

# **FIRE PATTERN PERSISTENCE AND PREDICTABILITY DURING FULL SCALE COMPARTMENT FIRE TESTS AND THE USE FOR COMPARISON OF POST FIRE ANALYSIS**

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## **ABSTRACT**

Fire Patterns, as defined by NFPA-921 are the visible or measurable physical effects that remain after a fire. Fire Pattern analysis has been a key factor in the determination of the origin and cause of fires for the past 50 years. During the International Conference on Fire Research for Fire Investigation, sponsored by the Federal Bureau of Alcohol, Tobacco and Firearms in November 1997 a number of fire pattern research issues were identified. Those research items included; “Means to validate identification of electrical faults as an ignition source, Impact of flashover on fire patterns and other indicators, Effects of ventilation on fire growth and origin determination, and Validation of fire models” among others. In addition, the National Fire Protection Association’s Fire Protection Research Foundation in a White Paper “Recommendations of The Research Advisory Council on Post-fire Analysis<sup>2</sup>” issued February 2002, also identified a number of fire pattern research needs. The White Paper in Section III Recommendations, Origin and Cause Investigation Methods made the following recommendations: “Since knowledge of the origin of a fire is, in nearly all cases, essential to determining cause, a high priority should be placed on new or improved methods for identifying the point or area of origin including burn pattern analysis”. And, “Methods for analyzing burn patterns concerning their meaning in the early growth history of the fire are also important. In particular, how does one determine when in the course of the fire event a particular pattern was made and how it might relate to a given potential ignition scenario”?

Many years prior to these two initiatives, the Advanced Fire Patterns Project (1985) had been formed as a partnership between the National Association of Fire Investigators (NAFI) and the Fire and Safety Engineering Technology Program, Eastern Kentucky University to complete research into the development of fire patterns on exposed surfaces and transfer that information to those that attended seminars and other educational programs sponsored by the two entities.

The purpose of this paper is to describe the results of the full scale test burns that were conducted at Eastern Kentucky University and sponsored by the Advanced Fire Pattern Project. A series of ten full scale tests over a three year span were conducted in identically constructed, finished and furnished compartments. In each of the tests with one exception all fires progressed to full room involvement. Additionally, a full scale test was completed on a specially constructed and furnished room to assist in studying fire growth and spread and the resulting pattern formation in comparison to the fire patterns that were witnessed in a compartment of an actual compartment fire in which there had been a fatality.

These full scale test burns provided a considerable amount of data concerning fire pattern development and evolution during fire growth and spread. Specifically, these test burns demonstrated fire pattern persistence and predictability during pre and post full room involvement fires. The full scale tests demonstrated that the fire patterns described in current literature are correct and when used properly can assist in the determination of the origin of a fire. The last and one of the most significant items was that if properly conducted, a post fire testing utilizing full scale burns and computer fire modeling may assist in the understanding of fire pattern development and fire growth.

## INTRODUCTION AND PROBLEM STATEMENTS

Fire Patterns, as defined in the 2008 Edition of NFPA-921 “Guide for Fire and Explosion Investigations”,<sup>1</sup> are the visible or measurable physical effects that remain after a fire. Fire Pattern analysis has been a key factor in the determination of the origin and cause of fires for the past 50 years.

In NFPA-921, Chapter 17 Origin Determination the following is included:

“17.1.2 Determination of the origin of the fire involves the coordination of information derived from one or more of the following:

- (1) Witness Information. The analysis of observations reported by persons who witnessed the fire or were aware of conditions present at the time of the fire
- (2) Fire Patterns. The analysis of effects and patterns left by the fire (See Chapter 6.)
- (3) Arc Mapping. The analysis of the locations where electrical arcing has caused damage and the documentation of the involved electrical circuits (See Section 8.10.)
- (4) Fire Dynamics. The analysis of the fire dynamics, that is, the physics and chemistry of fire initiation and growth (see Chapter 5), and the interaction between the fire and the building’s systems (See Chapter 7.)”

As indicated, one of the key methodologies included in this section is the analysis of Fire Patterns. Actually, the analysis of fire patterns has been included in all of the editions of NFPA-921 as well as many of the textbooks that have been written concerning fire investigation.

On the surface, this would not appear to be a problem. Since fire patterns and fire pattern analysis has always been a part of origin determination process, it must be correct. The process of validating something because it has been done that way for a long time, is not sufficient to validate the process.

During the International Conference on Fire Research for Fire Investigation<sup>2</sup>, sponsored by the Federal Bureau of Alcohol, Tobacco and Firearms in November 1997 a number of fire pattern research issues were identified. Those research items included; “Means to validate identification of electrical faults as an ignition source, Impact of flashover on fire patterns and other indicators, Effects of ventilation on fire growth and origin determination, and Validation of fire models” among others.

In addition, the National Fire Protection Association’s Fire Protection Research Foundation in a White Paper “Recommendations of The Research Advisory Council on Post-fire Analysis<sup>3</sup>” issued February 2002, also identified a number of fire pattern research needs. The White Paper in Section III Recommendations, Origin and Cause Investigation Methods made the following recommendations: “Since knowledge of the origin of a fire is, in nearly all cases, essential to determining cause, a high priority should be placed on new or improved methods for identifying the point or area of origin including burn pattern analysis”. And, “Methods for analyzing burn patterns concerning their meaning in the early growth history of the fire are also important. In particular, how does one determine when in the course of the fire event a particular pattern was made and how it might relate to a given potential ignition scenario”?

Fortunately, many years prior to these two initiatives that questioned the research, the Advanced Fire Patterns Project (1985) had been formed as a partnership between the National Association of Fire Investigators (NAFI) and the Fire and Safety Engineering Technology Program, Eastern Kentucky University to complete research into the development of fire patterns on exposed surfaces of full, half, and quarter scale compartments and transfer that information to those that attended seminars and other educational programs sponsored by the two entities.

## **General Theory**

Recent research into the development of fire patterns has shown that the primary mode behind fire pattern creation stems from the amount of heat flux that is being impinged on a materials surface.<sup>4,5,6</sup> Therefore, the plume is the primary means of pattern production. As the fire develops, a substantial upper layer begins to form and starts transferring heat to the wall and ceiling surfaces. This heat transfer can be regarded as relatively universal throughout the upper portions of the compartment, except at the plume interface. Obviously, at the interface of the plume the heat transferred will be greater and for a longer duration. As the temperature in the upper layer increases and the duration of contact between the upper layer and the wall/ceiling surfaces increases, the heat flux impinging on these surfaces reaches a critical threshold that begins damaging the material and creating patterns. As the compartment transitions through flashover and into full-room involvement, the upper layer descends to the floor and encompasses the entire volume of the compartment. Therefore, the walls, ceiling, and floor surfaces are now receiving almost identical heating or a similar magnitude of heat flux. Because of this, some fire investigators often regard the initial plume patterns as being destroyed or obscured. A major part of this research was to determine if the initial plume patterns persist past full-room involvement and to determine if the test results obtained be correlated to an actual fire.

This series of full scale fire tests were conducted in a manner to address the following problem statements:

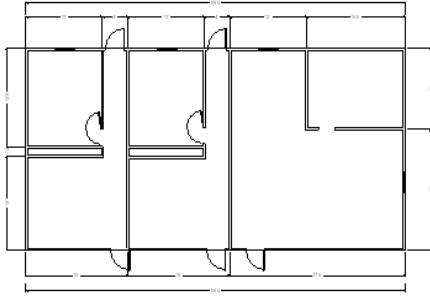
1. Do fire patterns persist through flashover and full room involvement?
2. Can fire pattern geometry be reproducible in minimal variable testing methods?
3. Can the tests conducted be correlated to an actual fire incident.
4. Can standard fire patterns analysis methodologies, such as heat and flame vector analysis, depth of calcination measurement, depth of char, and truncated cone patterns formation and analysis be reaffirmed? As an added value these research burns were designed to test the validity of content of the National Fire Code© component document, NFPA 921 “Guide for Fire and Explosion Investigations”<sup>1</sup> chapters on Fire Patterns, and Origin Determination.

## **FULL SCALE FIRE TESTS**

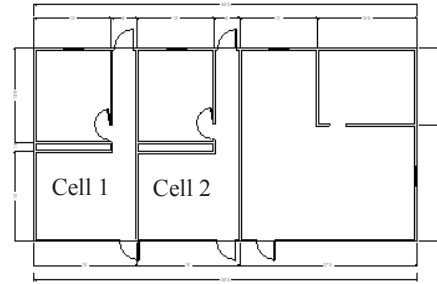
From March 2005 through March 2007 a series of 10 full scale fire tests were completed in the Eastern Kentucky University, Fire and Safety Engineering Technology Program’s burn facility. These fire tests were completed in conjunction with the Advanced Fire Pattern Research Project. Complete details of the 12 actual full scale tests can be found in several papers that have been presented during previous Fire and Materials Conferences and during The International Symposium on Fire Investigation Science and Technology<sup>7,8,9</sup> A summary of the results as well as sample photographs will be included in this paper for reference.

### **Test Facility**

The test facility, which opened during the Fall Semester, 2003 was specifically designed and built to afford students enrolled in the Fire and Safety Engineering Technology Programs, Fire, Arson and Explosion, Investigation option the ability to have access to “hands on laboratories” to investigate fire and explosion events. The test facility has two identical cells and a third cell that can be configured to specific sizes and layout as needed. (See Figure 1)



**Figure 1: layout of EKU test burn building**



**Figure 2: location of test cells**

### **Test Cells**

The test cells for this research project encompassed the north half of the facility configured into two identical 4.88 m by 9.75m (16' by 32') cells (see figure 2). The cells were constructed of 8" poured, reinforced concrete walls, which were lined with 2x4 studs and gypsum wallboard (See Figure 2). All dimensions are approximated. (See Figure 2)

### **Fire Tests**

Experiment Sets "A", "C", and "E": Each "Experiment Set" included two sets of burns in identically furnished rooms, Set "A" conducted March 2005, Set "C" conducted March 2006, Set "E" conducted March 2007 the rooms were bedrooms and living rooms. The contents of each bedroom included a bed, chest, two lamps, end tables, two nightstands, television (not included in experiment set #5, 9, and 10), clothing and a dresser with an attached mirror. The bedrooms had wall-to-wall carpeting on the floor. The contents of each living room included a couch, loveseat, coffee table, two end tables, and television. The living room as well as the hallway had wall-to-wall carpeting on the floor. Ignition occurred in the bedroom during each of these tests. (See Figure 3)

Experiment set "B" and "D": Each "Experiment set again included two sets of burns in identically furnished rooms, Set "B" conducted November 2005 and Set "D" conducted October 2006 The rooms were furnished as a residential living room. The living rooms consisted of a couch, loveseat, three end tables, two lamps and a coffee table. The bedroom consisted of a single mattress with bedding material Ignition occurred in the living room during each of these tests. (Figure 4).

### **Ignition**

Experiment sets "A"- "D" were ignited by the application of a propane torch to a small plastic bag containing a 4" x 4" piece of cotton fabric rag doused with about 4 ml gasoline. Experiment sets "A" and "C" were ignited near the head of the bed on the polyurethane bedspread. Experiment set "B" and "D" were ignited near the center of the couch at the base of the vertical cushion. Experiment Set "E" a wood crib that was placed inside of a night stand was ignited using a propane torch to a small plastic bag containing a 4" x 4" piece of cotton cloth doused with about 4ml of gasoline.

### **Instrumentation**

The rooms were instrumented for the measurement of temperature with thermocouple arrays strung vertically between the ceiling and the floor (a.k.a. thermocouple trees). A single thermocouple located close to the origin. Experiment set "C" also had a heat flux transducer placed in each cell. Data obtained is provided in the previous papers.

In addition to the above instrumentation, digital and 35mm 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 observations and written notes.

## TEST BURN RESULTS

### Results – Experiment Set “A” Experiments 1 and 2

In cell #1 (experiment #1), the technical indicator of 600°C (1112°F) in the upper layer for flashover was achieved at approximately 330s (seconds). The duration of the post-flashover/fully involved stage of the fire, the time between flashover and suppression, for experiment #1 was 360 s. In cell #2 (experiment #2), the technical indicator for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 190s. The duration of the post-flashover/fully involved stage of the fire for experiment #2 was 200s.

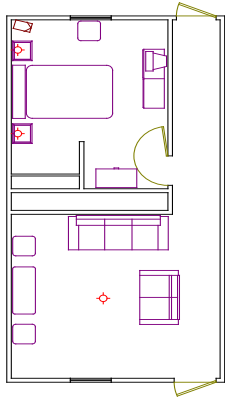


Figure 3 Furniture Layout for Experiment Set A, C, & E

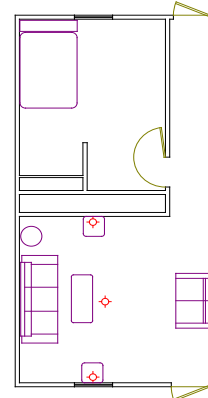


Figure 4 furniture layout for Experiment Set B & D

### Results – Experiment Set “B” Experiments 3 and 4

In cell #1 (experiment #3) the technical indicator for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 236s (seconds). Also, in experiment #3, the duration of the post-flashover/fully involved stage of the fire was 124s. In cell #2 (experiment #4) the technical indicator for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 212s. Also, in experiment #4, the duration of the post-flashover/fully involved stage of the fire was 120s. The temperature growth profiles from experiments #3 and #4 are almost identical.

### Results – Experiment Set “C” Experiments 5 and 6

The test in cell #1 (experiment #5) was stopped early due to hazardous weather conditions creating an unsafe work environment. In experiment #5, the technical indicator for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 1396s (seconds). However, the full transition of flashover into full-room involvement did not occur. This was evident from the radiometer readings, as well as the post-fire inspection of the furnishings. In cell #2 (experiment #6), the technical indicators for flashover of 600°C (1112°F) in the upper layer and radiant flux of 20kW/m<sup>2</sup> at the floor were achieved at 790s. The duration of the post-flashover/fully involved stage of the fire for experiment #6 was 215s.

As a note, initially, the researchers involved in this project were concerned that Experiment 5 was stopped early in the fire. However, by extinguishing the fire prematurely, we were able to examine the fire patterns that were developed just prior to the room transitioning to full room involvement and if the fire pattern did persist post flashover. They did and the resemblance was remarkable.

### Results – Experiment Set “D” Experiments 7 and 8

In cell #1 (experiment #7) the technical indicator for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 640s (seconds). Also, in experiment #7, the duration of the post-flashover/fully involved stage of the fire was 194s. In cell #2 (experiment #8) the technical indicator for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 488s. Also, in experiment #4, the duration of the post-flashover/fully involved stage of the fire was 216s.

## Results – Experiment Set “E” Experiments 9 and 10

In cell #1 (experiment #9), the technical indicator for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 738s (seconds) and extinguishment occurred approximately 224s later and a total elapsed time for this test of 962s. In cell #2 (experiment #10), the technical indicators for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 420s. The duration of the post flashover/full room involvement was 230s and extinguishment occurred after that time. A total elapsed time for this test of 750s.

## POST-FIRE ANALYSIS, PATTERN IDENTIFICATION AND CONCLUSIONS

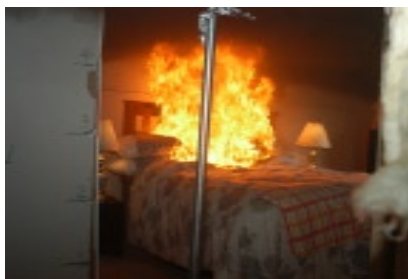
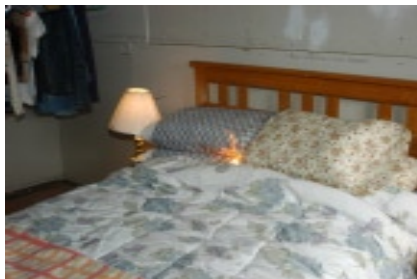
Following each of the fire experiments, the conditions of the room contents and the building components were analyzed. Each experiment was documented by photography, written notes, and diagramming.

Each experiment scene was thoroughly processed using generally recognized and accepted techniques and methods as outlined in NFPA 921 “Guide for Fire and Explosion Investigations”.<sup>1</sup> Specialized scene processing techniques were utilized including, Depth of Calcination and Heat and Flame Vector Analysis. Scene processing requires special knowledge and skills gained through years of “dirty-knuckles” scene processing. The initial scene evaluation for the research information and documentation was completed by qualified NAFI Certified Fire and Explosion Investigators (CFEI’s) and IAAI Certified Fire Investigators (CFI). After the initial scene processing, the March scenes were then reviewed by those attending the National Advanced Fire, Arson, and Explosion Investigation Science and Technology Program™ as well as students enrolled in FSE-450 Fire, Arson and Explosion Investigation II at Eastern Kentucky University. The November 2005 and October 2006 scenes were also processed by students enrolled in FSE-495, Fire, Arson, Explosion Case Preparation and FSE-350 Fire, Arson, and Explosion Investigation I. The later groups had not been present during the test burns, but did use fire pattern analysis techniques to determine the area or point of origin and the cause.

## BEDROOM TEST FIRES

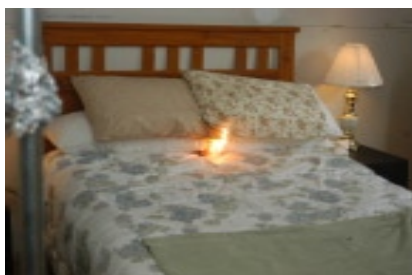
### Experiment Set A: Experiment 1

March 2005



### Experiment Set A: Experiment 2

March 2005



**Experiment Set C: Experiment 5**

**March 2006**



**Experiment Set C: Experiment 6**

**March 2006**



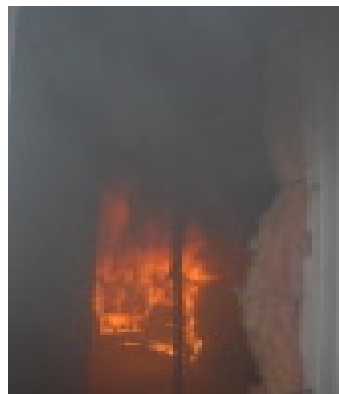
**Experiment Set E: Experiment 9**

**March 2007**



**Experiment Set E: Experiment 10**

**March 2007**



# LIVING ROOM TEST FIRES

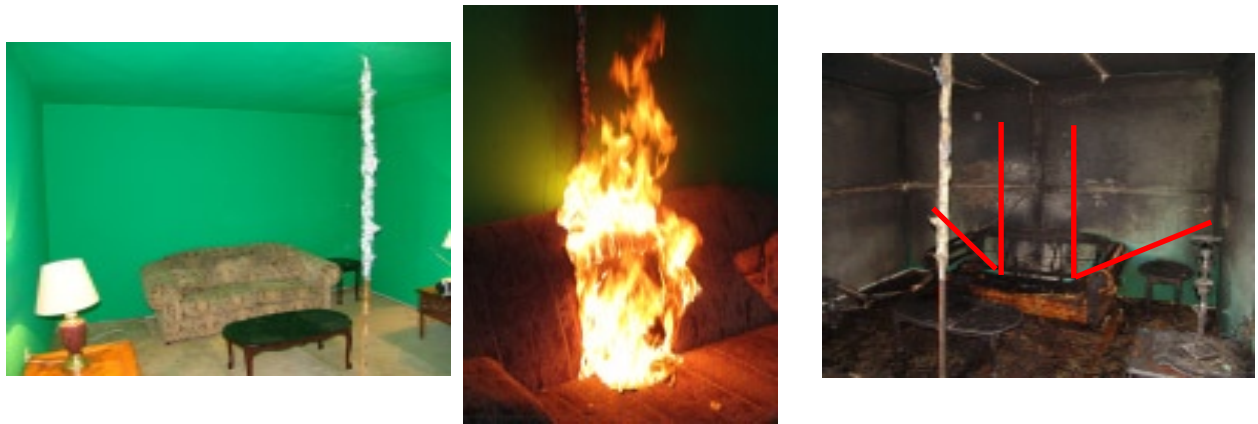
Experiment Set B: Experiment 3

November 2005



Experiment Set B: Experiment 4

November 2005



Experiment Set D: Experiment 7

October 2006



Experiment Set D: Experiment 8

October 2006





### **Conclusions, Experiment Sets “A” through “E”**

Unlike laboratory bench-top tests (i.e. flash point tests) where variables can be easily controlled, a full-scale room fire test has a wide variety of uncontrollable variables, mostly linked to ventilation. It is rare that full-scale tests can be completely reproducible. The tests reported here show reproducibility well within the parameters that can reasonably be expected. Regardless of the thousands of variables that can affect both fire growth and subsequent pattern formation, similarities in pattern formation between the experiment sets were observed and measured. The most important finding from these tests is that fire patterns provide substantial evidence for the accurate identification of the correct area of origin.

These tests reaffirmed that fire patterns persist during post flashover conditions, as well as provide evidence of the evolution of these fire patterns. This research revealed that the initial plume patterns are not lost, in fact, the experiments presented here have shown that the demarcation lines or initial fire patterns formed by the plume persist after flashover. The research shows that these patterns do begin to evolve from the sharp distinct demarcation lines into more subtle demarcation lines due to the descending upper layer and its resulting damage. However, the initial plume patterns are still present and have been reliably shown to assist in determining an area of origin.

### **FULL SCALE FIRE TESTS AND COMPARISON TO ACTUAL FIRE ANALYSIS**

While not a part of the original 10 fire test set, an opportunity did arise for the use of a room test fire to be completed based on an actual fire scenario, in which one child lost their life.

The actual fire occurred in a two story attached dwelling. The structure was a duplex built around 1900 (estimated based on Architectural style and construction), the exterior walls and the wall the separating the two residences were brick with lath and plaster attached as an interior finish. Interior walls and ceiling were wood frame covered with lath and plaster. The room of origin was about 10.45 square meters (112.75 square feet) excluding the closet and measured 3.12 meters (10.25 feet) x 3.35 meters (11 feet) with a ceiling height of 2.43 meters (8 feet). There was a small closet, .81 meters (2.66 feet) x .91 meters (3 feet), with a ceiling height of 2.43 meters (8 feet).

Furnishings in the room included a bunk bed, two chests four drawers, two plastic storage bins, desk, television, VCR, CD/Stereo Player, ceiling fan, and two other fans. The windows did not have curtains. The location of the room contents and other details were obtained by investigators and included in reports, statements, and depositions.

There also were photographs and room diagrams taken by investigators and investigative reports that were available to rebuild a test room.

A test room was built inside of the large room located on the south side of the fire burn building at Eastern Kentucky University to match the fire compartment. (See Figure XX) The room was constructed of wood frame, with a lath and plaster interior finish on walls and ceilings, wired and connected to electric service, doors were 5 panel solid wood, windows due to the size were constructed, and furnishings and carpet similar to those found in the original fire compartment.

### **Instrumentation and Data Collection**

The room was instrumented for the measurement of temperature with a thermocouple couple tree with a total of three thermocouples. Thermocouple 1 was at ceiling height, 2 mid level of the room, and 3 at the height of the bottom bunk bed mattress. Two additional thermocouples were utilized, with one on the bedroom door and one on the door handle outside. All thermocouple data was logged and stored

electronically at 4 second intervals. Additionally, a heat flux transducer was placed at floor level between the closet and bedroom door.

In addition to the above instrumentation, digital and 35mm still and video was used during the test to document the growth and progression of the fire. Photographic records of the compartment fire were supplemented by direct observations and written notes.

### **Ignition**

Ignition was accomplished by the application of a propane torch to a small plastic bag containing a 4" x 4" piece of cotton fabric rag doused with about 4 ml gasoline. Ignition was on the bottom bunk bed, on the south east end approximately .45 meters (1.5 feet) from the end of the bed, centered on a comforter.

### **Fire Suppression (Extinguishment)**

Fire Suppression for this test was similar to the methodology used for the 10 burn series described above. Knockdown was accomplished with a 1 3/4" hoseline equipped with a combination tip. Suppression personnel were instructed to minimize suppression damage to when applying water and overhaul operations.

### **Results**

The technical indicator for flashover of 600°C (1112°F) in the upper layer was achieved at approximately 884s (seconds) and extinguishment occurred approximately 120s later and a total elapsed time for this test of 988s. Maximum room temperatures achieved at the top of the mattress level (Thermocouple 3) occurred at 984s and the temperature was 1100°C (2012°F). Heat flux at the time of flashover was just over 25 kW/m<sup>2</sup> and the maximum heat flux recorded post full room involvement was 36.3 kW/m<sup>2</sup>

### **Post-Fire Analysis and Fire Pattern Identification**

As with the previous Test Fires, the conditions of the room contents and the building components were analyzed and documented. The methodologies utilized followed the recognized and accepted techniques and methodologies as outlined in NFPA-921 Guide for Fire and Explosion Investigations.<sup>1</sup> Specialized scene processing techniques were utilized including Depth of Calcination and Heat and Flame Vector Analysis. Scene processing was accomplished by trained and experienced NAFI CFEI's and IAAI-CFI's. Students enrolled in FSE-495, Fire, Arson, and Explosion Case Preparation and FSE-350 Fire, Arson, and Explosion Investigation I had the opportunity to view the remaining scene and review the scene documentation and results.

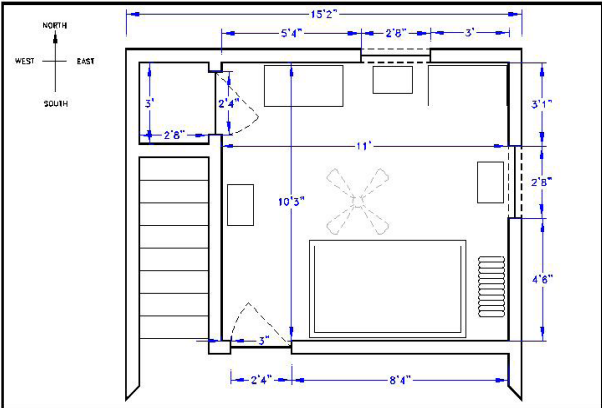
Due to the length of the paper, complete results of the Depth of Calcination and Heat and Flame Vector analysis cannot be reported. There were several areas within the compartment where there was calcinations of the plaster and in some locations part of the skim coat of plaster disassociated from the base coats. In the area of the bed and ceiling above, the full thickness of the plaster calcined and started to disassociate from the lath.

### **Conclusions**

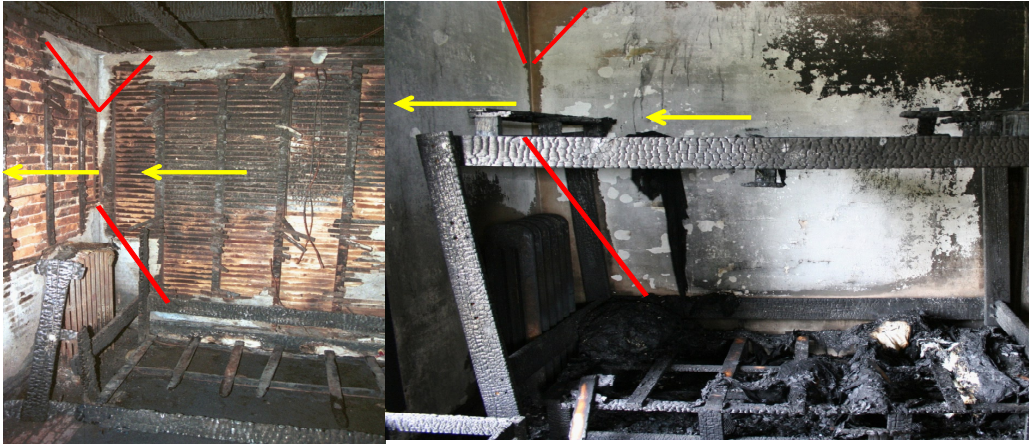
Since the original fire scene was not available to compare the results of the test, the researcher's utilized data gathered from the test fire and then compared those results to fire scene photographs taken at the time of the fire and by subsequent fire investigators. This comparison is utilized as the final analysis step. While the fire patterns developed in the test fire are not exact, they are within acceptable parameters to matching those in the actual fire. The fire patterns in the test fire were similar to those in the actual fire, but they did not progress and transition as far as the actual fire due to the length of the burn. The total burn time of the actual fire was not known, however, based on the fire scene photographs it is recognized

that it did burn longer than 2 minutes after full room involvement and extinguishment of the test fire.

The other variables observed in previous test fires are also true in this experiment. Factors such as exact fuel loading and ventilation cannot be exactly duplicated. However, in this test, it does not appear that ventilation of fuel loading caused any significant changes to the fire growth or fire pattern development.



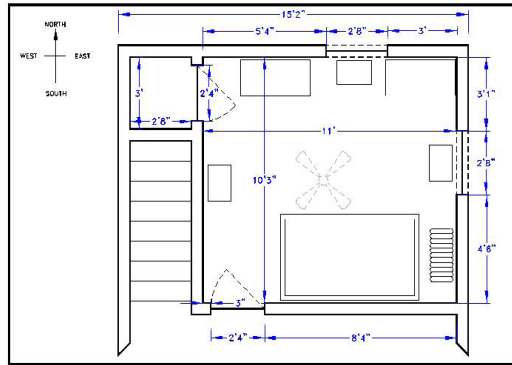
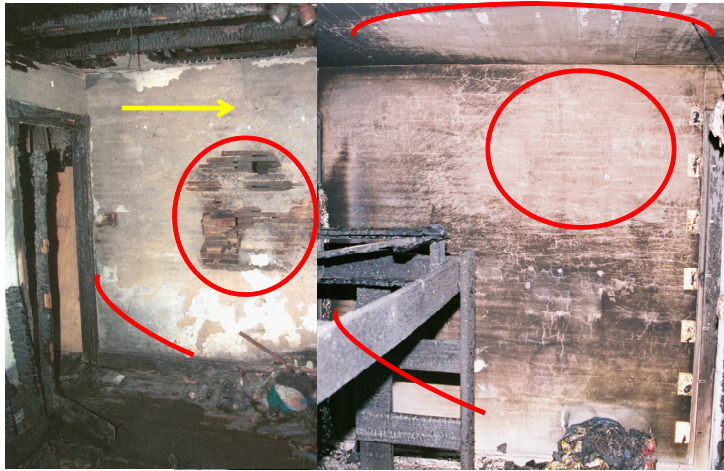
### South Wall



Actual fire on the left, test fire on the right



# West Wall



Actual fire on the left, Test fire on the right



# North Wall



# East Wall



## OVERALL CONCLUSIONS

The series of 11 test fires and the use of an actual fire to assist in the formulation of the overall conclusions to determine, fire pattern predictability and fire pattern persistence through and post full room involvement has been demonstrated. Concerns that limiting the test fire duration to 2 or 3 minutes after full room involvement cannot represent what the fire patterns will resemble in “real world” fires is not correct. While they will not look exactly the same, they should and will have many similarities as they continue to evolve the longer the fire continues.

Variables, there are many that have to be considered when conducting full scale fire tests and investigating fire scenes. Ventilation, as one, was attempted to be control at least in the early stages of fire development for the 10 identical tests. However, once windows failed, ventilation could not be controlled as it cannot be in an unplanned fire event. Regardless of the number of variables can affect both fire growth and fire pattern formation, similarities in fire pattern formation between the experiment sets were observed and measured.

Finally, it should be noted that fire investigators should not rely on a single fire pattern to identify the origin of a fire. Large boundary fire patterns after transition to full room involvement, differences of fire patterns near or at ventilation openings, effects of large fuel packages within the compartment all require further analysis. It is here that subtle fire patterns lead an investigator to a more defined area of origin or even a point of origin.

Research into fire pattern development is not finished; more will be required in the future. The research should focus on changing a variable such as the origin, continued research in the area of fire pattern persistence post-flashover, effects of ventilation limited fires, and then the addition of ignitable liquids to the ignition scenario.

### Acknowledgments

This three year research project and much of the other work that the Advanced Fire Patterns Research Project has completed since its inception in 1985 would not have been able to be completed without the efforts of many individuals, support of NAFI, and for this project specifically without of the financial sponsors listed at the end of this paper.

Those individuals that have been instrumental in this project include: Patrick M. Kennedy, Kathryn Kennedy, Gregory Gorbett, Bill Hicks, Mike Hopkins, Tom Thurman, and Bill Abney. Additionally, to numerous to name; the students enrolled in the Fire and Safety Engineering Technology Program that participated in the fire investigation seminars and assisted with construction, research, and extinguishment of the test fires, and those that have been enrolled in the fire investigation seminars sponsored by EKU, NAFI and NFPA for 24 years that assisted with the testing of our theories and validation of our studies.

Additionally, to continue to enhance the knowledge of the fire investigation community we were able to piggy back additional research into this project three arc mapping studies have been completed. The primary researchers in this area included Dan Churchward, Ryan Cox, Christopher Woods and Amanda Kimball.

### ABOUT THE AUTHORS

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**Patrick M. Kennedy, CFEL, CFPS, MIFireE**, John A. Kennedy & Associates, USA. Mr. Kennedy is a principle expert for John A. Kennedy & Associates. He serves as the Chairman of the Board of NAFI, is a member of the NFPA technical committee on Fire Investigation, and is Director of the NFPA's Fire Science & Technology Educators Section.

## END NOTES

1. National Fire Protection Association, "NFPA 921 Guide for Fire and Explosion Investigations", 2008 Edition, NFPA: Quincy, MA.
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