, away from the point where a fire plume impinges on the ceiling.

Throughout the ten test burns, it became apparent that one factor of fire pattern development, the effect of ventilation, was the least understood. In the first four tests, which were conducted in the full-scale burn facility of NIST, all exhaust gases were mechanically exhausted and collected for species analysis. This provided for a supply of fresh air into the bottom of the test room doorways and prevented the vitiation of the fire. The remaining tests were conducted in actual dwellings where the concentration of oxygen in the air supply to the fire was significantly reduced because of the smoke which accumulated in adjacent compartments. Consequently the fire's entrained make-up air became more and more contaminated with products of combustion, and vitiation of the fire occurred.

In addition, the path of travel of relatively "clean," oxygen-rich air also affected the production of patterns. Except in the cases when the fire originated in the corner itself, the corners of the test rooms acted like small dead-air spaces, where the patterns indicated that less burning was present. Placement of the furniture within the test rooms also had an effect upon the production of the "dead air" spaces. It became clear that the effects of ventilation on fire patterns was an additional factor which also needs more

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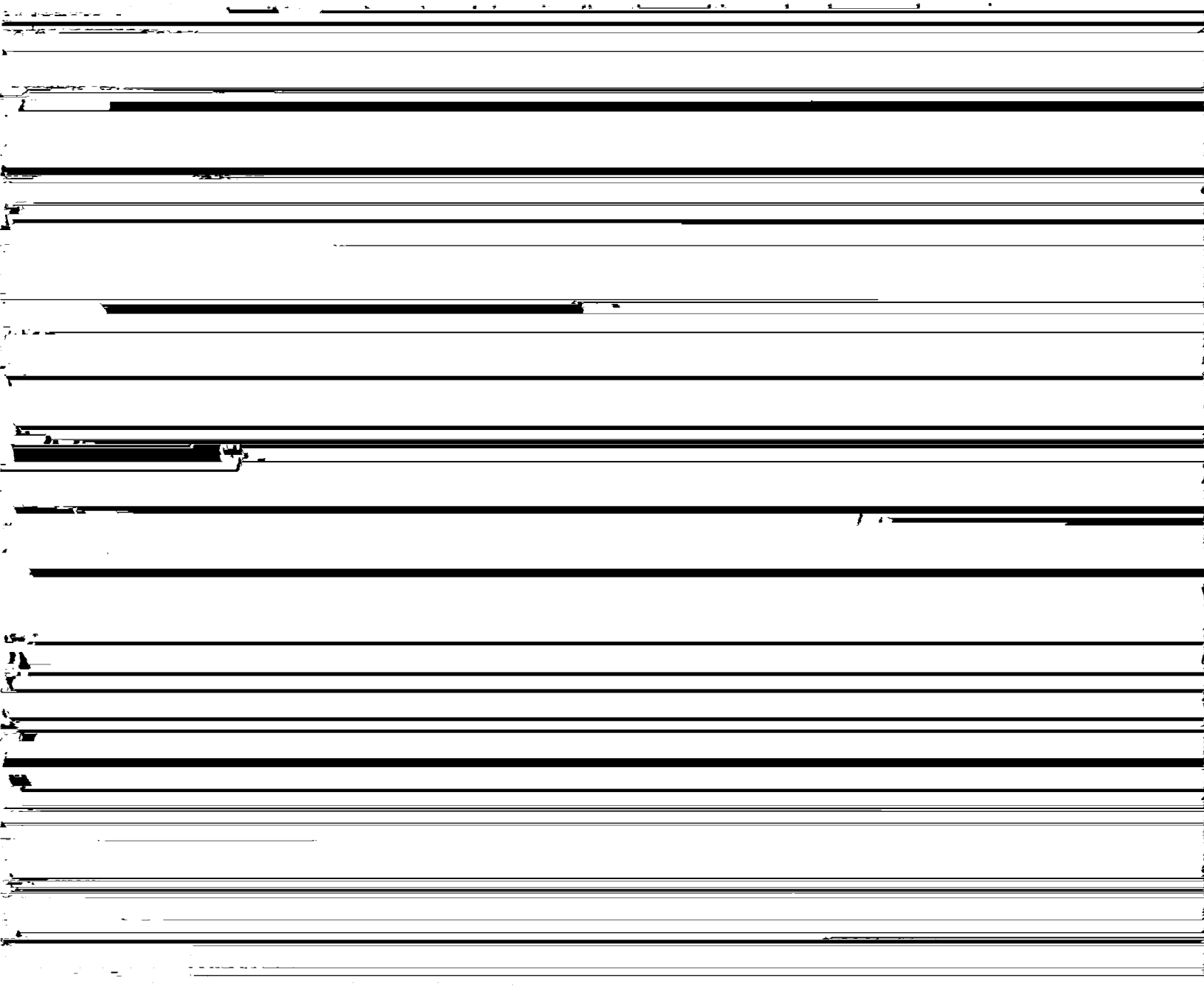
## *I. INTRODUCTION*

Fire and arson investigators often rely on fire patterns to determine the origin of fires. Fire patterns are visible manifestations of the heat and smoke produced by the fire which remain on room interior surfaces and furnishings after the fire is extinguished. These include thermal effects on materials, such as charring, oxidation, consumption of



character of materials, structural collapse, and other effects.

This program consisted of a series of full-scale compartment (room) fire tests that were designed to evaluate the fire characteristics of room fires under actual fire conditions and the effect those conditions have on fire pattern formation. Particular inquiry and analysis

and soot deposits, distortion, melting, color changes, changes in character of materials, structural collapse, and other effects.

In general, it has long been recognized by professional fire investigation experts that without a prior determination of origin, no accurate cause determination can be made[1][2]. Therefore, accurate research in fire pattern development is the cornerstone of fire investigation. If a fire investigator does not have a working knowledge of fire science and research as it pertains to patterns and patterns analysis, he or she is at a great

Over the years, there has been some informal full-scale fire testing leading to a body of fire pattern analysis lore seemingly based on a logical scientific approach. However, the identification, recognition, and analysis of what fire patterns really mean had been largely anecdotal. Up until this program, there had never been any controlled, scientific pattern research with published, peer reviewed results.

## III. TEST ROOM DESCRIPTION

The room size used for full-scale room fire tests are specified by ASTM as 8 by 12 feet, 10 by 10 feet, or 12 by 12 feet, with an 8 foot high ceiling[4]. A 12 by 12 foot room with an 8 foot high ceiling was recommended by the USFA Steering Committee and used for these tests. A standard-size doorway was located in one wall. This door, kept fully open during testing, provided a minimum 16 inch soffit on top to contain the smoke and hot gases.

Since the severity of a fire in its early stages will depend on the heat exchange with the bounding surfaces of the room, it was important that construction details, such as wallboard thickness, type, size and spacing of the studs and joists (16 inches on center), and the thermal insulation in the wall and ceiling cavities, be representative of the

BFRL), Gaithersburg, Maryland. This facility consisted of an instrumented compartment located within a fire test building. A total of four tests were conducted there.

The remaining six tests were conducted in acquired residential structures located in Florence, Alabama and Santa Ana, California. These structures were found by local fire departments, obtained and modified for training purposes. Selected rooms in these structures were prepared by the test team which included cleaning, application of new drywall to walls and ceilings, painting, and furnishing. In addition, the floor type for the specific test was installed. The rooms used were selected based on their similarity to the test protocol and earlier tests. The furniture was shipped from NIST to the test site and placed in the specified position.

In each test the approach was to ignite a fire in a specific and controlled manner, monitor the progress of the fire, extinguish the fire, and conduct a post-fire examination.

The post-fire examination was done in a manner typically used by fire investigators. The condition of the fire scene was documented through the use of still and video photography, observations, and diagramming. This examination was done by program personnel who were experienced in fire investigation and in accordance with NFPA 921 [1]. Specific details noted by the investigators included the condition of fuel packages, status of openings, extent of damage, presence of patterns, shape, location, and character of patterns on the walls, ceilings, floors, and furniture items. An additional detail which was studied in tests where it was possible, was the condition and thickness of any discernable calcination layers formed within gypsum wallboard. This was done through observation by program personnel and by using a dial caliper depth gage.

## *V. TEST FACILITIES*

### A. NIST-BFRL

The test facility utilized at NIST was the Large-Scale Fire Compartment located in Building 205. This facility was specifically designed and was used for large scale research fires. The test compartment was equipped with a large fire products collection hood. Each test room was constructed to the specification as a free standing room within the test compartment. The test rooms were constructed so that the collection hood was located to collect fire products as they were discharged from the room door opening. Within the fire products collector were ports for the sampling and analysis of the fire gases. Within each room thermocouples and radiometers were placed as specified below for the measurement of temperature and radiant flux.

For Tests 1 and 3 the installed floor was a noncombustible masonry board material installed on the wood floor joists. For Tests 2 and 4 the floor was plywood installed over the wood floor joists. On the plywood was installed new synthetic carpeting and pad, which covered the entire floor area.

Figure 1 which is located in section XVI below, is a diagram of this test room. Appendix A is a more detailed description of the test room construction and setup which was used as a specification for all of the tests.

### B. Florence, Alabama

With the cooperation of the Florence, Alabama Fire Department a residential structure

Figures 2 and 3 are diagrams of the test rooms for Tests 5 and 6, respectively and are located in section XVI below.

**C. Santa Ana, California**

With the cooperation of the Santa Ana, California Fire Department two residential structures were obtained and utilized for Tests 7, 8, 9 and 10. They were both single story wood frame structures built over an unfinished basement. Within each structure there were two rooms which were utilized for the actual tests. These rooms were similar in size and configuration to that specified in the original work proposal and to the room constructed at NIST. New gypsum wallboard was installed over the existing walls and ceiling. These surfaces were also painted as specified. For Tests 7 and 8 new, self-adhesive vinyl tile was installed on the existing wood floor. For Tests 9 and 10 the existing wood floor was cleaned and used without a covering.

Figures 4, 5, 6 and 7 are diagrams of the test rooms for Tests 7, 8, 9 and 10, respectively and are located in section XVI below.

## *VI. TEST PROCEDURE*

Two baseline test fires, Tests 1 and 3, were utilized to characterize fire heat release rates and growth rates in the standard test room and to establish baseline patterns on walls, ceiling and floor. A suitably sized wood crib (Test 1) and a pool of gasoline (Test 3) were used in separate tests for this. No furniture was present in the room for the baseline tests. The quantity of fuel utilized in both baseline tests was sufficient to create flashover conditions in the room.

The other eight pattern analysis tests utilized the standard test room with identical furniture items placed in it. The ignition scenarios were either accelerated or non-accelerated. The accelerated ignition scenario utilized a quantity of gasoline poured on the floor in one area of the room. The non-accelerated ignition scenario utilized several

sheets of newspaper placed and ignited in the easy chair. The test fires were allowed to free burn for some time period after flashover before the fire was extinguished. In the case where flashover conditions were not produced, the test was stopped and the remaining fire extinguished after a total burn time of approximately 7 minutes.

Suppression of the test fires was done using a spray nozzle utilizing a 30° fog pattern. This nozzle was connected to a 1-3/4 in. hose line which was supplied by at least a 500 gpm pump. The nozzle was held in place by a fire fighter. The water flow rate through the nozzle did not exceed 150 gpm and the pressure at the nozzle did not exceed 120 psi. A safety backup 2-1/2 in. hose line was also present and preconnected to the water supply. Water was applied only as needed to suppress the fire without causing unnecessary damage to room or furniture surfaces. Overhaul of the rooms was kept to a minimum.

## *VII. TEST MATRIX*

Table 1 presents the test matrix for this program. The major variables are the character of the ignition fire (accelerated or non-accelerated) and the floor covering.

**Table 1. Pattern Analysis Program Test Matrix**

| TEST# | LOCATION | IGNITION FIRE | FLOOR | FURNITURE |
|---|---|---|---|---|
| 1 | NIST 205 | WOOD CRIB | NONCOMB. | NO |
| 2 | NIST 205 | NEWSPAPER | CARPET | YES |
| 3 | NIST 205 | GASOLINE POOL | NONCOMB. | NO |
| 4 | NIST 205 | GASOLINE POUR | CARPET | YES |

## *VIII. INSTRUMENTATION*

All of the fire tests were conducted with the following parameters recorded as a function of time: ceiling temperature, upper layer temperature gradient(s), lower layer temperature gradient(s), floor temperatures, and incident radiant heat flux. For the tests conducted at NIST additional instrumentation was available and permitted measurement of oxygen concentration and flow rate of the exhaust gases collected in the hood. At the field tests (Florence and Santa Ana) portable oxygen analyzers were used to measure oxygen concentrations at two locations in each room.

Radiometers were placed on the floor inside the door opening and at the door opening. In Tests 1 through 4, a third radiometer was placed within 6 in. of the ignition fire. Radiometers were cooled with water to ensure their reliability and to minimize thermal damage to them.

Gas temperature measurements at locations throughout the compartment were obtained

In addition to the above specified instrumentation, still and video photography was used

during each test to document the growth and progression of the fire. Photographic records of the compartment fire were supplemented by direct observation and dictation using audio recorders.

To aid in the identification of flashover conditions, each test utilized a piece of newspaper placed in the center of the floor. When this "tell tale" ignited by exposure to radiant energy, it became a good indicator of flashover conditions.

## ***IX. PROCESSING THE SCENE***

Each fire test scene was processed using generally recognized techniques and methods as outlined in such references as:

- NFPA 921, *The Guide for Fire and Explosion Investigations*[1];
- International Association of Arson Investigators-Massachusetts Chapter Accelerant Evidence Collection Guide[5];
- National Fire Academy, Fire Investigation Curricula[6]; and
- Open Learning for Fire Service Program Curricula[7].

Scene processing requires knowledge and skills gained through years of actual scene processing. Such skills were not available at NIST. Therefore scene processing was done by and at the direction of the USFA Fire Pattern Program Steering Committee and its technical advisor.

(i.e., fuel geometry, radiation effect, conduction effect, etc.). Classification utilized accepted terminology and description, as found in Chapter 4 of NFPA 921[1].

Measurements were taken of the dimensions of the room and features such as window and door sizes and locations, for the purpose of producing a diagram of each test.

Using the depth gauge of a dial caliper, the thickness of the layer of dehydrated gypsum in the walls and ceiling were determined at various locations. The general procedure was to insert the depth gauge with sufficient force to penetrate the outer, darker layer but not enter the inner, lighter layer. The caliper reading indicated the depth of the layer of dehydrated gypsum. Generally, this procedure was started at a given height on a wall, and then readings were taken every 12 inches along the wall, noting the readings and any trends. This procedure worked best where the paper covering of the wallboard had burned away but the gypsum had not crumbled away.

Full Heat and Flame Vector Analyses were conducted and Vector Diagrams produced for Tests 5 and 6.

## *X. TEST DESCRIPTIONS AND OBSERVATIONS*

### A. Test 1

***Description***

Test 1 was conducted on November 7, 1994 at the NIST facility. In the room was placed a 40 Kg (88 lb.) wood crib. With the exception of wood trim items and the interior finish, the crib was the only fuel package in the room. The floor covering was marinite, a non-combustible building material.

This crib was constructed of nominal 2 in. by 2 in. wood members stacked and nailed 6 to a row with a total height of 16 rows. This crib was sized to produce a peak heat release rate of 500 kW. The mass of the crib was 42.7 Kg (93.9 lb.).

The crib was placed against and in the middle of the right wall as shown in Figure 1. Under the crib was placed a small metal pan, approximately 6 by 6 by 2 in., which contained 100 ml of heptane. The heptane was ignited with an electric match device. The crib was ignited by the burning heptane.

***Observations***

After approximately 2 minutes the wood crib was burning with about 25% of its surface area involved and the resulting flame was approximately half the room height, 3.5 ft. After approximately 3 minutes the flames from the burning crib were impinging on the ceiling. Smoke production at this time was very light. After approximately 5 minutes the drywall in the vicinity of the crib began to char, and after approximately 6 minutes it started to burn with the fire spreading on the wall surface. After approximately 8 minutes the fire was burning at floor level and indicators of flashover were present. These included upper layer temperatures in excess of 600°C (1112°F ), flame jet at the ceiling from the crib, flames coming from the door opening, and ignition and combustion of wood trim at floor level. The production of visible smoke which had been very light up to this point in the test, increased. After approximately 20 minutes the intensity of the fire had diminished considerably and was extinguished with water a short time later.

The total test burn time was 20 minutes.

***Photographs***

Photographs 1 through 6 shown in Section XVII below were from Test 1.

***Data***

Figure 10 shows the temperature-time history for Test 1. Figure 11 shows the

**B. Test 2**

***Description***

Test 2 was conducted on November 22, 1994 at the NIST facility. The test room was fully furnished as described above. In the chair was placed 2 sheets of

[redacted]

newspaper. Ignition of the newspaper and chair was achieved by an electric match.

***Observations***

After 1 minute approximately 50% of the top surface of the chair was involved and burning with a flame height of approximately 2 ft. above the chair. Smoke production was light. After 2.5 minutes the surface of the chair was 75% involved with a flame height of approximately 4 ft. Visible smoke production increased significantly at this point. A smoke layer with a thickness of approximately 2 ft. was observed at 3 minutes. The window was still intact at this

*Data*

The data collection system malfunctioned during this tests and no data were recorded or preserved.

**C. Test 3**

***Description***

poured 1.25 liters (0.33 gal.) of regular unleaded gasoline. The gasoline was poured on the floor on the left side of the room, centered against the left wall. With the exception of wood trim items and the interior finish, the gasoline pool was the only fuel package in the room. The pool that formed had a diameter of approximately 4 ft. The floor covering was marinite, a non-combustible building material.

***Observations***

*Data*

Figure 13 shows the heat release rate history for Test 3. Figure 14 shows the floor level radiant heat flux for Test 3. Figure 15 shows the ceiling-to-floor temperature profile in the center of the compartment for Test 3. Figure 16 shows the ceiling-to-floor temperature profile at the doorway of the compartment for Test 3. Figure 17 shows the ceiling-to-floor temperature profile at the window of the compartment for Test 3.

**D. Test 4**

*Description*

Test 4 was conducted on January 10, 1995 at the NIST facility. For this test the room was fully furnished as specified and the floor was covered with carpet and pad. The test was started by pouring 1.25 liters (0.33 gal) of regular unleaded gasoline in the room and igniting it with an electric match. The gasoline was poured in the area of the chair so that it wetted the left side of the chair and formed a pool on the floor on the left side and in front of the chair. An additional quantity of gasoline, 0.5 liters (0.13 gal), was poured as a trailer from the pool near the chair to the door opening.

*Observations*

Almost immediately after ignition the pool of gasoline was involved as well as the

opening. The fire was allowed to continue post-flashover in a ventilation controlled state until 10 minutes when it was extinguished.

The total test burn time was 10 minutes, 20 seconds.

***Photographs***

Photographs 22 through 27 shown in Section XVII below were from Test 4.

***Data***

Figure 18 shows the heat release rate history for Test 4. Figure 19 shows the floor level radiant heat flux for Test 4. Figure 20 shows the ceiling-to-floor temperature profile in the center of the compartment for Test 4. Figure 21 shows the ceiling-to-floor temperature profile at the doorway of the compartment for Test 4. Figure 22 shows the ceiling-to-floor temperature profile at the window of the compartment for Test 4.

**E. Test 5**

***Description***

Test 5 was conducted on June 6, 1995 in Florence, Alabama. The test utilized a furnished room in a residential structure as specified above. The floor was covered with the same carpet and pad as used on previous tests. Several sheets of

Observations of the growth and spread of this fire and Test 6, could not be made as easily as at the NIST facility because of the accumulation of fire products in the rest of the structure. All descriptions of the fire were from the video cameras, instrumentation, or from exterior observation.

***Observations***

After 2 minutes the chair seat was fully involved. At 3 minutes the oxygen level in the room started to decrease. At 4 minutes the upper layer temperature had reached 750°C (1382°F) and the chair and wall behind it were well involved. At 4 minutes 20 seconds a piece of newspaper left on the floor, the "tell tale", ignited and a few seconds later the bedspread and carpet ignited. This indicated that flashover conditions had been achieved. After flashover the window glass cracked and then fell out some time later. At 5 minutes the oxygen level at floor level inside the room was at 19%, at 6 minutes it was 11%, and at 7 minutes it was 7%. At 7 minutes suppression efforts were started.

The total test burn time was 7 minutes.

***Photographs***

Photographs 28 through 40 shown in Section XVII below were from Test 5.

***Data***

Figure 23 shows the floor level radiant heat flux history in the test room and the adjoining hallway for Test 5. Figure 24 shows the oxygen content approximately 12 in. above the floor at the doorway for Test 5. Figure 25 shows the floor to

**F. Test 6**

***Description***

Test 6 was conducted on June 6, 1995 in Florence, Alabama, in the same structure as Test 5. The test utilized a different room, fully furnished as specified above. The floor was covered with the same carpet and pad as used on previous tests.

The test was started by pouring 1.25 liters (0.33 gal) of regular unleaded gasoline in the room and igniting it. The gasoline was poured on the floor in front of the chair so that it formed a pool on the floor. An additional quantity of gasoline, 0.5 liters (0.13 gal), was poured as a trailer from the pool to the door opening. This trailer was ignited with a road flare.

Two thermocouple trees were installed and used: one at the room center and the other at the door opening. One radiometer was located on the floor in the center of the room and one was on the floor of the halllway, outside the door to the test room. Two oxygen concentration measurements were taken at the door to the test room, one was located at floor level and the other was located 12 in. above the floor.

***Observations***

Almost immediately after ignition the pool of gasoline was involved as well as the front of the chair which was very close to the burning pool. Within 30 seconds thermocouples recorded temperatures in the upper layer which exceeded 600°C (1112°F) and temperatures at the doorway had reached 900°C (1652°F). At 1.5 minutes a small fire was noticed below the room in the crawl space/basement

This fire was immediately extinguished. After approximately 2 minutes the gasoline fire intensity was decreasing and the oxygen concentration at floor level inside the room had dropped to 19.5%. At 3 minutes the glass in the window cracked but the glass pieces did not fall out. Oxygen concentration at this time was 17.5%. At 4 minutes fire could be seen at floor level near the base of the chair. Temperatures had dropped to 300°C and oxygen concentration was down

to 15.2%. At 7 minutes suppression efforts were started. Flashover conditions were not observed.

The total test burn time was 7 minutes.

***Photographs***

Photographs 41 through 51 shown in Section XVII below were from Test 6.

***Data***

Figure 27 shows the floor level radiant heat flux history in the test room and the adjoining hallway for Test 6. Figure 28 shows the oxygen concentration at approximately 4 and 12 in. above the floor at the doorway for Test 6. Figure 29 shows the floor-to-ceiling temperature profile in the center of the compartment for Test 6. Figure 30 shows the floor-to-ceiling temperature profile at the door of the compartment for Test 6.

**G. Test 7**

***Description***

Test 7 was conducted on July 10, 1995 in Santa Ana, California. The test utilized a furnished room in a residential structure as specified above. The floor was covered with a self-adhesive tile which was applied to an existing wood floor. The tiles were white with a gray pattern. Several sheets of newspaper were placed on the chair and were ignited with an electric match.

Three thermocouple trees were used: one each at the window, room center, and doorway. One radiometer was located in the center of the floor and one was on the floor immediately outside the door. Oxygen analyzer sample collection tubing was located 12 in. above the floor in the center of the room and at the doorway.

*Observations*

Observations of the growth and spread of this test fire and Tests 8, 9 and 10 could

not be made as easily as at the NIST facility because of the accumulation of fire products in the rest of the structure. All descriptions of the fire were from the video cameras, instrumentation, or from exterior observation.

After 40 seconds the top surface and left arm of the chair were involved with a flame height of approximately 18 in. At 1 minute 12 sec nothing was visible from outside the structure. At 2 minutes a smoke layer was observed in the hallway outside the test room which filled the upper one-third of this room. No flames were visible in the hallway at this point. At 3 minutes the fire was continuing to grow and the smoke layer in the hallway filled half of this room and was more

*Data*

Figure 31 shows the floor level radiant heat flux history in the test room and the adjoining hallway history for Test 7. Figure 32 shows the oxygen content approximately 12 in. above the floor in the center of the room and at the doorway [redacted] Figure 33 shows the floor-to-ceiling temperature profile in the center of the compartment for Test 7. Figure 34 shows the floor-to-ceiling temperature profile at the window of the compartment for Test 7. Figure 35 shows the floor-to-ceiling temperature profile at the door of the compartment for Test 7.

**H. Test 8**

*Description*

Test 8 was conducted on July 10, 1995 in Santa Ana, California. The test utilized a furnished room in the same residential structure as Test 7. The floor was covered with a self-adhesive tile which was applied to an existing wood floor, the same as Test 7.

The test was started by pouring regular unleaded gasoline in the room and igniting

***Observations***

Immediately following ignition the trailer and gasoline were fully involved. At 30 seconds the window glass had cracked, by 1 minute it had fallen from the frame, and flames were observed coming from the opening. At 1 minute the room oxygen concentration at floor level had dropped to 5%, upper layer temperatures exceeded 600°C (1112°F). At 1.5 minutes flames persisted from the window opening. By 2 minutes the flame continued coming from the window and flame could be observed in the room in the vicinity of the bed. At 6 minutes flame could no longer be seen in the room and it was no longer coming from the window opening. At 7 minutes suppression efforts were started.

The total test burn time was 7 minutes.

***Photographs***

Photographs 61 through 71 shown in Section XVII below were from Test 8.

***Data***

Figure 36 shows the floor level radiant heat flux in the test room and the adjoining hallway history for Test 8. Figure 37 shows the oxygen content approximately 10

was. Several sheets of newspaper were placed on the chair and were ignited with an electric match. The chair was located in a corner of the room.

Three thermocouple trees were used: one each at the window, room center, and doorway. One radiometer was located in the center of the floor and one was on the floor immediately outside the door. Oxygen analyzer sample collection tubing was located 12 in. above the floor in the center of the room and at the doorway.

***Observations***

At 3 minutes there was light smoke visible from the outside. The upper layer temperatures were approximately 200°C (392°F). At 3.5 minutes flame was observed under the chair. At 3 minutes 45 sec the fire had spread to the bed and seconds later the newspaper "tell tale" ignited. At 4 minutes the window glass cracked. It fell from the frame at 4.5 minutes. At 4.5 minutes flame was observed in the room which extended to and impinged on the ceiling. Flame came from the window opening intermittently. Flashover conditions were observed including upper layer temperatures which exceeded 800°C (1472°F). At 5 minutes a steady body of flame was coming from the window opening. The oxygen concentration in the room had dropped to less than 1%. At 6 minutes the flame from the

43 shows the floor-to-ceiling temperature profile in the center of the compartment for Test 9. Figure 44 shows the floor-to-ceiling temperature profile at the window of the compartment for Test 9. Figure 45 shows the floor-to-ceiling temperature profile at the door of the compartment for Test 9.

**J. Test 10**

***Description***

Test 10 was conducted on July 11, 1995 in Santa Ana, California. The test utilized a furnished room in the same residential structure as Test 9. The floor was the same as Test 9, the cleaned original wood. The chair was located in a

flames were confined to the room, and were over the area of the bed. The oxygen concentration in the room was at 11%. At 4.5 minutes the intensity of the fire was decreasing. At 7 minutes suppression efforts were started.

During the course of Test 10, the window glass of the test room became sooted and finally cracked with one or more long undulating fractures. There was no crazing of the glass, even though the initial fuel source for the accelerated fire was gasoline. When

fell to the ground outside the test building, some of them were purposely sprayed with a small amount of water from a pressurized water portable extinguisher. This caused the glass which was still hot, to craze. The glass which had fallen from the window and was not sprayed with water did not craze or show any evidence of crazing after it had cooled.

The total test burn time was 7 minutes.

***Photographs***

Photographs 82 through 90 shown in Section XVII below were from Test 10.

fer Tests 5 and 6. Over 1000 photographs were taken during the course of the program. Ninety of these photographs are discussed in detail here and are shown in Section XVII, below. These ninety photographs were selected for their ability to depict observations and results, and they are representative of the total photographs taken. Looking at photographs of fire scenes often requires special skill and experience to "see" a particular pattern or result. Looking at other photographs from the same fire of adjacent areas is often helpful in establishing the context of the photograph and in observing the fire patterns. Fire investigators often shoot a series of photographs in a mosaic fashion which can be put together to depict an entire wall or other larger areas.

**A. Test 1**

**General post-fire description**

The surface of all of the walls showed evidence of heat exposure. The surface of the gypsum wallboard had changed colors and texture. In most areas the paper covering of the wallboard had burned away. At the drywall edges which had been taped, and the screw heads which had been covered with joint compound, a difference in color was noted between these areas and the remainder of the walls. The ceiling suffered a partial collapse of the gypsum wallboard. This fire was suppressed by the application of less than 1 gallon of water from a portable fire extinguisher directly on the remains of the wood crib. With the exception of the wet area behind the wood crib which shows as a very dark area, none of the patterns on the walls, ceiling or floor were due to suppression efforts.

**Pattern identification**

On the walls there were several patterns which indicated that the fire had started in the area of the crib and moved away. Photograph 1 is of the back wall and corners of the room. The crib (point of origin) was on the left. On the back wall was visible a lighter area with a sloping right side. This pattern indicated that the fire was located at the left side and the perimeter of its plume extended onto the back wall. The pattern was formed because of the higher temperatures of the

plume which caused greater damage to the gypsum wallboard and also was able to burn off much of the soot which had been deposited on the wall earlier in the fire. The area to the right of this pattern is darker because the deposited soot remains. This pattern is commonly known as a "clean burn" pattern. The areas of the wall which were covered with joint compound show less damage. This is due to the higher moisture content of the joint compound which provided an additional degree of protection to the wall surface. These protected areas are largest in the lower right corner and smallest in the upper left. This pattern establishes that the exposure temperature was greatest at the left and decreased moving to the right.

At the top of Photograph 1 a similar clean burn pattern is visible on the left side of the ceiling. This is the area of the ceiling which was in contact with the part of the fire plume which was hot enough to burn away the soot. Similar protected areas were visible on the ceiling from the joint compound.

Photograph 2 shows the wall which was behind the wood crib. Visible on this wall is an almost white area which was directly above the wood crib. This is also a clean burn pattern and its shape is a good example of an inverted cone pattern. The wall behind this area is cracked and the ceiling above has collapsed which indicates that these areas of wallboard were exposed to elevated temperatures

Additional damage can be seen at the header (top of the wall studs) and on the ceiling joists. The shape of the visible pattern is that of an inverted cone. This photograph shows how pattern analysis may still be done after a significant overhaul has been conducted and how additional patterns may be hidden. One reason this pattern was present is that there was a penetration of the wall in this vicinity for an electrical outlet.

Photograph 5 shows the left side of the doorframe. The charring patterns on the wood members of the frame are indicative of the flashover conditions which were produced and can be used to reconstruct the position of the upper/lower layer interface. The top half of the frame had char formation with extensive blister formation while the lower half is charred with little blistering and some areas of undamaged wood.

Photograph 6 shows patterns on the floor which were areas protected by insulation placed around the leads to instrumentation. Although the floor was covered by non combustible marinite, floor patterns were created by the heat flux produced during and after flashover.

**B. Test 2**

**General post-fire description**

The surface of all of the walls showed evidence of heat exposure. The surface of

Close examination of glass remaining in the window frame showed that suppression water had been sprayed on it and the glass was crazed[3].

**Pattern identification**

Photograph 7 shows the room during the test, in the post-flashover phase. A solid body of flame is visible at the lower boundary of the discharging smoke plume which fills the top half of the door opening. The bottom half of the door opening was where the fresh air entered the test room as evident from the brighter flame color and the direction of the flames.

Photograph 8 shows the exterior of the test room at the door opening after the test. The pattern visible at the top half of the opening is a combination clean burn and charring pattern on the gypsum wallboard. The wood members of the doorframe

show charring at the top half also. These patterns are from the fire plume which exited the room and burned in this vicinity. A pattern like this is very helpful in establishing that the fire traveled from this room to the outside, and not from the outside to the inside.

shows how the side of the dresser burned intensely because of the inflow of fresh air. Comparison of the difference in damage on an item such as this dresser constitutes an intensity pattern.

Another pattern visible in photograph 10 is in the corner formed with the front of the dresser and the wall. The pattern is a clean area (unburned) on the wall and on the wood baseboard beneath it. This pattern was caused by the lack of fire gas circulation/movement (i.e., dead air) which resulted in this area because of the arrangement of the furniture. Clean (unburned) areas like this were seen in other tests in areas which had no or reduced gas circulation/movement.

Photograph 11 shows the area above the chair where the fire was started. In this photograph there is a very prominent clean burn pattern which is above the chair and to the right of it. A large clean burn pattern starts to the right of the chair and extends into the corner of the room, at floor level. It also goes up the wall to ceiling level, and continues across the ceiling as shown in photograph 12. This

Close examination of the remains of the chair, as shown in photograph 14, did not provide any patterns which are indicative of the origin.

Further analysis of this fire would entail close examination of the temperatures recorded to determine the location of the dominant fire plume. However, this is not possible for this test because of the loss of the data.

Another indication of patterns caused or influenced by ventilation is visible in photograph 15. The clean burn pattern visible under the window is a result of fresh air entering the room from the bottom of the window, mixing with pyrolyzate, igniting and burning in this area.

area on the left is an area that was protected by the dresser. The white colored

**Pattern identification**

Photograph 18 shows the test fire in progress. Burning of the gasoline at low level is visible.

Photograph 19 is the wall closest to the location of the gasoline pool and the fire. A pattern in the shape of an inverted cone is visible on the wall within a wider, lighter cone pattern. These patterns extend the full height of the wall and across the ceiling. At ceiling level the effect of the ceiling on the fire plume is visible and it can be seen how the corners of the room turned the ceiling jet[5] and forced it downwards. The corner is shown in photograph 20. The angles of demarcation approximately matched the similar angle of the cone pattern created by the wood crib, non-acelerated fire of Test 1.

Photograph 21 is a close-up of the area where the gasoline was poured. The straight edges of the floor pattern were caused by the joints in the marinite sheets used for the floor. Burning at these cracks and at the baseboard persisted longer here than in the center of the pour. An effect of ventilation can be seen in the shape of the dark inverted cone pattern on the wall. The left side of the pattern shows the result of the "push" of the ventilation on the plume, compared to the right side which is much straighter.

**D. Test 4**

**General post-fire description**

This test room suffered the greatest damage of all ten tests as a result of the longer burn time. Much of the wall, ceiling and floor surfaces were destroyed which exposed the wood construction members beneath. All of the combustible materials of the furniture items were consumed.

**Pattern identification**

Photograph 22 shows the exterior of the test room and the extent of the damage. The patterns on the doorframe are similar to those discussed above for Test 2, and indicate that the origin of the fire was within this room.

Photograph 23 shows the wall which was located behind the chair where the fire was started. The damage to the wall studs is greatest at their tops. Photograph 24 shows the back left corner of the room. The damage to these wall studs was greater than those shown in photograph 23 which were closer to the point of origin. There is also greater damage to the surface of the exterior gypsum wallboard and this damage starts about 12 in. above the floor. This is the same area where the clean burn pattern was produced in Test 2. Again, it is evident that there was a ventilation influence on the production and location of these patterns.

Photograph 25 shows the floor joists on the left side of the room, where the gasoline was poured. The remains of the mattress are visible on the right edge of the photograph. The degree of damage to the surfaces of the joists is fairly consistent overall. A protected area is visible on the left side of the photograph where the chair was located. There are no patterns evident which give an indication of the point of origin.

Photograph 26 shows the ceiling joists located on the left side of the room above the dresser and chair. Of the five joists visible in this photograph, the center one has the greatest damage along the length and depth of the joist. The damage is less on the adjacent joists both in extent and magnitude. This is a useful intensity pattern for establishing the origin of this fire.

Photograph 27 is the back wall and right rear corner of the test room where the bed and night stand were located. The extent of damage to the wall studs and the gypsum wallboard behind them is an intensity pattern useful for indicating where the fire started. The damage to the studs and wallboard on the left side of this

wall starts at floor level and goes all the way up to the ceiling. Moving from the left to the right side of this wall, the lowest point of damage rises, and on the right side some of the interior wallboard is still intact. This is the right side of a truncated cone pattern and indicates that the fire exposure was greatest on the left side and that the fire originated on the left side.

**E. Test 5**

**General post-fire description**

The surface of all of the walls and ceiling showed evidence of heat exposure. The surface of the gypsum wallboard had changed colors and texture. In most areas the paper covering of the wallboard had burned away. At the drywall edges which had been taped there was a difference in color. The ceiling suffered a partial collapse, roughly 10%, of the gypsum wallboard immediately above the chair. This collapse occurred during the investigation. This fire was suppressed using a 1-1/2 in. hoseline. It was found that some water spray patterns were present on

Photograph 31 is the area to the left of the chair including a corner. Different patterns are visible on the walls. Going from the chair to the left around the corner is the left side of another truncated cone pattern which is visible as a darker gray area in the upper half of the room. On the left side of the photograph behind the table with the lamp, is a door opening which was covered with gypsum wallboard. On this piece of wallboard there is another brown/black pattern. The right edge of this pattern is straight and extends lower than the left edge which is curved. Photograph 32 shows this same pattern and the area to the left. It can be seen that this movement pattern continues from the covered door opening and across the wall behind the bed, and it indicates the direction of fire travel. As the pattern crosses the wall behind the bed it slopes upward. On the portion of the ceiling visible in this photograph the extent of the pattern which started above the chair can be seen.

Photograph 33 shows the dresser which was in this room, immediately on the left

resulted from the combustion of the carpet and pad which were ignited by the flashover conditions in the room.

Photograph 37 is a close view of the arms and seat of the chair. The polyurethane foam which was used for the chair cushions was completely consumed, while the wood parts of the chair burned but remained intact. Close examination of the top surface of both arms of the chair shows intensity patterns which are useful for establishing that the fire originated in the chair. Photograph 38 is a closer view of the top surface of the right arm and photograph 39 is the left arm. The inside of both arms show greater damage in the form of charring and heating than the outsides. These patterns taken with the other patterns in the room establish that the fire originated in the chair.

Photograph 40 is a view of a wall surface outside the door opening to the test room. This wall was finished with wallpaper on plaster. The missing area of wallpaper was caused by a jet of flame which exited the test room, pyrolyzed, and ignited the paper. The shape is characteristic of a flame which would have been produced outside the room post-flashover. The dark smoke staining on the upper [redacted]

produce flashover conditions. This is evidenced by the degree of damage to the room and to furniture items. An obvious odor of gasoline remained in the area of the pour and in the basement area below the room.

**Pattern identification**

Photograph 41 shows the interior of the test room through the door opening. The side of the chair which faced the door was most heavily damaged. The damage to the chair extended to floor level. This is also shown in photograph 42. The chair did ignite and burn but not to the same extent as in Test 5, as indicated by the remains of polyurethane foam and cotton fabric. Photograph 43 shows how the damage to the chair is greatest on the left side (facing the chair). The back of the chair shows a fire pattern made by the consumption of material which extends lower on the left than the right. As shown in photograph 44, the right side of the chair has very little damage and did not ignite.

The damage to the wall is greatest to the left and behind the chair as shown in photograph 43. On this wall is a truncated cone-shaped fire pattern which extends up from floor level. This pattern was caused by clean burn of the soot deposited by the fire plume.

Photograph 48 and 49 show the same floor area as photograph 47 after the debris has been removed and the surface cleaned with water. These photographs were taken after a portion of the floor was removed and the wood baseboard was removed and flipped upside down. The floor patterns are irregular in shape and extend from the room threshold into the room. The pattern in the center foreground of photograph 48 corresponds to where the chair was located and was caused by burning on and under the chair. The floor pattern which starts at the door opening and extends away from the chair corresponds to the area where the gasoline was poured.

As shown in photograph 48, the burn pattern extends right up to the wall. This extension did not take place under the chair. A close-up photograph of the underside of the baseboard in this location is shown in photograph 50. This type of pattern is consistent with the use of a liquid fuel which is capable of flowing under construction members.

Another indicator of the presence of a liquid fuel is shown in photograph 51 which depicts the underside of the test room floor and the floor joists. During the test, fire communicated to this area and caused this damage. There were no penetrations available through which burning solid material could drop, but there

damaged. The vinyl tiles which had been applied to the floor showed shrinkage

bubble formation on the top surface of the tile and the tops of the bubbles were mostly charred or at least darkened. This damage was almost uniform across the

this part of the room. The damage to the dresser represents another pattern which was produced by exposure to the hot upper gas layer and the fire plume from the chair.

In photographs 56 and 57 there is a lamp visible which has a distorted light bulb in it. This distortion was caused by the softening of the glass of the bulb and the expansion of the gas inside the bulb from exposure to the fire. This resulted in a "pulled" light bulb. Generally, a light bulb will "pull" on the side that was exposed to the fire and if it survives the rest of the fire, can serve as an indicator of the path of fire travel. In this case the bulb points in the direction of the head of the bed. This is consistent with other patterns and data which indicate that the flow of fire gases in this room was in a counterclockwise direction and this flow was produced by the ventilation conditions present in the room.

Photograph 58 shows the area under the bed after the removal of the mattress. Visible is an extension of the fire damage found on the rest of the floor. Photograph 59 shows the underside of the box spring which was on the bed. It is evident in these two photographs that the fire was able to spread and cause damage under the bed. This is consistent with the counterclockwise flow of room fire gases discussed above.

Photograph 60 shows the floor area in the center of the room. Also visible are portions of the bed, dresser, chair and night stand. The white square in the center of the floor was created by the instrumentation. Visible is the distinctive bubbling of the floor tiles which was greatest close to and in front of the chair and was less severe toward the left..

**H. Test 8**

**General post-fire description**

The surface of all of the walls and ceiling showed evidence of flame, heat and smoke exposure. The surface of the gypsum wallboard had changed color and

texture from either clean burn or smoke deposition. In most areas the paper covering of the wallboard had burned. The vinyl tiles which had been applied to the floor showed shrinkage and deformation from fire exposure and burning, similar to what was observed in the previous test except that the damage was generally greater. The fire in this room did produce flashover conditions. This test was one which did not produce many obvious, distinctive patterns on the room surfaces.

**Pattern identification**

Photograph 61 is an exterior view of the only window to the test room. This

photograph was taken approximately 1 minute after ignition. Notable, and the reason the photograph is included here, is the light color and quantity of smoke coming from the window as a result of this accelerated fire.

Photograph 62 shows the chair and a portion of the bed. The damage patterns to the chair and bed indicate that the fire origin was in front of the chair. On the

back wall of the closet is a truncated cone pattern. The base of this pattern is above floor level because the location of the actual fire was more toward the center of the room, away from this wall. The top of this pattern was limited by a wood shelf in the closet which is visible in the photograph. An extension of the pattern can be seen on the small width of wall between the closet and the door opening.

Photograph 65 shows the area under the bed after the mattress and box spring were removed. Some damage to the floor is visible especially at the left corner of the foot of the bed. This area was closest to the origin of the fire.

Photograph 66 shows the cloth trailer and its location near the door opening and the chair (visible in the upper left corner of the photograph) prior to the test. Photograph 67 shows this same area after the test. A pattern is discernible among the floor debris where the trailer had been. After the debris was removed and the floor swept, the trailer pattern could still be seen. Photographs 68 and 69 show this. Beyond the trailer pattern no other floor patterns were discernible as shown in photograph 70.

Photograph 71 is of the underside of the chair. Fire damage is visible on the left side of the underside of the chair, with little damage to the right underside of the chair. This is consistent with the location of the fire and where the gasoline was poured.

**I. Test 9**

**General post-fire description**

The surface of all of the walls and ceiling showed evidence of flame, heat and smoke exposure. The surface of the gypsum wallboard had changed color and texture from either clean burn or smoke deposition. In most areas the paper covering of the wallboard had burned. The wood floor was covered in debris after the fire and the floor was not visible until it was cleaned. The fire in this

room did produce flashover conditions. This test was one which did not produce many obvious, distinctive patterns on the room surfaces.

**Pattern identification**

Photograph 72 is an exterior view of the only window to the test room. This photograph was taken approximately 5 minutes after ignition. Notable, and the reason the photograph is included here, is the presence of dark, thick smoke and flame from a non-accelerated fire within 5 minutes of ignition.

This is consistent with flashover conditions. Behind the bed and chair the baseboard was protected and did not ignite. The clean wall area to the left of the headboard of the bed was produced by the ventilation to the room which prevented fire gases from reaching that area.

Photograph 79 shows the floor area between the bed and the chair. The floor had a fairly uniform burn pattern on its surface, consistent with a room which has had flashover conditions.

Photograph 80 shows the floor area in the corner of the room where the chair was located. The surface of the floor here is similar to that shown in photograph 79 except that there is a pattern produced by burning under the chair.

Photograph 81 is of the wall which contained the window and against which were placed the dresser and the night stand. The damage pattern on the wall below the window and on the side of the dresser which was closest to the window shows the effect of the ventilation from the window. The damage to these surfaces is worse than that to other areas and it extends down to floor level.

**J. Test 10**

**General post-fire description**

As with the other test fires where flashover occurred, the surface of all of the walls and ceiling showed evidence of flame, heat and smoke exposure. The surface of the gypsum wallboard had changed color and texture from either clean

the chair starts at floor level. The pattern on the wall between the foot of the bed and the chair was produced by the burning which occurred in this area.

Photograph 83 shows the back of the chair and another damage pattern which indicates that the origin of the fire was to the left of the chair toward the bed.

The damage to the bed is fairly uniform on the exposed surfaces as shown in photograph 84. The pattern on the walls adjacent to the bed indicate that there was fire in this area and that its base was closer to the foot of the bed than to the head. This is confirmed by the pattern on the wall behind and to the left of the head board of the bed.

The remainder of this wall is shown in photograph 85 which also shows the bottom of the window and the night stand. The circular opening in the wall under the window was a view port for a video camera.

Under the bed, as shown in photograph 86 there is evidence that there was fire here and that it burned from the floor up. This is indicated by the protected strips of cardboard which had covered the top of the box spring. On the feet of the bed were plastic casters, one of which is visible in this photograph after it has melted and re-solidified.

Photograph 87 is of the floor in front of the bed and chair. The darker area of the floor in the center of the photograph corresponds with the area between the bed and chair. The remainder of the floor shows fairly consistent and uniform damage

gasoline which was poured in this area to start the fire. As indicated by the pattern, some of the gasoline flowed behind the chair and burned there. This pattern could not have been caused by flashover because of the protection provided by the chair, and examination of photograph 83 will show that this part of the chair did not burn.

Photograph 89 shows a closer view of the floor area shown in photograph 88. The two small unburned circular areas on the floor are from the feet of the bed which protected these areas.

Photograph 90 shows a large portion of the test room floor after all debris was removed and the floor swept. Except for the floor patterns discussed above, there are no other floor patterns visible in this photograph which can be attributed to the burning of the gasoline pool.

## *XII. HEAT AND FLAME VECTOR ANALYSIS*

Heat and Flame Vector Analysis is a "state-of-the art" system for using fire/heat patterns to determine fire origin(s)[1]. It is a system where the location and size of fire patterns, and the direction of fire/heat travel which such movement patterns display are plotted on a diagram of the fire scene. "Heat and Flame Vectors" are arrows which represent the location, magnitude, and direction of individual fire patterns. The length of the vector is used qualitatively to show the intensity of the particular pattern. By tracing and evaluating the positions and directions of the various complimentary or opposing vectors, the investigator can get a visual reference indicating from where the fire spread. When the vector diagram is complete, the investigator can analyze the totality of the patterns and make a cumulative determination of the source of fire/heat energy. Thereby the investigator can draw conclusions as to the origin of the heat energy which created the patterns.

Formal heat and flame vector analyses were conducted for Tests 5 and 6.

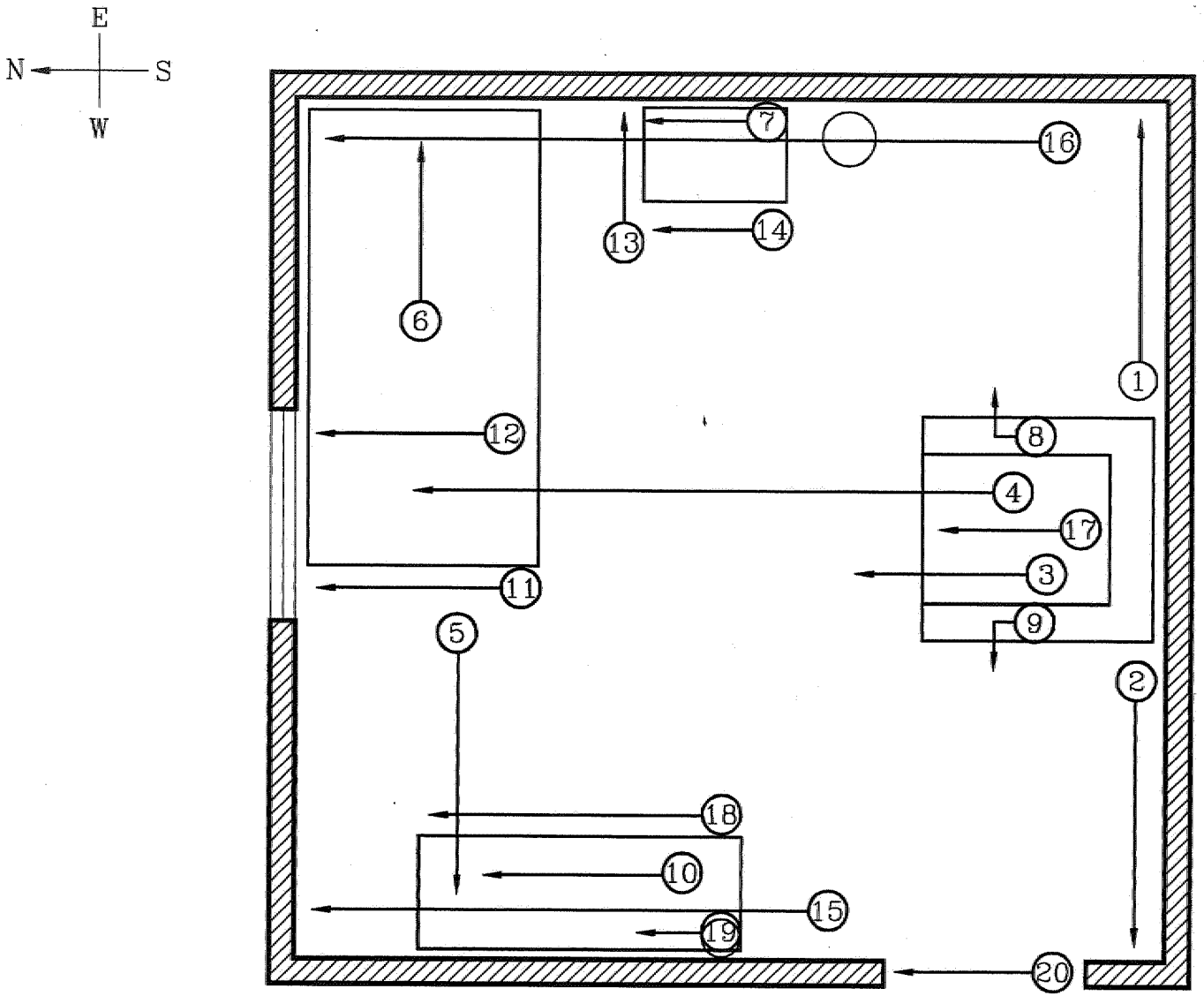
**Test 5 Heat and Flame Vector Analysis**

[redacted]

vectored as shown in Vector Diagram 1. Table 2 describes each of these vectors and Vector Diagram 1 shows their location.

**Table 2. Heat and Flame Vectors for Test 5**

| Vector | Location | Analysis |
|---|---|---|
| 1 | South Wall | Truncated cone pattern on the east end of south wall with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves east along the south wall, indicating fire travel from |




VECTOR DIAGRAM 1
(TEST 5)

**Table 2 continued**

| Vector | Location | Analysis |
|---|---|---|
| 4 | Ceiling | Truncated cone movement pattern with fire/heat damage decreasing as one moves outward to the north from the area over the chair. |
| 5 | Ceiling | Truncated cone movement pattern with decreasing fire/heat damage as one moves from east to west from the foot of the bed, complementary to Vectors 6, 11, and 12. |
| 6 | Ceiling | Truncated cone movement pattern on the ceiling over the east end of the bed with fire/heat damage decreasing as one moves from west to east over the bed, complimentary to Vector 5. |
| 7 | East Wall | Truncated cone pattern on wall above night stand with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves north along the east wall, indicating fire travel from south to north, complementary to Vectors 4, 13, 14, and 16. |
| 8 | Chair Frame | Depth of char measurements on the east (left) arm of the chair show decreasing fire/heat damage from west to east. |
| 9 | Chair Frame | Complementary pattern to Vector 8, depth of char measurements on the west (right) arm of the chair shoe decreasing fire/heat damage from east to west. |

**Table 2 continued**

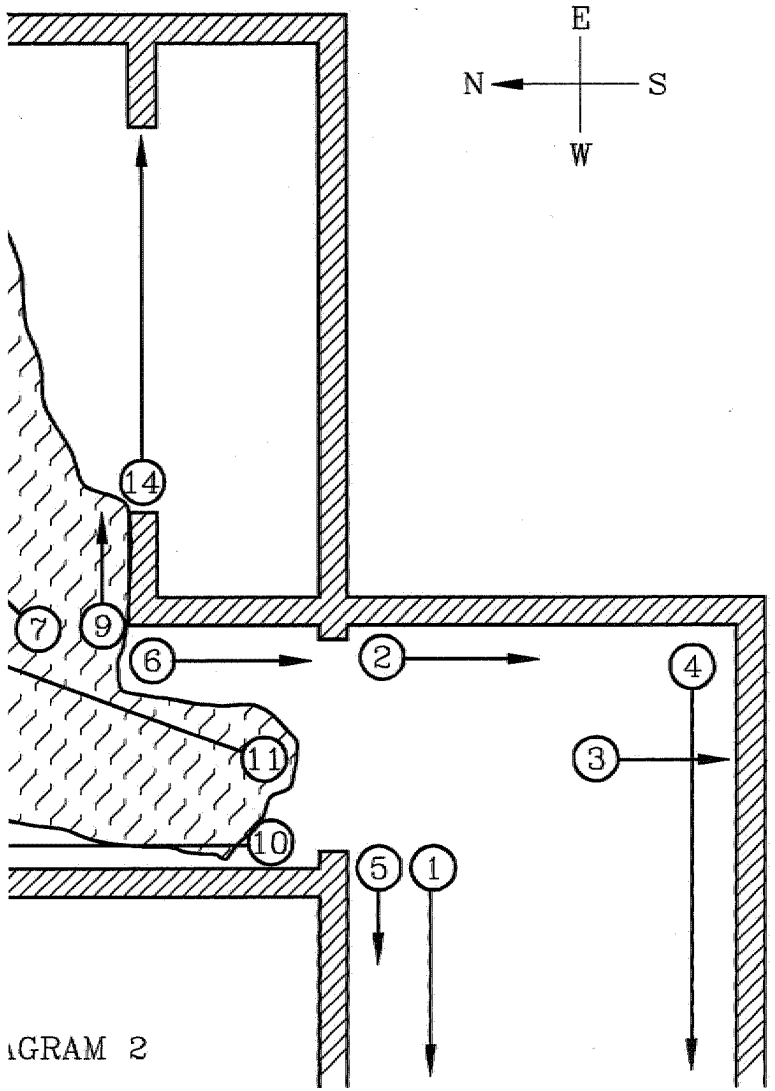
| Vector | Location | Analysis |
|---|---|---|
| 10 | Top of Dresser | Decreasing heat treatment and disassociation of lamination on the dresser top, indicate fire travel from south to north, complementary to Vectors 4, 15, 18, 19, and 20. |
| 11 | Side of Bed | Truncated cone pattern with decreasing heat treatment on side of the foot of the |

**Table 2 continued**

| Vector | Location | Analysis |
|---|---|---|
| 15 | West Wall | Truncated cone pattern on west wall over the dresser with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves north indicating fire travel from south to north, complimentary pattern to Vectors 4, 10, 18, and 19. |
| 16 | East Wall | Truncated cone pattern, showing decreasing fire/heat damage to a wall paper border as one moves to the south indicates fire travel from south to north, complimentary pattern to Vectors 4 and 15. |
| 17 | Chair Frame | Depth of char measurements on the chair frame indicate less char depth as one moves to the south to indicate fire travel from south to north (the back of the chair to the front). |
| 18 | Dresser | Truncated cone pattern on the front surface of the dresser with decreasing fire/heat damage and |

Table 2 continued

| Vector | Location | Analysis |
|---|---|---|
| 19 | West Wall | Truncated cone pattern on the west wall behind the dresser at the south end with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves north, indicating fire travel from south to north, complimentary to Vectors 4, 10, 15, and 18. |
| 20 | Door Jams | Comparison of the height of fire/heat damage on the south jam, indicating fire travel from the south to the north, complimentary to Vectors 2,3, 4, 10, 15, 18, and 19. |




ıGRAM 2

6)

**Table 3 continued**

| Vector | Location | Analysis |
|---|---|---|
| 2 | East Wall | Truncated cone pattern on east wall of hallway with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves south away from the test room doorway, indicating fire travel from north to south, complementary to Vectors 1, 3, 4, and 5. |
| 3 | South Wall | "U"- shaped, truncated cone pattern on south wall of the hallway with lower vertex in line with the center of the doorway across the hall, indicating fire travel from north to south, complementary to Vector 1, 2, 4, and 5. |
| 4 | South Wall | Truncated cone pattern on the south wall of the hallway with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves west away from the test room doorway, indicating fire travel from east to west, complementary to Vectors 1, 2, 3, and 5. |

**Table 3 continued**

| Vector | Location | Analysis |
|---|---|---|
| 6 | East Wall | Truncated cone pattern on the east wall of the entrance way into the test room with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves south toward the test room doorway, indicating fire travel from north to south, complementary to Vectors 2 and 3. |
| 7 | Carpet | Burn damage on the carpet with decreasing fire/heat damage as one moves northeast into the test room from the area of the doorway, complementary to Vectors 8, 9, 10, and 11. |
| 8 | Chair | Comparison of the burn damage differences between the two sides of the chair. The south (left) side of the chair displays lower and more severe fire/heat damage that the north side, indicating fire travel from south to north, complementary to Vectors 10, 12, and 13. |
| 9 | South Wall | Truncated cone pattern on south surface of the wall west of the closet with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves east away from the test room doorway, indicating fire travel from west to east, complementary to Vectors 7, 8, and 11. |

**Table 3 continued**

| Vector | Location | Analysis |
|---|---|---|
| 10 | West Wall | Truncated cone pattern on west wall of the test room, south of the chair, with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves north away from the test room doorway, indicating fire travel from south to north, complementary to Vectors 7, 8, 9, and 11. |
| 11 | Ceiling | Truncated cone pattern on the ceiling of the test room with decreasing fire/heat as one moves northeast away from the test room doorway, indicating fire travel from southwest to northeast, complementary to Vectors 7,8, 9, and 10. |
| 12 | Lamp | Heat treatment patterns on the inside surfaces of the lampshade show decreasing fire/heat damage and increasing minimum line of demarcation height as one moves east away from the test room doorway, indicating fire travel from west to east, complementary to Vectors 8, 10, and 13. |
| 13 | Chair | Truncated cone pattern on the East surface of the chair back with decreasing fire/heat damage and increasing minimum line of demarcation height as one moves east away from the test room doorway, indicating fire travel from west to east, complementary to Vectors 8, 10, 11, and 12. |

**Table 3 continued**

| Vector | Location | Analysis |
|---|---|---|
| 14 | Closet | Truncated cone pattern of elevations of fire/heat damage on moldings around closet doorway with decreasing damage and increasing minimum line of demarcation height as one moves east, indicating fire travel from west to east, complementary to Vectors 7 and 9. |

## *XIII. RESULTS*

The results for this test program are summarized below. Where possible, a representative photograph is listed which depicts the particular result. These results are those which are supportable by the test data and observations. Other possible results may be evident in the data but they are not reported here because they could not be supported by the data with any confidence.

1. Patterns were useful in the identification of the point of origin in these test fires including those which produced flashover conditions. The best examples of this were seen in Tests 1, 2, 3, 4, 5, 6 (no flashover), and 10. Tests 8 and 9 produced some patterns but they were indistinct and could not be used to establish the origin. In the case of Test 2 and 4 distinctive patterns were produced which

could be seen on the surfaces after flashover in varying quantities. Higher in the room and closer to the fire, the quantity of material was greater than that of other areas. When this material was subjected to the higher temperatures of flashover

5. Patterns on floor surfaces were produced in many of the test rooms. This occurred in all of the test fires where flashover conditions were produced and they were produced without the use of an ignitable liquid as an accelerant. The best examples of this were Tests 2, 5, 7 and 9.

6. Patterns which indicate burning under furniture items were observed in test fires which did and did not use an ignitable liquid as an accelerant. This was especially true for the bed and chair, which both had polyurethane foam in them. The best examples of this were Tests 2, 7, 8, 9, and 10.

7. Low points of burning and patterns from it were observed after many of the test fires, both near to and away from the point of origin. Low points of burning were produced in fires where an ignitable liquid was and was not used as an accelerant. Many of these patterns were not indicative of the point of origin. The best examples of this were Tests 2, 4, 7 and 9.

8. The description and characterization of patterns as having a "truncated cone" as a base geometry were demonstrated in many of the test fires. The best examples of this were Tests 2 (photograph 8 and 12), 4 (photograph 27), 5 (photograph 28 and 31), and 8 (photograph 64).

9. Intensity patterns which were produced by relative differences in damage were useful in establishing the point of origin. In several cases, patterns were observed which would permit establishing the point of origin within a margin of inches. The best examples of this were Tests 3 (photograph 19), 4 (photograph 23, 24, and 25), 5 (photograph 37, 38, and 39), 9 (photograph 73, 75, 76 and 81), and 10 (photograph 82).

10. Clean burn patterns, discussed in number 2 above, were observed outside the room of origin. This is as a result of flames or heated gases venting from the

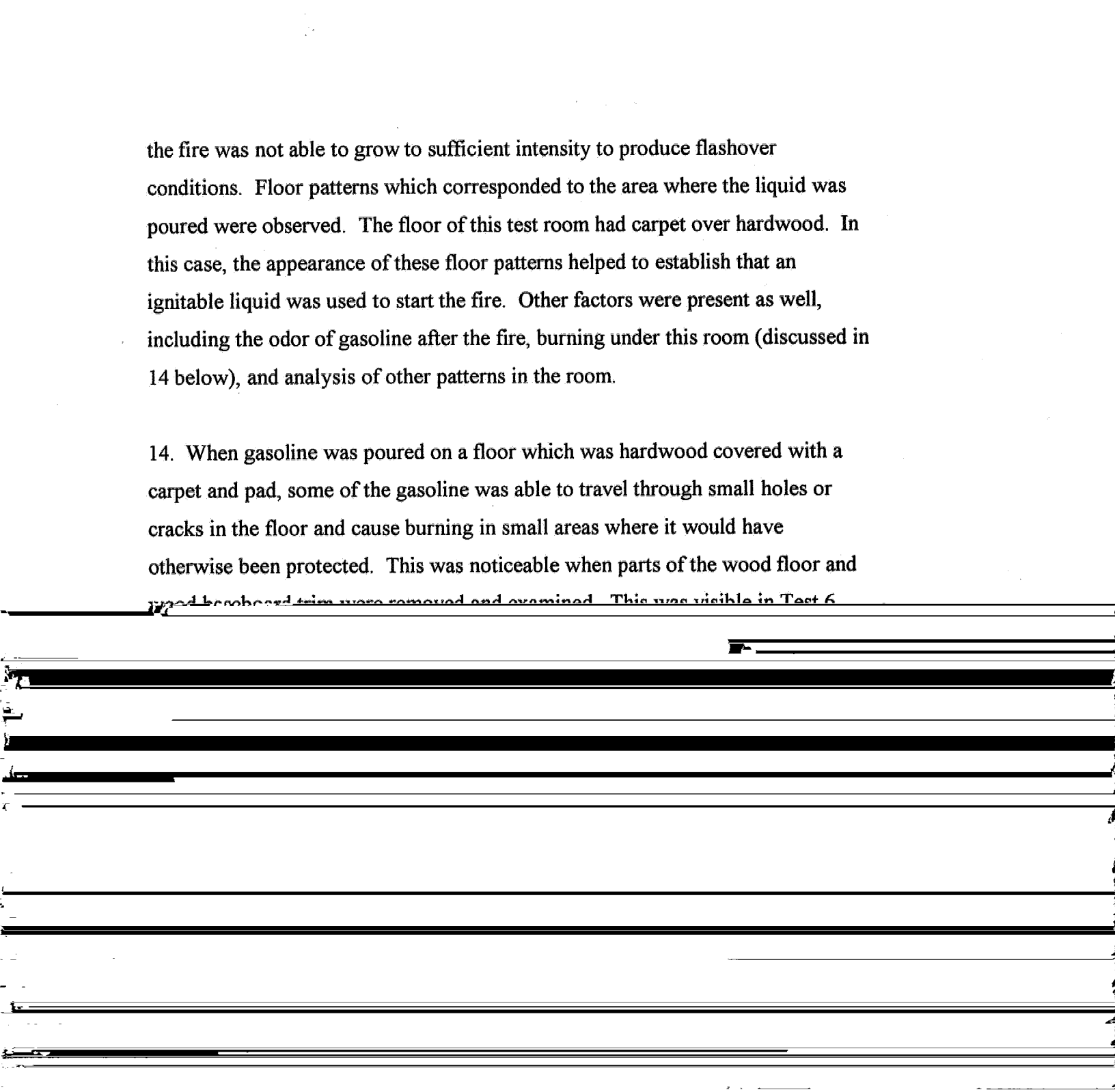
room of origin and producing these patterns on the walls and ceilings of adjacent rooms. Generally these patterns were visible on the upper portion of the walls near the door opening or on the ceiling near the door opening. Clean burn patterns were not seen outside the room of origin at low levels or near the floor. The best example of this was Test 5 (photograph 40).

11. Water from a fire department hoseline was used in most of the test fires for extinguishment. Where the water spray contacted walls or ceilings a pattern was often visible. Close examination of the shape, color and intensity of these spray patterns clearly showed characteristics which would enable differentiation between these patterns and those caused by the fire. The water spray patterns were composed of many elongated streaks which were often less than 1 inch in length. They were grouped and oriented so that they resembled a spray pattern. It was evident that the water did not wash all of the deposited material away from the wall or ceiling surface because the patterns had a color which was lighter than the surrounding area but not as light as a clean burn or protected area. The best example of this was in Test 5 (photograph 40).

12. The use of an ignitable liquid in a room (in this test series only gasoline was used) can reduce the oxygen content in the room to very low, near zero levels rapidly. This reduced the heat release rate of the fires in these tests and resulted

the fire was not able to grow to sufficient intensity to produce flashover conditions. Floor patterns which corresponded to the area where the liquid was poured were observed. The floor of this test room had carpet over hardwood. In this case, the appearance of these floor patterns helped to establish that an ignitable liquid was used to start the fire. Other factors were present as well, including the odor of gasoline after the fire, burning under this room (discussed in 14 below), and analysis of other patterns in the room.

14. When gasoline was poured on a floor which was hardwood covered with a carpet and pad, some of the gasoline was able to travel through small holes or cracks in the floor and cause burning in small areas where it would have otherwise been protected. This was noticeable when parts of the wood floor and wood baseboard trim were removed and examined. This was visible in Test 6



where flashover conditions were not produced. In test fires where flashover conditions were produced with and without the use an accelerant, this burning was also produced. This was observed in Test 5.

15. When gasoline was poured on a floor which was hardwood covered with a carpet and pad, some of the gasoline was able to travel through small holes or cracks in the floor and reach the crawl space below the room of origin. This was seen in Test 6. During this test, a small fire started beneath the test room due to the gasoline which had leaked through it. Apparently a large enough opening was

which did and did not have flashover conditions. The best examples of this were seen in Test 6 (no flashover) and Test 7 (flashover).

17. Clean burn areas were observed on wall surfaces under windows which

20. Test fires which were started with the use of an ignitable liquid (gasoline) were observed to produce light to moderate quantities of light colored smoke within 1 minute of ignition. The best example of this was Test 8.

21. No relationship or correlation was found between the shape of patterns on walls and the use of an ignitable liquid as an accelerant. Truncated cone patterns were observed on walls in the shape of a "V" and were produced with the angle of the "V" ranging from wide to narrow. "V" patterns which were wide were observed when accelerants were used. This contradicts the rule-of-thumb that narrow "V" patterns correspond to "fast" fires which are fires with a rapid rate of growth.

22. When a piece of cloth was used in conjunction with a pour of ignitable liquid (gasoline) as a trailer, a protected area pattern was discernible on the floor after the test fire. This was produced in Test 8 which did produce flashover conditions.

23. Floor patterns produced by the ignition of an ignitable liquid were not always visible after a fire which produced flashover conditions. It was observed that flashover also produced patterns on the floor as a result of the pyrolysis and/or ignition of the floor surface. This was able to obscure floor patterns which existed prior to flashover. The best examples of this were Tests 8 and 10. The floor type did not appear to make a difference in this result.

24. Ignitable liquids poured on floors traveled some distance from the pour site and traveled under furniture items. This was evident from patterns on the floor and from corresponding patterns on the underside of the furniture item. This was observed in Tests 6, 8 and 10. When the composition of the furniture item included a material which produced an ignitable liquid during pyrolysis or combustion, similar patterns were observed. Discerning the difference requires analysis of the available fuels and the size, shape and orientation of the patterns. An important factor which is helpful in discerning the ignition mode is that if the

area under the furniture item where the pattern is located was protected from the flow of hot fire gases and the radiation from the hot upper layer, then ignitable liquids should be considered as the cause of the pattern. If there is evidence of

Generally, the patterns remaining on room walls and ceiling surfaces and on furniture items were useful in determining the area and point of fire origin. Some patterns were very obvious and distinct while others were less so. In a few cases patterns were observed which would have confused an unstudied origin determination and may have led to an incorrect determination or a determination of multiple origins. Patterns produced outside the room of origin were helpful in establishing the direction of fire spread.

1. The ventilation of the room of fire origin has a great effect on the growth and heat release rate of a fire and, for this reason, greatly affects pattern formation. Patterns which indicated areas of intense burning but were remote from the point of origin were observed and were determined to be from ventilation effects only. This was observed in rooms which had flashover conditions where clean burn areas were produced under windows away from the origin. This was also observed on walls opposite door openings.

In this case, observations indicated that the fresh air being drawn into the room through the lower portion of the door mixed with excess fuel and produced a jet

evidenced by the leaning or pushing of one side of the pattern away from the source of ventilation.

2. The color and intensity of smoke emerging from exterior windows of the room of origin is not a reliable indicator of the mode of ignition or of the presence of an ignitable liquid.

3. The presence of floor patterns in a room which has had flashover conditions is not a reliable indicator of the presence of an ignitable liquid introduced for incendiary purposes. It was observed that floor patterns were consistently produced on different floor surfaces by the pyrolysis and combustion of the floor surface caused by flashover, with and without the use of an accelerant.

An exception to this conclusion was when a piece of cloth soaked in an ignitable liquid was used as a trailer. A discernible and persistent protected area pattern resulted under the trailer material. This pattern was produced as a result of the protection provided to the floor surface by the trailer material, to the radiant heat flux consistent with flashover conditions.

4. The presence of floor patterns in a room which has not had flashover conditions is a reliable indicator for an ignitable liquid used to start the fire and accelerate its growth. However, prior to making any conclusions from a floor pattern, investigation must be conducted to rule out other reasons for the formation of a floor pattern and other non-incendiary sources for an ignitable liquid. This includes burning material falling to the floor and ventilation effects.

In considering the source of an ignitable liquid, components of furniture items which contain polyurethane or other polymers which produce an ignitable liquid during thermal decomposition must be included.

5. Indications of burning under furniture items is not a reliable indicator for the

observed that fire gases of sufficient quantity and temperature were able to travel under some furniture items causing them to ignite and causing patterns to form on the floor and on the underside of furniture surfaces. Radiation effects from the

liquids were produced during the thermal decomposition of polyurethane components of furniture items, were ignited, and burned under the furniture item.

6. A reliable indicator for the greater rate and quantity of heat transfer inherent in the area of origin is the depth (thickness) of dehydration or calcination layer in walls and ceiling made of gypsum wallboard. It was observed that the depth of this layer which was observed as a change of color and cohesiveness (exposed side darker and less cohesive) was consistently greatest in the area of origin.

7. When flashover conditions have been produced in a room, patterns which are located at low levels on the walls (as low as the floor) may be produced in areas not related to the origin. These low patterns may be produced by the burning of furniture items or ventilation effects. Accurate origin determination can not be

ventilation this may deplete the oxygen in the room, reduce the heat release rate of the fire, and prevent flashover. In this situation, patterns indicative of the accelerant use were easily recognized and residue of the accelerant could still be smelled.

11. No correlation was found between the shape of a pattern on a wall and the use of an ignitable liquid as an accelerant. This includes "V" shaped patterns on walls.

12. Residue of ignitable liquids will remain and are detectable after a fire. This is true when the fire was suppressed within minutes of the onset of flashover conditions. It is not known how long after flashover this will remain true.

13. The presence of crazed glass at a fire is not a reliable indicator of the use or presence of an accelerant. Crazing is an indicator of how rapidly the glass was cooled and is not dependent on the type or configuration of fuel.

## ***XV. REFERENCES***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3. Custer, R.L.P., Kennedy, P.M., and Levine, R., "Program for Study of Fire Patterns," a discussion paper distributed by the National Institute of Standards and Technology, Building and Fire Research Laboratory, Gaithersburg, Maryland (August 26, 1992).

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5. International Association of Arson Investigators-Massachusetts Chapter, *Accelerant Evidence Collection Guide,* Saugus, MA (1992).

6. National Fire Academy, Fire Investigation Curricula, US Fire Administration, Emmitsburg, MD (1990).

7. Open Learning for Fire Service Program Curricula, Fire Investigation Module, United States Fire Administration, Emmitsburg, MD (1990).

## ***XVI. FIGURES***

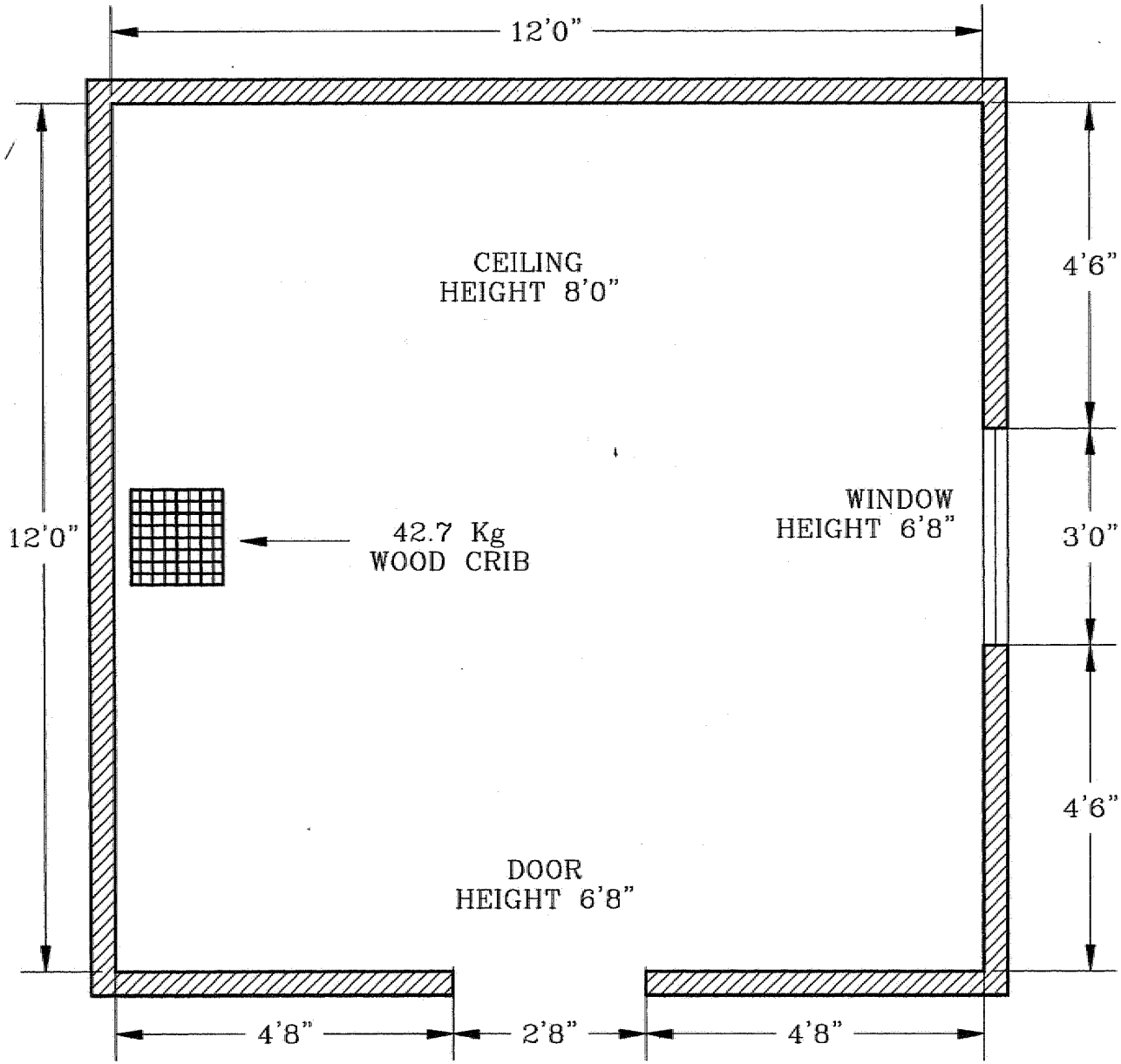



FIGURE 1
(TEST 1)

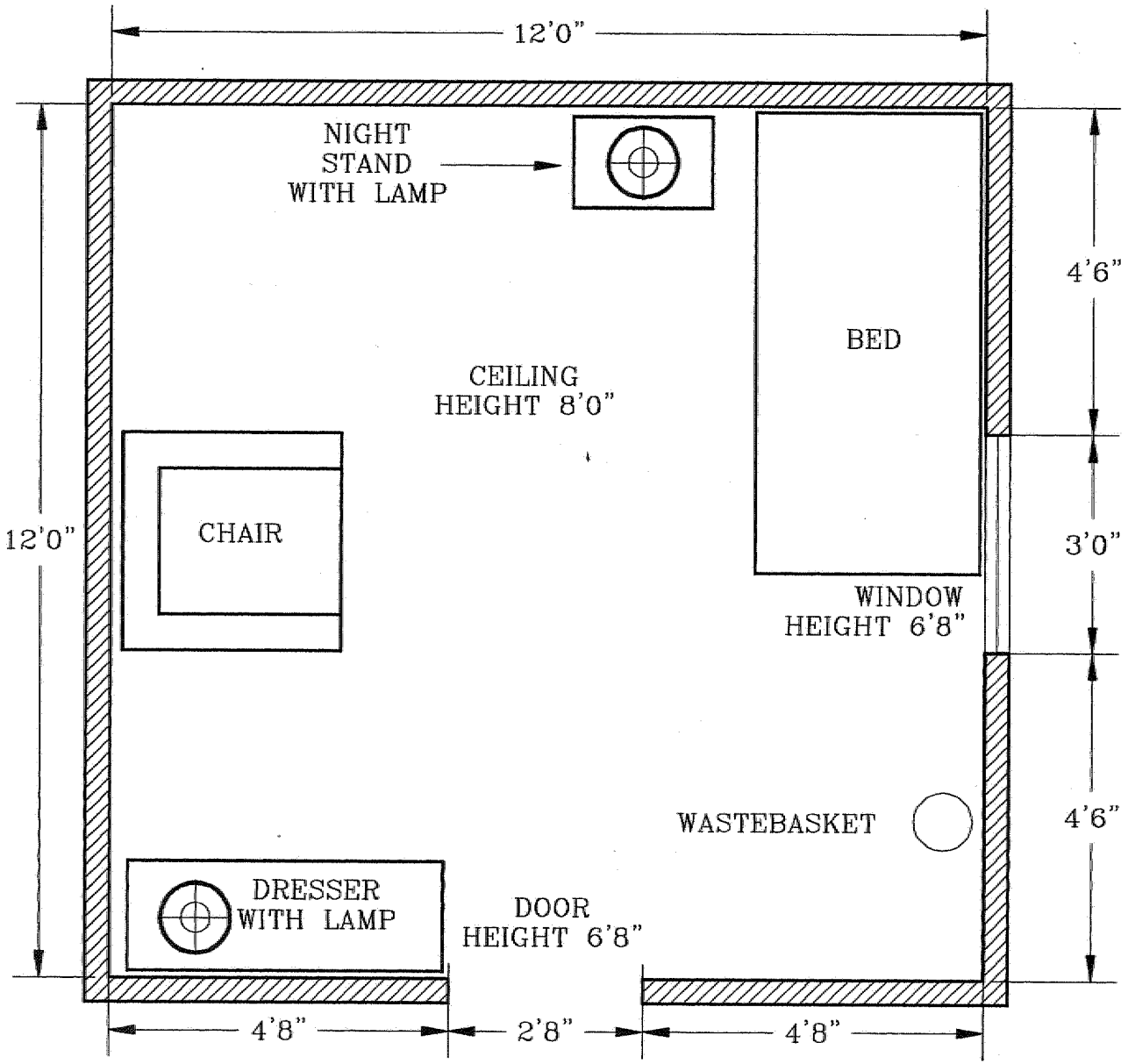
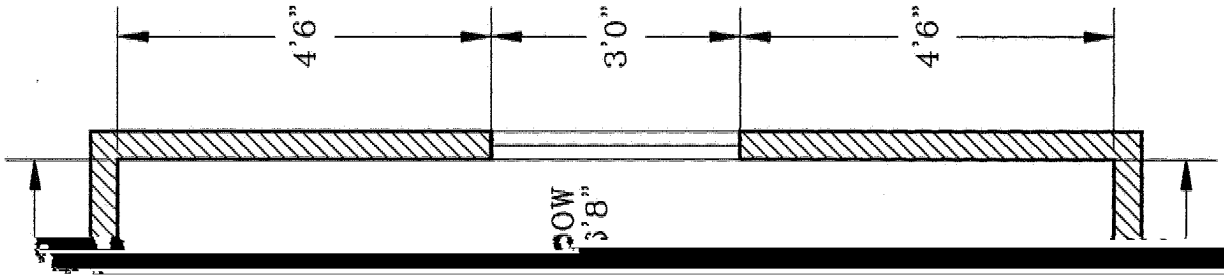



FIGURE 2
(TESTS 2 and 4)


4'6"
3'0"
4'6"
3'8"

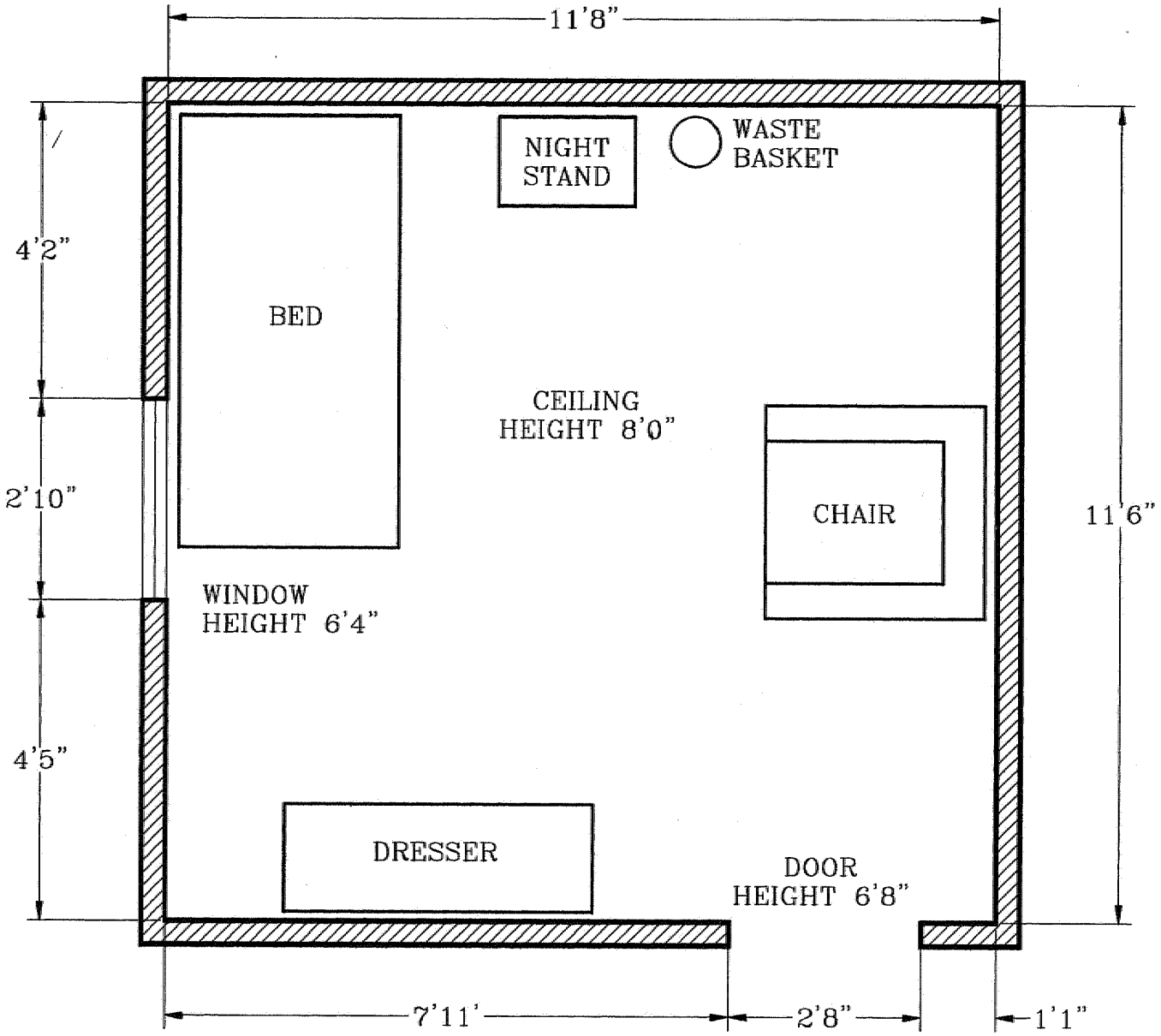



FIGURE 4
(TEST 5)

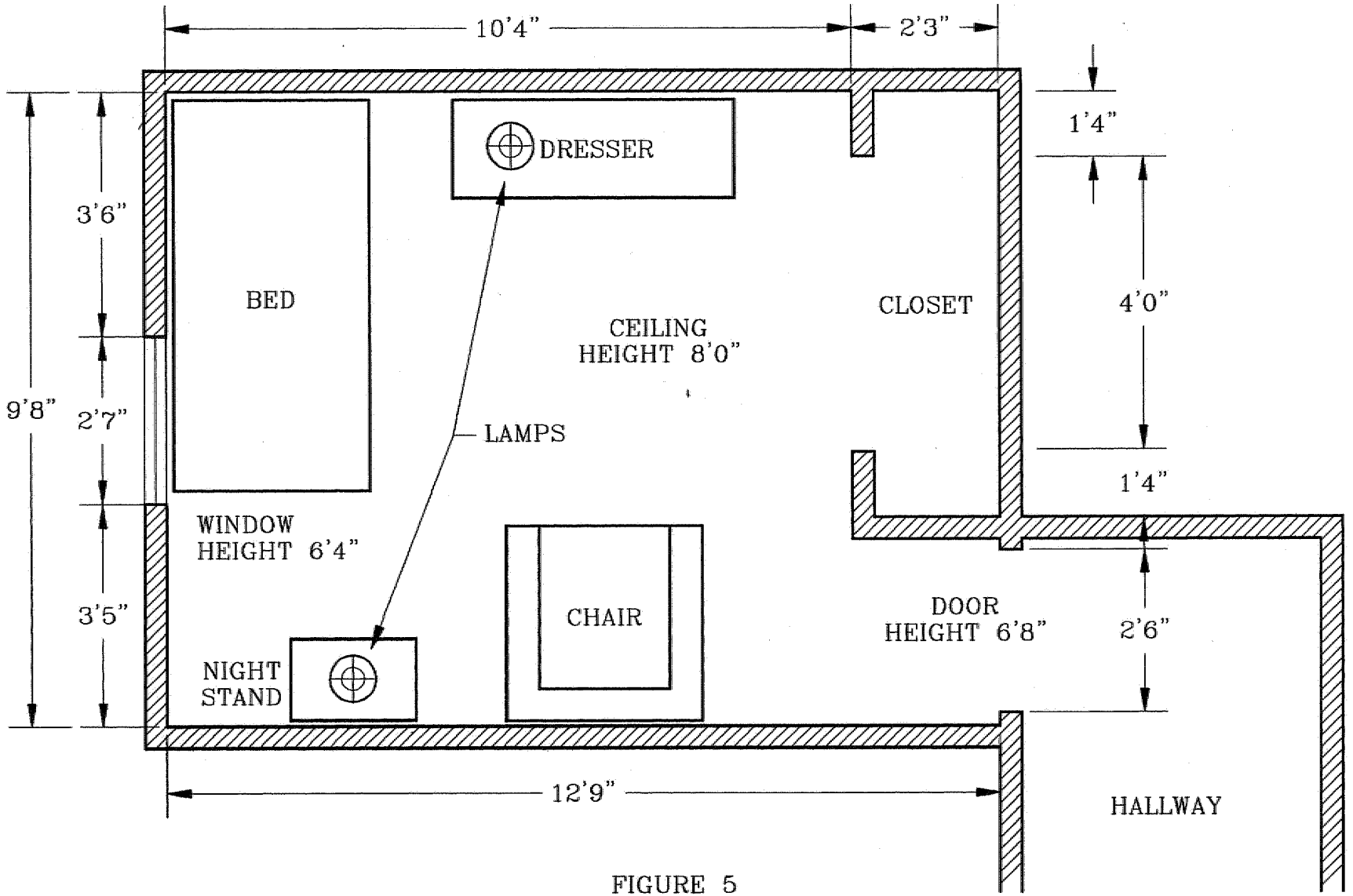



FIGURE 5
(TEST 6)

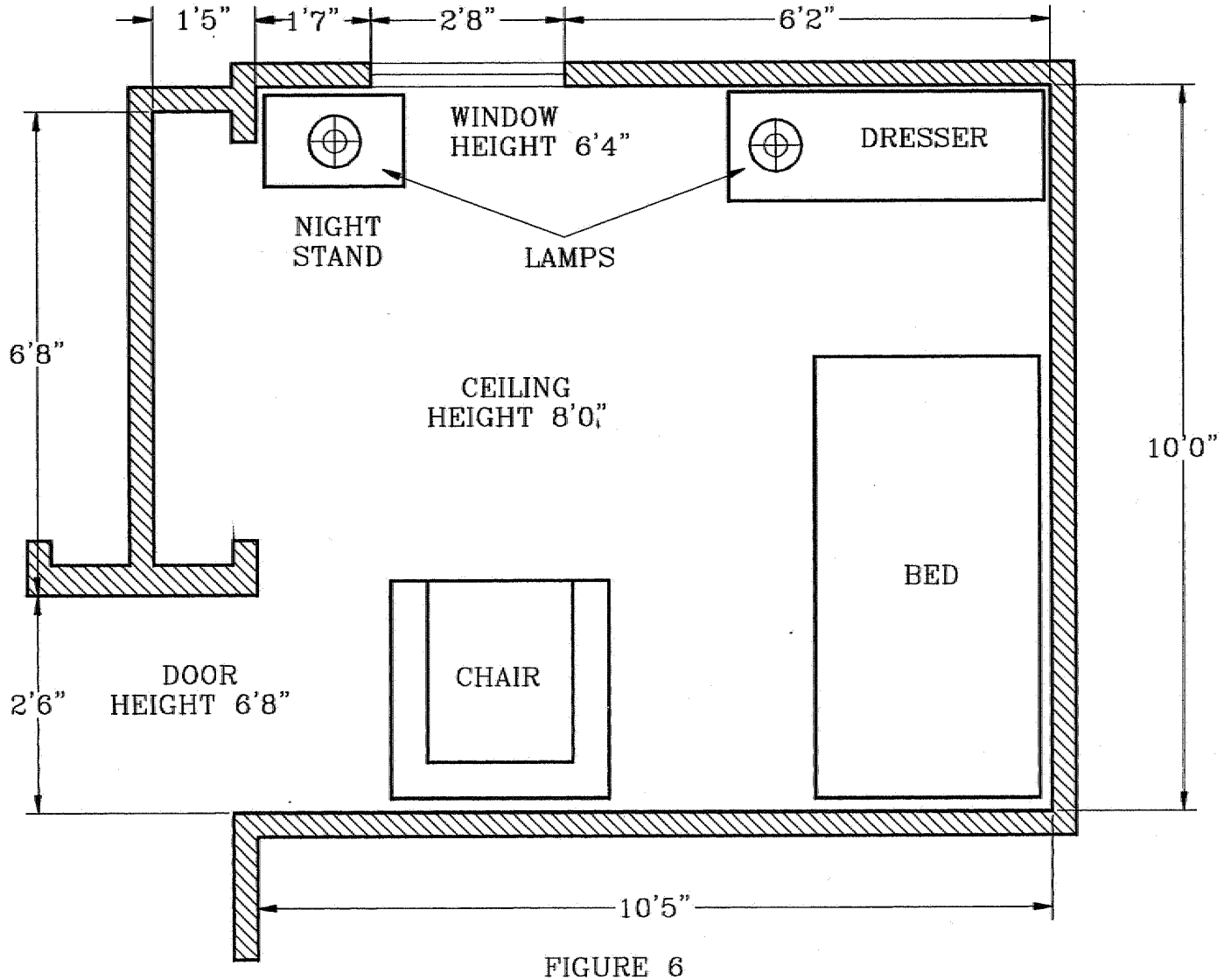
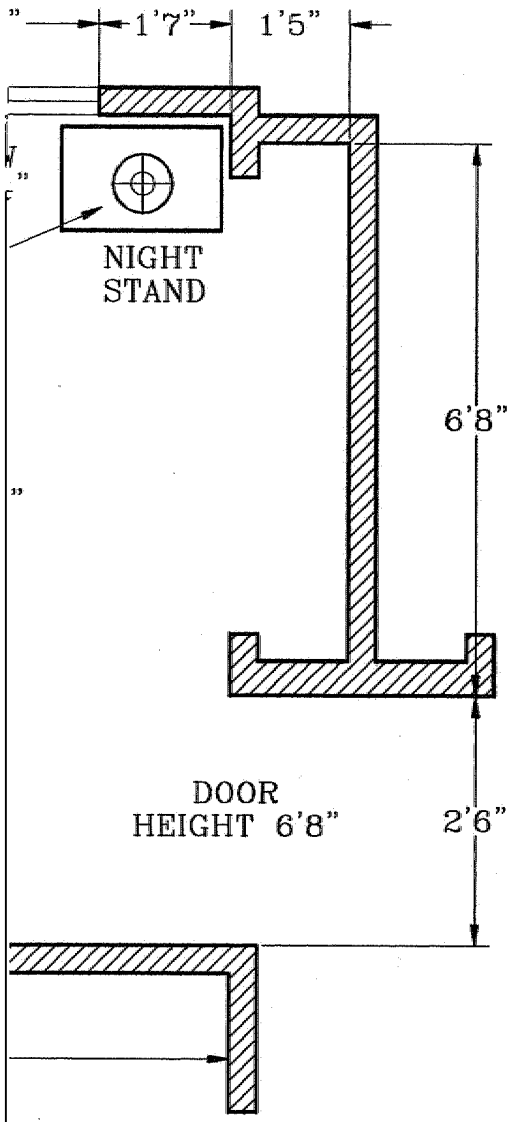



FIGURE 6
(TEST 7)


1'7"
1'5"
NIGHT
STAND
6'8"
DOOR
HEIGHT 6'8"
2'6"

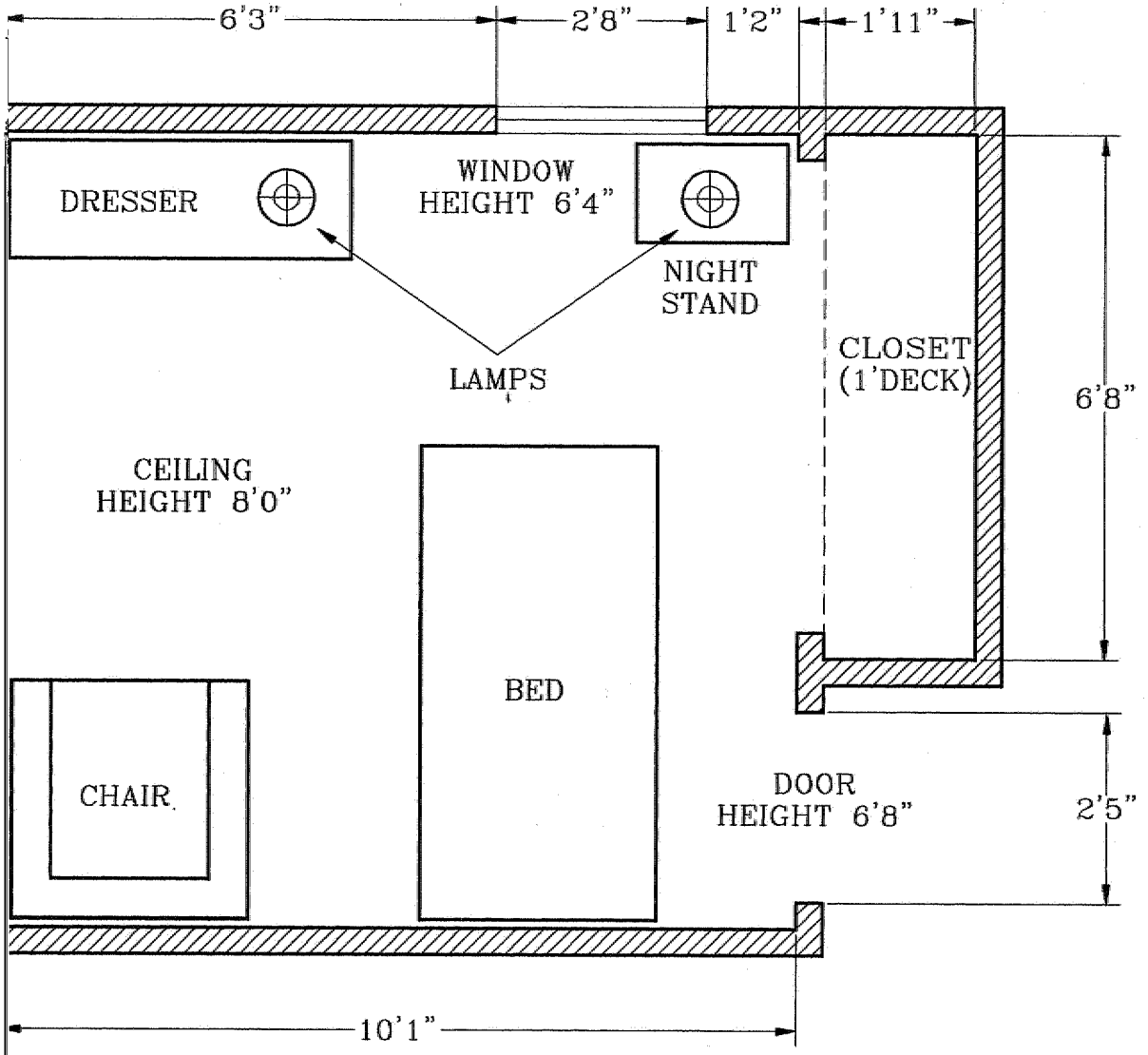



FIGURE 8
(TEST 9)

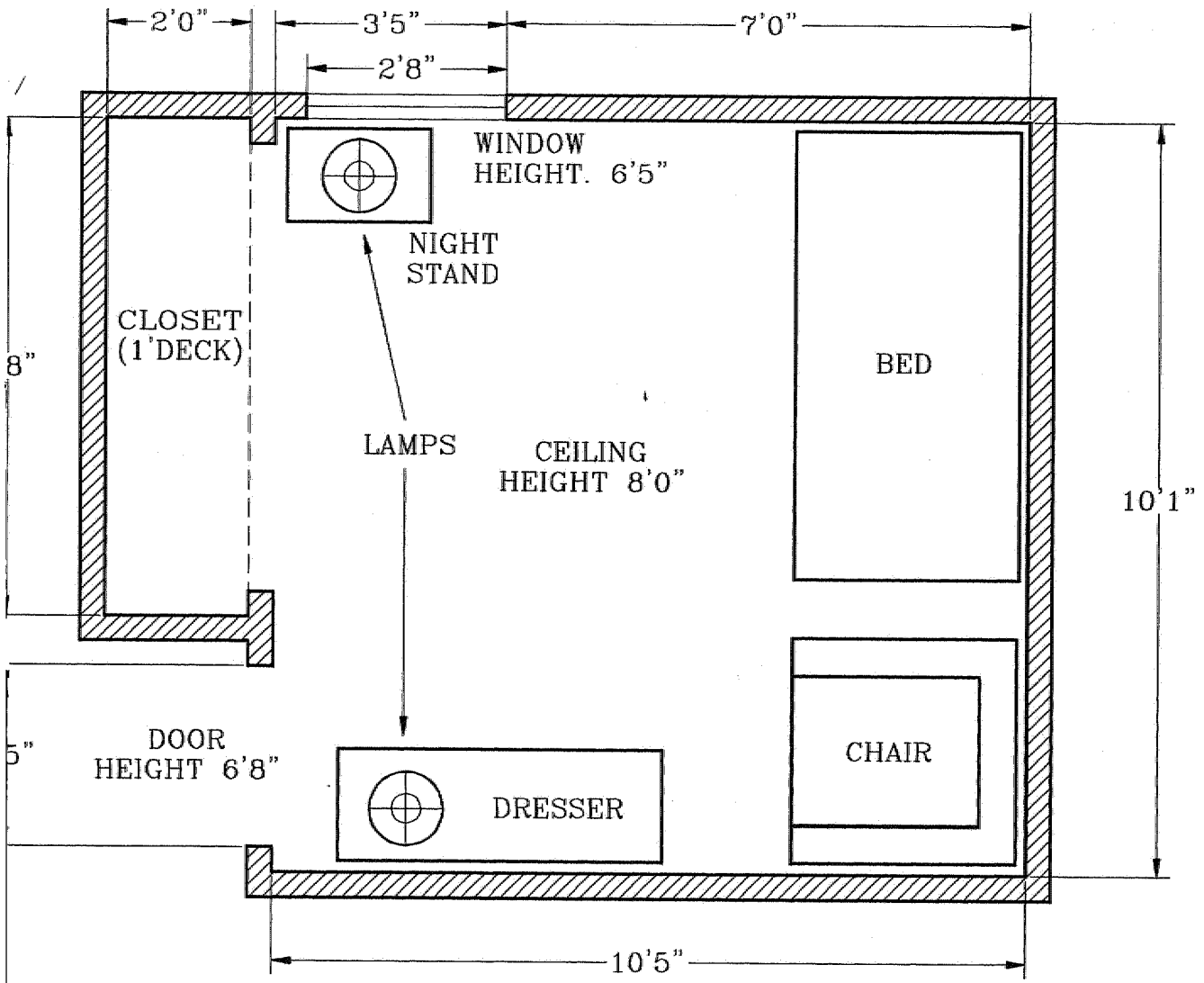



FIGURE 9
(TEST 10)

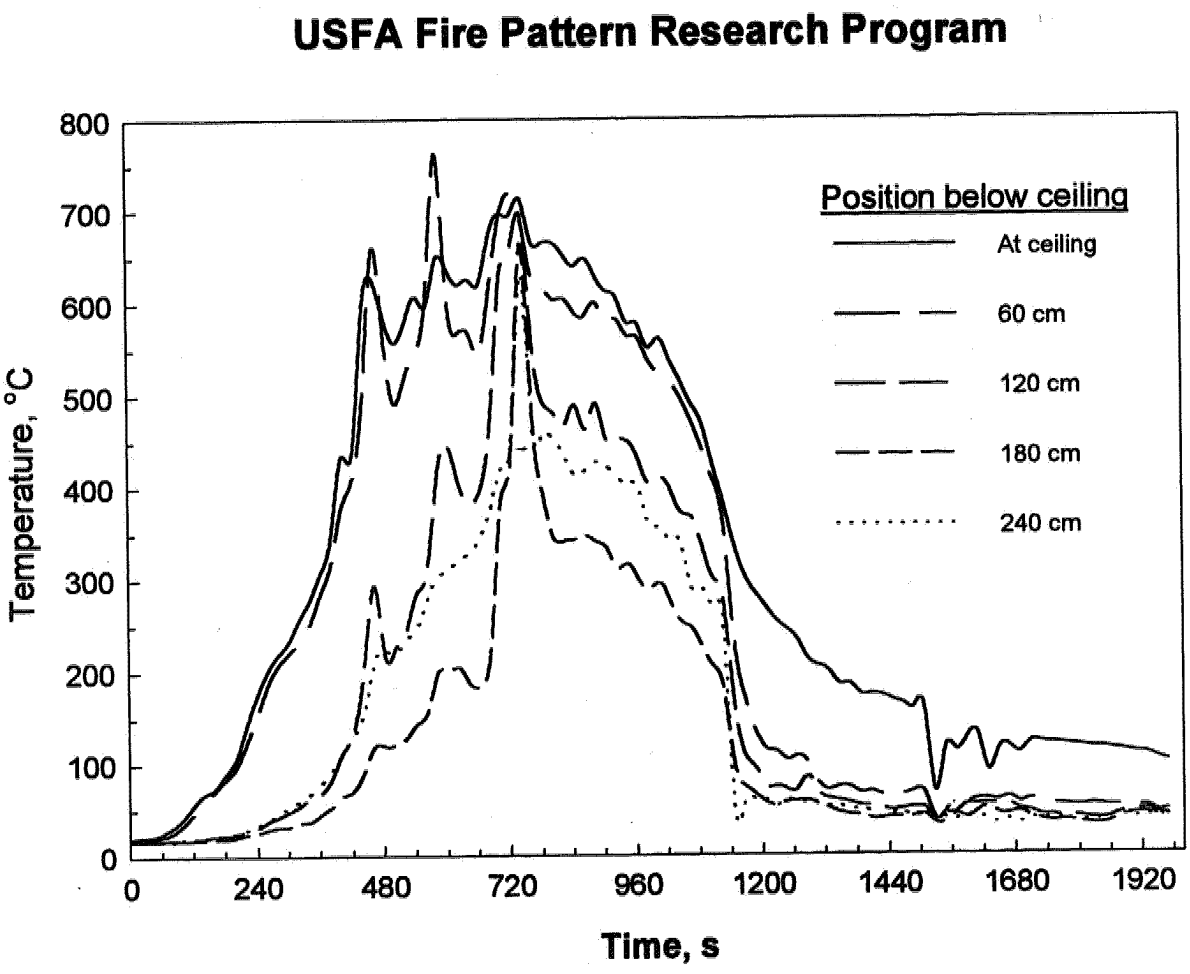



**Figure 10 Center of Room Temperature Profile, Test 1**

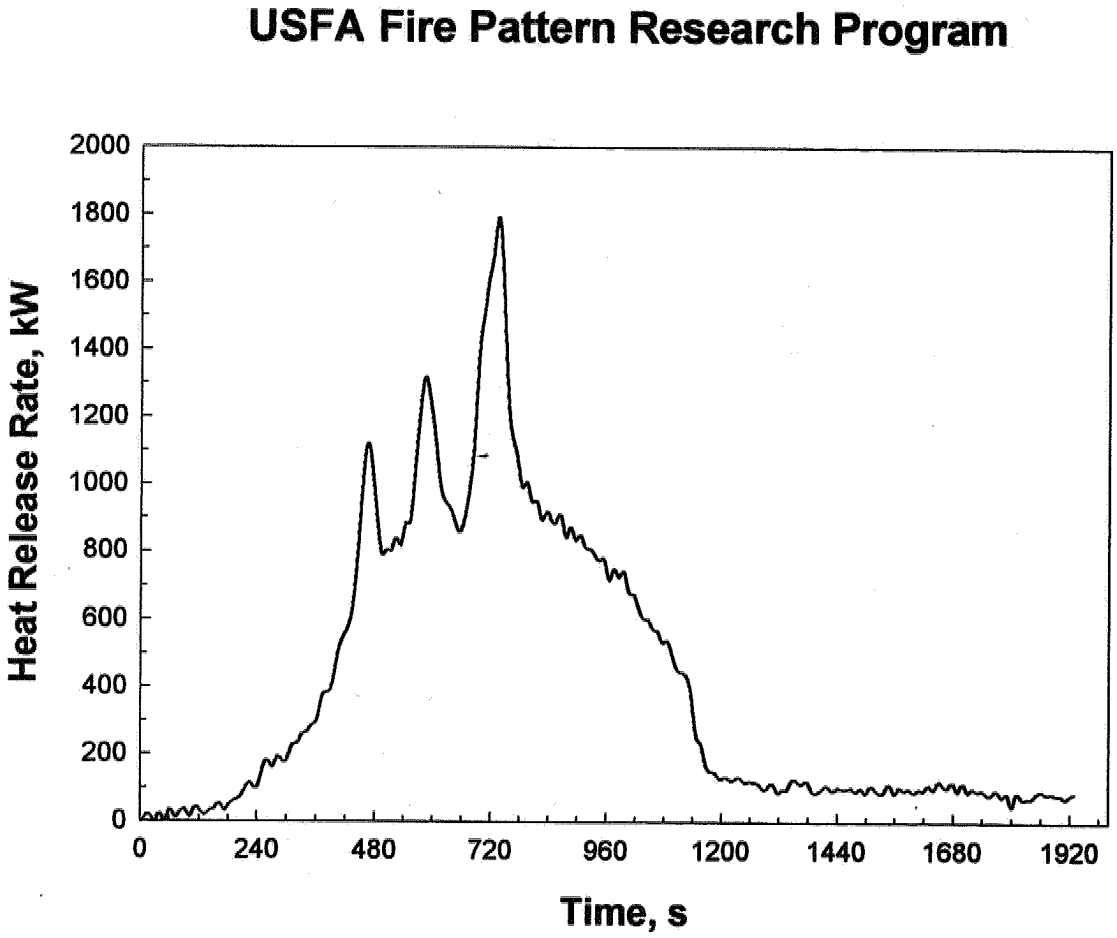



**Figure 11 Heat Release Rate for Test 1**

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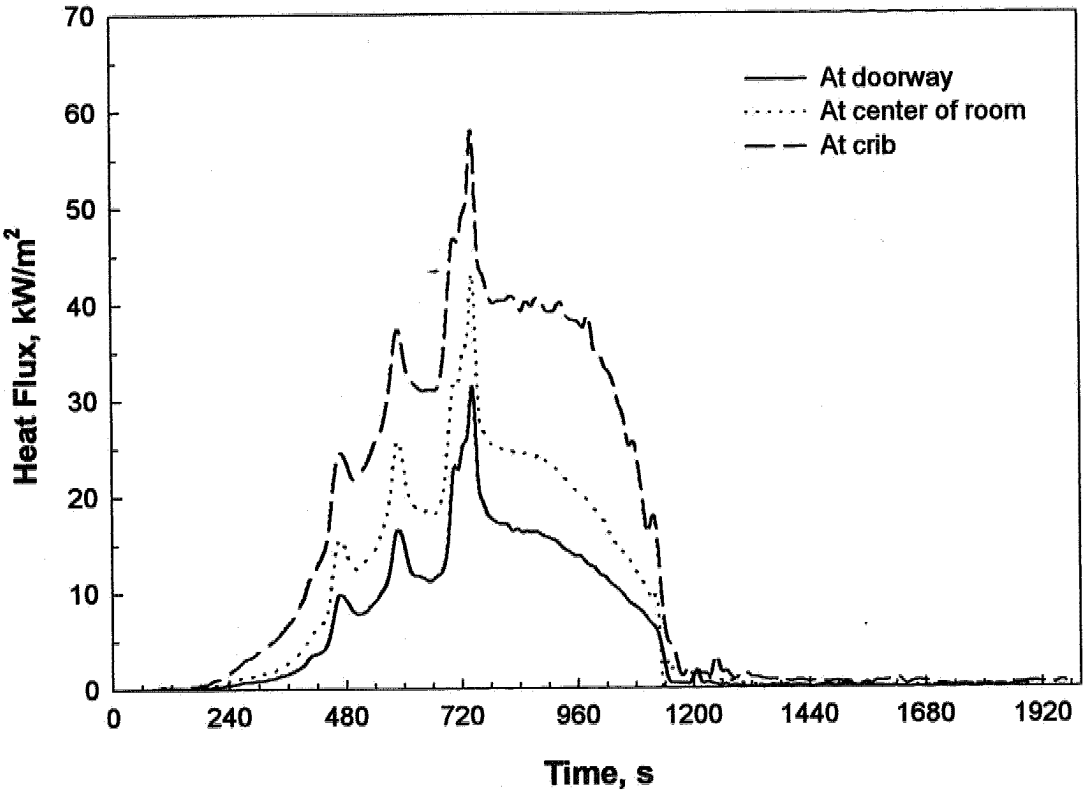


**Figure 12 Radiant Heat Flux at Floor, Test 1**

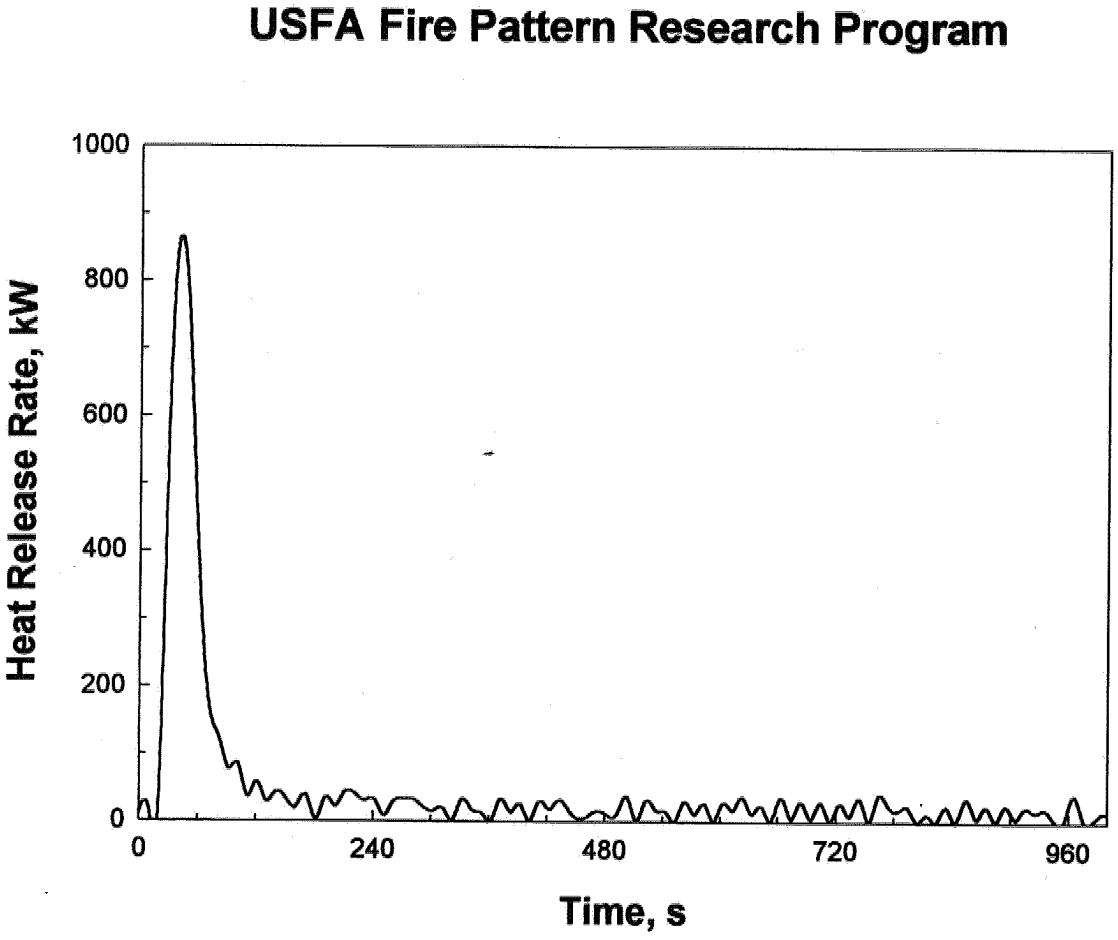


Figure 13. Heat Release Rate for Test 2

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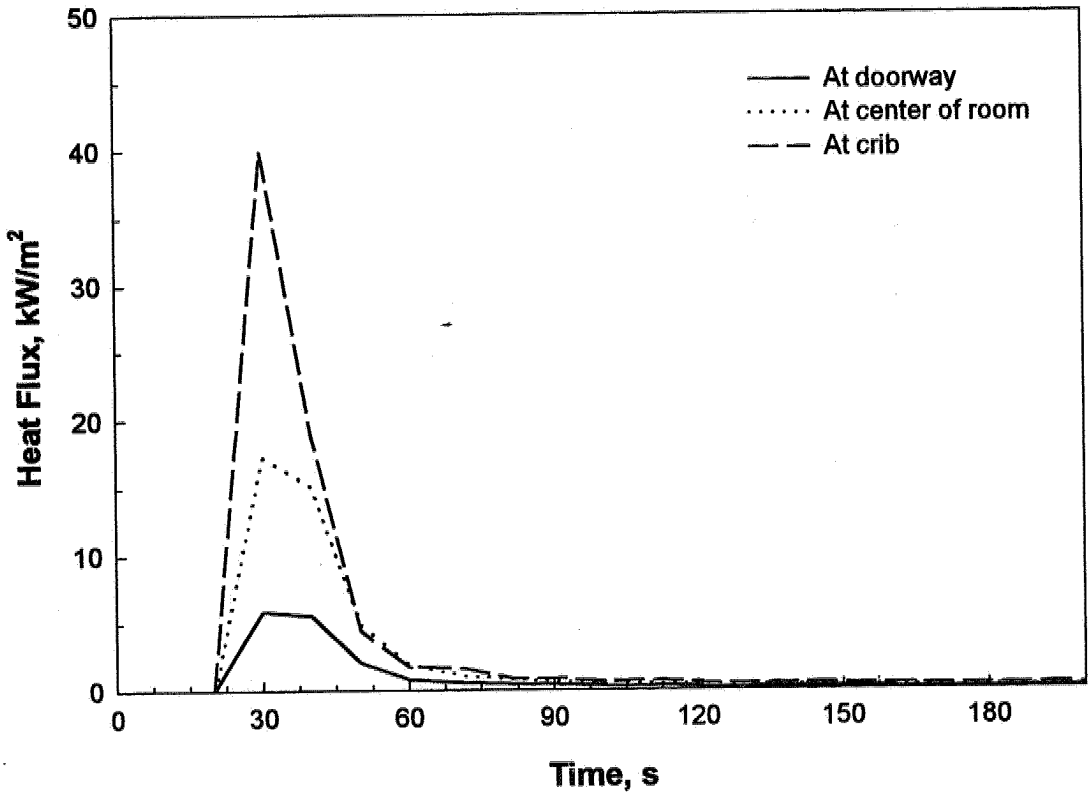



**Figure 14 Radiant Heat Flux at Floor, Test 3**

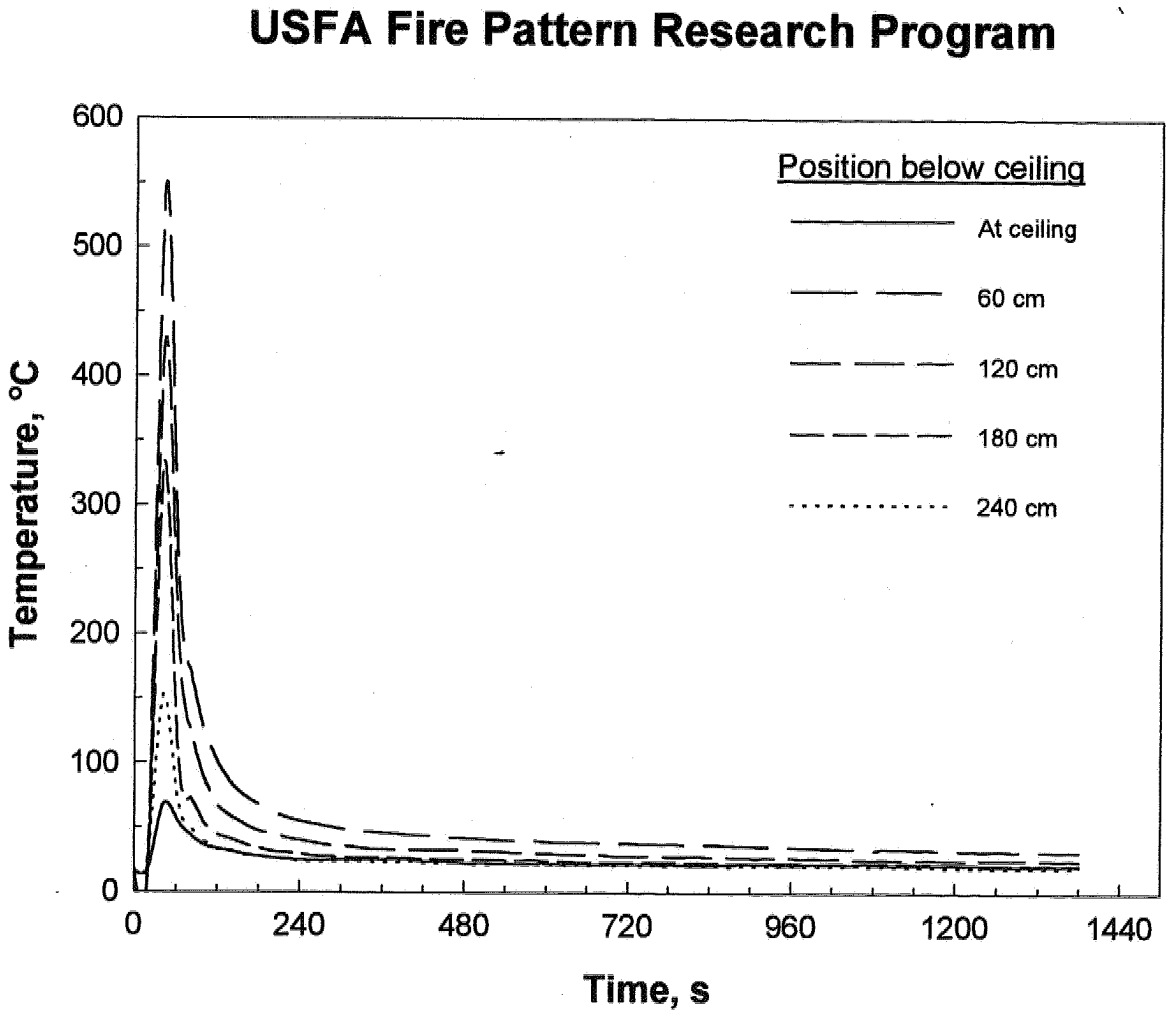



**Figure 15 Center of Room Temperature Profile, Test 3**

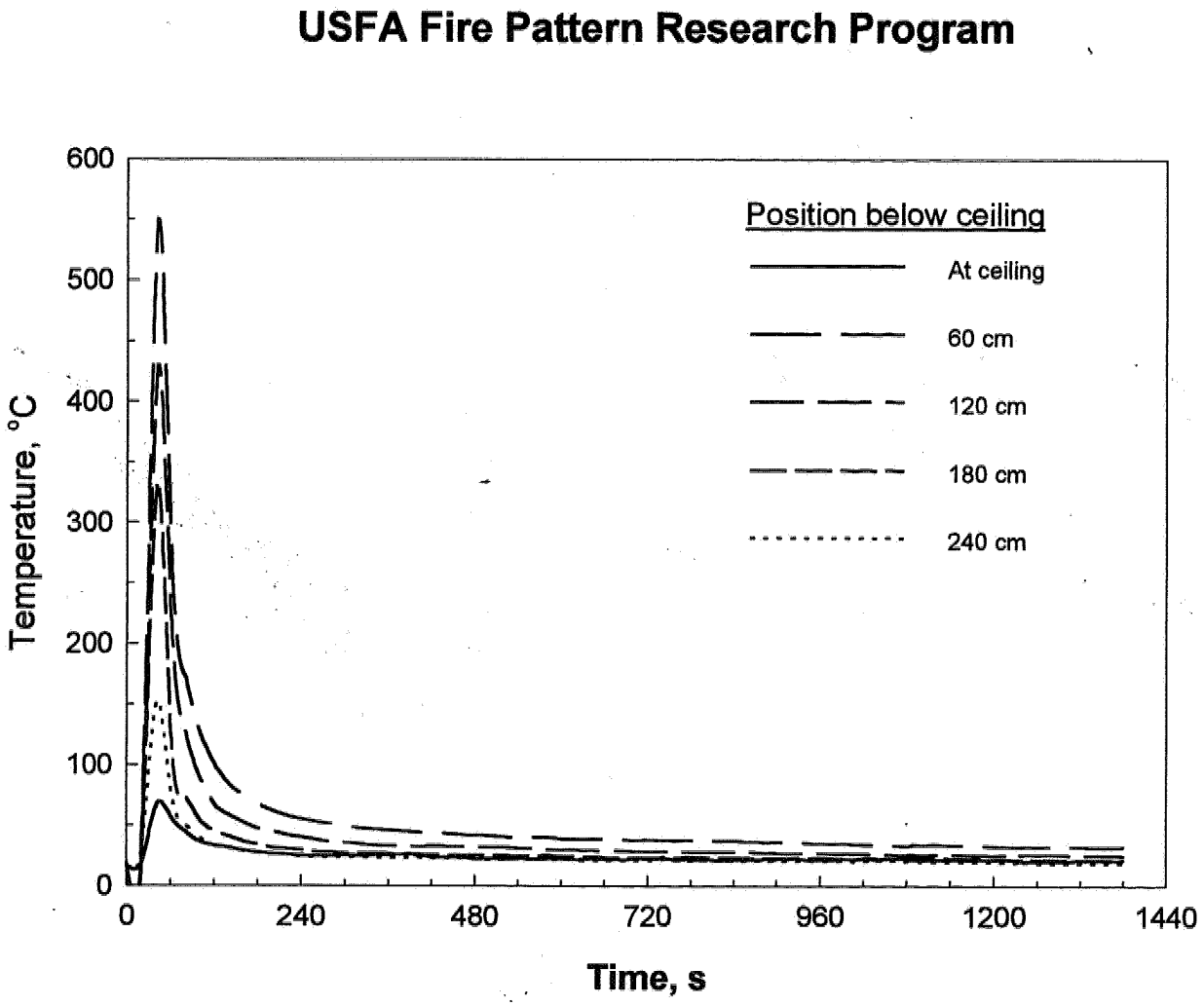
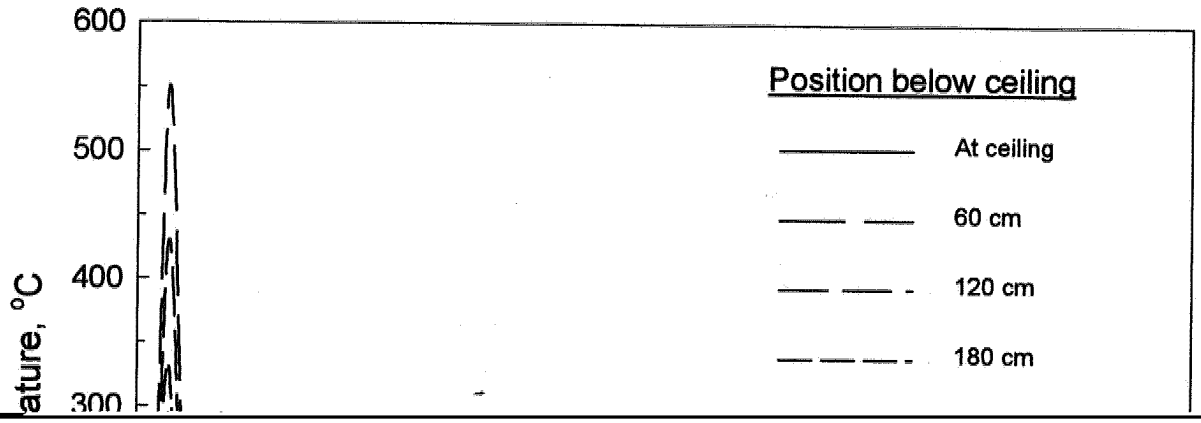



**Figure 16 Doorway Temperature Profile, Test 3**

## USFA Fire Pattern Research Program



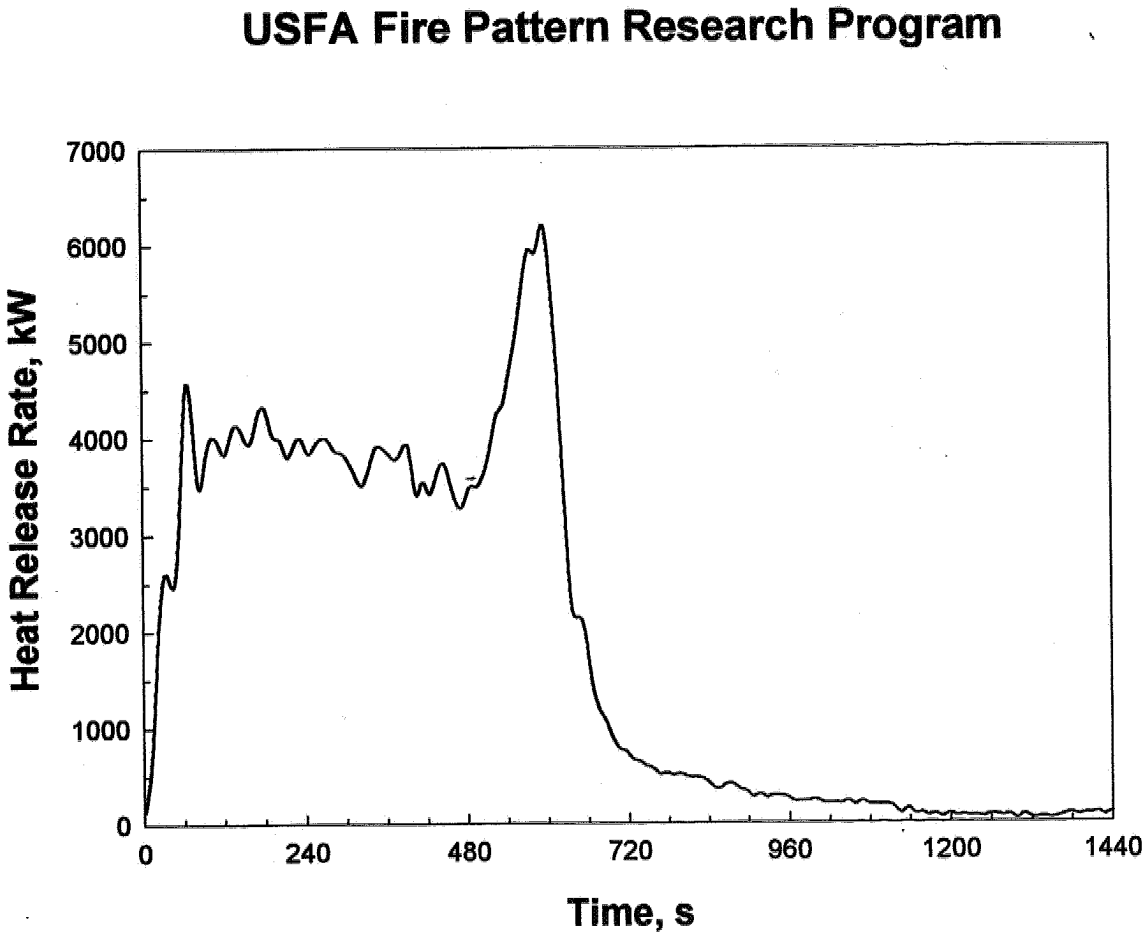



**Figure 18 Heat Release Rate for Test 4**

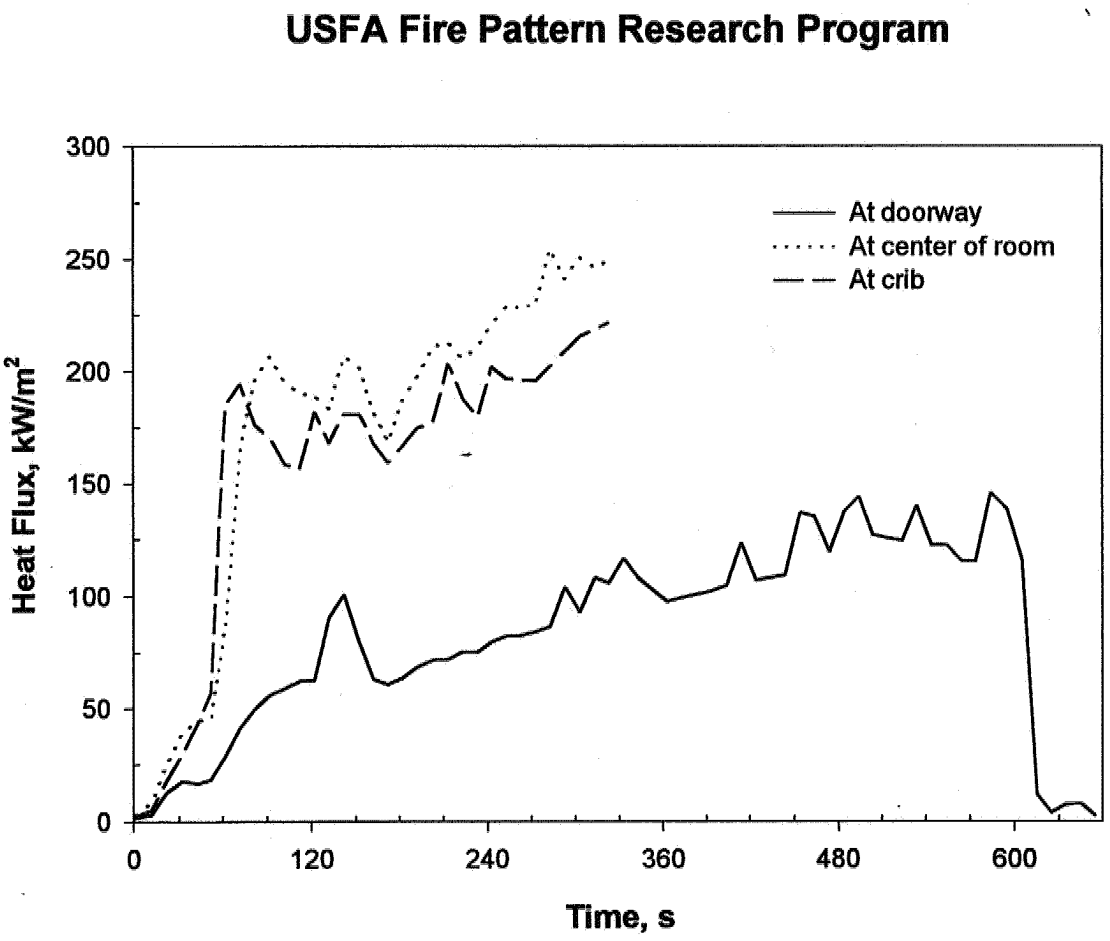



**Figure 19 Radiant Heat Flux at Floor, Test 4**

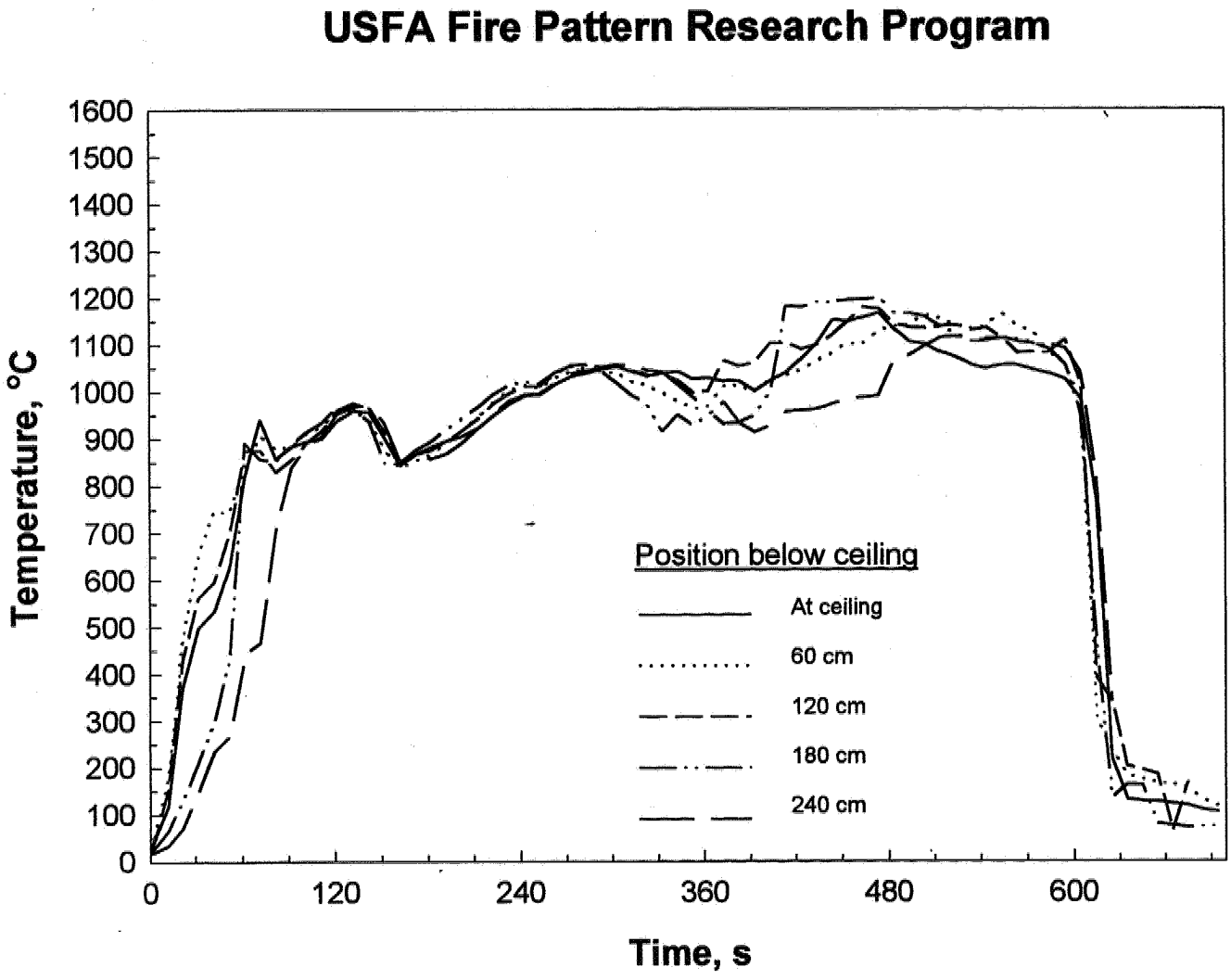



**Figure 20 Center of Room Temperature Profile, Test 4**

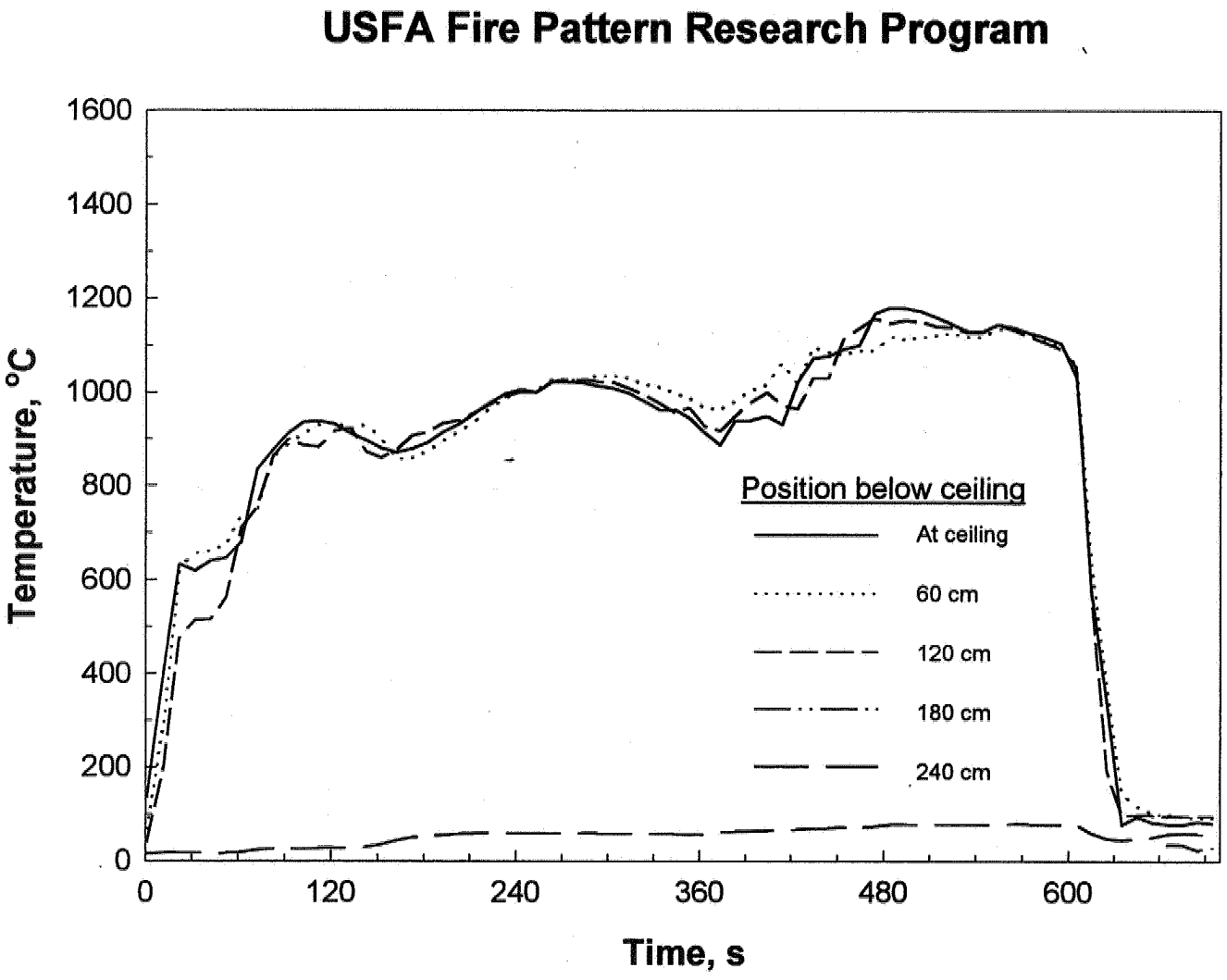



**Figure 21 Doorway Temperature Profile, Test 4**

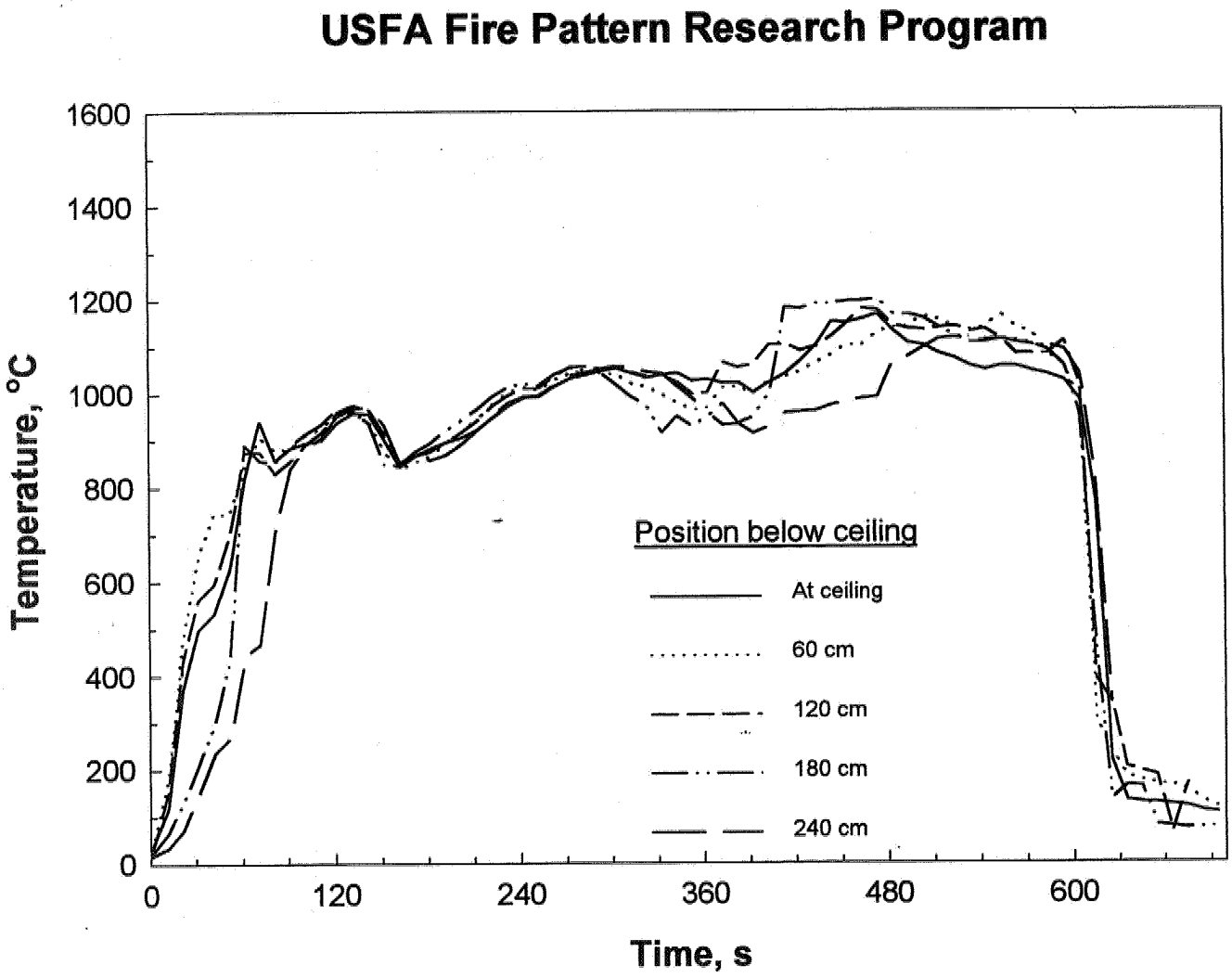



Figure 22. Window Temperature Profile, Test 4

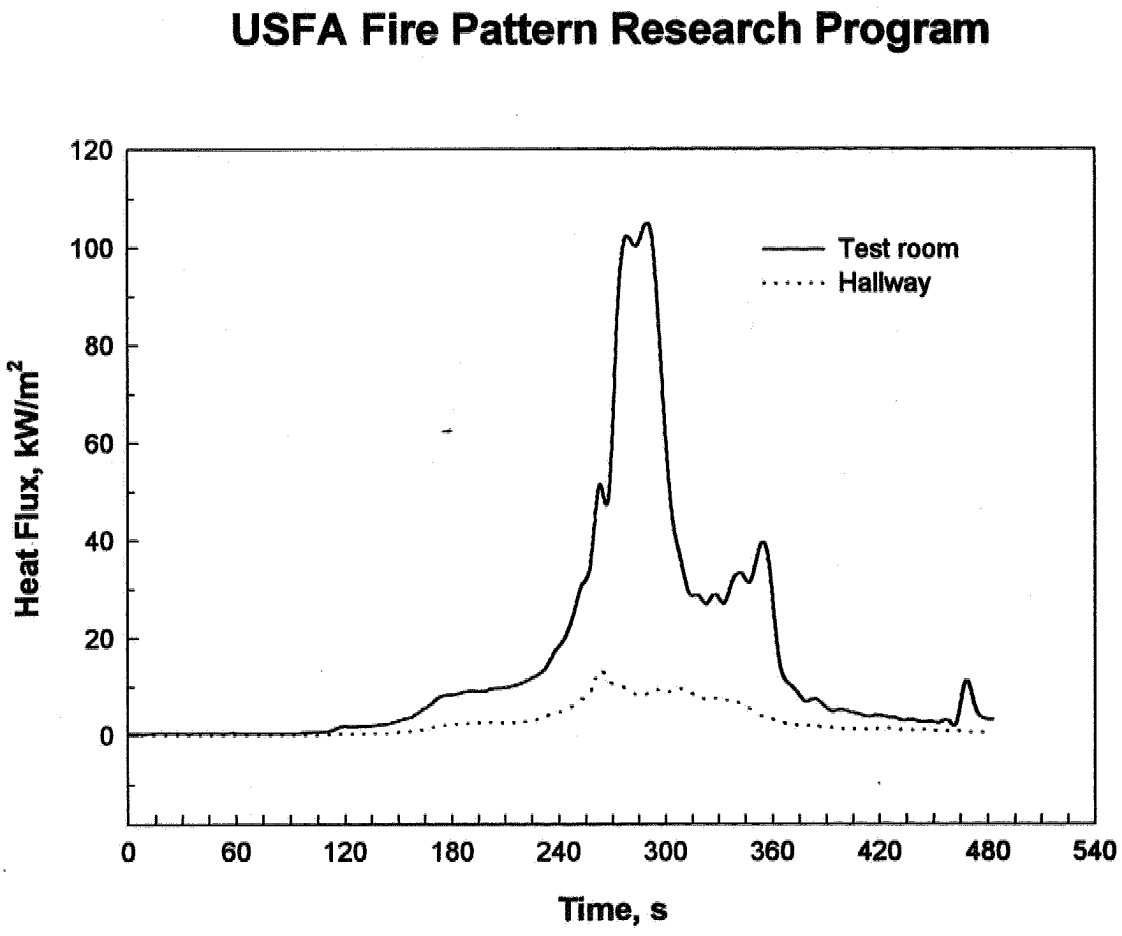



**Figure 23 Radiant Heat Flux at Floor, Test 5**

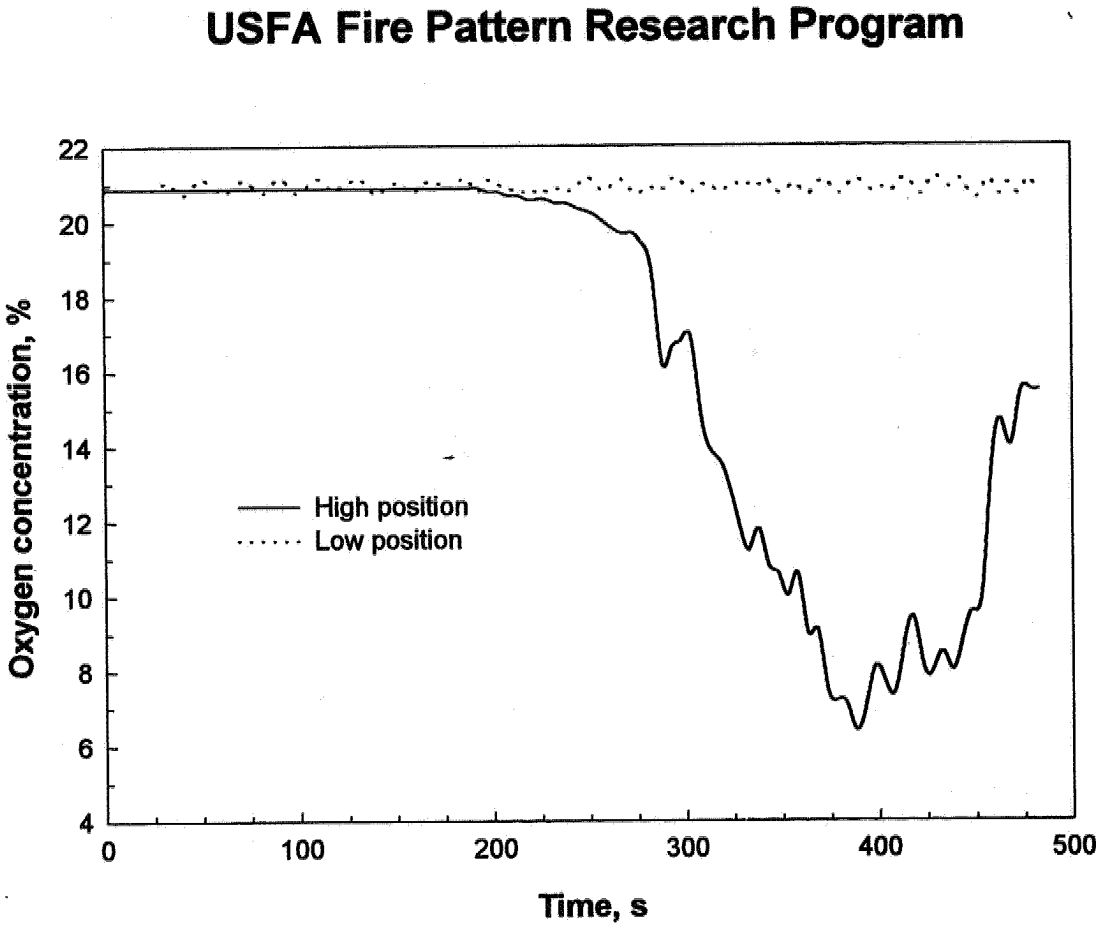
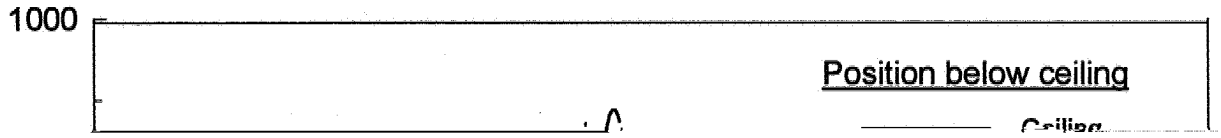
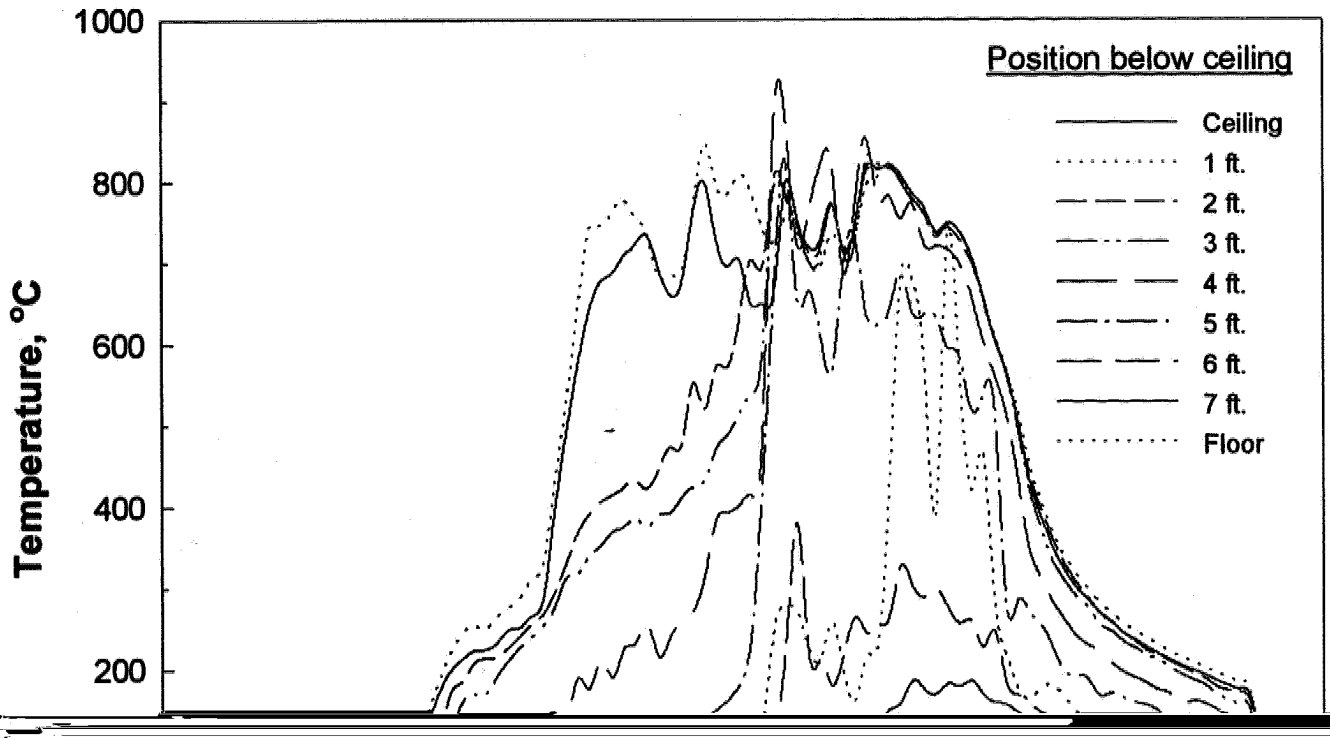



**Figure 24 Oxygen Concentration at Doorway, Test 5**

# USFA Fire Pattern Research Program



# USFA Fire Pattern Research Program



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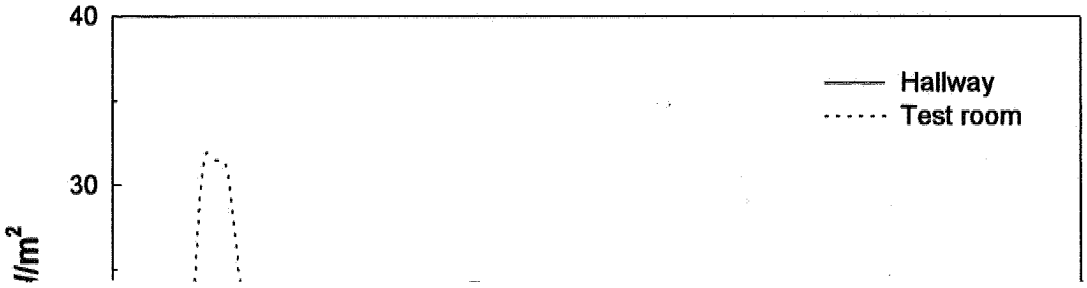


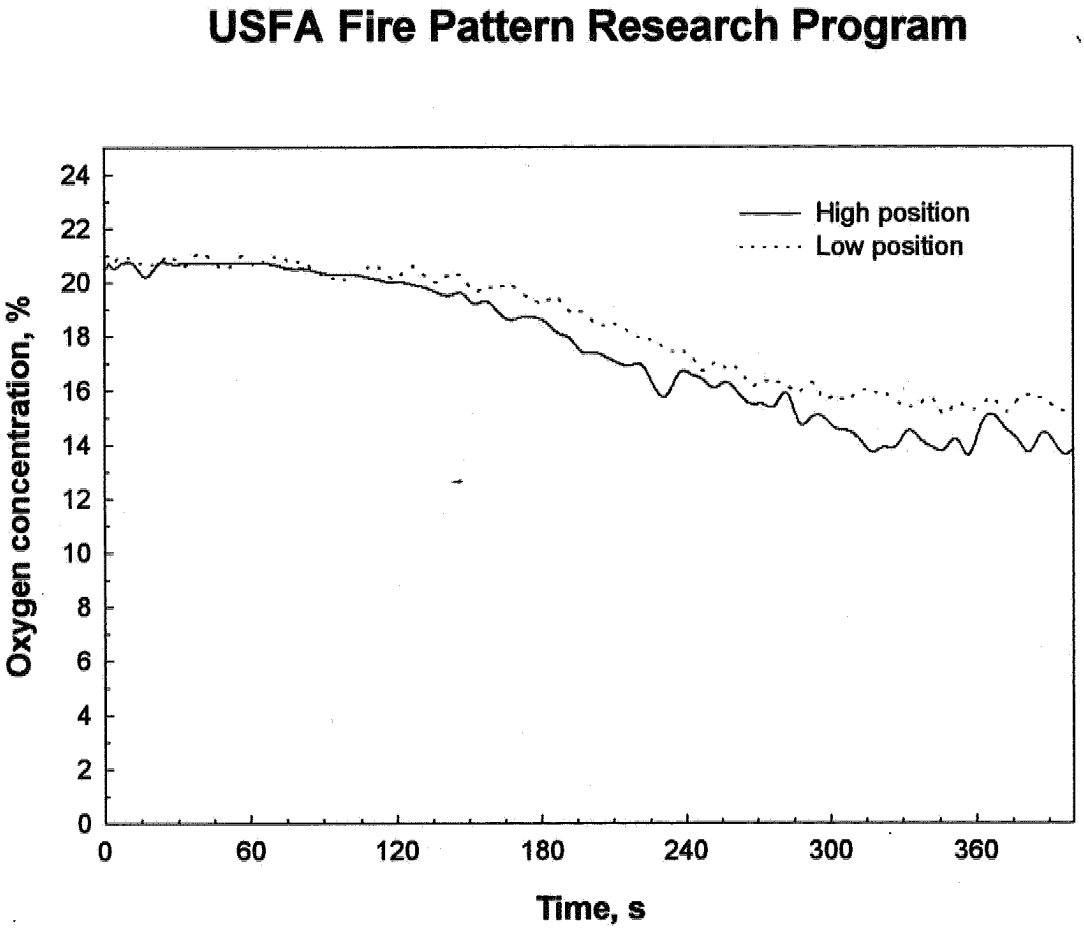



**Figure 28 Oxygen Concentration in Test Room, Test 6**

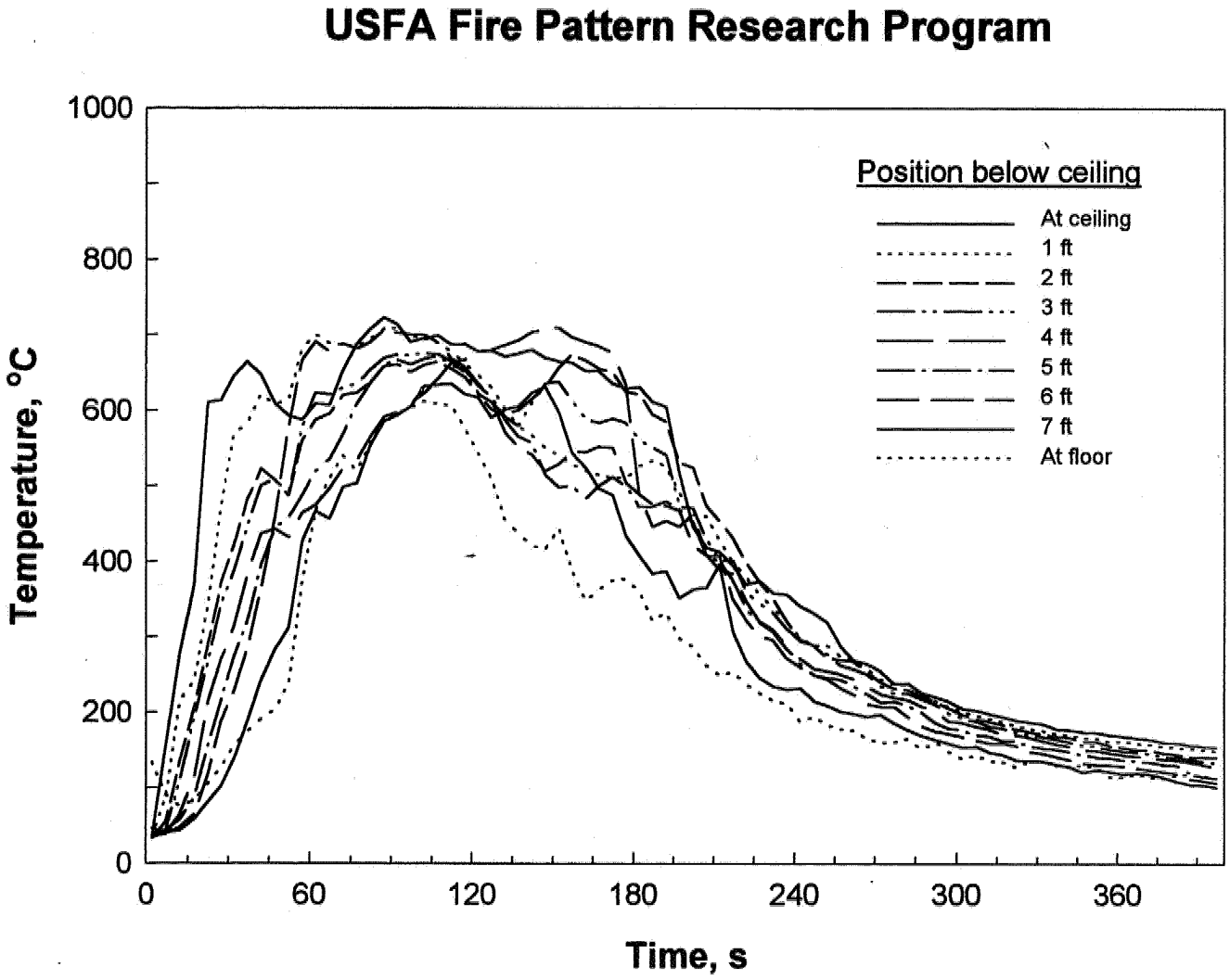



**Figure 29 Center of Room Temperature Profile, Test 6**

# USFA Fire Pattern Research Program

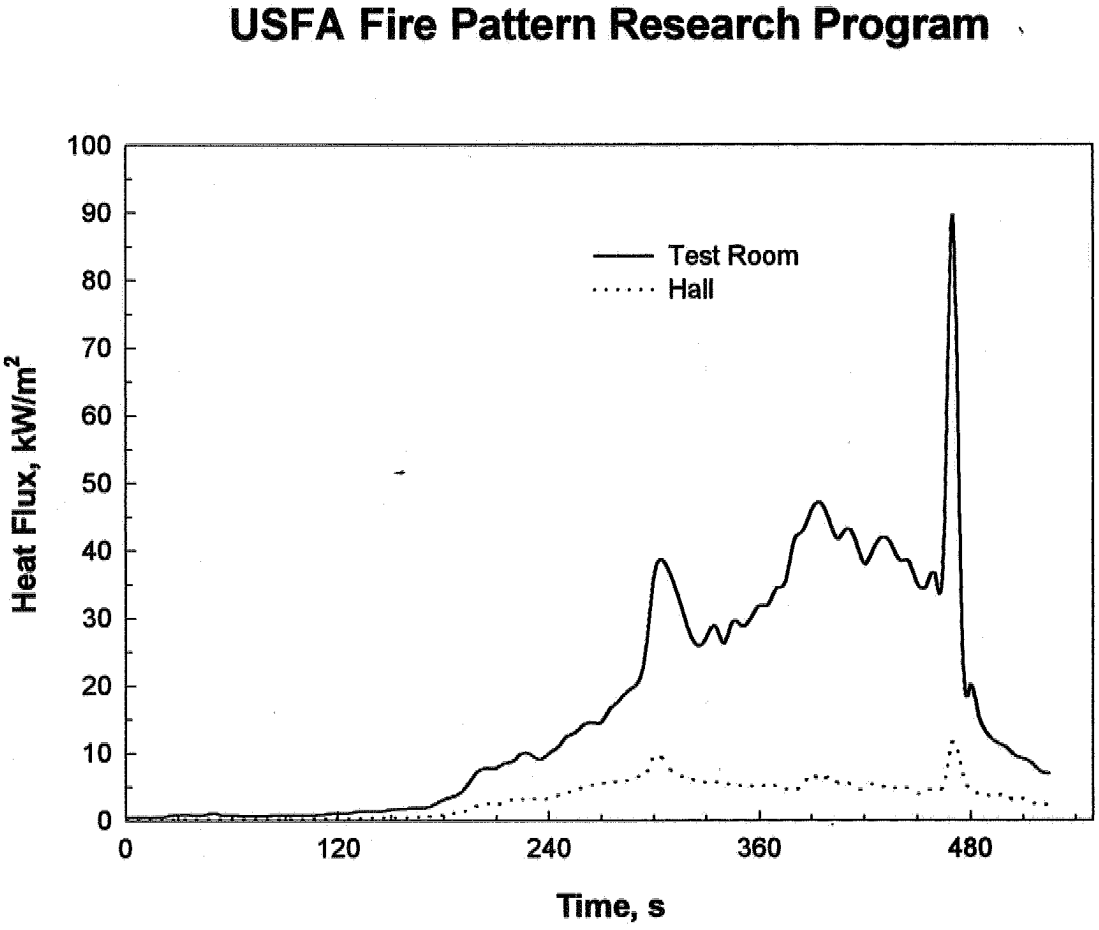



**Figure 31 Radiant Heat Flux at Floor, Test 7**

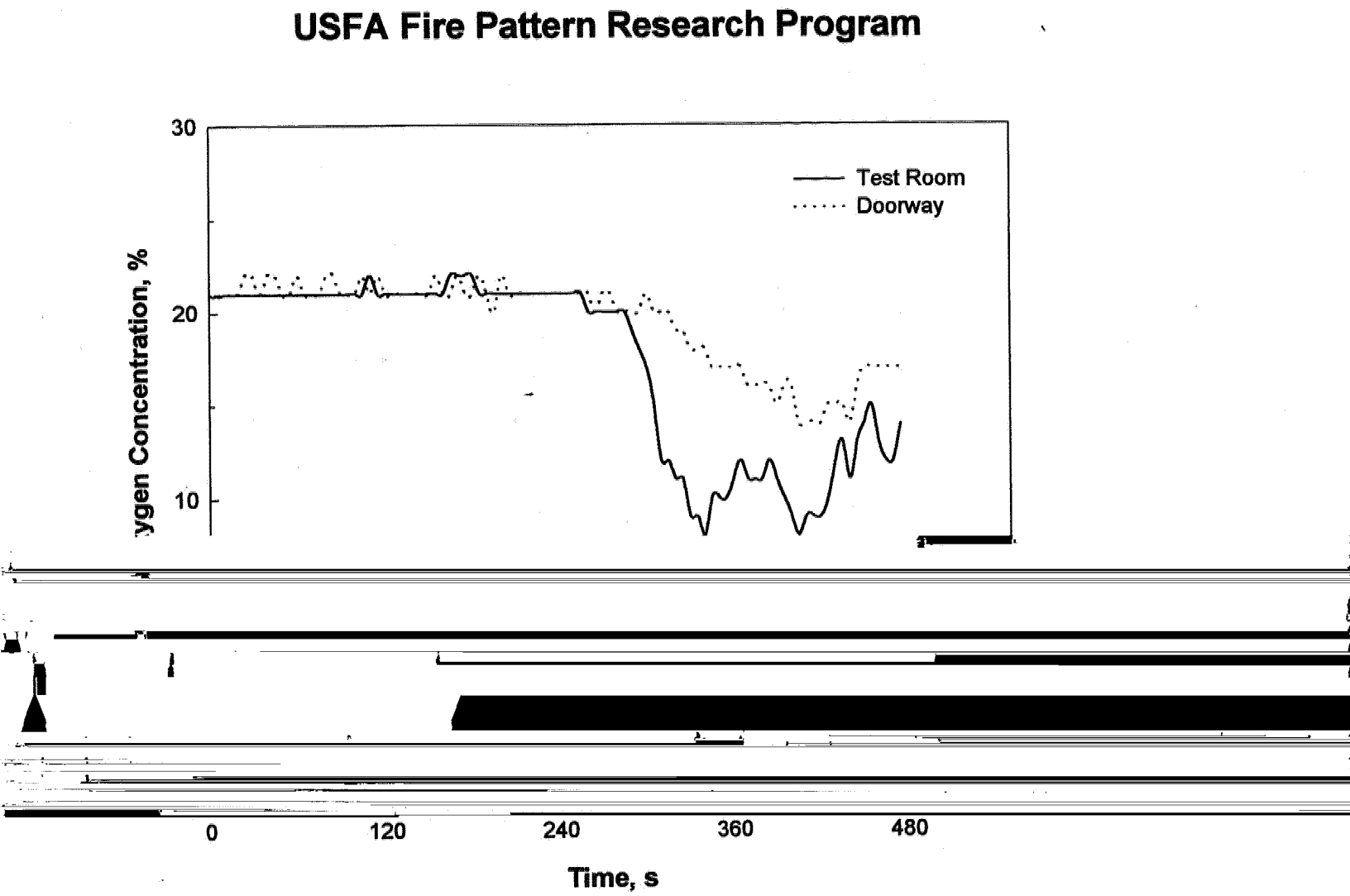



Figure 32 Oxygen Concentration Near Floor, Test 7

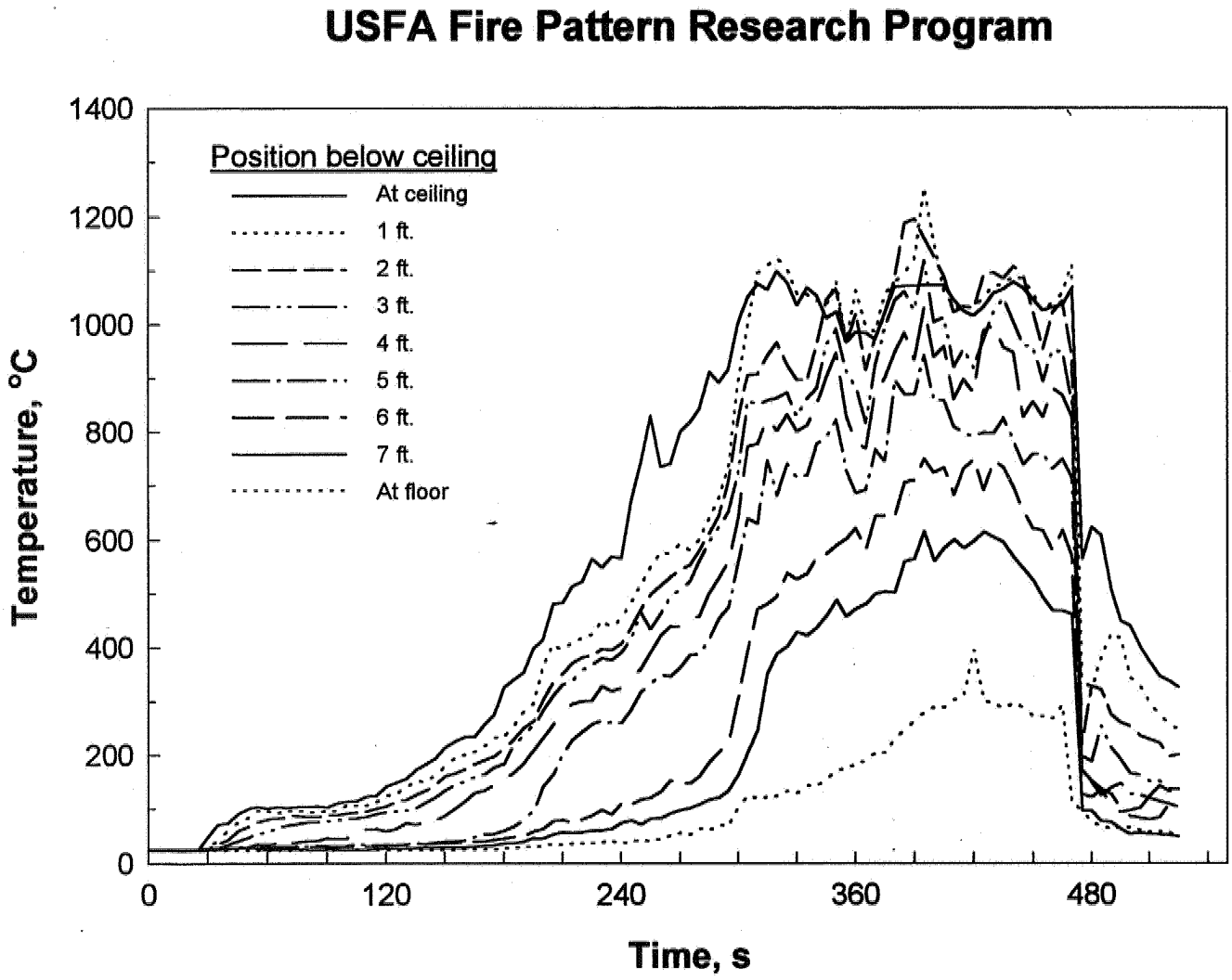
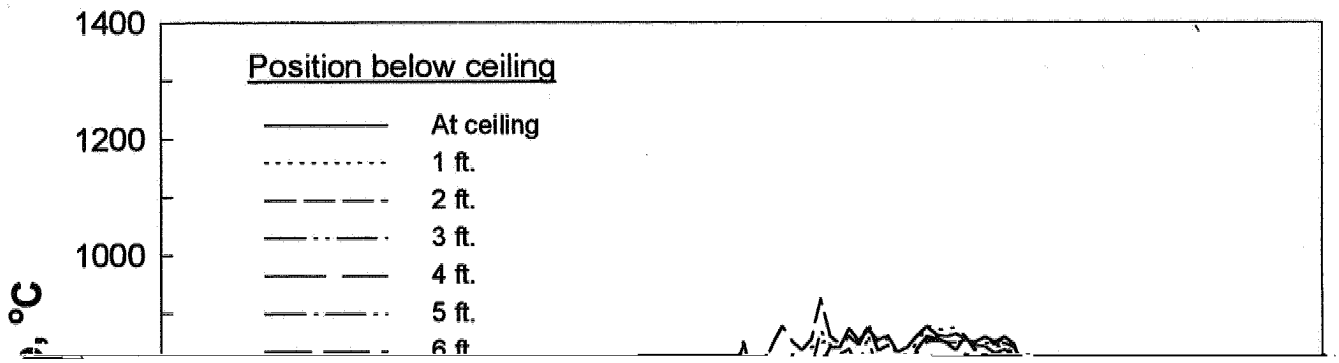



Figure 22. Center of Room Temperature Profile, Test 7

# USFA Fire Pattern Research Program



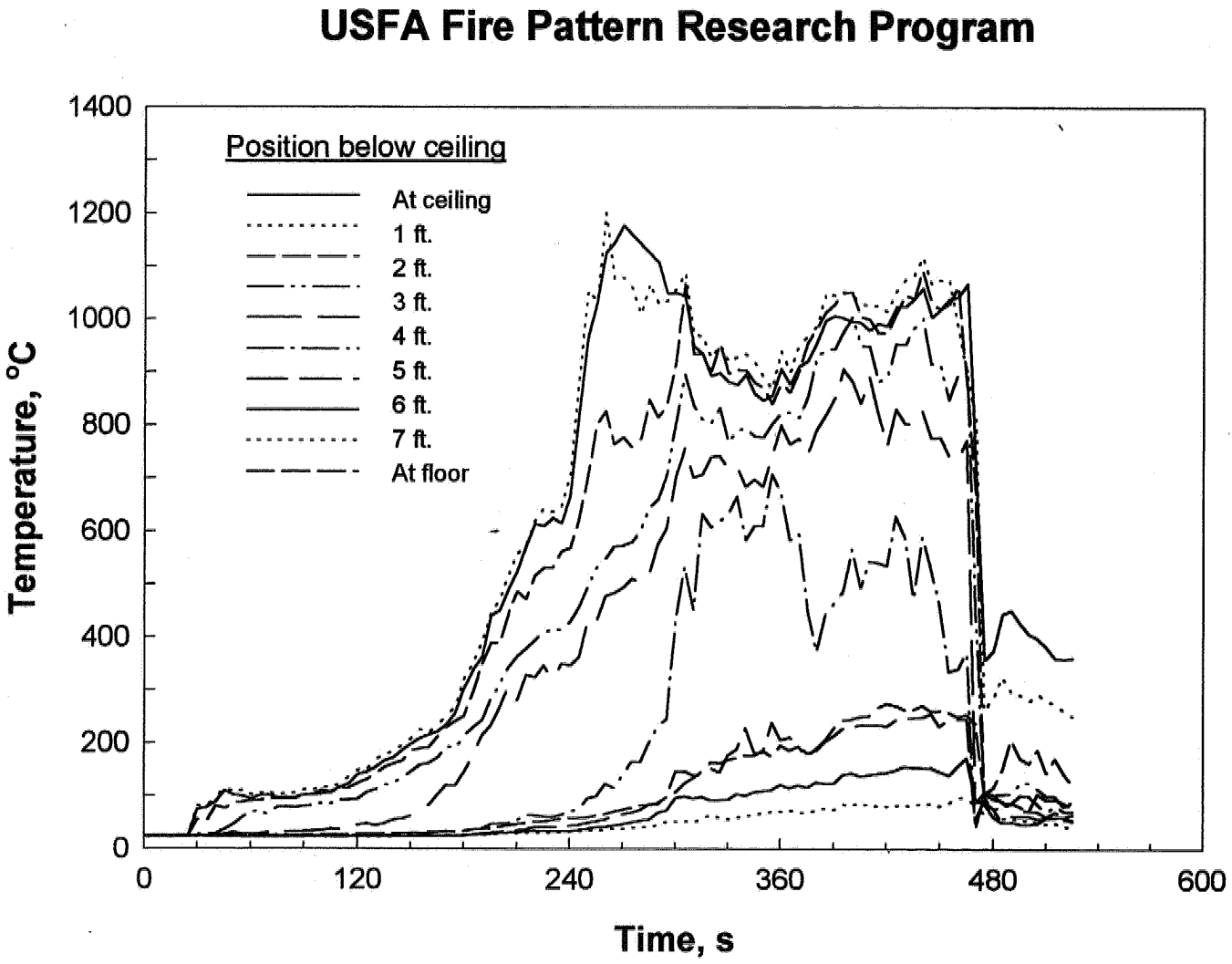



**Figure 35 Door Temperature Profile, Test 7**

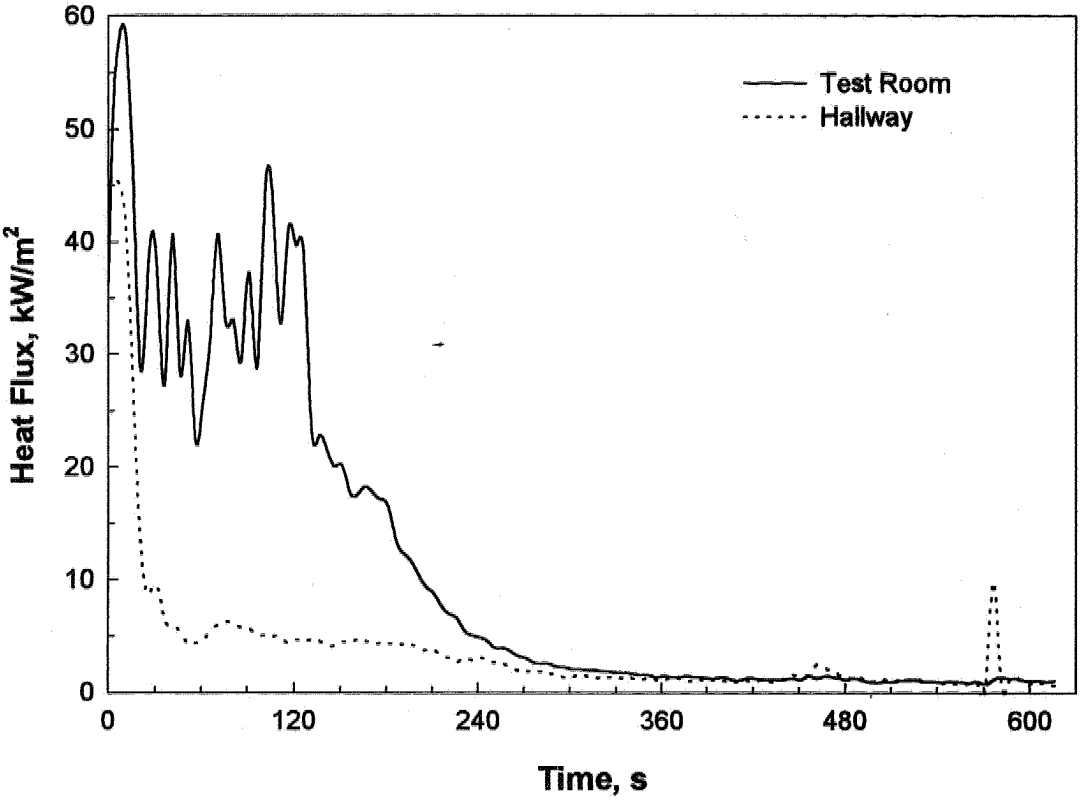
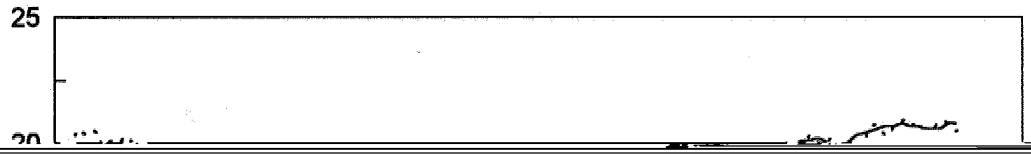



Figure 36 Radiant Heat Flux at Floor, Test 8

# USFA Fire Pattern Research Program



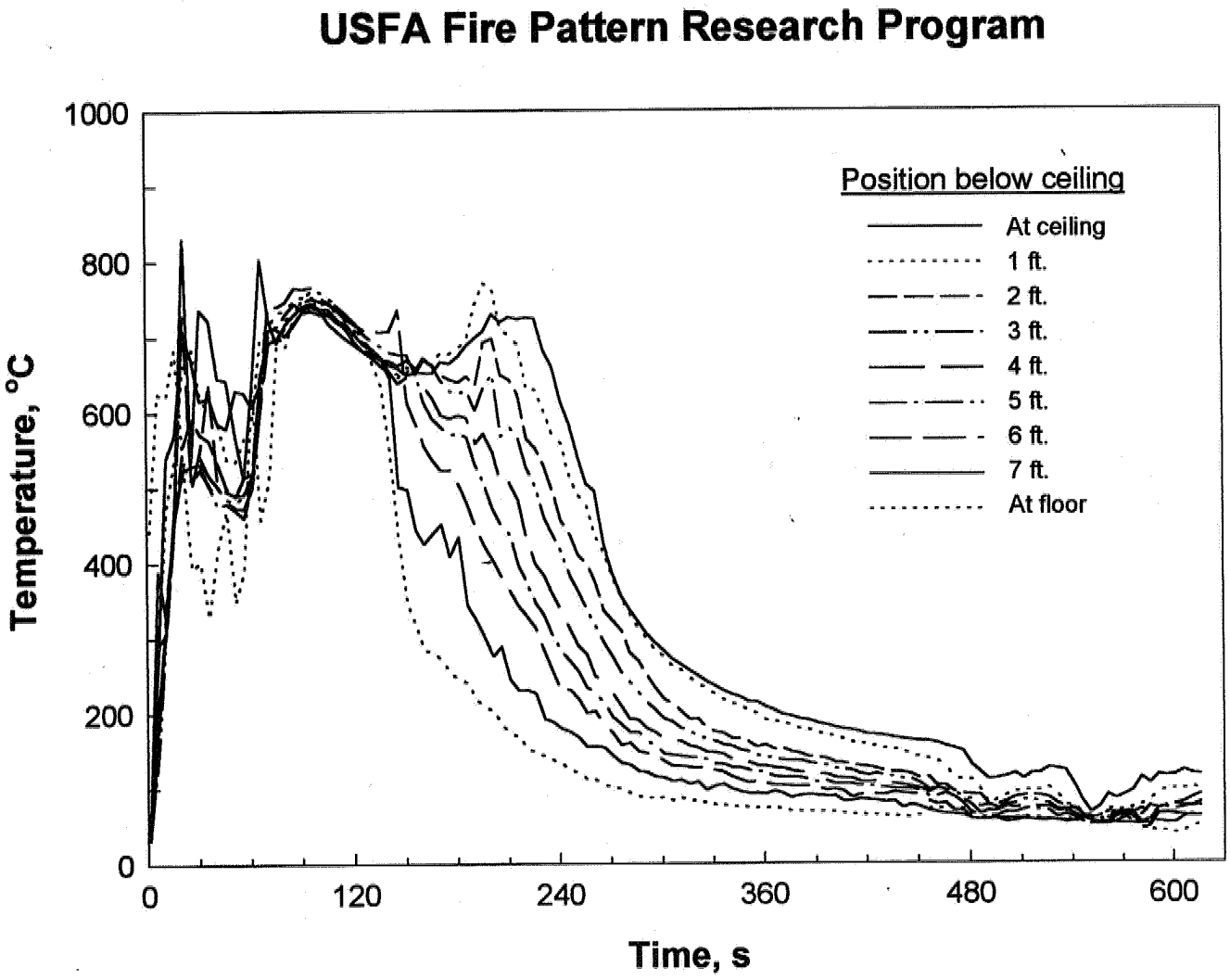
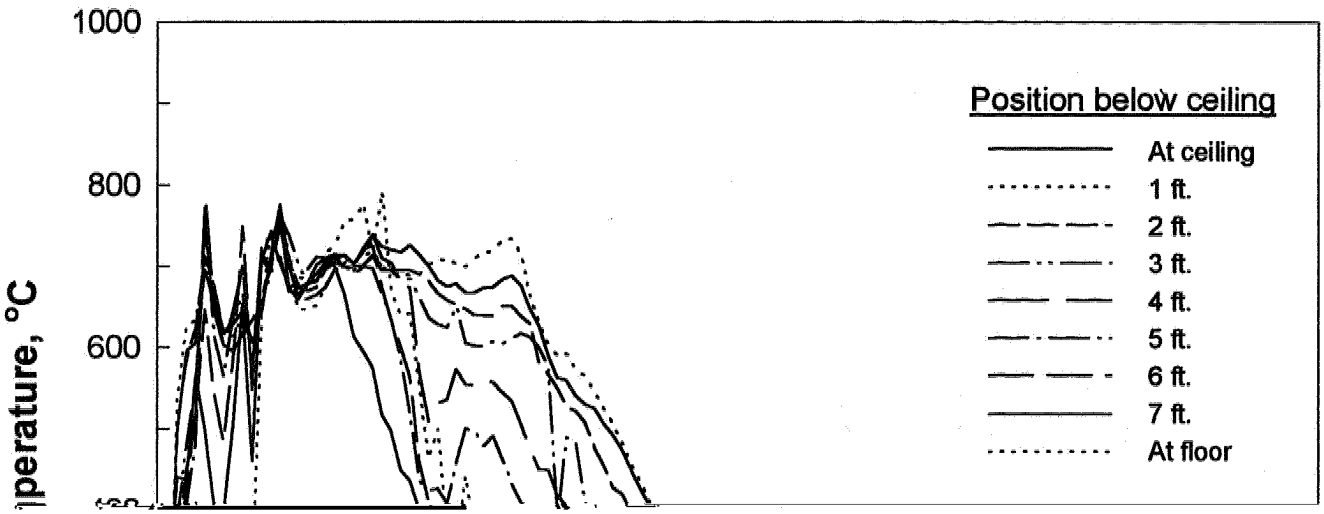



**Figure 38 Center of Room Temperature Profile, Test 8**

# USFA Fire Pattern Research Program



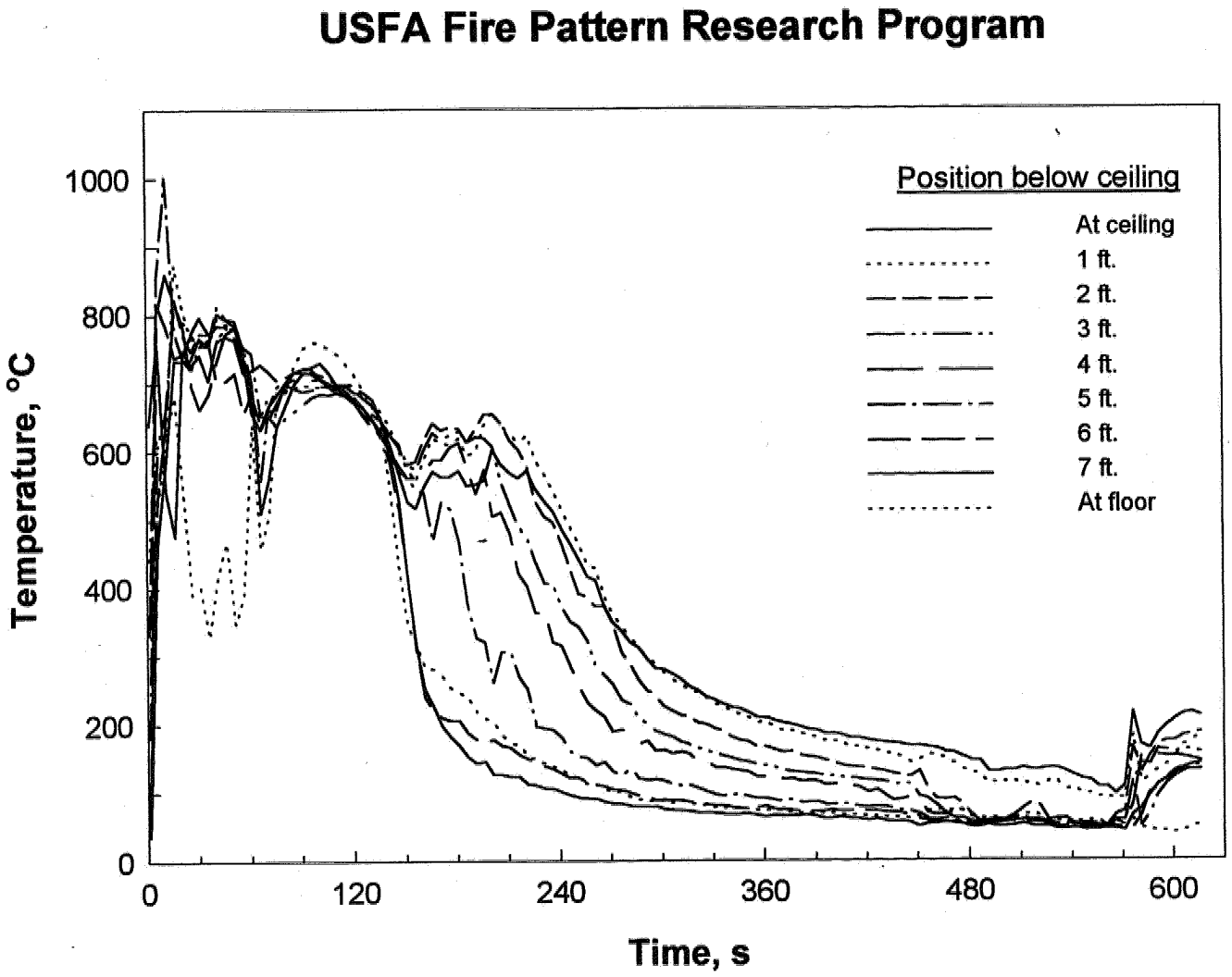



**Figure 40 Door Temperature Profile, Test 8**

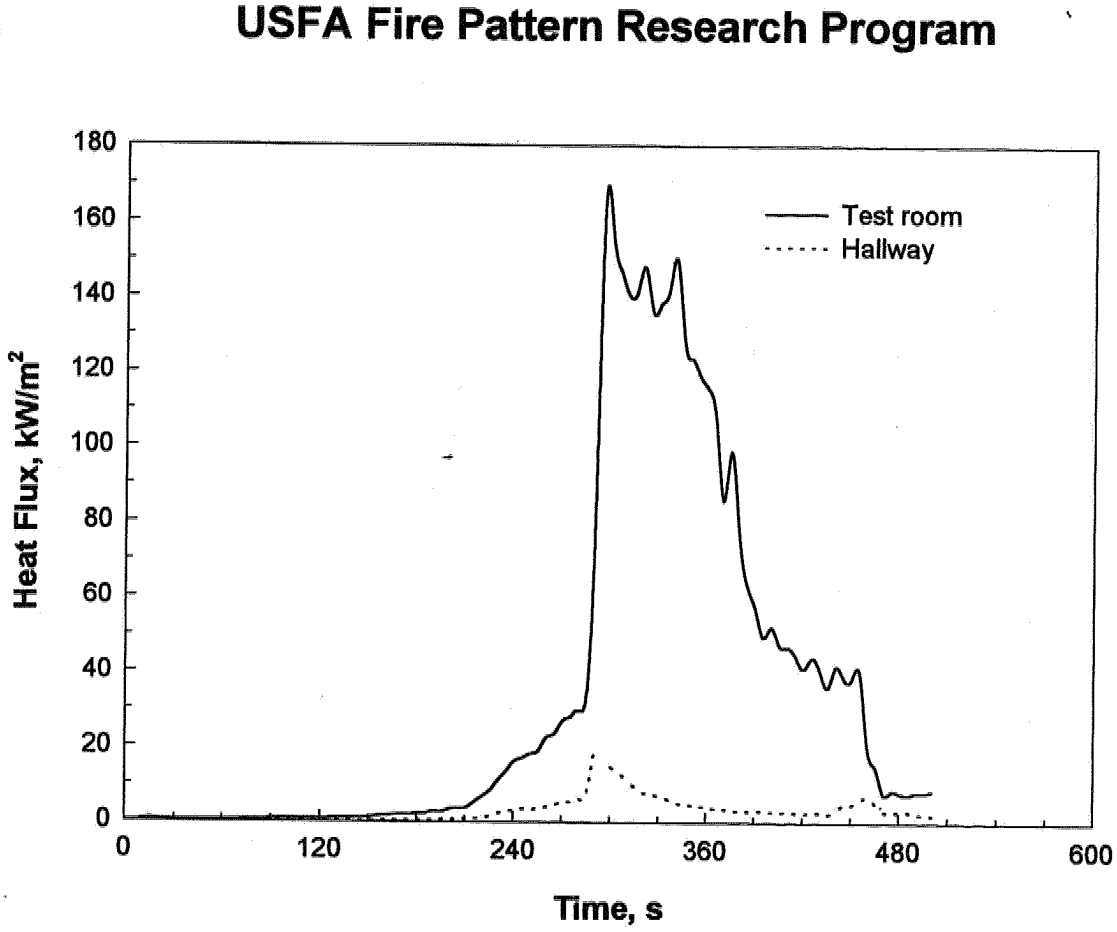



Figure 41 Radiant Heat Flux at Floor, Test 9

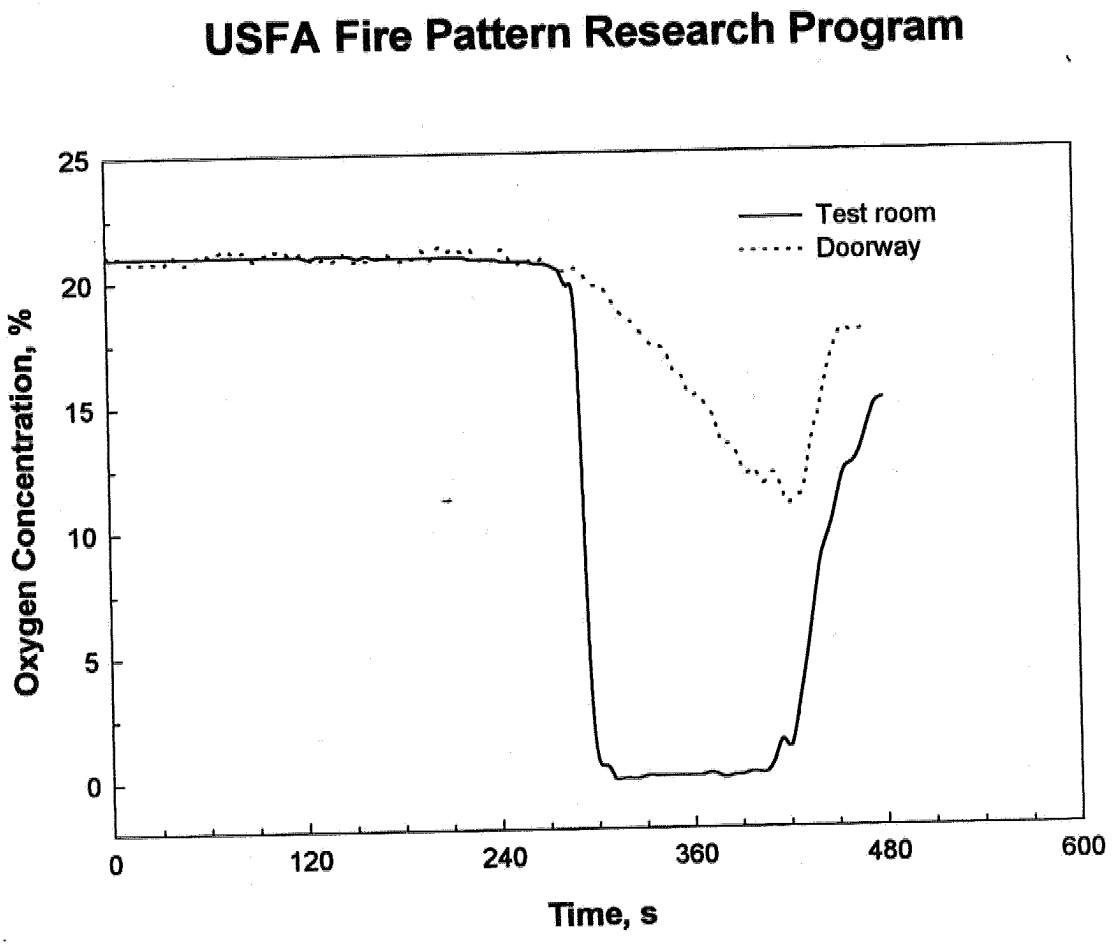



Figure 42 Oxygen Concentration at Floor, Test 9

# USFA Fire Pattern Research Program

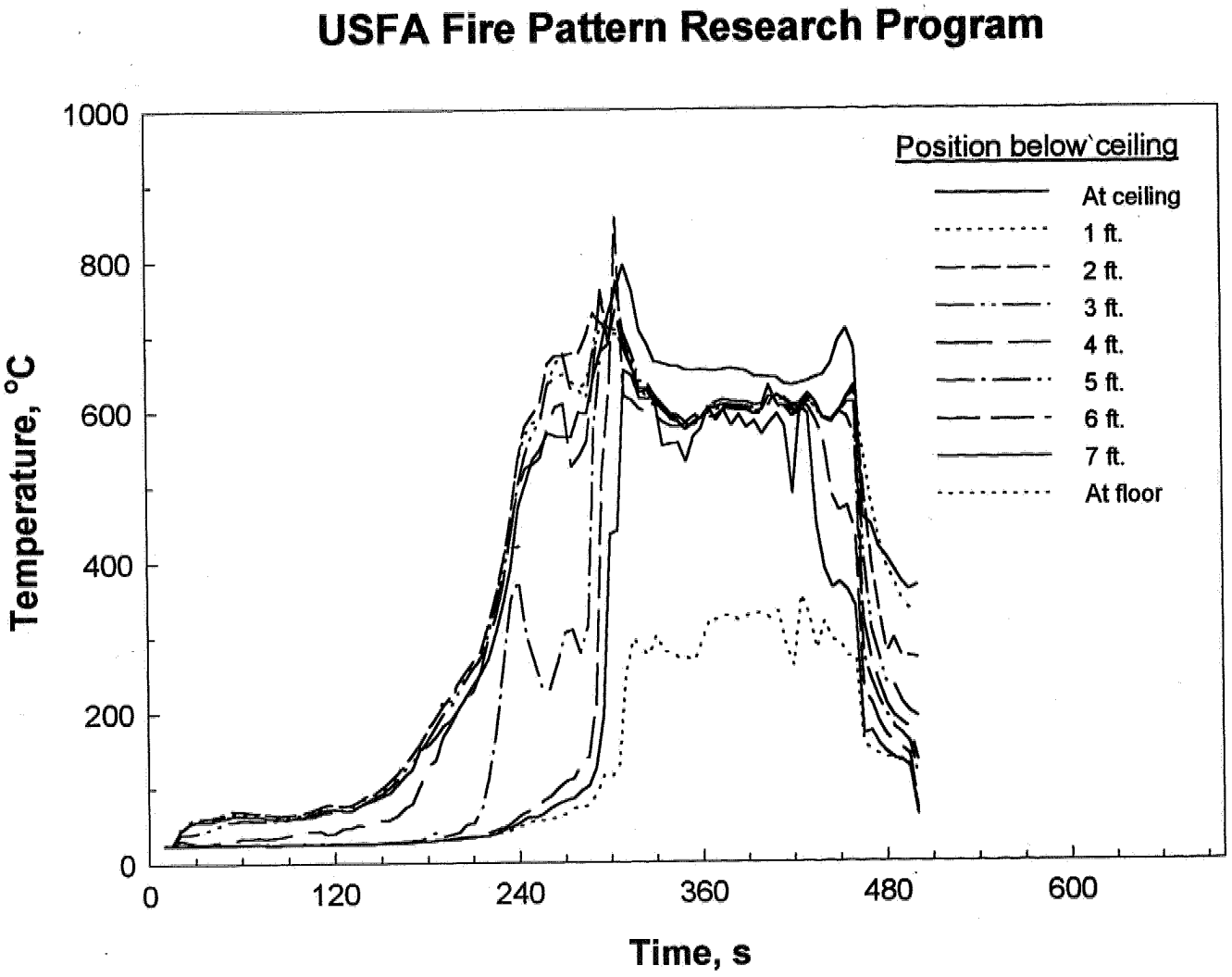



**Figure 44 Window Temperature Profile, Test 9**

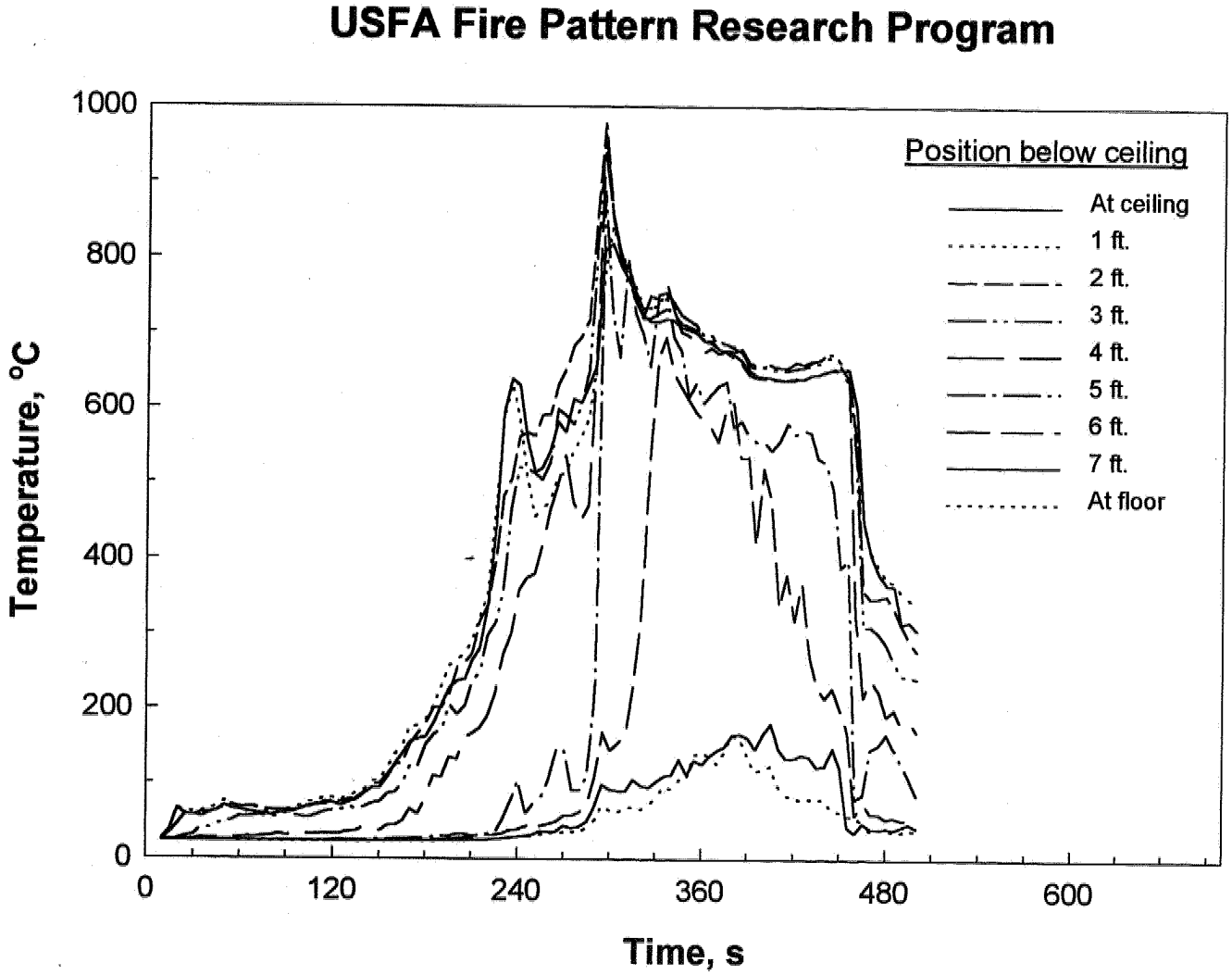



Figure 45. Door Temperature Profile, Test 9

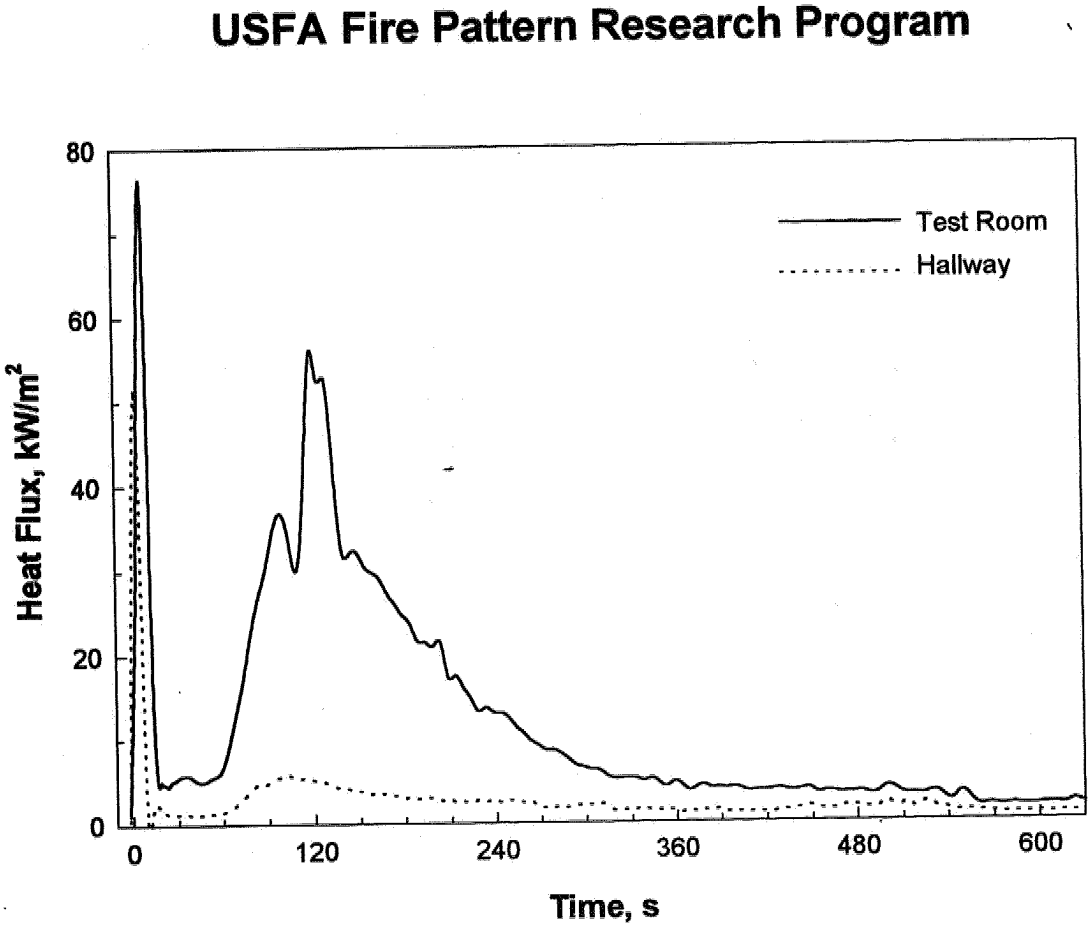



**Figure 46 Radiant Heat Flux at Floor, Test 10**

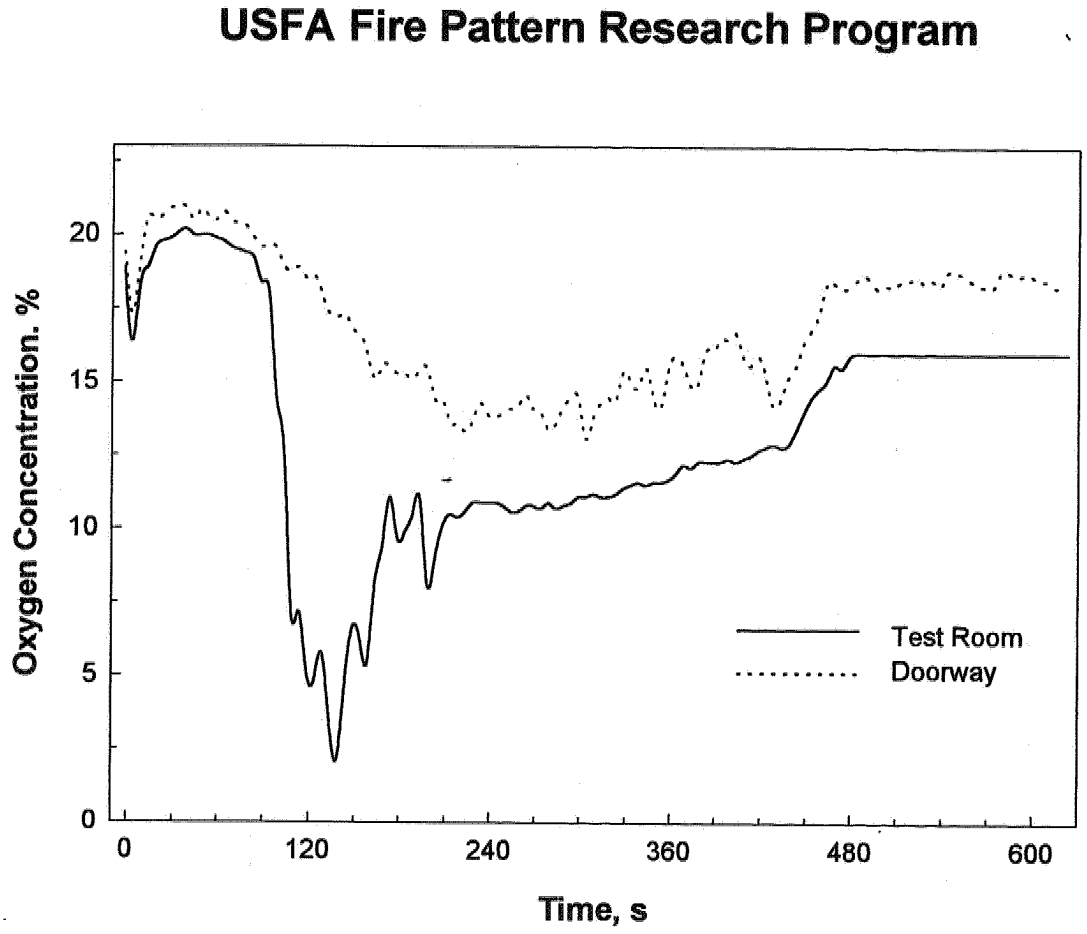



**Figure 47 Oxygen Concentration at Floor, Test 10**

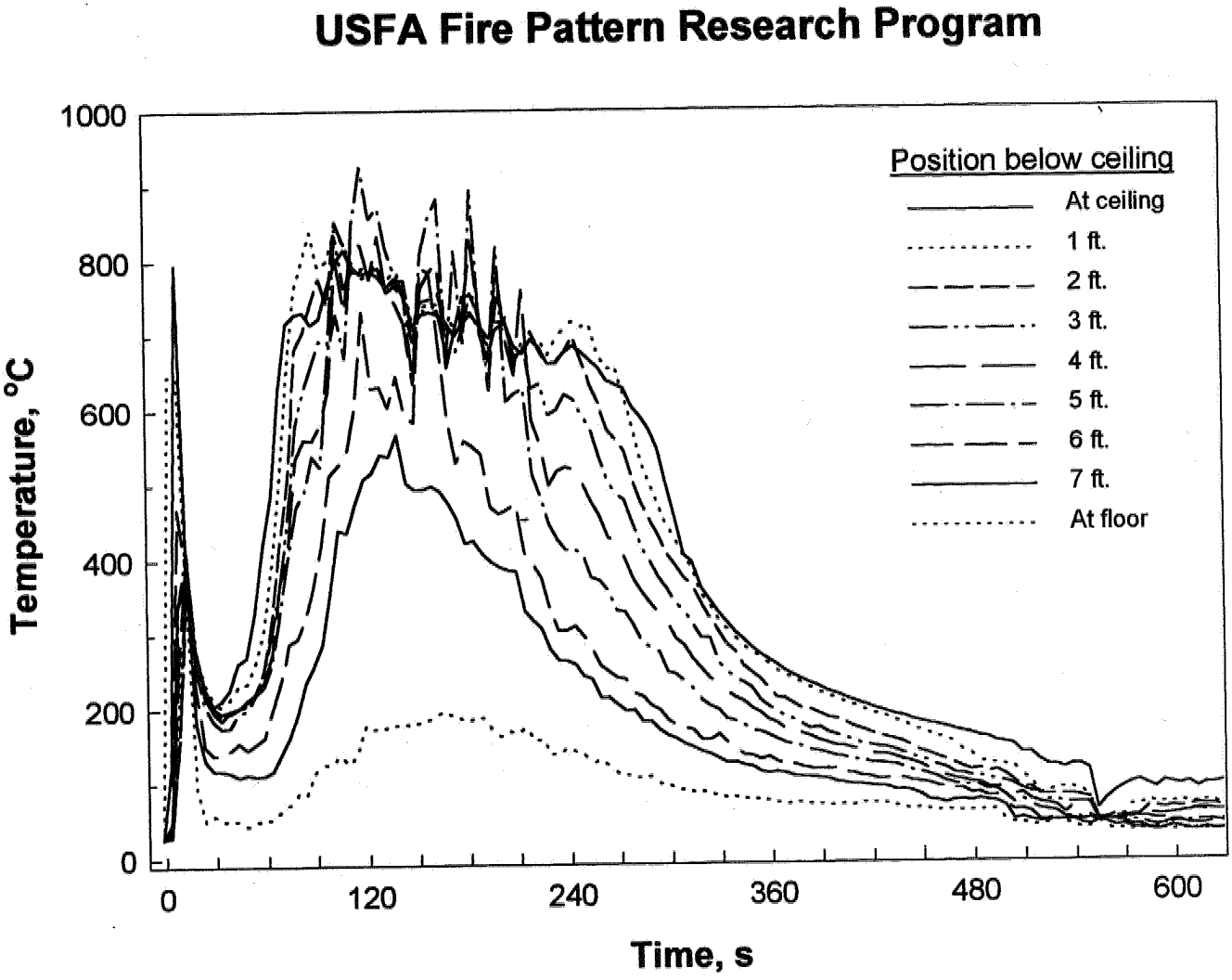



**Figure 48 Center of Room Temperature Profile, Test 10**

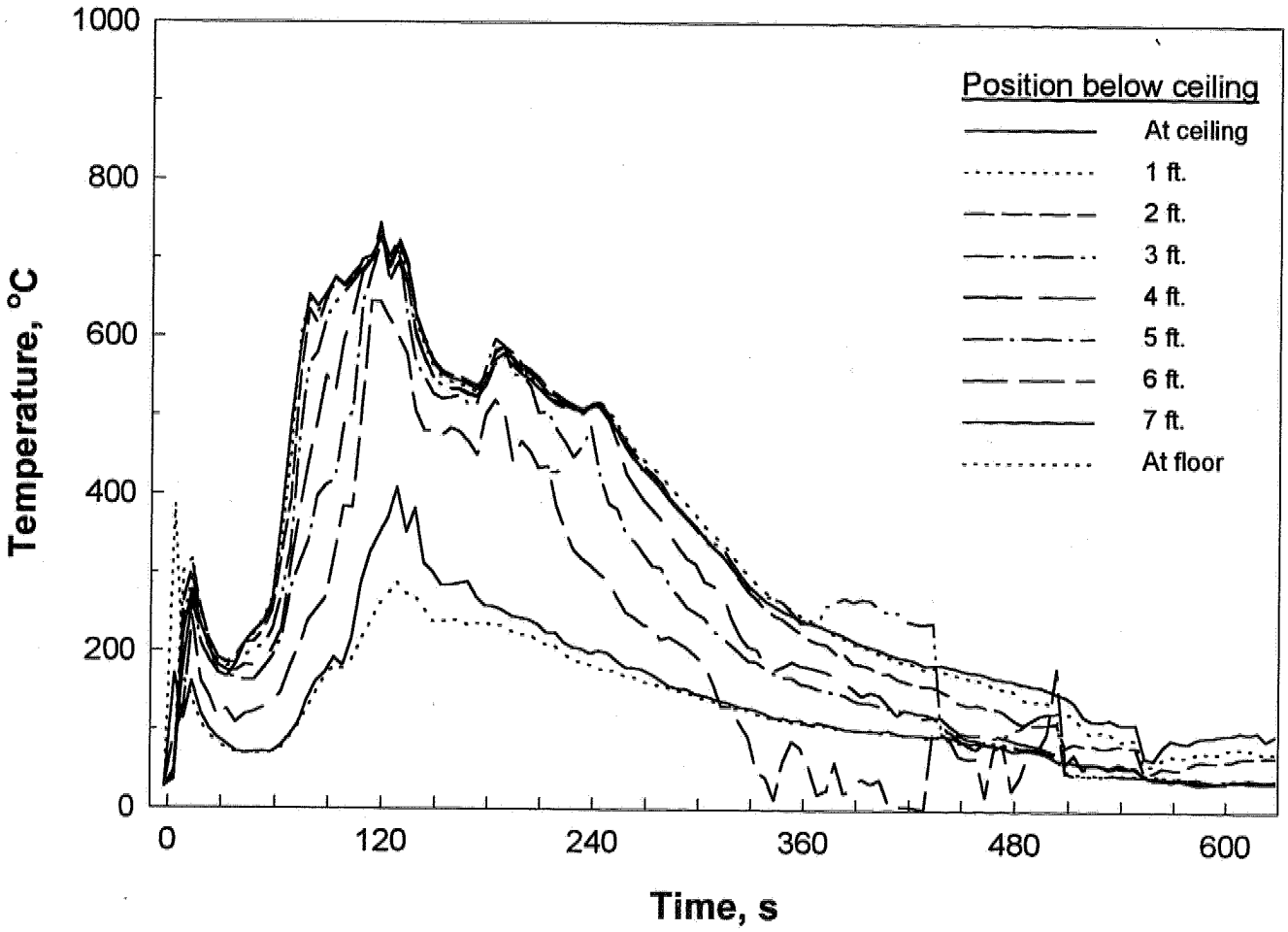



**Figure 49 Window Temperature Profile, Test 10**

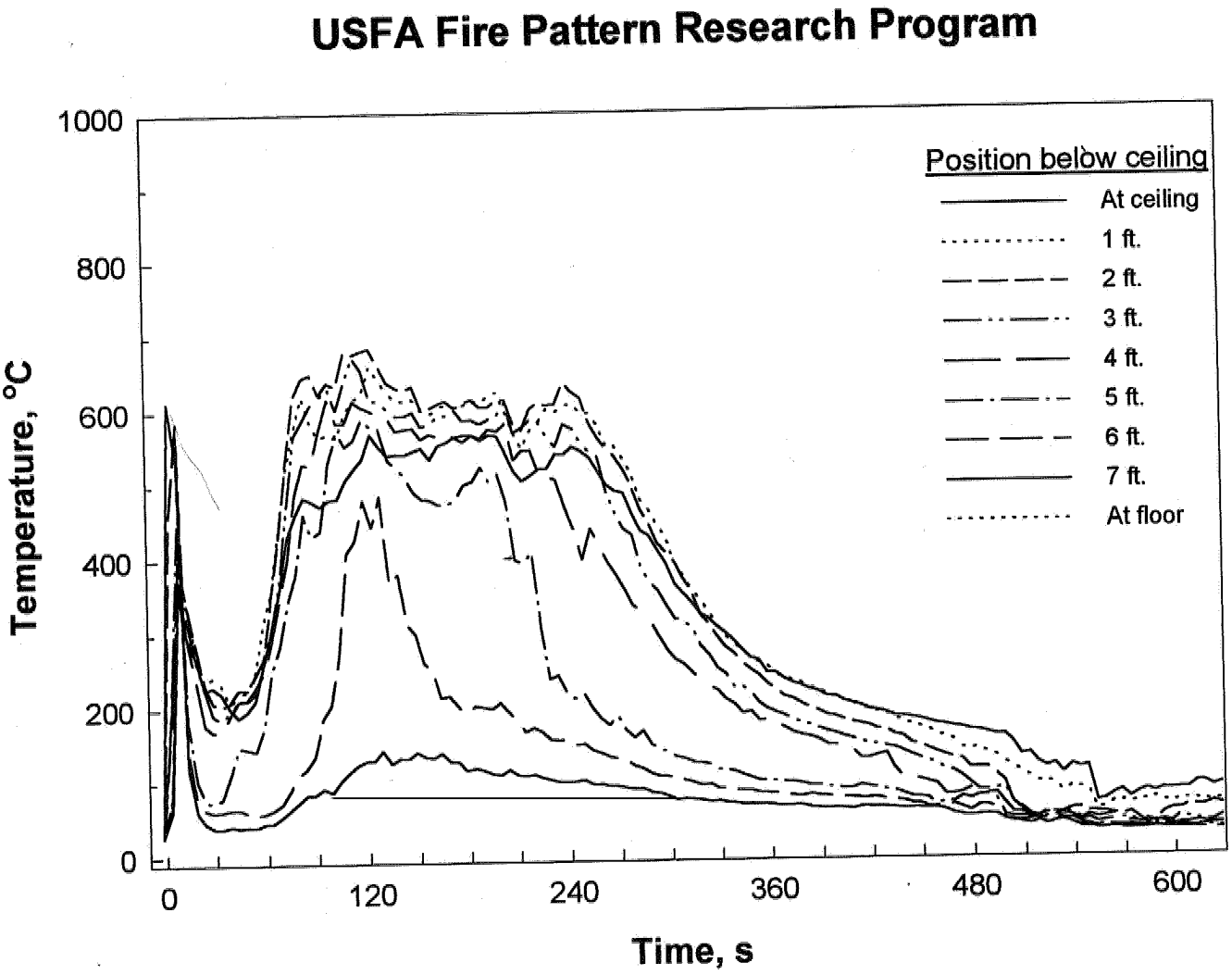
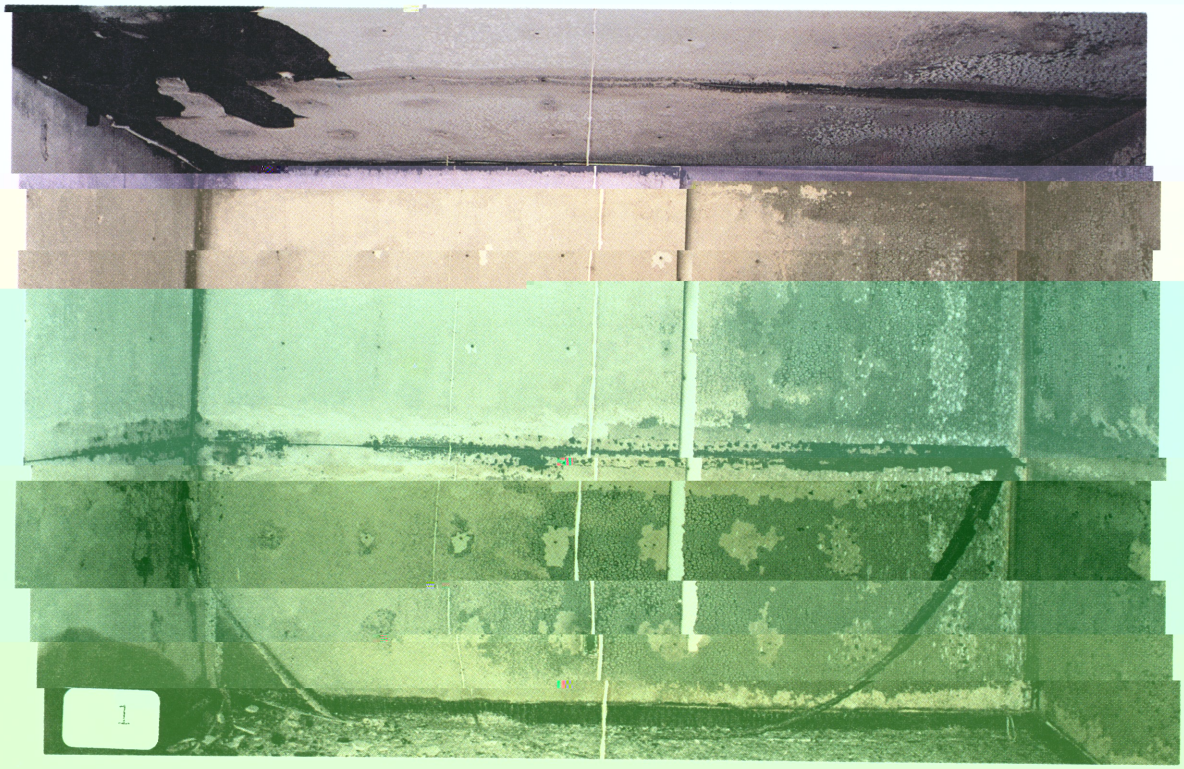



**Figure 50 Door Temperature Profile, Test 10**

## ***XVII. PHOTOGRAPHS***

# USFA FIRE PATTERN RESEARCH PROGRAM

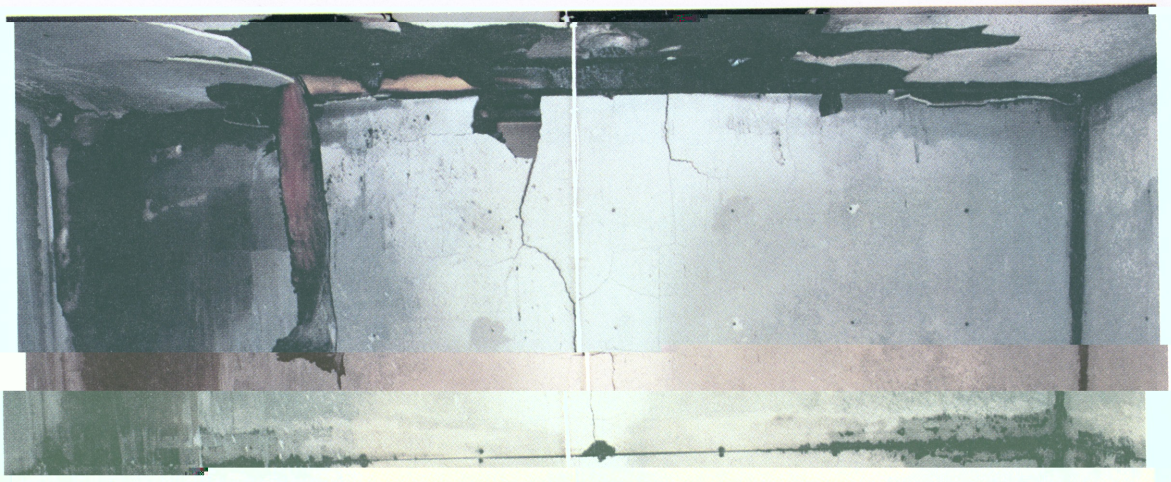
## TEST PHOTOGRAPH




**Photograph 1 (Test 1)**

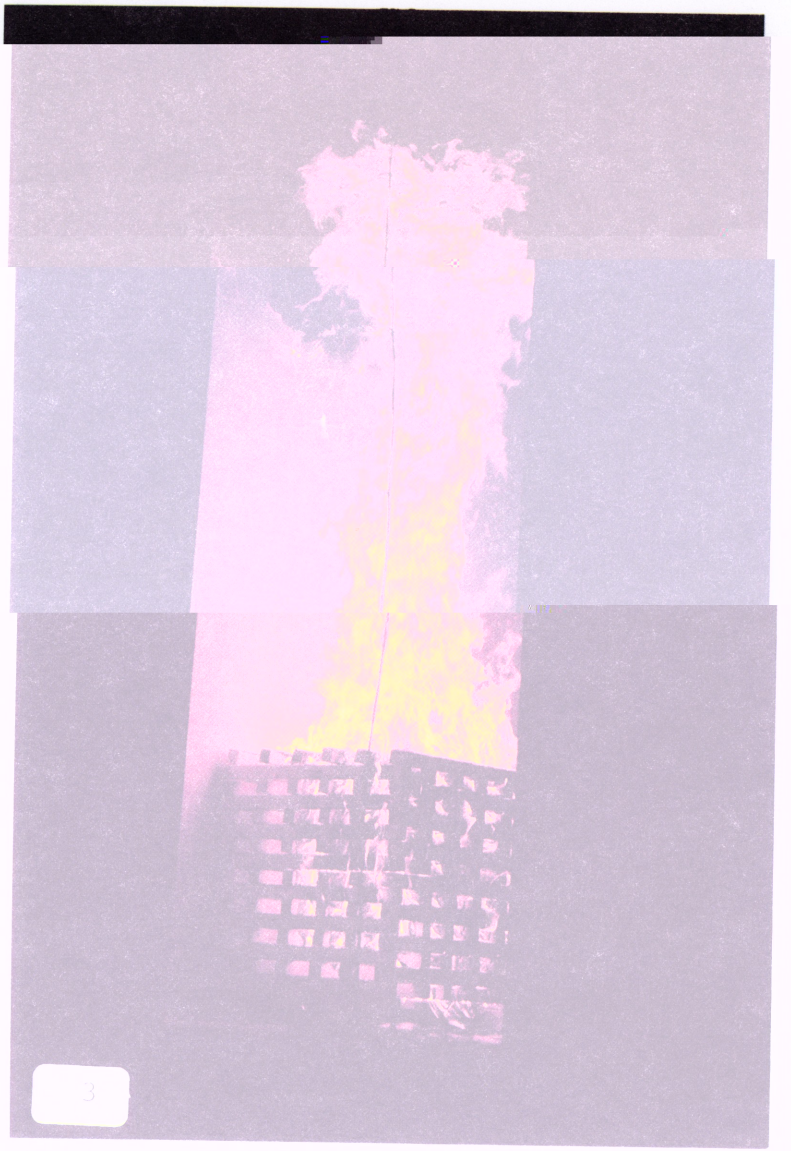
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



# USFA FIRE PATTERN RESEARCH PROGRAM

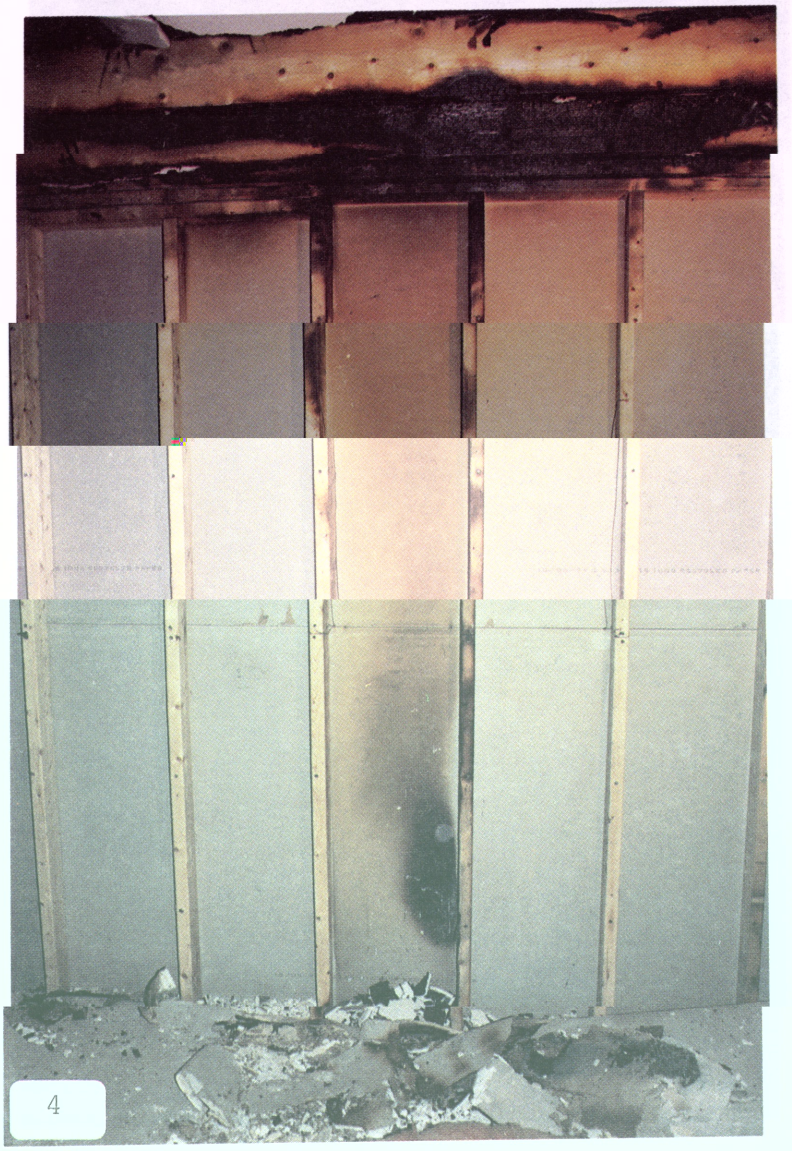
## TEST PHOTOGRAPH




Photograph 3 (Test 1)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



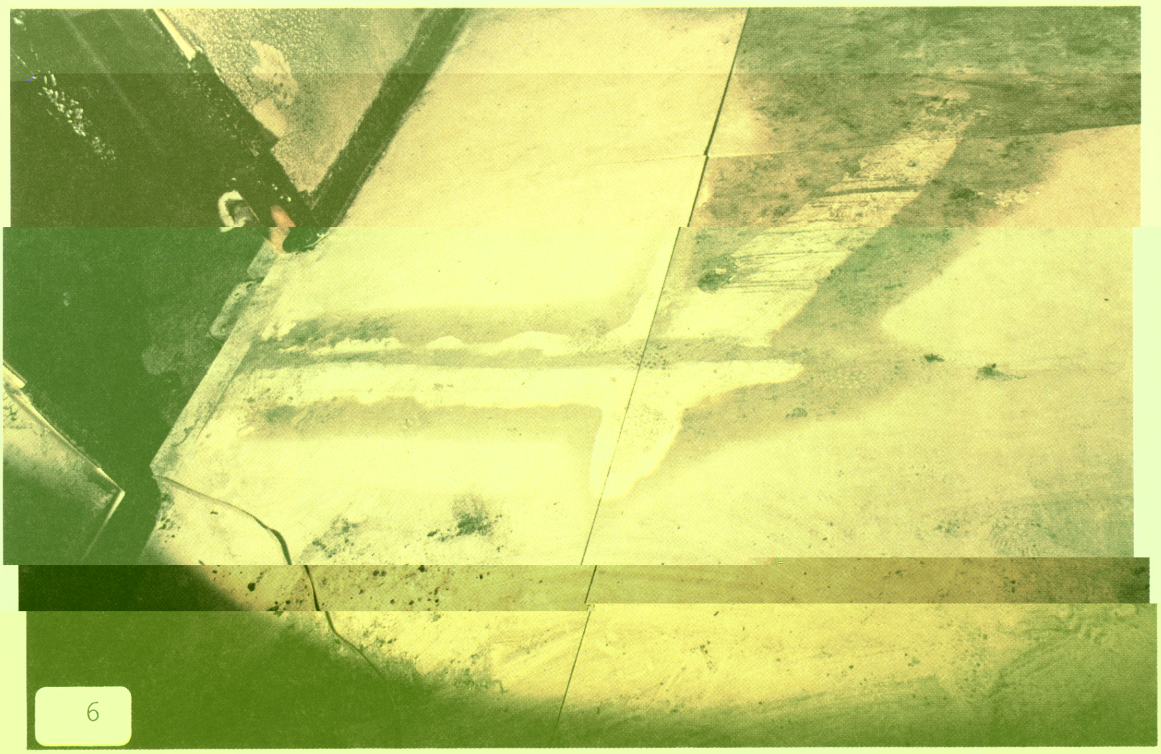

**Photograph 4 (Test 1)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 5 (Test 1)

## TEST PHOTOGRAPH




**Photograph 6 (Test 1)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 7 (Test 2)

**USFA FIRE PATTERN RESEARCH PROGRAM**

**TEST PHOTOGRAPH**

Photograph 8 (Test 2)

## TEST PHOTOGRAPH

Photograph 9 (Test 2)

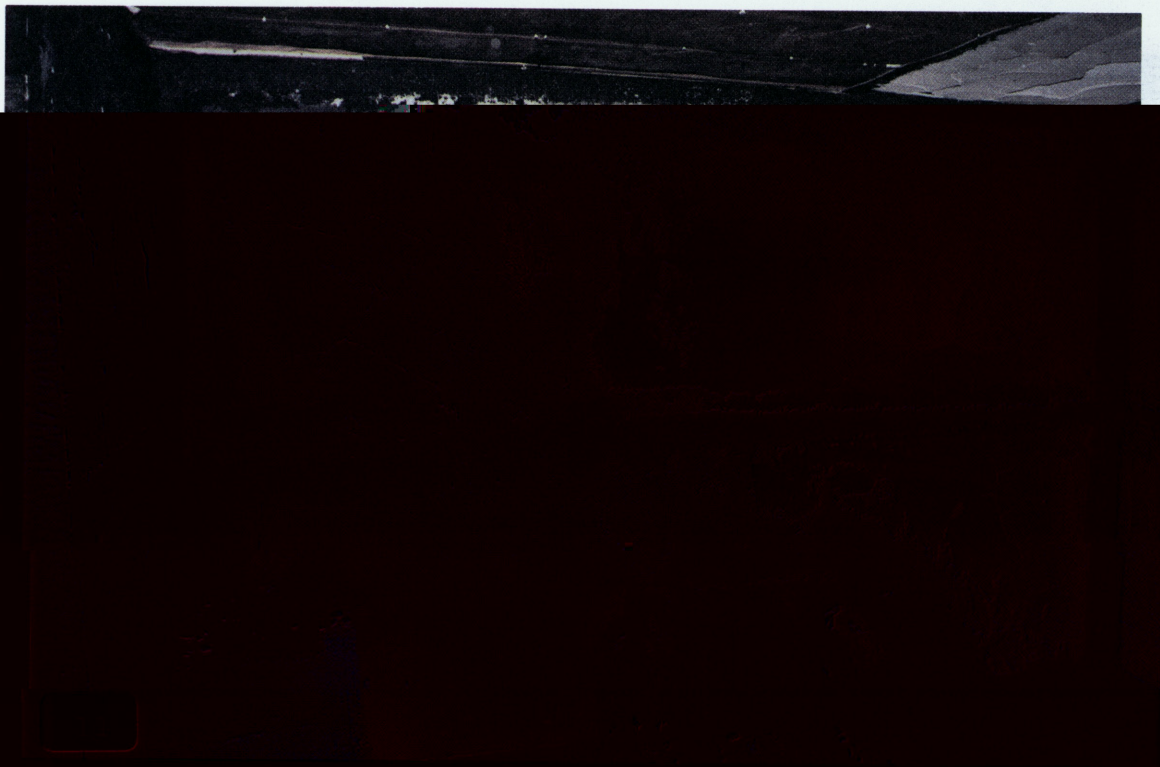
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 10 (Test 2)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

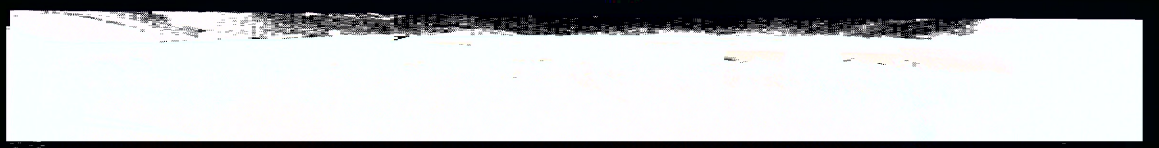


USFA FIRE PATTERN RESEARCH PROGRAM

TEST PHOTOGRAPH

USFA FIRE PATTERN RESEARCH PROGRAM

TEST PHOTOGRAPH



# USFA FIRE PATTERN RESEARCH PROGRAM

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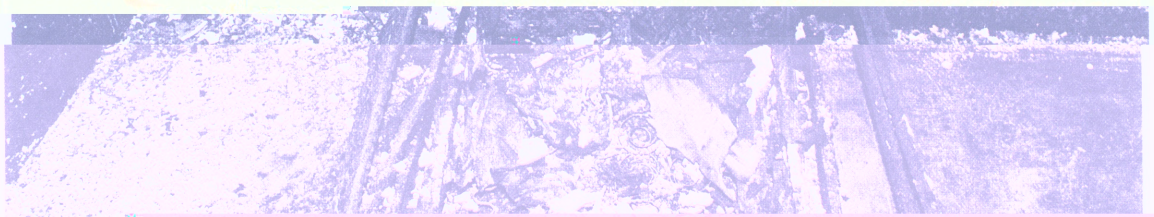


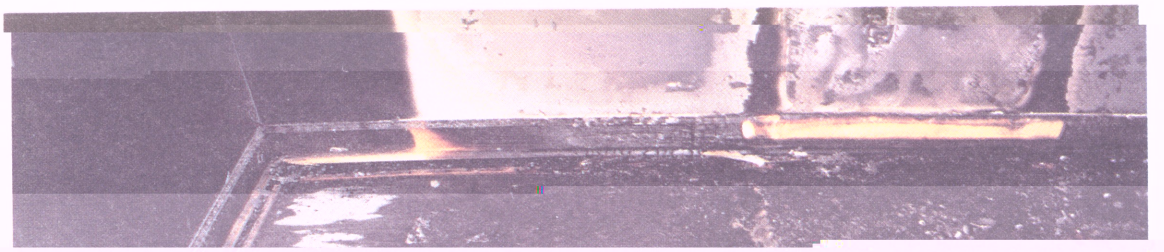
TEST PHOTOGRAPH

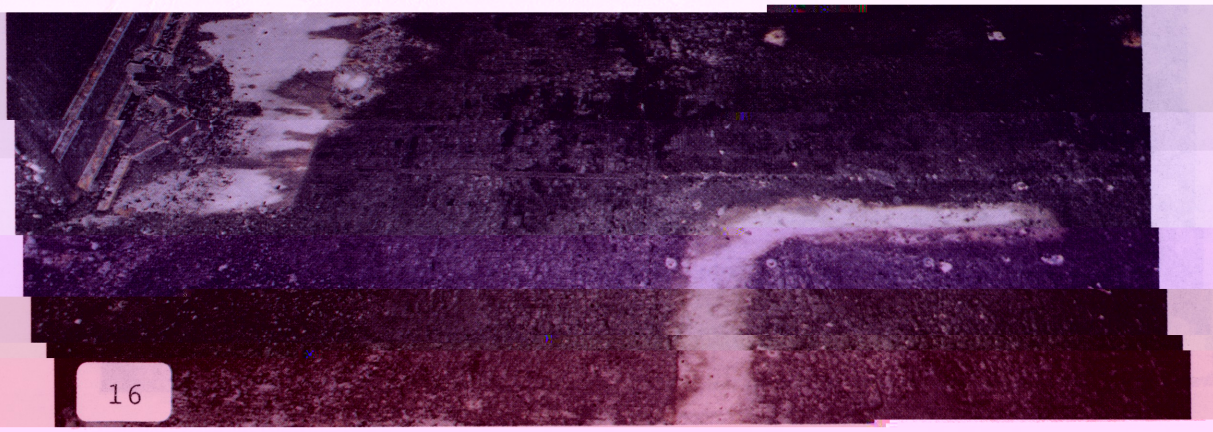


Photograph 15 (Test 2)

USFA FIRE PATTERN RESEARCH PROGRAM

# TEST PHOTOGRAPH





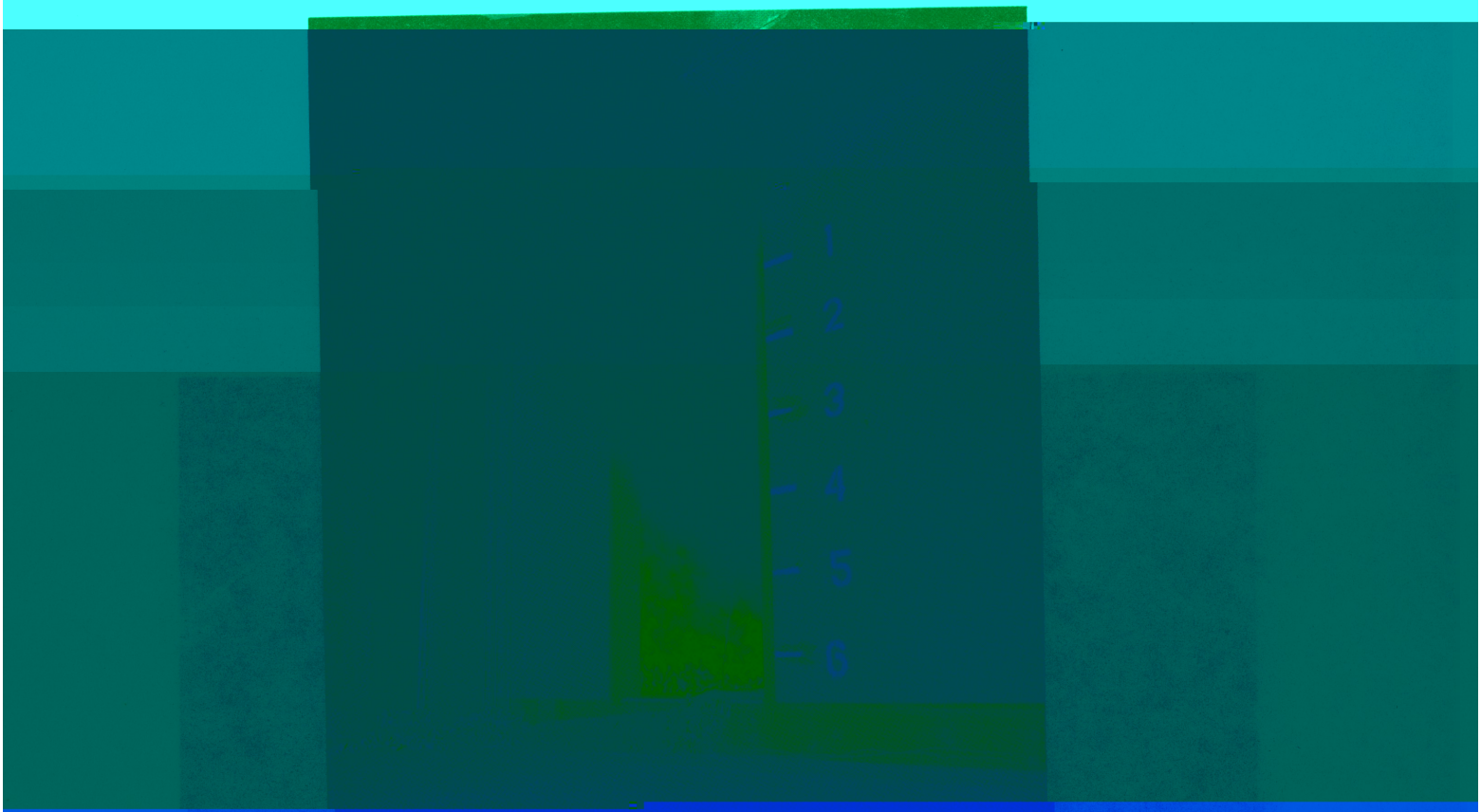
USFA FIRE PATTERN RESEARCH PROGRAM

TEST PHOTOGRAPH

Photograph 17 (Test 2)

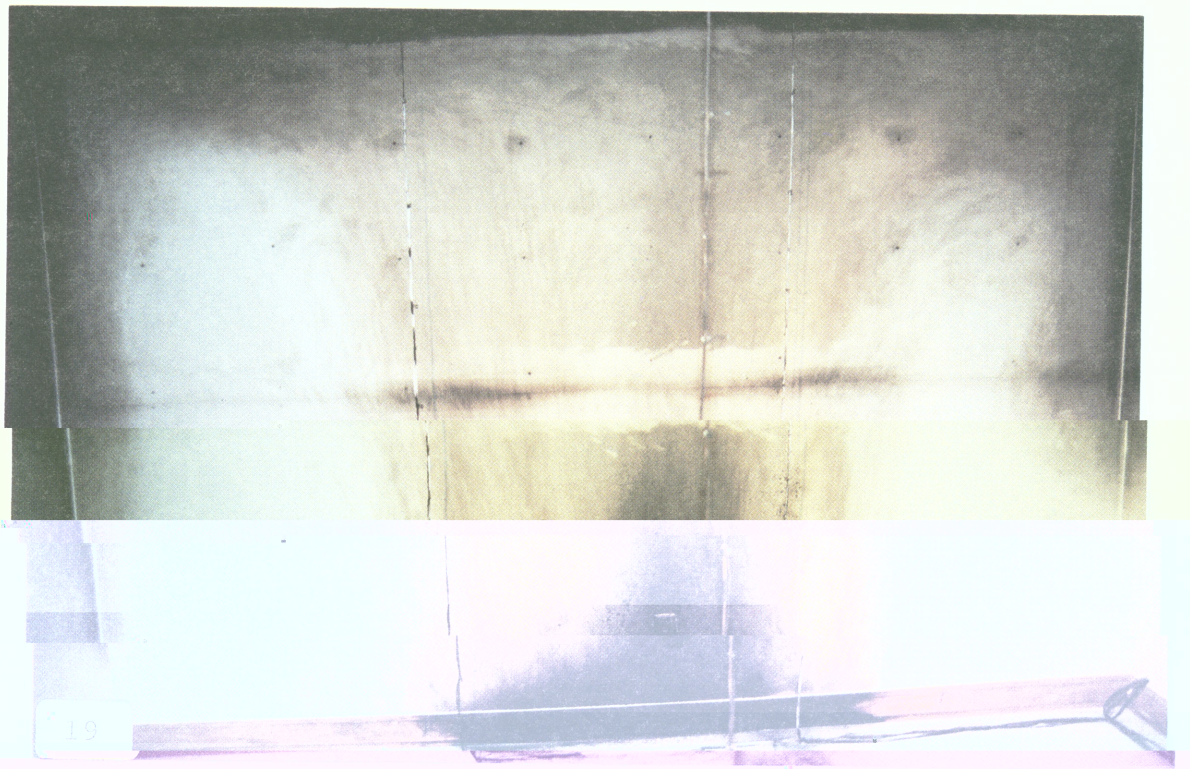
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



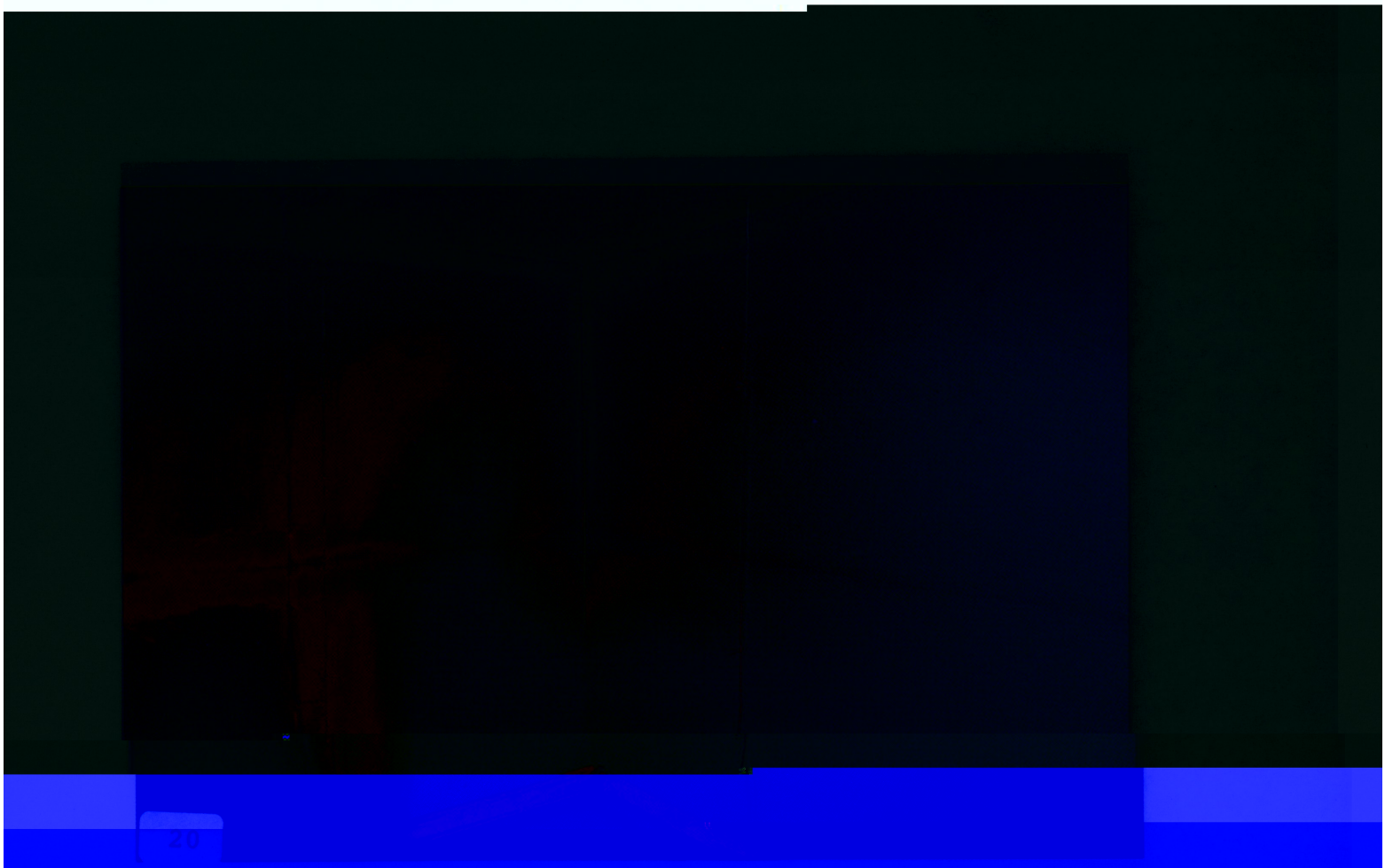
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




Photograph 19 (Test 3)

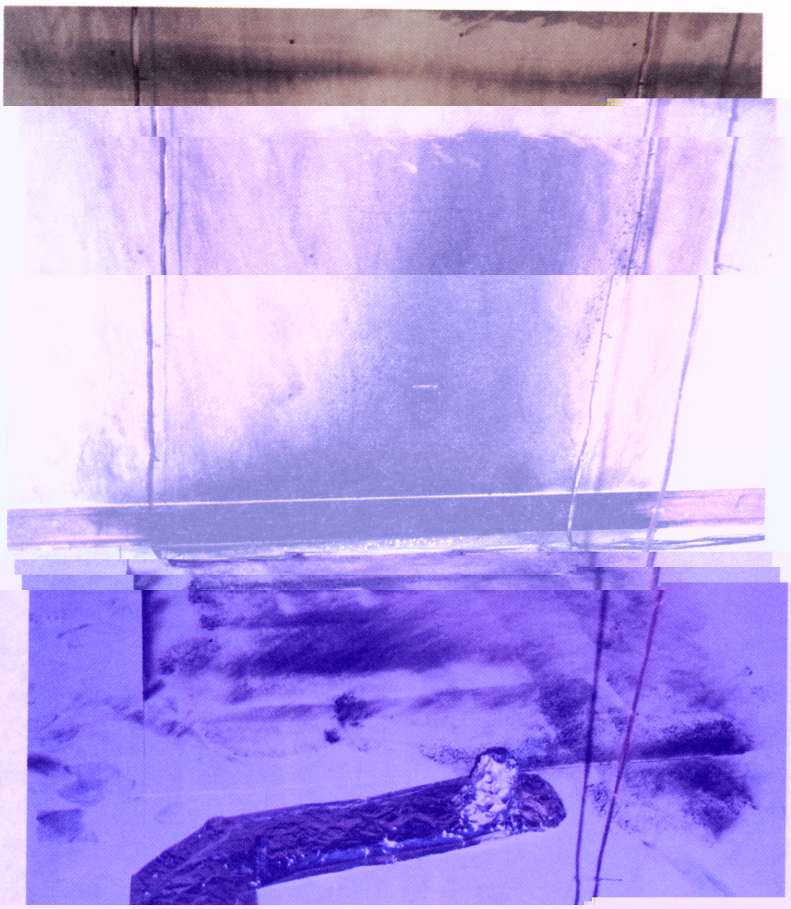
TEST PHOTOGRAPH




Photograph 20 (Test 3)

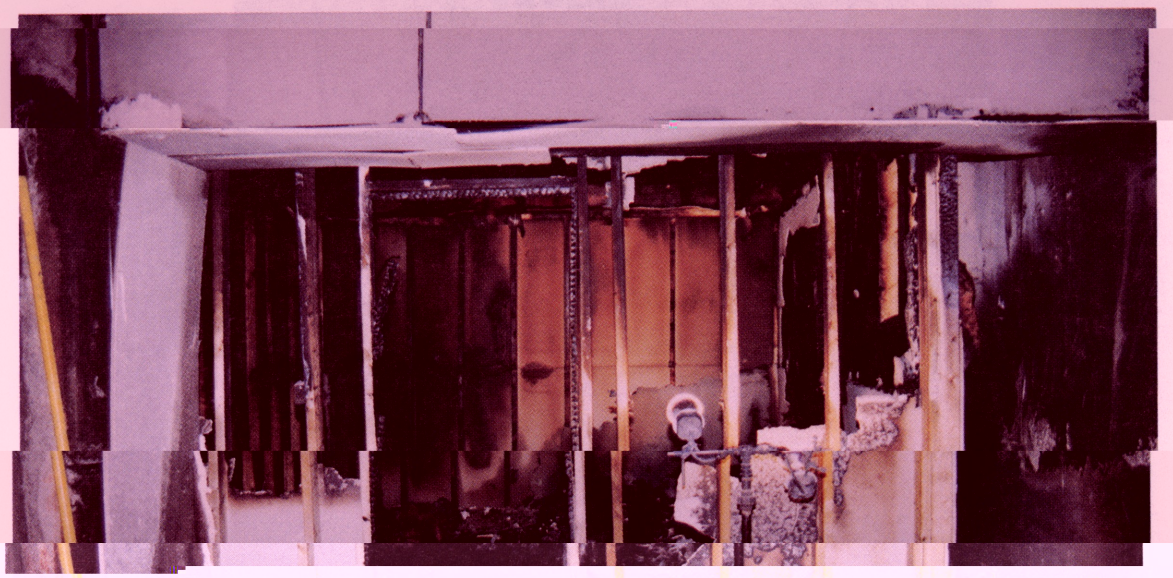
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

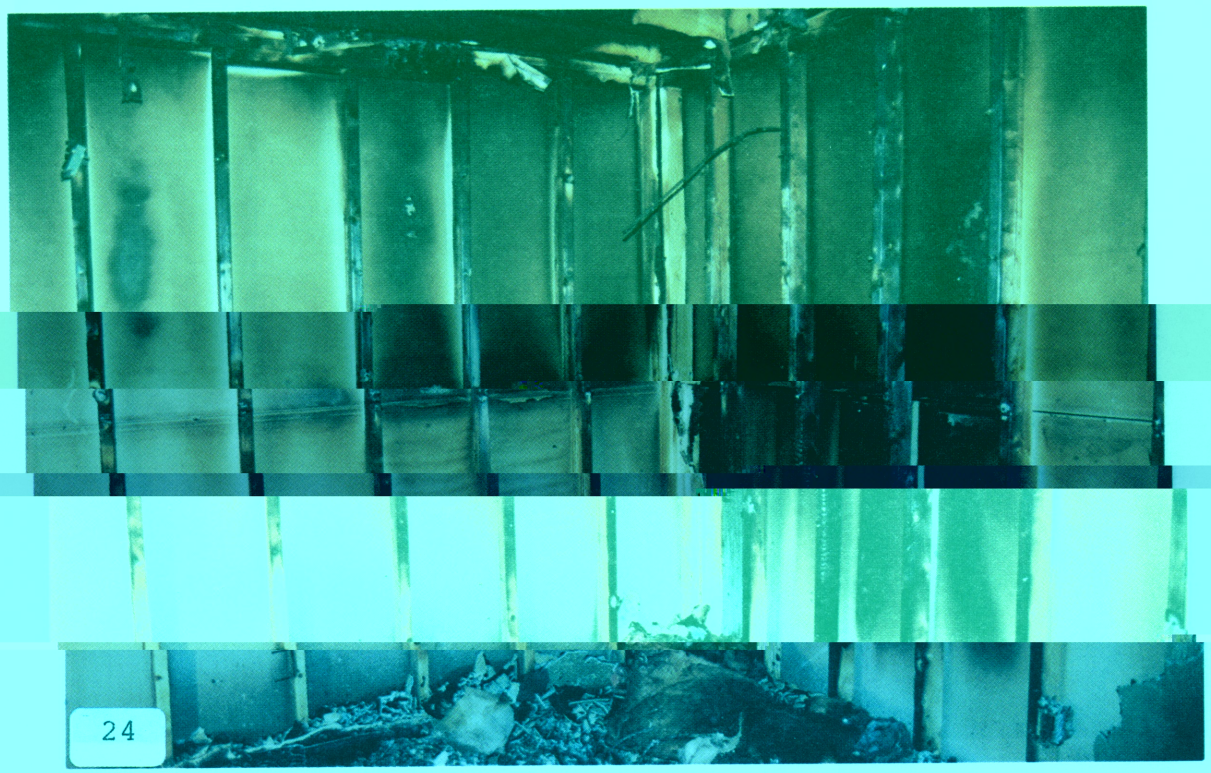


# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

## USFA FIRE PATTERN RESEARCH PROGRAM

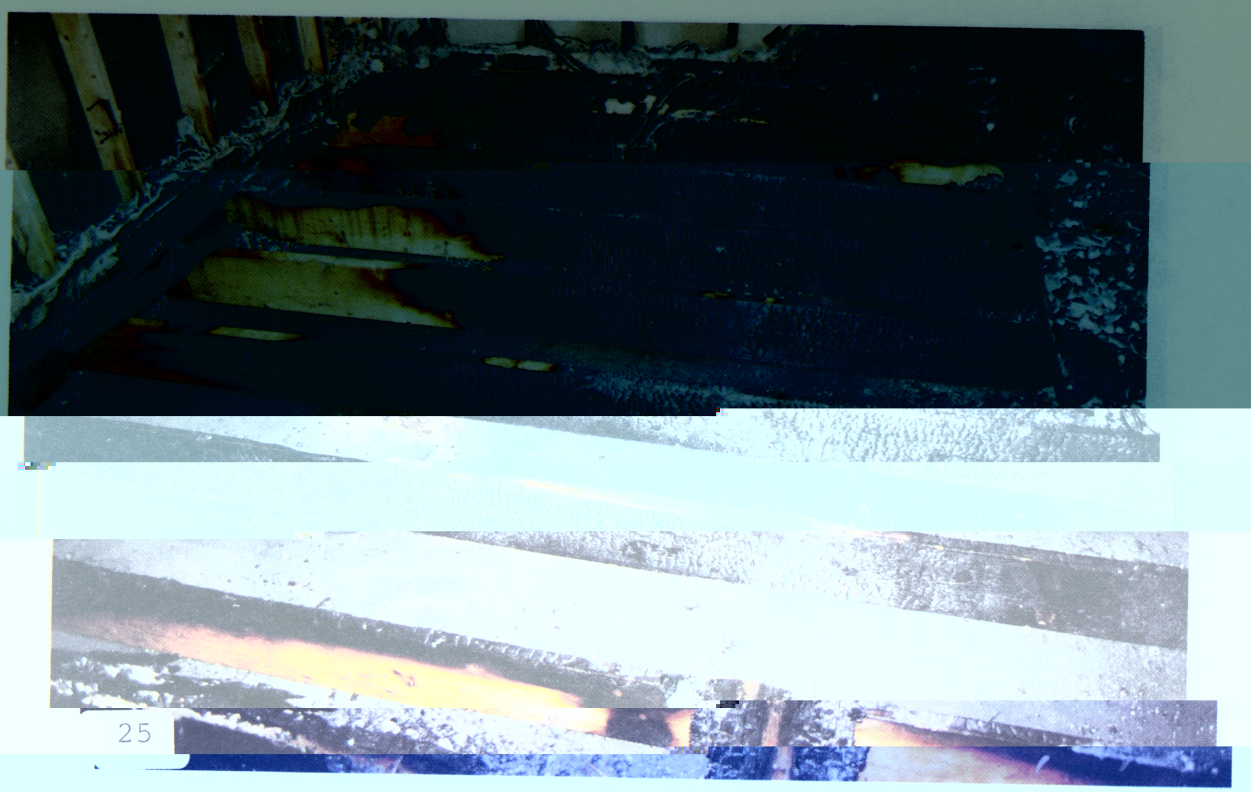
## TEST PHOTOGRAPH




**Photograph 24 (Test 4)**

# USFA FIRE PATTERN RESEARCH PROGRAM

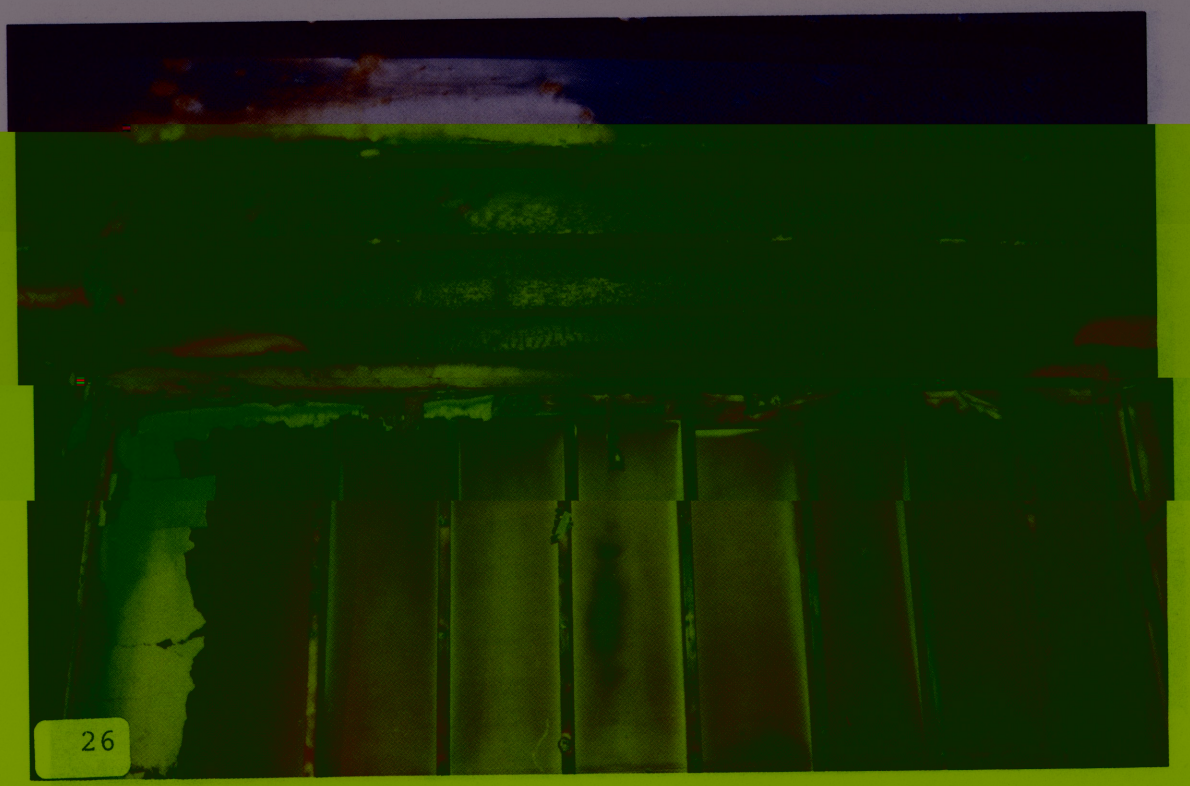
## TEST PHOTOGRAPH




**Photograph 25 (Test 4)**

# USFA FIRE PATTERN RESEARCH PROGRAM

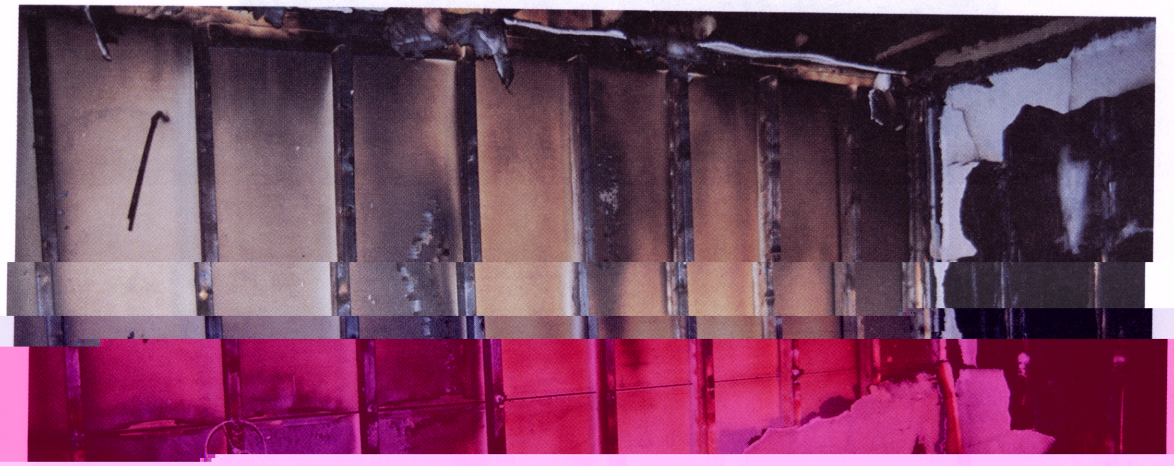
## TEST PHOTOGRAPH




**Photograph 26 (Test 4)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



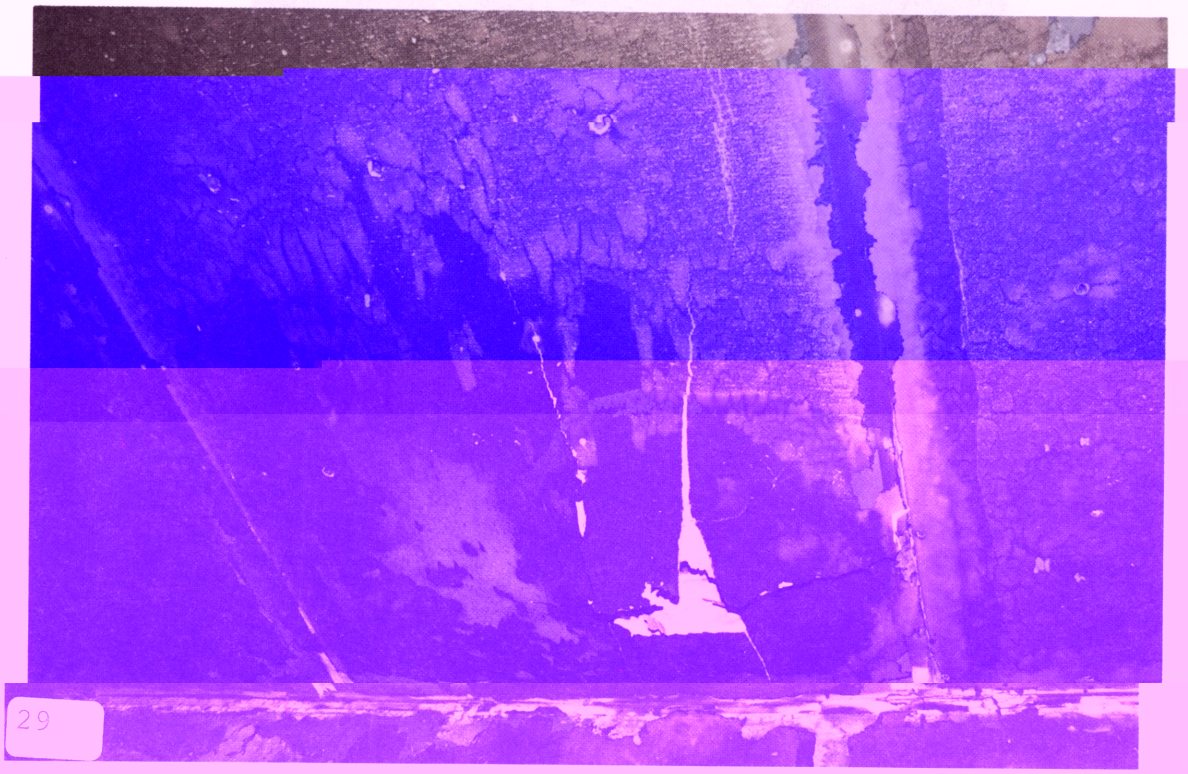
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 28 (Test 5)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




Photograph 29 (Test 5)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 30 (Test 5)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 31 (Test 5)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 32 (Test 5)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 34 (Test 5)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 35 (Test 5)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

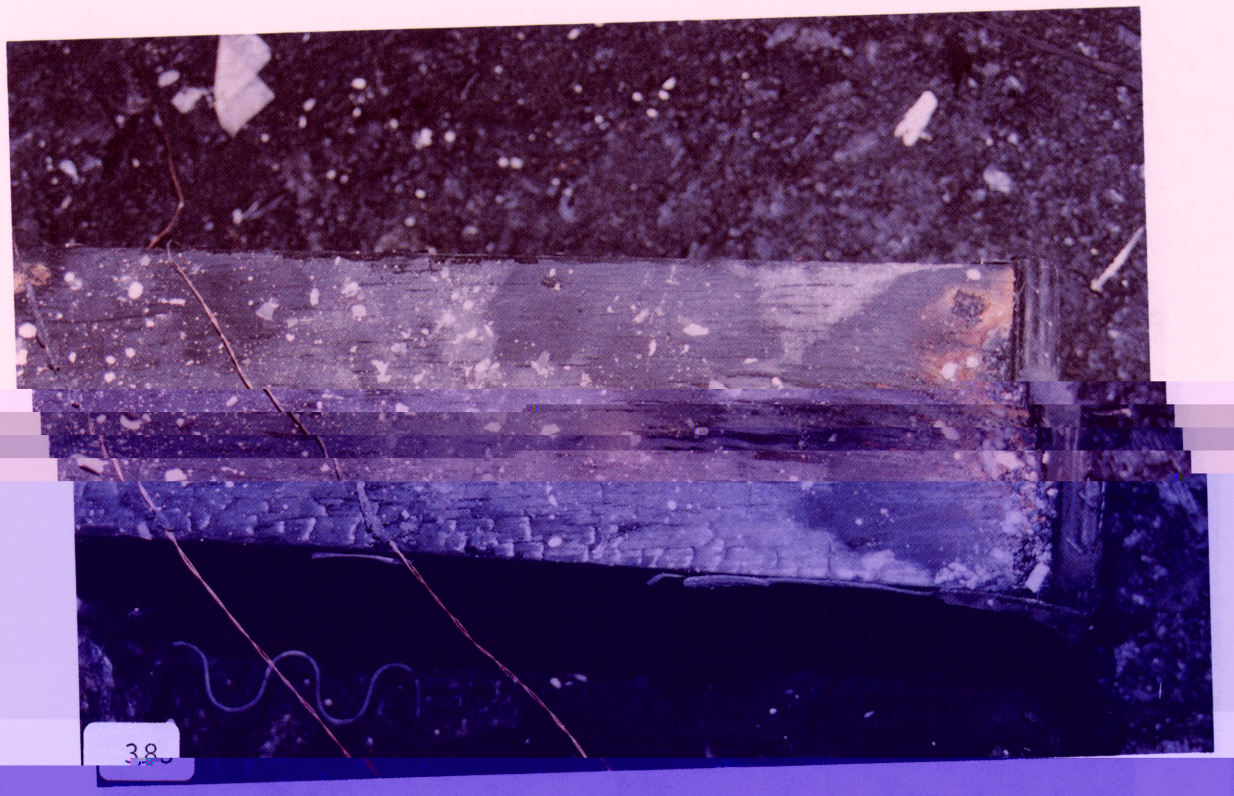
**Photograph 36 (Test 5)**

# USFA FIRE PATTERN RESEARCH PROGRAM

# TEST PHOTOGRAPH

# USFA FIRE PATTERN RESEARCH PROGRAM

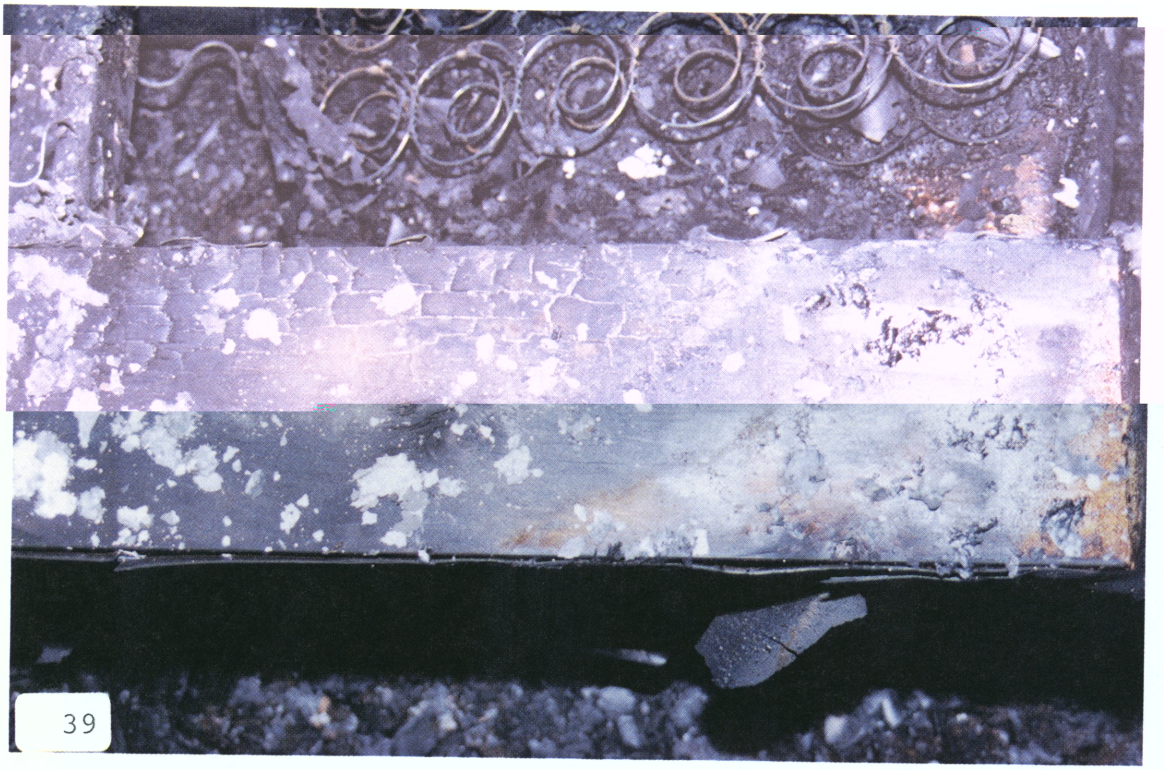
## TEST PHOTOGRAPH



**Photograph 38 (Test 5)**

# USFA FIRE PATTERN RESEARCH PROGRAM

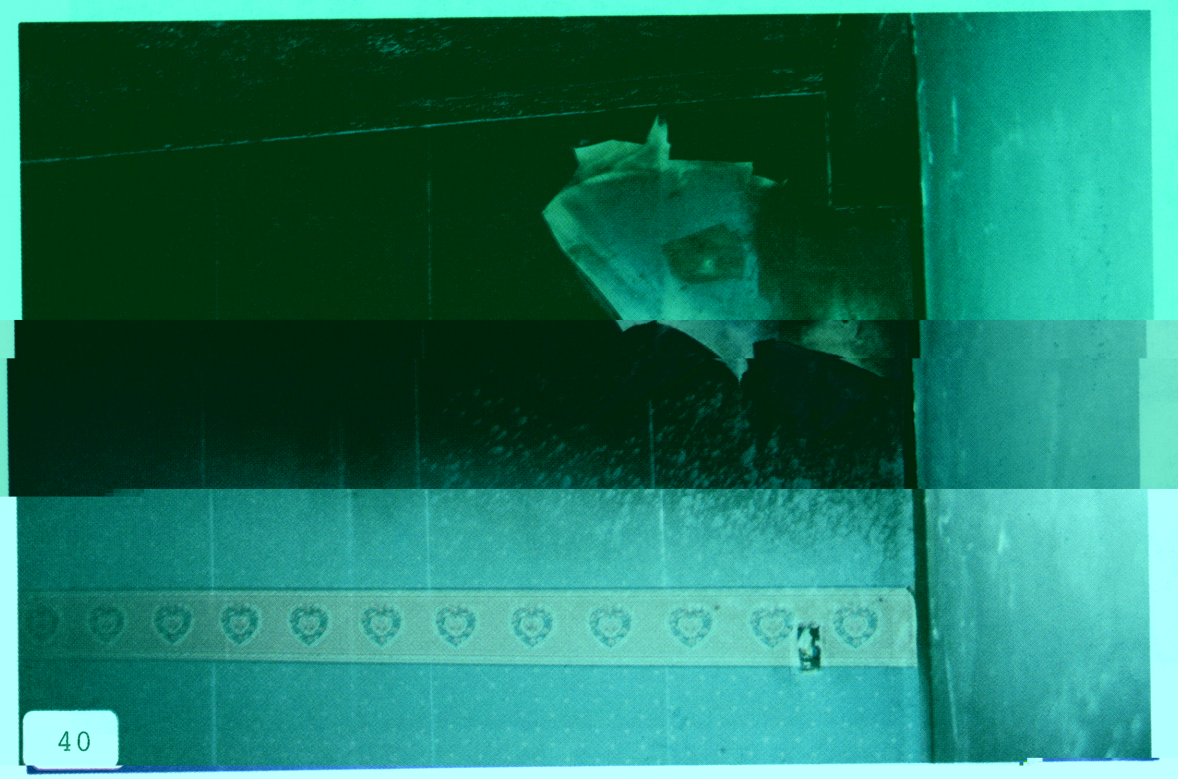
## TEST PHOTOGRAPH




**Photograph 39 (Test 5)**

# USFA FIRE PATTERN RESEARCH PROGRAM

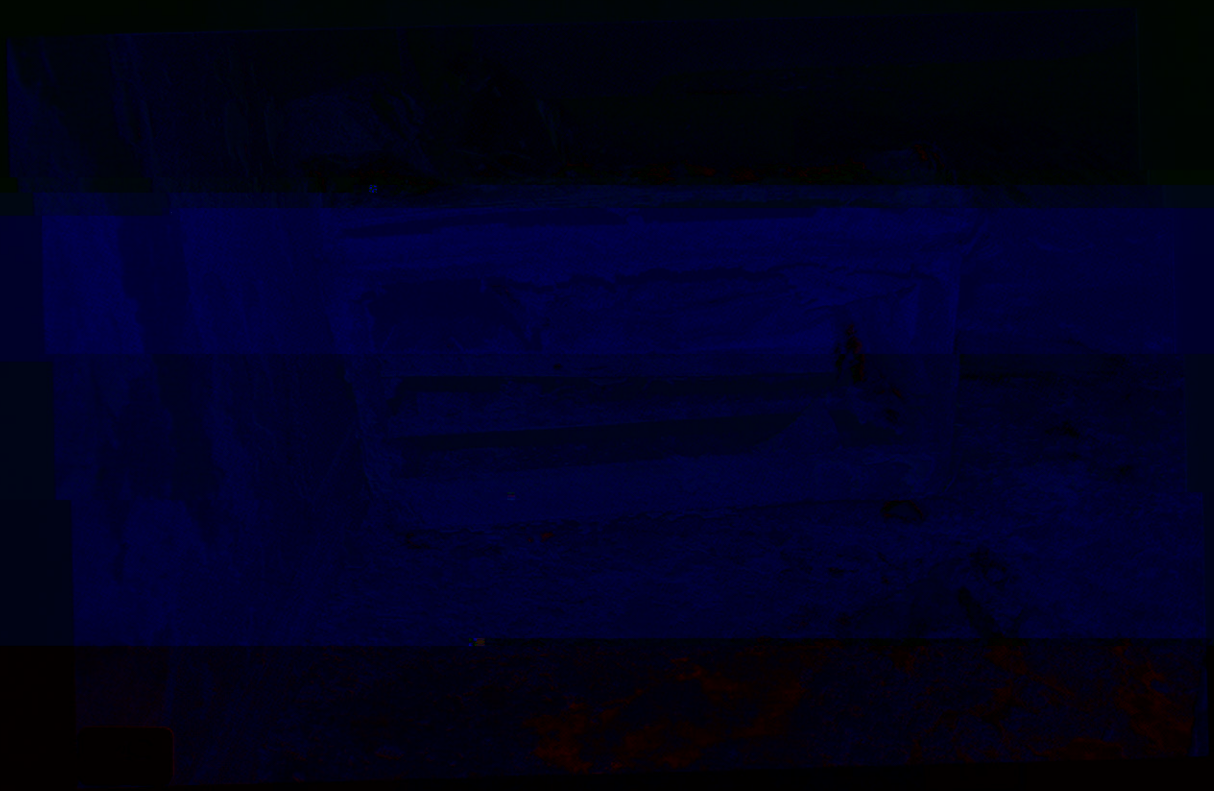
## TEST PHOTOGRAPH




**Photograph 40 (Test 5)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 43 (Test 6)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

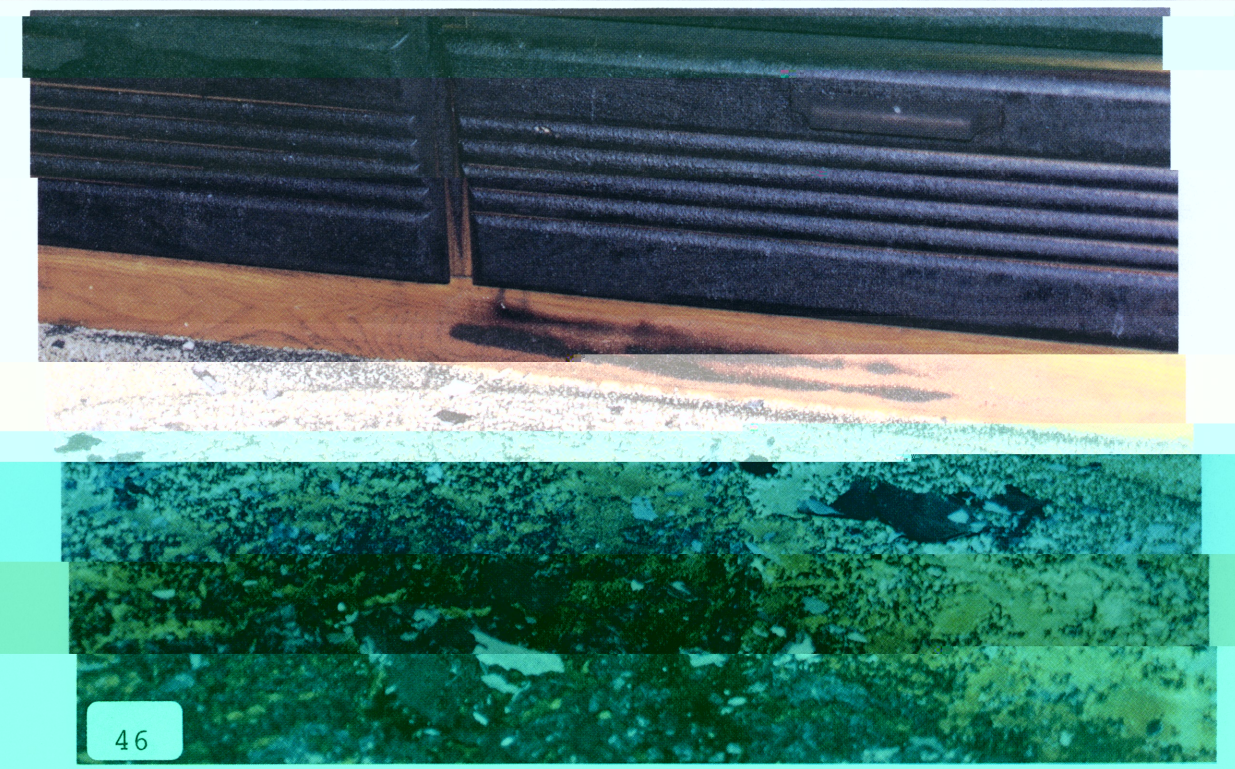
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 45 (Test 6)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




Photograph Test

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

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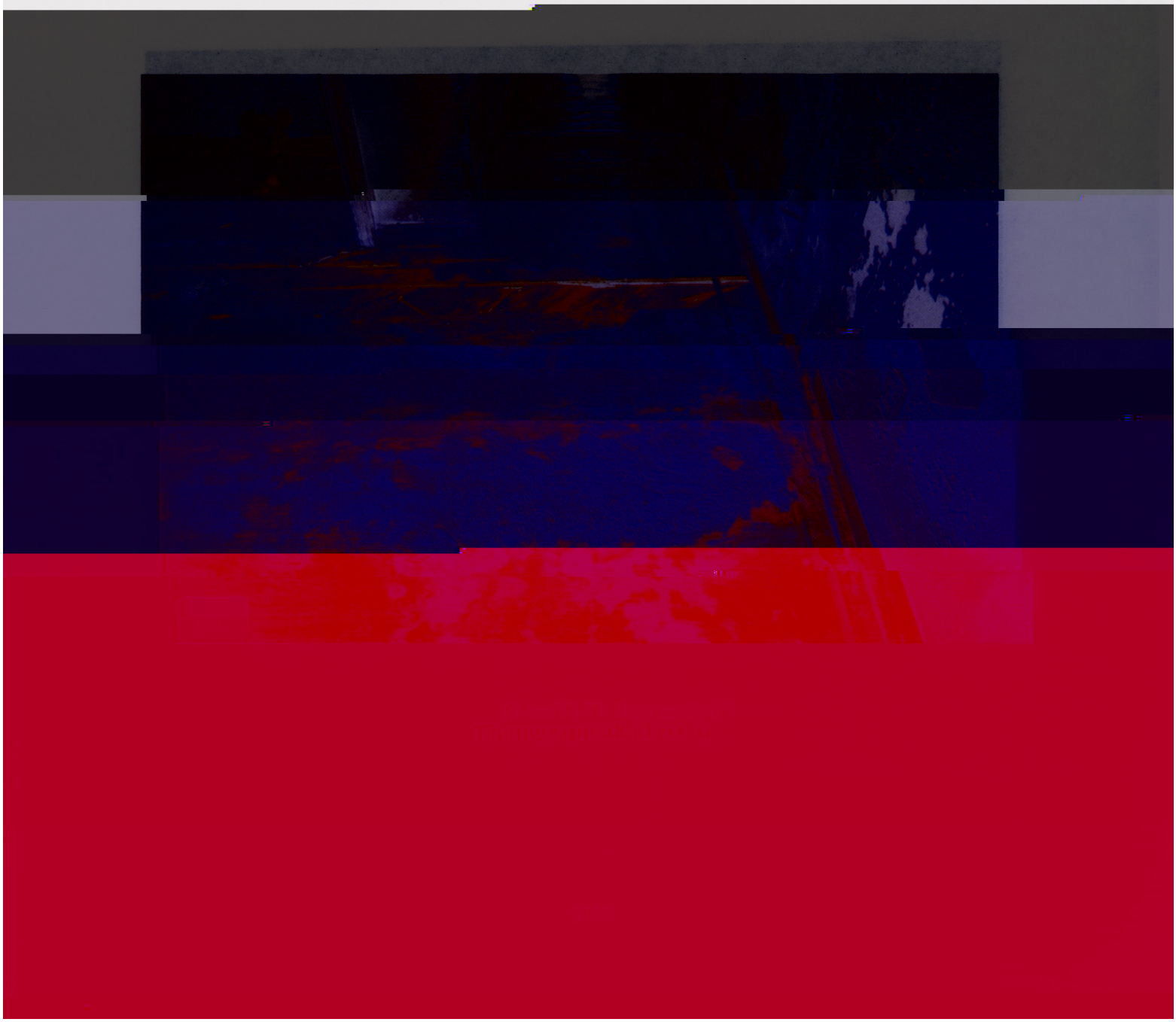
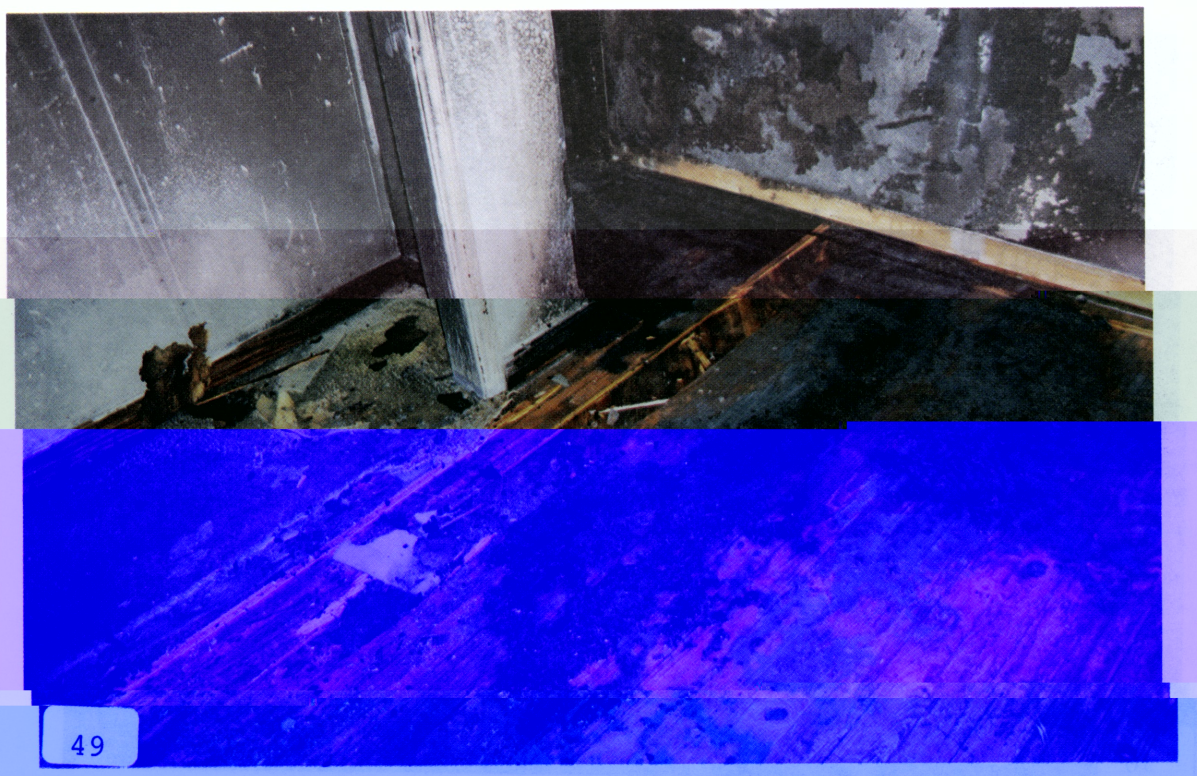


# USFA FIRE PATTERN RESEARCH PROGRAM

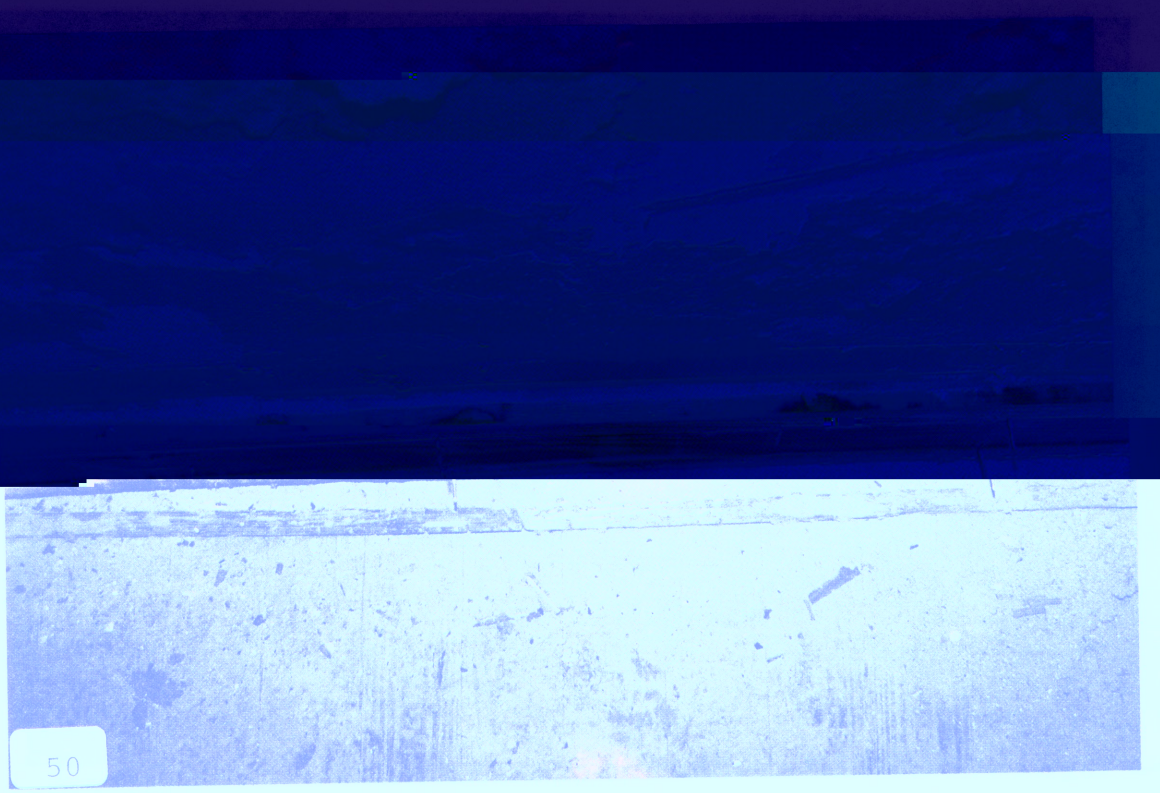
## TEST PHOTOGRAPH




**Photograph 49 (Test 6)**

USFA FIRE PATTERN RESEARCH PROGRAM

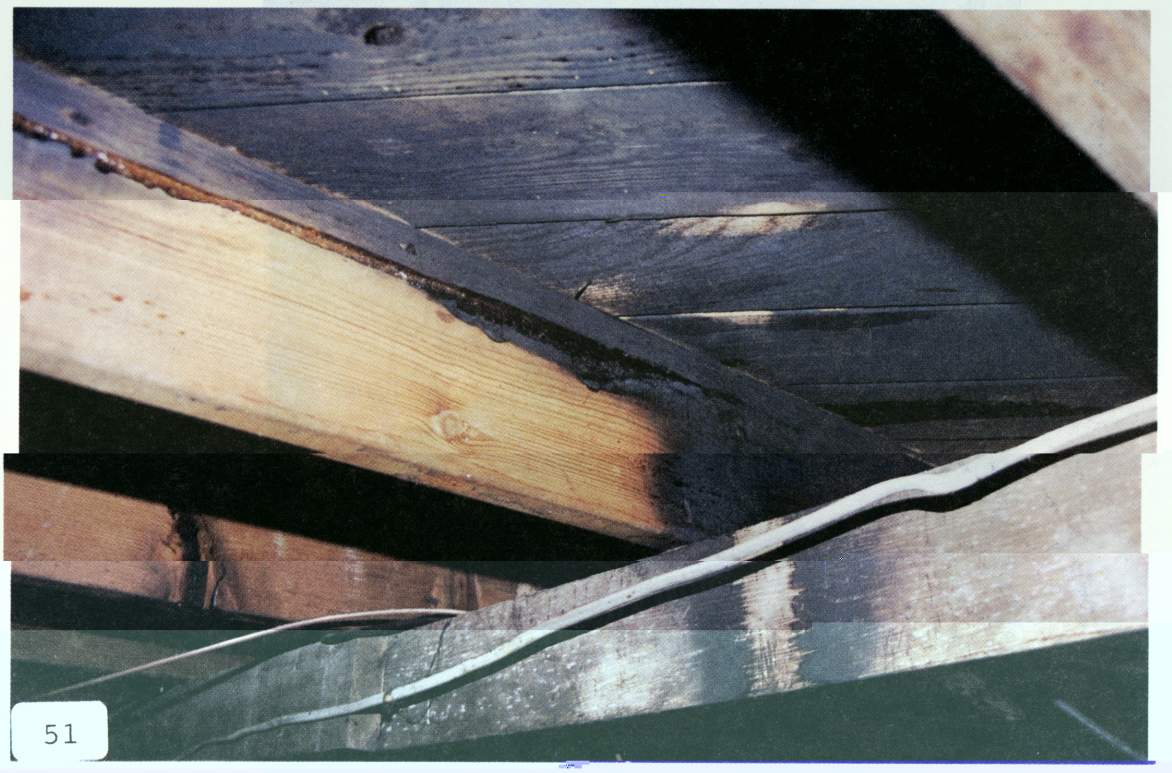
TEST PHOTOGRAPH




Photograph 50 (Test 6)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




Photograph 51 (Test 6)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 52 (Test 7)**

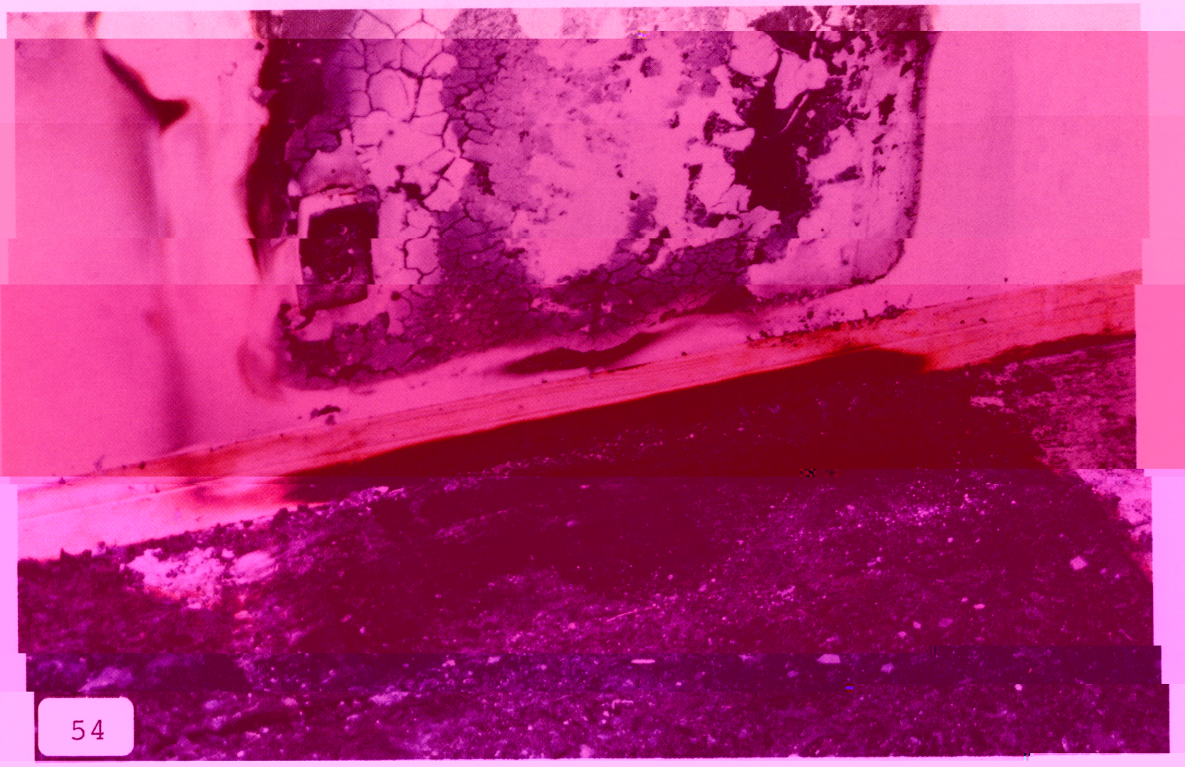
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 53 (Test 7)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




Photograph 54 (Test 7)

# USFA FIRE PATTERN RESEARCH PROGRAM

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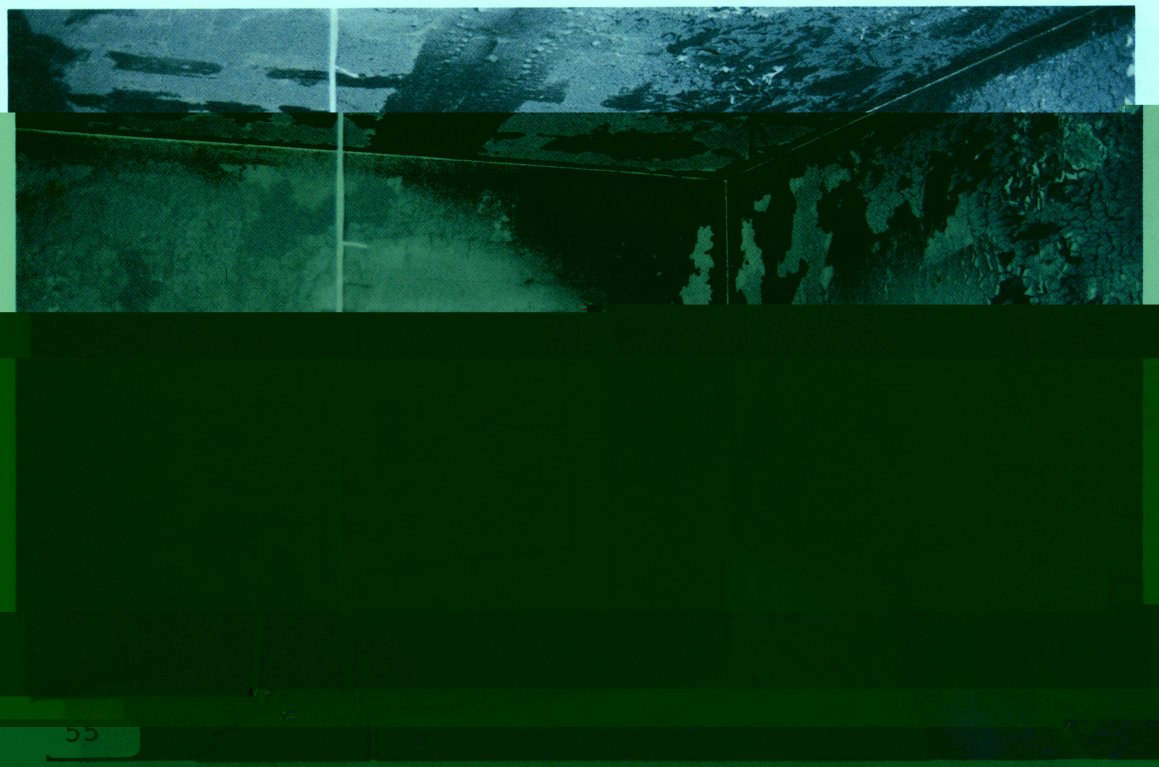



**Photograph 55 (Test 7)**

**USFA FIRE PATTERN RESEARCH PROGRAM**

**TEST PHOTOGRAPH**

**Photograph 56 (Test 7)**

USFA FIRE PATTERN RESEARCH PROGRAM

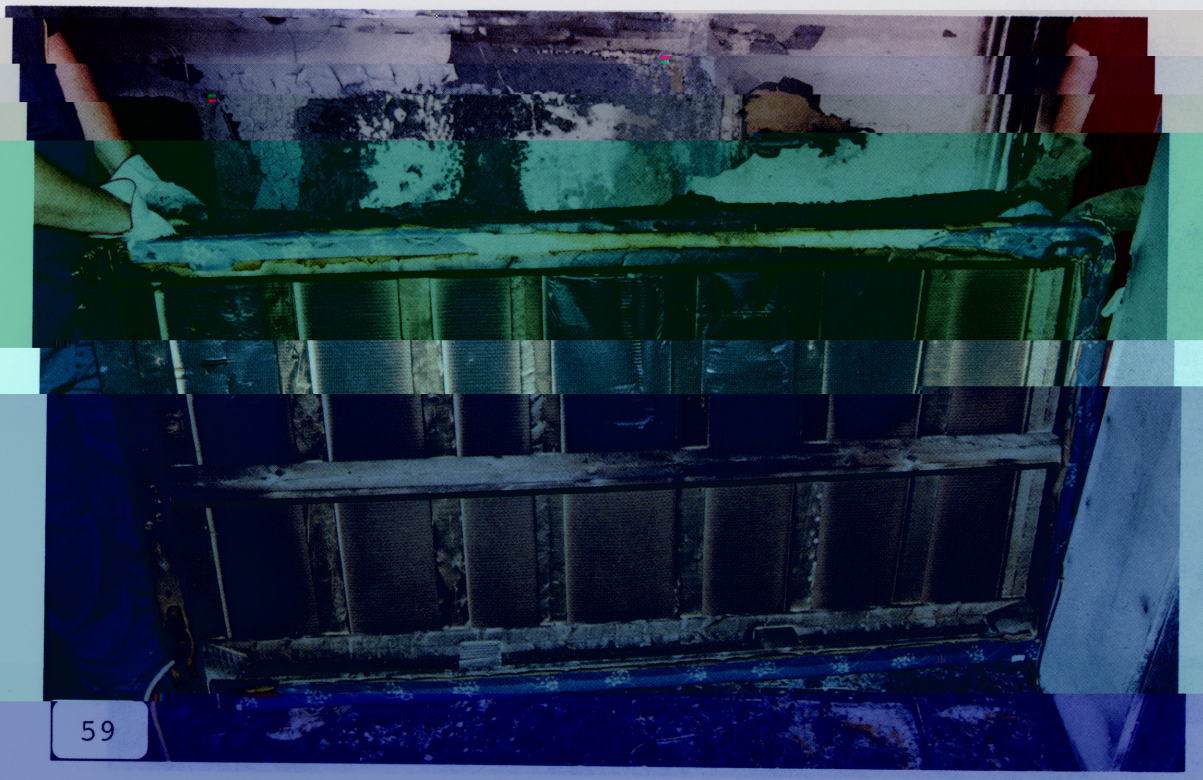
TEST PHOTOGRAPH

USFA FIRE PATTERN RESEARCH PROGRAM

TEST PHOTOGRAPH

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




**Photograph 59 (Test 7)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

60

Photograph 60 (Test 7)

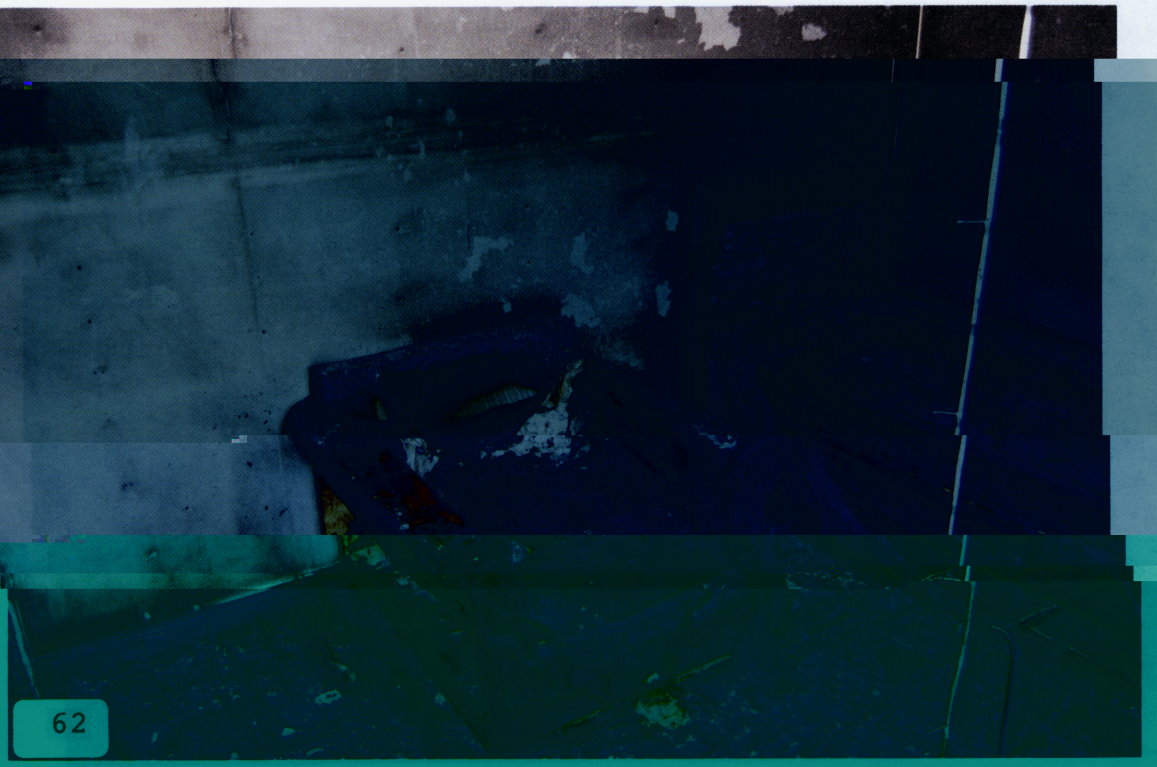
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 61 (Test 8)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



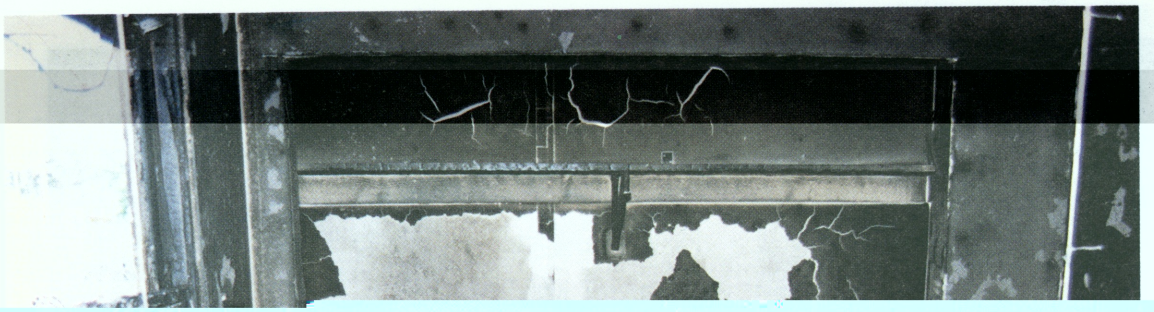

**Photograph 62 (Test 8)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



# USFA FIRE PATTERN RESEARCH PROGRAM

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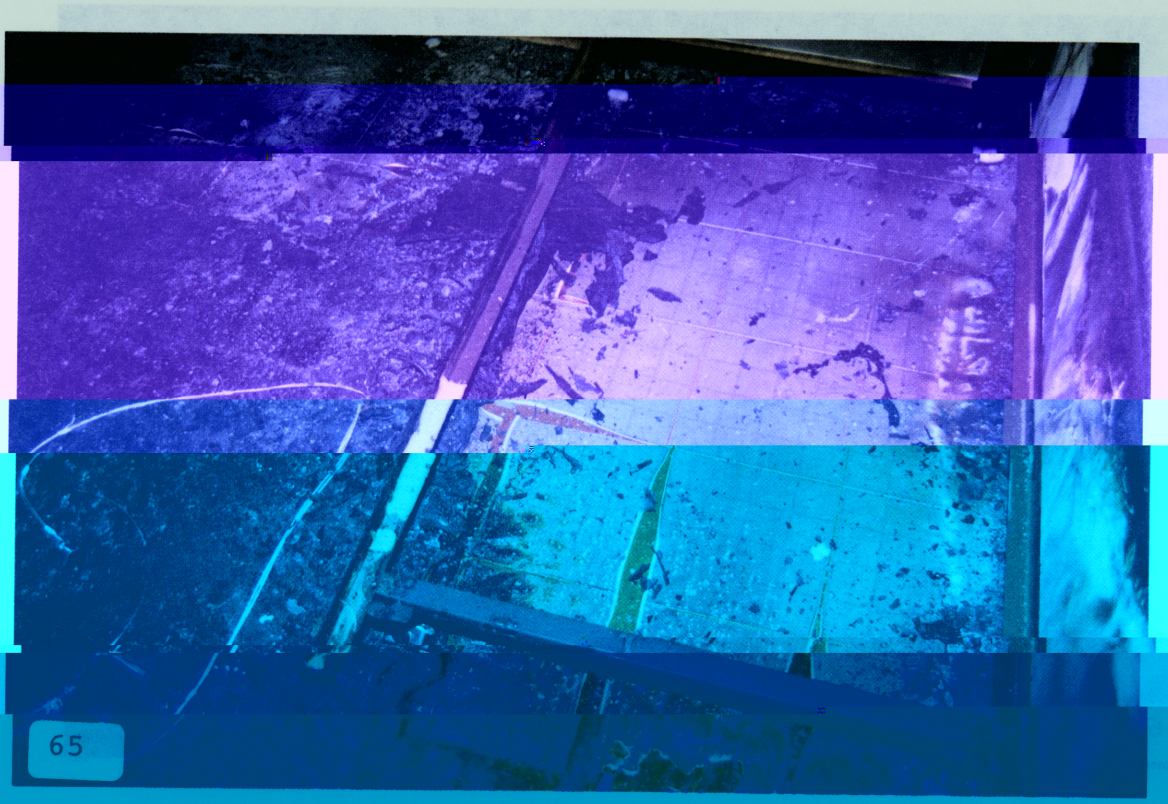



**Photograph 65 (Test 8)**

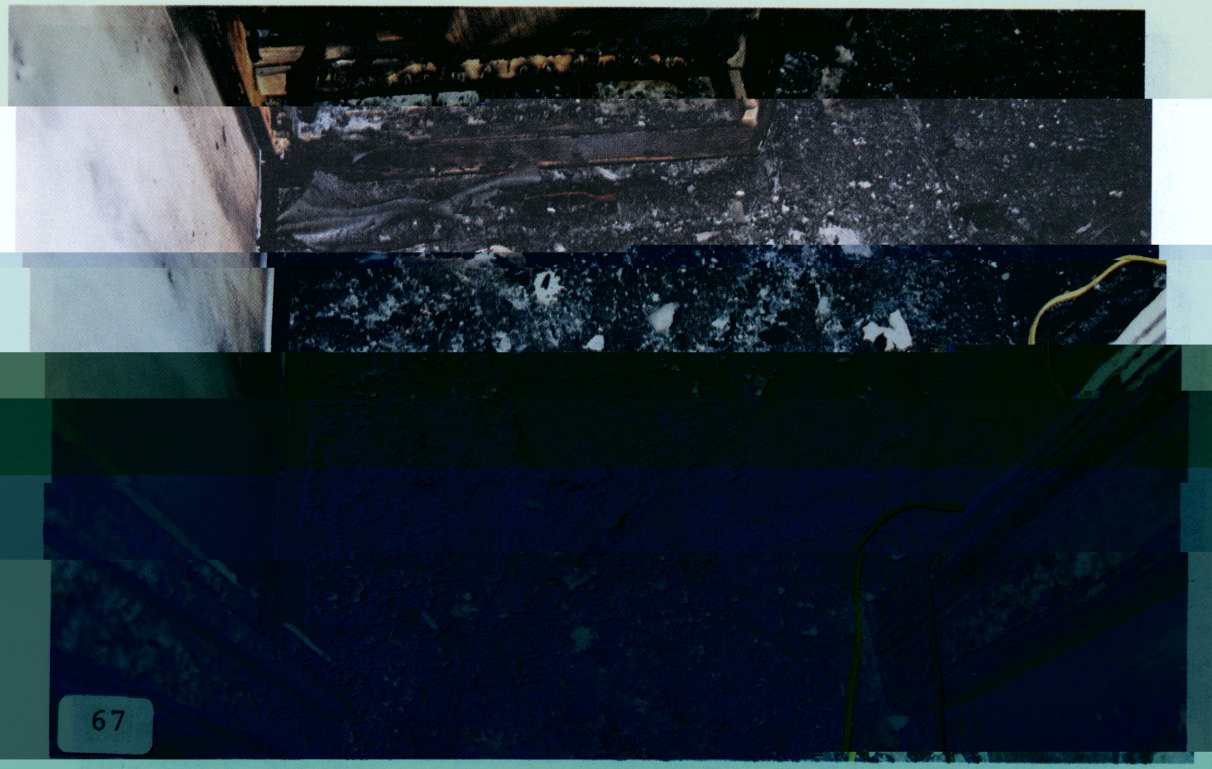
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 66 (Test 8)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




**Photograph 67 (Test 8)**

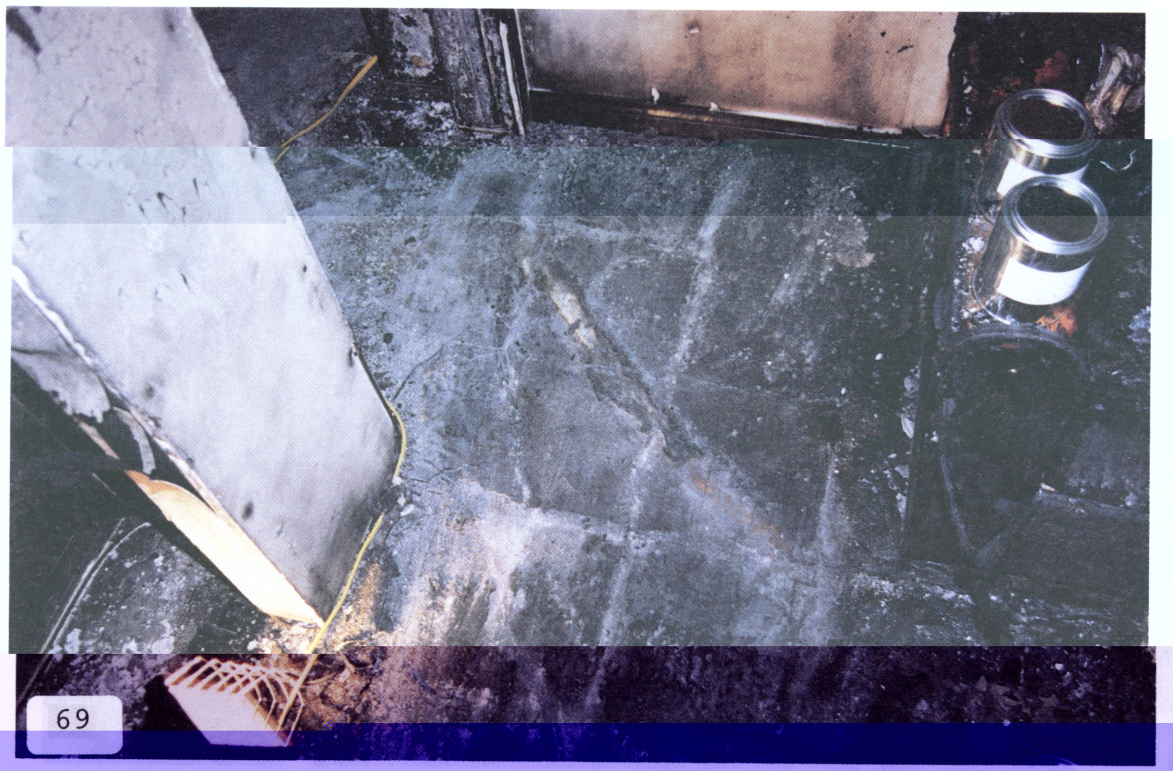
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 68 (Test 8)

# USFA FIRE PATTERN RESEARCH PROGRAM

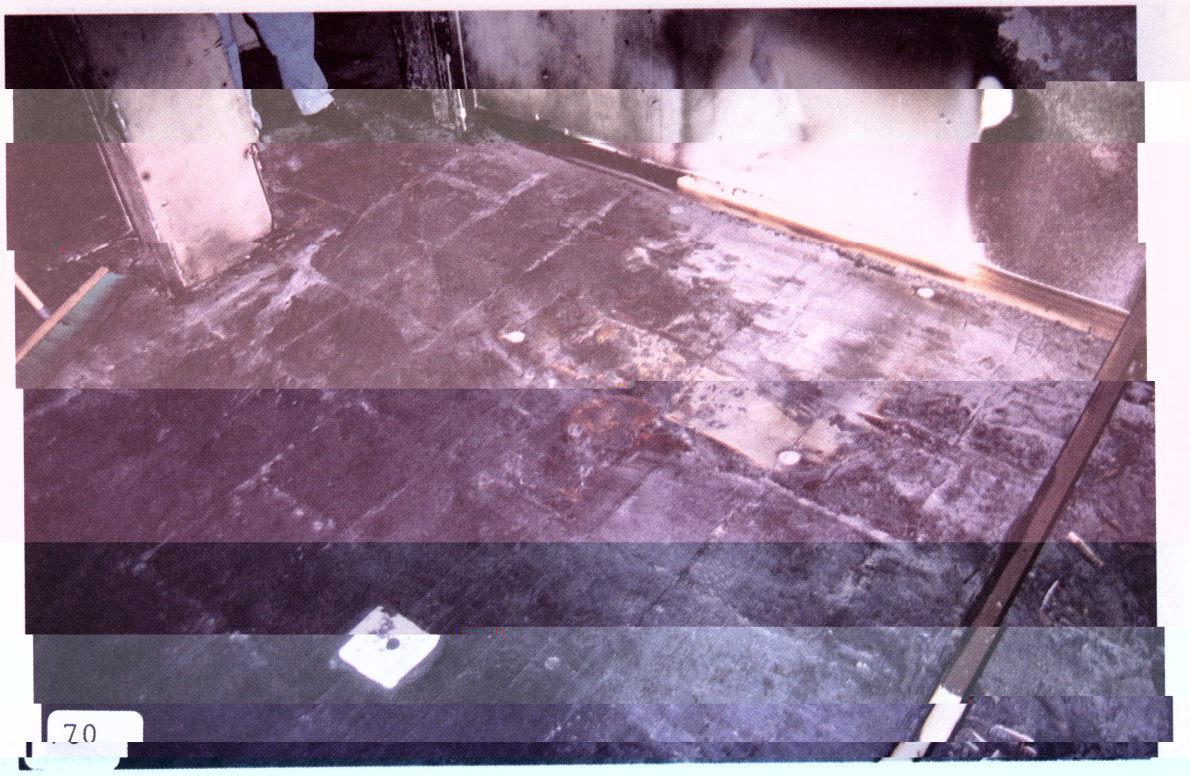
## TEST PHOTOGRAPH




**Photograph 69 (Test 8)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




**Photograph 70 (Test 8)**

**USFA FIRE PATTERN RESEARCH PROGRAM**

**TEST PHOTOGRAPH**

**Photograph 71 (Test 8)**

**USFA FIRE PATTERN RESEARCH PROGRAM**

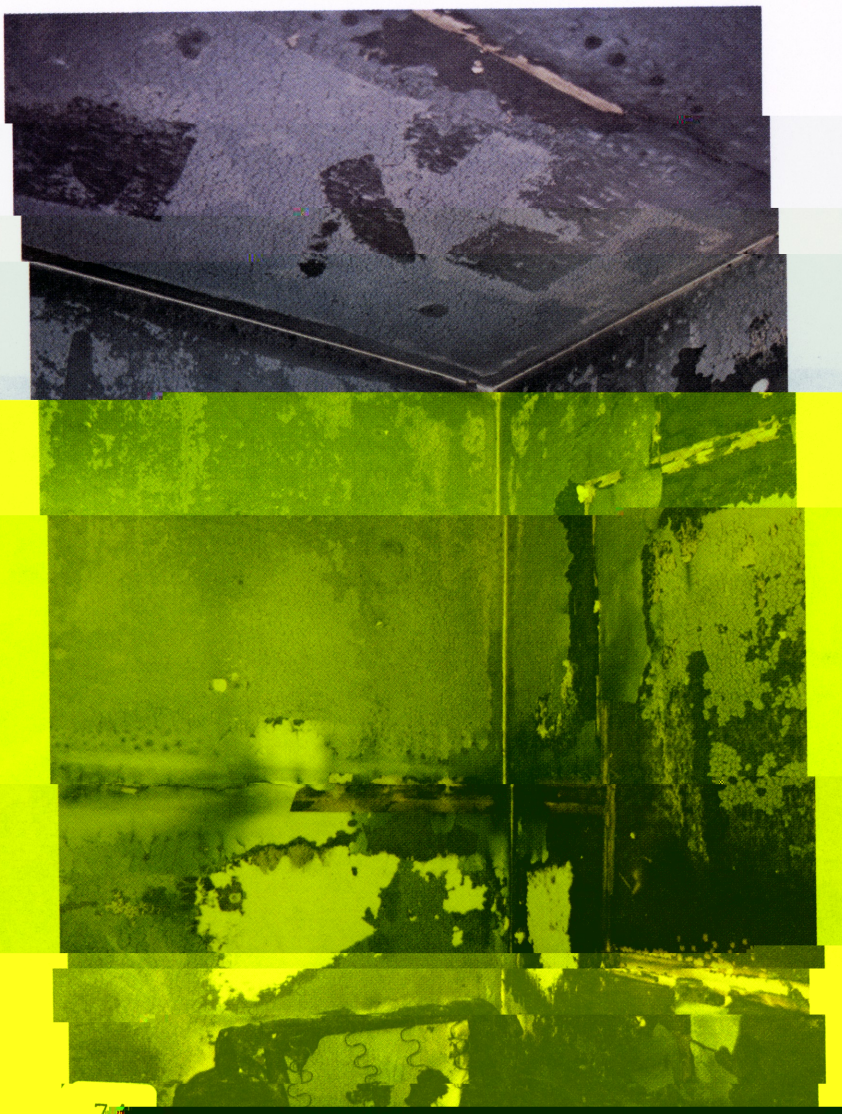
**TEST PHOTOGRAPH**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



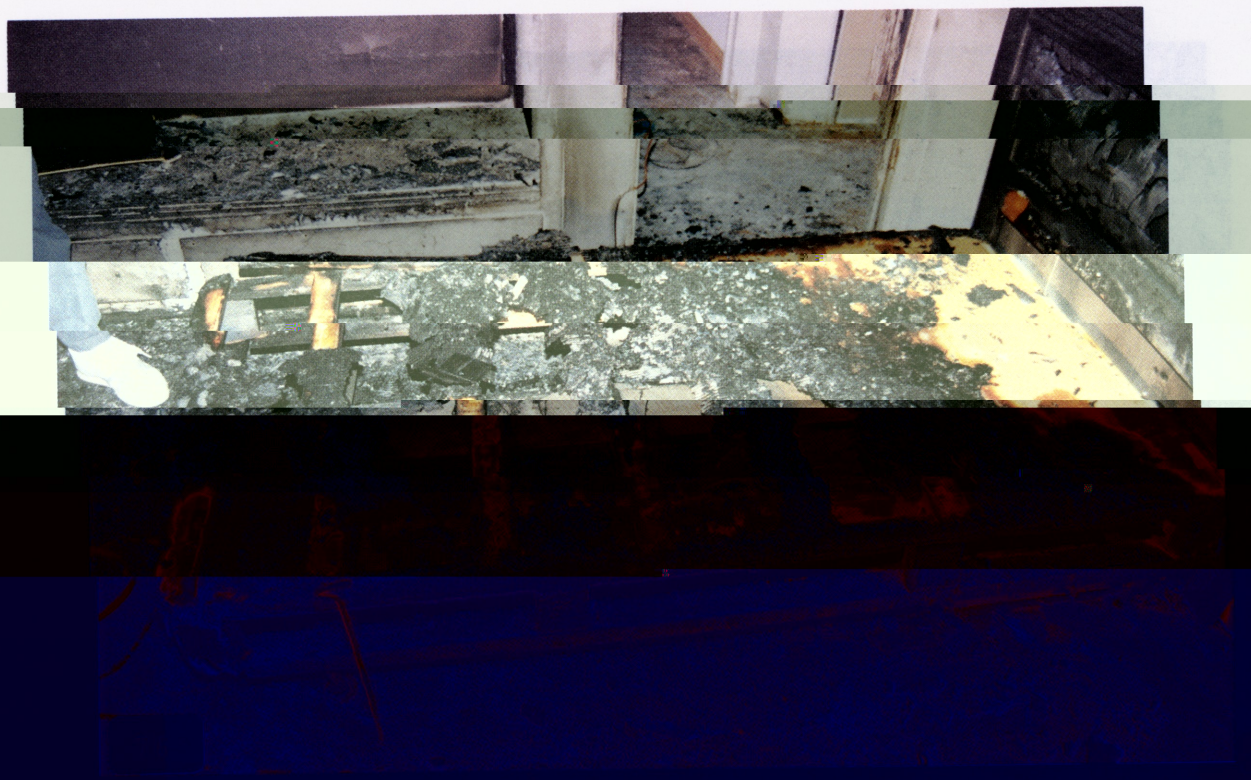
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 75 (Test 9)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH



# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 78 (Test 9)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

USFA FIRE PATTERN RESEARCH PROGRAM

# TEST PHOTOGRAPH

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

Photograph 81 (Test 2)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

# USFA FIRE PATTERN RESEARCH PROGRAM

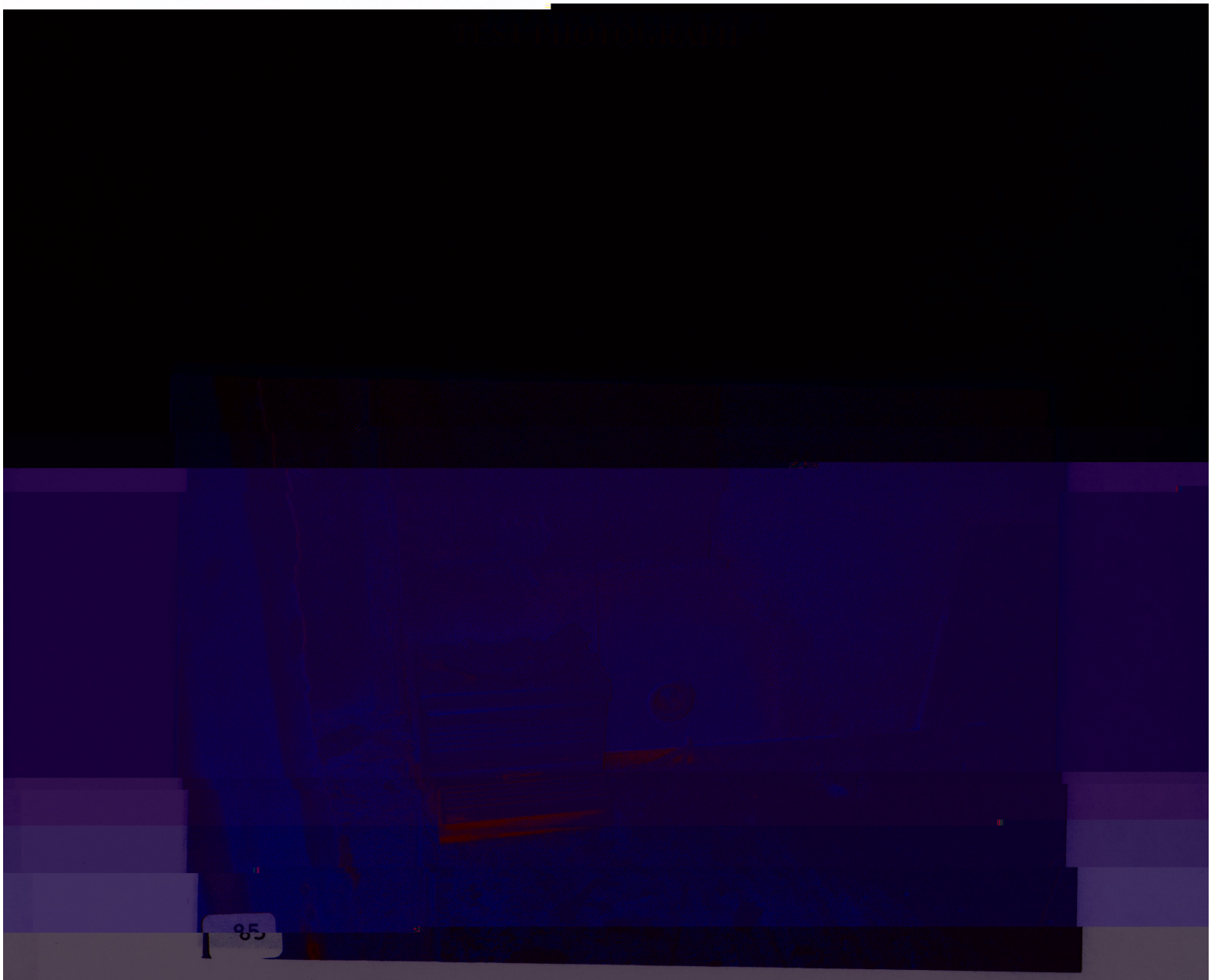
## TEST PHOTOGRAPH

**Photograph 83 (Test 10)**

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 84 (Test 10)**




**Photograph 85 (Test 10)**

# USFA FIRE PATTERN RESEARCH PROGRAM

# TEST PHOTOGRAPH

**Photograph 86 (Test 10)**

USFA FIRE PATTERN RESEARCH PROGRAM

# TEST PHOTOGRAPH

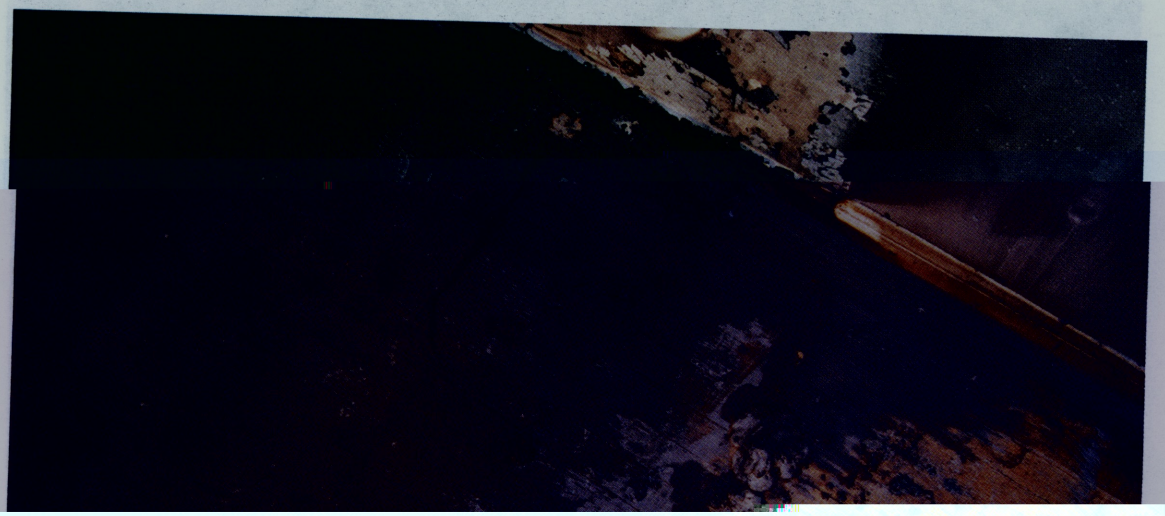
# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH

**Photograph 88 (Test 10)**

# USFA FIRE PATTERN RESEARCH PROGRAM

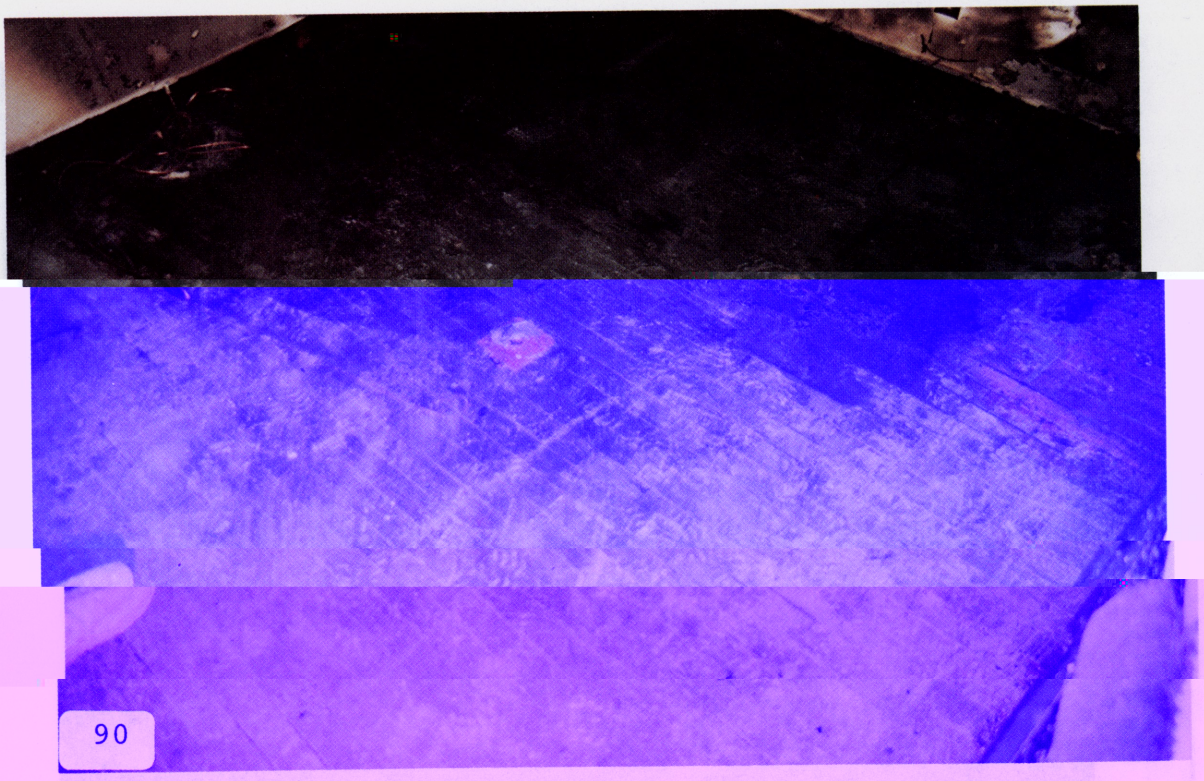
## TEST PHOTOGRAPH



Photograph 89 (Test 10)

# USFA FIRE PATTERN RESEARCH PROGRAM

## TEST PHOTOGRAPH




**Photograph 90 (Test 10)**

## Appendix A

### TEST ROOM SPECIFICATION

The specific details of the fire test rooms are outlined below. Specific details are provided where they are important to the test results. Most selections were made to reflect commonly used materials or methods in residential construction in the United States. In the case of the three structures which were used in Florence, Alabama and Santa Ana, California, the rooms were selected which most closely resembled the specified test room. Construction features and interior finish materials were added where necessary.

A. Room size: 12 ft. by 12 ft. with 8 ft. ceiling

B. Door opening: 3 ft. by 6.75 ft., no sill, 1.25 ft. soffit, standard wood doorframe around opening without any door

E. Ceiling:

1. 1/2 in. drywall, taped and painted, screwed in place
2. 16 in. centerline wood ceiling joists, 2 in. by 8 in. nominal, installed at right angles to doorway
3. 3/8 in. plywood attached to top of joists to simulate floor above
4. joist space insulated with fiberglass batts, 1 layer
5. ceiling painted with off-white flat latex paint, 2 coats

F. Floor:

1. 3/8 in. plywood decking on 2 in. by 8 in. wood floor joists, spaced 16 in. on center
2. baseline tests utilized non-combustible marinite covering,
3. pattern analysis tests used one of three possible floor finishes: vinyl floor tile, tongue and groove wood , or carpeting with pad
4. floor tile was1 ft. by 1 ft., self adhering vinyl (PVC) tile, light in color and with little or no pattern on it
5. wood flooring was of typical grade oak, tongue and groove, finished with a common polyurethane based stain. Flooring may be pre-finished.
6. carpet was of typical grade, medium pile, solid color, fastened in place over a typical and common foam pad

G. Accessories:

1. wall outlets per NFPA 70 NEC, 50% metal, 50% plastic
2. single toggle switch at doorway installed in metal box
3. wall hanging with aluminum frame, glass cover

H. Furniture[1]:

1. chair: polyurethane foam accent chair
2. bed: twin size, mattress and box spring, wood headboard, metal frame, provided with typical bedding materials
3. night stand: wood laminate, typical size
4. lamp: table lamp, 60W incandescent bulb, on night stand
5. chest of drawers: 4 ft. high, melamine or wood laminate
6. wastebasket: plastic with trash conten

[1] Furniture items were identical for each room fire test. Exact make and model of furniture items were based on availability, economy, fuel load requirements, and typical nature. Exact specifications were determined by consensus of the USFA Pattern Program Research Committee and the selected test laboratory.