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Proceedings of the

International Conference of Fire Research for Fire Investigation

Prepared by

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Laboratory Services

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Preface

This book contains the report of the International Conference of Fire Research for

Fire Investigation held at the Baltimore-Washington International Airport Sheraton Hotel. The Conference was held November 11-14, 1997. The purpose of the Conference was

- to assess the current state of the art of fire investigation and its use of scientific principles and methodology,
- to identify fire investigation needs for research and education,
- to recommend the role that the ATF Fire Investigation, Research and Education (FIRE) Center should play advancing fire investigation and research, and
- to recommend capabilities and staffing for the FIRE Center based on the needs identified and analysis conducted.

The appendices contain results of needs surveys conducted with ATF Certified Fire Investigators and others, as well as the raw data generated by the Conference breakout groups used to develop the report recommendations.

The Conference attendees represented a broad, diverse group that included fire investigators, fire researchers, academicians, and training/information specialists from five countries. This included representatives from a number of major fire investigation professional organizations. The program was a mix of formal presentations and breakout group exercises to address the Conference goals. Keynote speakers made presentations on fire investigation needs, fire scene reconstruction requirements, training/education necessities for investigators, and the role of fire research, which provided a foundation to discuss the Conference objectives. The second day of the Conference also included a panel discussion on how fire testing is done around the world. Copies of the keynote speakers' presentations and a summary of the panel discussion comments are included in the appendices.

This Conference would not have been possible without the sponsorship of the Bureau of Alcohol, Tobacco and Firearms, and the support of Mr. Patrick Schambach (Assistant Director, Science and Information Technology), Mr. Pete Gagliardi (Deputy Assistant Director, Science and Information Technology), Mr. Michael Ethridge (Director, Laboratory Services) and Mr. Arthur Peoples

(Executive Assistant to the Director, New Building Projects Office). Thanks also to the University of Maryland, Department of Fire Protection Engineering, the National Institute of Standards and Technology, Building and Fire Research Laboratory, and Hughes Associates for the work that went into planning and organizing the Conference. A special thanks goes to the members of the Organizing Committee: Jesse Beitel, Nelson P. Bryner, Daniel Madryzkowski, Harold E. Nelson, James G. Quintiere, Ph.D., and William Stratton. Their efforts made the Conference a success.

Richard E. Tontarski, Jr.

Forward

Message from the Assistant Director

Office of Science and Technology

The Bureau of Alcohol, Tobacco and Firearms was fortunate to be able to host the *International Conference on Fire Research for Fire Investigation.* Through the willing participation of over 70 fire science experts from six countries, we were able to identify critical areas of fire investigation that will benefit from the development of our Fire Investigation, Research and Education (F.I.R.E.) Center.

These *Proceedings* are a resource for the fire investigation and fire research communities. They document the highest priorities for fire investigation research and fire investigator technical training. They also identify "best practices" and design features ATF should consider for the F.I.R.E. Center, building on the extensive expertise and testing experiences of the attendees at the conference.

I appreciate the time and effort the Organizing Committee and Conference attendees have given to this effort. ATF looks forward to continuing to work with the fire investigation community to fully develop the F.I.R.E. Center and its capabilities to best meet your requirements. We expect to be a full participant in the fire research community as well, conducting research and documenting that work in scholarly and technical fire investigator publications.

The *International Conference on Fire Research for Fire Investigation* and this report represent another step in ATF's commitment to enhancing fire investigation and protecting the public.

Patrick R. Schambach

Assistant Director

Sponsorship and Support

Sponsored by: The Bureau of Alcohol, Tobacco & Firearms

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Baltimore, MD

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Building and Fire Research Laboratory

Gaithersburg, MD

University of Maryland

Department of Fire Protection Engineering

College Park, MD

Organizing Committee

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Nelson P. Bryner Chemical Engineer, NIST

Daniel Madryzkowski, P.E. Fire Protection Engineer, NIST

Harold E. Nelson Hughes Associates, Inc.

James G. Quintiere, Ph.D. Professor, Department of Fire Protection Engineering

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ATF National Laboratory Center

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Executive Summary

International Conference on Fire Research for Fire Investigation

Mr. Patrick R. Schambach, ATF Assistant Director for Science and Technology working with the Department of Fire Protection Engineering at the University of Maryland, the Building and Fire Research Laboratory of the National Institute of Standards and Technology, and Hughes Associates, Inc. (HAI) convened the International Conference on Fire Research for Fire Investigation.

Approximately 70 leading authorities from the fields of fire research, investigation, and education from the Unites States and five other countries gathered at the Sheraton International Hotel at Baltimore-Washington International Airport, MD on November 12 through 14, 1997. The Conference was charged with the following:

a) Assessing the current state of the art in fire investigation from a scientific and applied technology view point;

b) Assessing the current needs for research, education, and related resources in the field of fire investigation;

c) Recommending the role and direction that the ATF F.I.R.E. Center should take in advancing the capabilities and credibility of fire investigation and analysis;

d) Advising what specific types of tests and facilities should be incorporated in the ATF F.I.R.E. Center;

e) Making recommendations on the staffing that will be needed for the F.I.R.E. Center.

The Conference addressed its charges and came to the following determinations.

a) Current Scientific State of the Art in Fire Investigation

While in recent years there have been important advances in the understanding of

fire, transfer of the advances to the fire investigation field has been primarily by serendipitous spill-over from work performed for different objectives. Science advances have resulted in challenges to traditional methods of fire incident analysis as misconceptions or at least misapplication.

In each case, the challenge is not that there is no meaning to these indicators. Rather the challenge is that the traditional one-on-one cause-effect interpretation is indefensible. Unfortunately, while the challengers present sound cases for declaring the traditional conclusions improper, the state of the art of fire science applied to fire investigation problems has not yet produced the in depth understanding of what forces of physics generate these specific patterns and other types of fire produced evidence.

This results in a chaos in the fire investigation community where some factions present the traditional interpretations as still valid while others attack them as misconceptions. Meanwhile, the rank and file of dedicated fire investigators plead for a sound, defendable scientific resolution of the dispute and the production of validated means of fire incident analysis.

While there are fire research organizations around the world that investigate fire phenomena, there are no fire research facilities in the US, or elsewhere, dedicated to the needs of fire investigation. Until the F.I.R.E. Center institutes programs directed at the specific needs of fire investigation, advances in scientifically credible information will depend on serendipitous information from research directed at different objectives than fire investigation.

b) Needs for Fire Investigation Research and Education

The Conference addressed the needs of fire investigation in terms of research needs, training and education needs, and data repository needs.

(1) *Research Needs*

There were over 80 subjects that one or more participants felt important and worthy of scientific investigation. All are covered in the report and its appendices. A few of the needs identified as most important included the following:

(a) Fire incident reconstruction,

(b) Validation of fire pattern analysis: residues, marks, and fire indicators,

(c) Ignition studies (experimental and theoretical) • What ignition sources can ignite what material, under what conditions? What are the reliability and uncertainties involved in ignition analysis?

(d) Burning rates for different items and effects of configuration and ignition source on burning; Development of a data base,

(e) The ability of electrical sources to ignite an exposed fuel; Evaluation methods for physical evidence. Did the fire cause the arc or did the arc cause the fire?

(f) The phenomena of flashover and the impact of post flashover burning on patterns and other fire indicators,

(g) The effects of ventilation (natural and forced) on fire development, fire growth and origin determination,

(h) The validation of existing mathematical fire models and the development of new models as needed, and

(i) Fire investigator occupational health and safety.

(2) *Training and Education Needs*

There is a recognized need to train fire investigators. The CFI programs are run by ATF; the International Association of Arson Investigators (IAAI), and the National Association of Fire Investigators (NAFI) attest to this. The general educational consensus was that there is an important need to continually upgrade the knowledge of the practicing fire investigators in both the current state of knowledge and in new knowledge as it emerges. Conference attendees envisioned that one of the ATF F.I.R.E. Center roles supporting this theme would be providing training that would produce a cadre of accredited/certified fire investigators. These investigators would be well grounded both theoretically, through solid academic training provided by the University of Maryland Fire Protection Engineering Department (or other

academic sources), and practically, through hands-on experience observing and conducting fire science testing, coordinated by the ATF F.I.R.E. Center.

(3) *Data Repository Needs*

The general consensus of the Conference was that a repository (i.e., library) is an essential need. There is a need that the library be complete in its collection of work produced by ATF (e.g., test methods, analytical findings, test data, research reports, etc.) and as extensive as possible in other work bearing on the science of fire investigation. It was also considered important that the access to the resource be as open as possible to all qualified persons and that it be accessible through remote access points such as on the Internet and CD-ROM releases. A close cooperative relationship with the Fire Research Information Service (FRIS) at the National Institute of Standards and Technology (NIST) to supplement and extend each other was recommended.

c) Role Recommended for the ATF F.I.R.E. Center

The Conference felt that all of the needs identified in this report are appropriate for the F.I.R.E. Center. It is essential that the Center have scientific credibility in all of its work and conduct its tasks in a manner that is unbiased and scientifically competent. The Conference made a number of specific recommendations relative to the Center operations. These include the following:

(1) The Center serve as a model for state and local agencies as well as being an international model;

(2) The Center be knowledge-based and scientifically creditable and neutral;

(3) The Center be an "open", facility and a center of excellence for fire investigation. The Center should be visitor friendly including exhibits etc., for the general public;

(4) The Center evaluate existing "knowledge" that is now being disseminated in fire investigation and analysis. One conferee recommended that the starting point for such evaluation could be the scientific bases for the statements in NFPA Standard 921, Guide for Fire and Explosion Investigation; Kirk's Fire Investigation (Fourth

Edition), and the course material of the fire investigation course at the National Fire Academy;

(5) The Center provide a focus/center for knowledge dissemination. A research/teaching hospital is a model for the Center: teaching, research, clinical work; and

(6) The Center use fire incident reconstruction as a tool, not only to appraise individual cases, but also to proof-test models and other analytical analysis methods. Fire incident reconstruction also should be used to determine where additional research is needed. Whenever possible, the incident should be analytically evaluated prior to the test and the predicted results compared to the test results measured during incident reconstruction tests. Fire incident reconstruction tests should also be used to validate the effectiveness of small scale tests and the data base of material properties.

d) Tests and Facilities Recommended for the ATF F.I.R.E. Center

It was determined that the F.I.R.E. Center should provide a wide range of standard and unique tests. These potential tests range from small-scale fire tests to very large fire tests. The one overriding factor that was expressed, was that the facility must be very flexible in terms of its capabilities, since the exact nature of future work is not well defined.

The small-scale portion of the facility will require laboratories that will provide for equipment/tests such as

- Cone calorimeter;
- LIFT apparatus;
- Bench-top types of fire tests (limited size and intensity);
- Chemical Analysis, such as wet chemistry, GC, and mass spectrometer; and
- Flash point.

An additional small-scale laboratory was suggested where electrical testing can be performed. This laboratory will be unique to the evaluation of the potential for electrical items, wiring, etc. to initiate a fire event. This laboratory will require extensive and specialized electrical requirements.

The full-scale test laboratories are the most important feature of the facility. In these laboratories, fire tests from the size of a trash can fire to full-room burnout tests will be performed. The primary equipment to be used in these laboratories will be hood/exhaust systems that will allow for the measurement of heat release rates (HRR). The design and size of the hood systems will dictate the capability of the system to make accurate measurements. For example, a very large hood system will have difficulty accurately measuring the HRR of a small fire. Based on the potential uses of the facility, several hood/exhaust systems will be required:

- Very large hood system (10 - 20 MW HRR maximum)
- Intermediate size hood system (~0 - 5 MW HRR), and
- Small size hood system (0 - 500 kW HRR)

As with any fire test laboratory, significant ancillary spaces will be required. These include the following:

- Storage areas
- Materials handling and staging areas
- Instrumentation room(s)/ portable test equipment racks
- Control room area
- Conditioning room(s)
- Observation room(s)
- Specialized storage such as evidence areas
- Loading dock area, and
- Computer modeling/graphics room

Besides the above mentioned ancillary areas, areas for the general conduct of business will also be required. These areas include but are not limited to the following:

- Reception area
- Offices for use by engineers, administrative personnel, etc.
- Classroom areas
- Locker/shower area
- Break room area
- Library area

The above listed test apparatuses and test facilities are conceptual in nature and are

based on the Conference attendees experience and potential uses for the lab. This listing, while general in nature, provides a basic framework for the design of the lab and its facilities. The next phase of this program will take this conceptual information and provide specific details for the design and layout of the fire test laboratory.

e) Staffing Recommendations for the ATF F.I.R.E. Center

The estimation of staffing needs was developed with major input from the conferees who are active leaders in fire research facilities, education, and library operation. The estimated staff size ranged from a bare bones minimum of about 30 persons to a fully adequate staff of about 60. With the minimum staffing, the Center will experience difficulty responding to the needs of the field in terms of designing and conducting tests within the time frames required to match the development of cases.

f) Immediate Staffing and Testing Needs

It was suggested that an interim F.I.R.E. Center facility/staff be immediately established. The rationale for establishing a "core" staff before the facility is designed and built includes the following:

- Recruiting, selecting and hiring the key personnel will take time
- Key F.I.R.E. Center staff have a stake in the design and operation of the facility and should participate in the Center design and the development of operational protocols
- Programmatic development in testing, research, and education can begin which will help maximize the Center potential when the facility is operational

Arrangements should be made with existing fire test facilities to conduct at least limited fire phenomena investigations and fire incident reconstruction tests as soon as possible. Doing this kind of work, in cooperation with experienced fire researchers, would provide invaluable experience to staff who will work in the F.I.R.E. Center. The experience gained will provide the following:

- Help meet the existing fire research case support need

- Establish the ATF fire research role
- Provide practical guidance for the Center design
- Facilitate the establishment of test protocols and work flow procedures
- Enhance the Center's credibility

The Conference urged ATF to quickly hire selected key personnel for staffing the Center. Those positions considered most important include the following:

(1) Laboratory Director,

(2) Top Scientist,

(3) Top Technician,

(4) Education Specialist,

(5) Information Specialist, and

(6) One or more experienced ATF CFIs.

Report of the International Conference of Fire Research for Fire Investigation

1.0 GENERAL

This is a report of the proceedings and determinations of the ATF International Conference on Fire Research for Fire Investigation held November 12-14, 1997 in Baltimore, Maryland.

2.0 BACKGROUND

The United States Congress has directed the Bureau of Alcohol, Tobacco and Firearms (ATF) to establish a Fire Investigation, Research, and Education (F.I.R.E.) Center dedicated to advancing the science of fire investigation. The F.I.R.E. Center will undertake research, education, and case support for fire investigation and analysis. The scope of work of this new Federal facility will include scientific research directed at the determination of fire cause and origin, related fire growth and spread, and other research to advance the science of fire investigation. The F.I.R.E. Center will also advance the competence of fire investigation through educational activities and the establishment of a repository of knowledge and reference information pertinent to scientifically sound fire investigation. The objective is to develop, as an international resource, the best possible research and education facility for advancement of knowledge, technology transfer, and case support related fire cause investigation and fire reconstruction.

The F.I.R.E. Center will give law enforcement agencies, and other fire investigators across the nation, access to a source of scientific research and the forensic support needed to determine the causes and characteristics of suspicious fires. The F.I.R.E. Center will disseminate the knowledge through both scholarly publication in the scientific and investigation literature, and through education programs directed at the enhancement of the ability of ATF agents, other law enforcement officers and the general investigation community. The F.I.R.E. Center repository will be the central collection of scientific facts, experimental results, material property data, and other knowledge related to fire incident investigation, analysis and reconstruction research. In addition, the F.I.R.E. Center will provide case support related to specific fires in the form of incident reconstruction and expert testimony. The F.I.R.E. Center will be a participant in the world-wide community of fire research laboratories.

The ATF has produced the following proposed statement of the mission and strategic goals for the F.I.R.E. Center:

The F.I.R.E. Center is a unique and innovative international partnership among law enforcement, fire services, public safety agencies, industry, and academia that

uses the most advanced scientific, technical, educational, and training methods to make ATF and its partners a leader in fire investigation science to serve and protect the public.

Strategic Goals

· Conduct related research that validates fire scene indicators and improves fire evidence analysis;

· Support fire investigations and the resolution of fire related crimes;

· Develop better investigation and prosecutorial procedures using scientifically validated methods that integrate the assets of ATF and its partners to enhance fire investigation personnel expertise; and

· Provide a repository of fire investigative research data and disseminate the knowledge gathered to improve public safety.

3.0 THE INTERNATIONAL CONFERENCE ON FIRE RESEARCH FOR FIRE INVESTIGATION

Given the above mission Mr. Patrick R. Schambach, ATF Assistant Director for Science and Technology, working with the Department of Fire Protection Engineering at the University of Maryland, the Building and Fire Research Laboratory of the National Institute of Standards and Technology, and Hughes Associates, Inc. (HAI) convened the International Conference on Fire Research for Fire Investigation. The Conference was charged with the following:

1. Assessing the current state of the art in fire investigation from a scientific and applied technology view point
2. Assessing the current needs for research, education, and related resources in the field of fire investigation
3. Recommending the part and directions that the ATF F.I.R.E. Center should take in advancing the capabilities and credibility of fire investigation and analysis

4. Advising what specific types of tests and facilities should be incorporated in the ATF F.I.R.E. Center
5. Making recommendations on the staffing that will be needed for the F.I.R.E. Center.

Approximately 70 leading authorities from the fields of fire research, investigation, and education from the United States and five other countries gathered at the Sheraton International Hotel at Baltimore-Washington International Airport, MD on November 12 through 14, 1997. The detailed list of Conference participants is contained in Appendix A to this report.

The Conference brought this select group of experts together in a workshop environment to exchange ideas and to develop a statement of the research and reconstruction testing needs of the fire investigation community, recommendations for the role the ATF F.I.R.E. Center should play in fulfilling these needs, and recommendations for the physical facility that will be needed for the Center.

4.0 DESCRIPTION OF THE CONFERENCE

4.1 General

This section describes the conduct of the Conference and the pre-Conference preparations. The discussions in this section are general in nature directing the reader to the appropriate appendices for the details of the actual work produced.

4.2 Conference Preparation Activities

Prior to the Conference, data were gathered from both ATF and other sources relative to the needs of the fire investigation community as discussed below. Each attendee was provided with a Conference notebook containing the described material. The data provided are contained in the appendices of this report.

4.2.1 ATF CFI Survey

In July 1997, a Needs Survey addressing the perceived needs of practicing ATF Certified Fire Investigators (CFIs) was completed by 40 ATF CFIs. The data developed were entered into a data base and analyzed as background and supplemental data for the Conference and this report. The survey form used is contained in Appendix B of this report. A summary of the subjects felt to need research by these investigators is presented in terms of the frequency of mention in Appendix C, and the specific statements of "top five fire research projects" that the Center should investigate are contained in Appendix D.

4.2.2 Survey of Other Than ATF CFIs

A survey form patterned after the CFI Survey, but adjusted to the specific aims of the Conference and the range of activities and talents of the experts who attended the Conference, was developed by HAI. Prior to the Conference, each attendee and several individuals who were interested in the Conference but unable to attend (a total of 45 persons) were telephone interviewed by an HAI representative, and the data were entered into a data base. The survey form used is contained in Appendix E. A summary of the subjects felt to need research by these interviewees in terms of frequency mentioned is given in Appendix F. There are also appendices providing the specific statements of the individual interviewees covering answers to a number of subject areas as follows:

Appendix G. Fire Research Needs,

Appendix H. F.I.R.E. Center Facility Needs,

Appendix I. Existing Fire Testing Facility Capabilities,

Appendix J. Non-ATF Top Research Needs,

Appendix K. Training and Educational Needs,

Appendix L. Training Facility Requirements,

Appendix M. Central Repository Needs, and

Appendix N. Other Comments and Suggestions.

4.3 The Process of the Conference

The theme of the Conference was an information exchange and collective brainstorming involving leaders in fire investigation, fire research, large scale laboratory activities, and technology transfer. Both the public and private sectors were represented in each area. (See Appendix A.)

The Conference time was divided between presentations, organized work sessions, and informal (coffee break) sessions. The Conference agenda is contained in Appendix O.

The presentations were divided into two sessions, one session on Wednesday, November 12th and the other on Thursday, November 13th. The Wednesday presentations addressed the needs requirements — fire investigation needs, fire reconstruction needs, education requirements, and fire research needs. Each presentation was given by a prominent authority in the subject matter. The presentations are covered in greater depth in Appendix P. The Thursday presentations consisted of an overview of existing fire research equipment/facilities and a panel discussion by international experts that focused on the capabilities, use, and needs of fire research and testing laboratories throughout the world. The focus of the discussions was how their experience, good and bad, can assist ATF in developing the design of the F.I.R.E. Center. The presentations are covered in greater detail in Appendix Q.

On each day following the presentations, the assembly divided into four separate breakout groups of approximately 15 conferees led by a participant facilitator and supported with a recorder. Each of the recorders was a graduate students from the Fire Protection Engineering Department of the University of Maryland. All four breakout groups were given the same assignment. On Wednesday, the breakout groups addressed the research and related needs of the fire investigation profession. On Thursday, these same groups addressed the facility needs and staffing needs of the F.I.R.E. Center. Appendix R lists the breakout groups assignments.

Each group recorder produced a report of the deliberations from each breakout session. The reports produced from the Wednesday sessions are contained in Appendix S and those from the Thursday session in Appendix T.

On Thursday morning, the facilitators, recorders and other interested participants met and combined the report of the Wednesday breakout groups into a single list. This was then presented to the entire Conference assembly. The assembly divided the resulting list of needs into two categories, those considered essential and those considered desirable. The division was made by vote, any item where there was significant response was judged essential. Some of the items not marked essential were felt essential by one or more conferees. Appendix U is the resulting report. Those needs that the Conference judged essential are marked with an asterisk.

A similar approach was used for the Thursday secessions covering the laboratory needs. Unfortunately, time did not allow consolidation of the results into a single list. The results were, however, reviewed and accepted by the assembled Conference.

All conferees were given the opportunity to submit post Conference comments. To date, such comments have been received from Ms. Jason, Mr. Ide, and Dr. Ettling. Their comments are included as Appendix V.

5.0 CONFERENCE DETERMINATIONS

The Conference addressed its charges and came to the following determinations.

5.1 Current Scientific State of the Art in Fire Investigation

In some areas, such as the detection of trace evidence of ignitable liquids at the ATF National Laboratory and elsewhere, significant progress has been made in the application of science to fire investigation. The ability to discern the presence of accelerants among a conglomeration of residual fire products

is continually improving through the improvement of analytical equipment and advances in interpreting results. The ATF National Laboratory has been a leader in this area.

Also, over recent years, there have been important advances in the general knowledge of fire and the development of methodologies of predicting its growth and spread from a given initiating fire source. While these advances have primarily been applied to elements of building design and the development of building codes and standards, they have to some extent been applied to fire incident analysis. The actual physics of fire is the same whether the desire is to predict the potential of fire in a building for design purposes or to appraise how the harm or damage resulting from a fire was produced and initiated. However, the scientific/engineering information and approach, as well as the need for detail, are often dramatically different. In the design case, the analyst is not normally concerned with how a fire can start, but rather the worst fire that may be inflicted on the facility and how that facility and its occupants may react to the resulting impact. This approach allows simplifying assumptions not appropriate in the case of fire investigation. In the case of fire investigation, the investigator is faced with fire debris and other remains as left by an as yet undefined fire. The investigator is assigned the task of regressing from that scene to an accurate and defendable reconstruction of the fire including the specific ignition source, point or area of origin, and means of occurrence.

Many of the currently practiced methods of fire scene analysis depend on the analysis of the scene for indicators in the remains. In fire investigation parlance, those indicators found on building elements or contents are often referred to as "patterns." Over the years, traditional interpretations of such evidence have been developed from field experience, some testing, and some judgement, much of which has not been either recorded in scientific literature or subjected to sound scientific scrutiny. Recent documents, based on understandings of the science of fire and investigative testing, have challenged commonly held interpretations of pattern and other information. Many of these are presented in the National Fire Protection Association's "Guide for Fire and Explosion Investigation," NFPA Standard 921.

Examples of traditional interpretations now challenged as misconceptions include the interpretation of large of shinny char blisters as indicator of the

presence of flammable liquids, the angle of slope of the soot or scorch pattern on a vertical surface as an indicator of the intensity of the fire, spalling of concrete floor slabs as a definitive indicator of a flammable liquid fire, and the presence of extensive char near the floor level as an indicator of a slow developing fire.

In each case, the challenge is not that there is no meaning to these indicators. Rather, the challenge is that the traditional one-on-one cause-effect interpretation is indefensible. Unfortunately, while the challengers present sound cases for declaring the traditional conclusions improper, the state of the art of fire science applied to fire investigation problems has not yet produced the in depth understanding of what forces of physics generate these specific patterns and other types of fire produced evidence.

This results in a chaos in the fire investigation community where some factions present the traditional interpretations as still valid while others attack them as misconceptions. Meanwhile, the rank and file of dedicated fire investigators plead for a sound, defendable, scientific resolution of the dispute and the production of validated means for fire incident analysis.

While there are fire research organizations around the world that investigate fire phenomena, there are no fire research facilities in the United States or elsewhere dedicated to the needs of fire investigation. Until the F.I.R.E. Center institutes programs directed at the specific needs of fire investigation, advances in scientifically credible information will depend on serendipitous information from research directed at different objectives than fire investigation.

5.2 Needs for Fire Investigation Research and Education

A major thrust of the Conference was to identify the needs of the fire investigation community for scientifically based knowledge that can be satisfied by research and education or other means of technology transfer from the scientific community to the those actually investigating and analyzing real world fires. The Conference, in both the pre-Conference preparation and during the meeting, addressed the needs in terms of the areas of research and education/training as well as archiving data and knowledge.

5.2.1 Research Needs

In the pre-Conference phase, all of the participants and selected ATF Certified Fire Investigators (CFIs) were queried regarding their vision of the fire research topics most needed to provide the required level of scientific foundation for fire investigation. These data were used as background, support, and expansion of the Conference deliberations. Discussion of the inquiry methodology used is discussed in Section 4.2 above.

All of the research needs cited in both the pre-Conference and Conference activities are considered valid and are listed in the appendices. Those research needs considered most pressing and in need of prompt attention are discussed in this section of the report. While the Conference did not establish a formal priority list, the issues are listed by the approximate level of importance derived from the Conference.

a) Fire Incident Reconstruction

Many times, it is necessary to reconstruct all or certain aspects of a fire incident scene and actually burn it under laboratory conditions with environmental control and instrumentation to either determine how the fire ignited and developed to proof test a hypothesis. There is a major need for the Center to undertake such reconstruction both as support to field investigations, and as scientific investigation and testing of scientific theory.

b) Validation of Pattern Analysis; Residues, Marks, and Fire Indicators

The marks and scars left by a fire and the residues and remains of materials, devices, and equipment found on the scene are the essential physical evidence available to the fire investigator in attempting to analyze and understand the initiation and development of a fire. The subject of patterns is not a single issue but covers a wide range of specific types of evidence left by the fire. Some of the important and disputed areas include the following:

(1) Patterns that can be left by the distribution of an accelerant liquid on the floor or other surface are often referred to a "pour pattern." What is the relationship between the cooling of the evaporating liquid and the eventual

marks? Are there other means of producing the same patterns? What is the impact of the form or texture of the surface where liquid burns on the resultant patterns? The actual physics occurring in the burning of an accelerant, including the heat transfer from the liquid to the impacted surface needs to be scientifically understood and explained.

(2) Patterns traced on walls, ceilings and other surfaces result from exposure to the flame and heat generated by the fire. There are many unproven propositions in use today that claim to explain these patterns. Prominent among these is a common conception that a "v" shaped pattern points to the source of a fire. This may or may not be true in a specific incident. As with pour patterns, the actual physics involved needs to be understood and explained. The solution, however, involves additional complexities. The exposing fire conditions are frequently much more complex and involve the configuration of the space, and the flow of flame and hot gases. The impact of ventilation and the impact of flashover, separately discussed below, are also important factors. Understanding wall and ceiling patterns requires understanding the fundamental development of fire in a space. Conversely, the understanding of the type of fire conditions required to produce wall and ceiling patterns will assist in understanding the course of fire development.

(3) Char depths and characteristics are a function of the thermal exposure. Char is a special type of pattern. It has often been interpreted as an indicator of the temperature, duration, or source of a fire. As previously mentioned, it has sometimes been credited with the ability to identify the use of an accelerant. A definitive laboratory scale study of the generation of char with full scale proof testing is needed to provide a truly scientific basis for interpretation of the meaning of char characteristics.

(4) Residual materials are left or deposited by the fire. As fire burns, it changes the state and composition. Products may melt and flow, may be carried in and deposited by the smoke, or may remain in place. The ability to analyze these residuals to identify their source and the extent of heating would greatly assist in analysis of both fire origin and spread.

c) Ignition Studies (Experimental and Theoretical) • What ignition sources can ignite what materials under what conditions? What are the reliability and uncertainties involved in ignition analysis?

All fire investigations need to establish the fire ignition sequence and the parts played by the ignition sources and the initially ignited fuels. In addition, fire spread resulting from subsequent ignition of other previously unignited portions of the initial fuel package need to be understood. The fundamental theory of ignition (for both initial ignition and subsequent spread) involves the transfer of heat from an energy (potential ignition) source to a combustible material in sufficient quantity and duration to heat that material to its ignition temperature. It is primarily a heat transfer and material response issue. In recent years, several small scale tests have been developed that produce data that can be used to model the ignition and fire spread sequences. The small scale tests have been challenged as being too small to properly represent all materials and all of the elements involved in testing. A concentrated research effort in the area of ignition and flame spread as sequential ignition is needed. The investigation community needs a data base of the pertinent properties of potential ignition sources and exposed materials that can be applied in a valid model of ignition and fire spread.

d) Burning Rates for Different Items and Effects of Configuration and Ignition Source on Burning • Development of a Data Base

Many of the currently available analytical models and other computational tools now available for the investigator's use in analyzing fire require that the burning rate and similar data be known and entered in the calculation as a source term. The current data base of tested materials and assembled fuel packages is limited and is usually based on a single type and position of an ignition source. For the field to advance, it is necessary that a broad extensive data base of tested and proven rates of heat release be developed and made available to all persons involved in fire incident analysis. As this data base is developed, it is also important that the theory of fire development and burning rates be advanced to the point where material properties, configuration information, and data on the exposing fire energy can be used to reliably calculate the burning rate of furniture and other materials without specific full scale tests.

e) The Ability of Electrical Sources to Ignite an Exposed Fuel. Evaluation Methods for Physical Evidence of Ignition Sources. Did the Fire Cause the

Arc or Did the Arc Cause the Fire?

The possibility of an electric fire cause is often present and must be considered in constructing a sound and defensible hypothesis of the fire incident. While there is much known about electric system failures in the absence of fire, the fire investigator must frequently depend on non-electrical and less positive indicators of fire propagation to infer the potential of an electrical ignition source. A major need is a field or laboratory analysis method to firmly determine if an obvious arc pattern occurred while the wire and its insulation was cold (i.e., causing the fire exposure) or as a result of external heating from an already developed fire source. There is also a need to better understand the potential for various electrical appliances to be an ignition source.

f) The Phenomena of Flashover and the Impact of Post Flashover Burning on Patterns and Other Fire Indicators

Flashover is a phenomena of serious fires in confined spaces. It is defined in NFPA 921 as a transition phase in the development of a contained fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space. This transition, which often occurs in serious fires, changes the burning condition from a fire feeding on individual fuel sources to a fully involved room where the fire where gases burn in a furnace like mixture above and not directly related to a specific fuel. With flashover, flames normally emit from any openings in the burning compartment and the temperature of the gases and level of radiation rise precipitously. Flashover was first reported in British fire research studies soon after World War II. A full explanation of the specific phenomenological elements in the transition, however, has yet to be made. It is known, however, that the transition to flashover occurs in the range of about 500° C to 600° C (roughly 900° F to 1100° F) and that post flashover the fire gas temperatures in the compartment will often be in the 800° C to 1200° C range (roughly 1500° F to 2100° F) depending on the availability of combustion air and other conditions. These high temperature conditions produce a very strong radiator that can significantly affect fire patterns developed prior to flashover and can create new, potentially deceptive, patterns. Research is needed to better understand flashover, define the patterns it produces, and search for ways to determine facts regarding the

patterns that existed earlier in the fire.

g) The Effects of Ventilation (Natural and Forced) on Fire Development, Fire Growth, and Origin Determination

Ventilation as used here addresses the sources of air for combustion and the general air flow into the fire area. In some large scale laboratory tests, the position and rate of flow of incoming air has resulted in fire patterns on walls that could easily be misinterpreted. In other cases, when fires in test rooms and cells were repeated in actual buildings, the restrictions on air flow to the fire presented by the rest of the building and the closed exterior resulted in limiting or even extinguishing the fire. While the basic fundamentals of the relationship of air to combustion is known, there are extensive unknowns on how air actually reaches the combustion zone. In some fully involved fires, the actual location and form of the mixing of air and fire produced fuel gases is unknown. Until the part played by ventilation is understood and quantified, there will remain significant potential for misinterpretation of the course of fire development and resulting misidentification of fire cause.

h) The Validation of Existing Mathematical Fire Models and the Development of New Models as Needed

In the last decade, mathematical fire models have been increasing used in the analysis of fire incidents. The models are used to test and proof hypotheses and to attempt to deduce ignition sources, the fire growth and spread sequence, and other factors that are considered necessary to the fire analysis, but are not apparent from the fire remains or other known data. The models range from very simple correlations to very complex fluid mechanics and heat transfer computer codes. Some are easy to misuse and produce misleading results. None of the models now in use were specially designed to fill the needs of fire incident analysis, but can be useful in such analysis. The fire investigation field needs to study existing models to identify capabilities and limitations. A companion effort is needed to develop models that directly address the data available to and fire development information needed by fire investigators to mathematically simulate fire incidents.

i) Fire Investigator Occupational Health and Safety

This need, while not actually in the highest group in any of the listings, is included with the priority items because of its potential impact on those whose duty requires them to regularly enter fire scenes. Typically, the fire investigator must enter and physically disturb a site where the exact conditions are unknown and the exposure to hazards materials may or may not be present. In many cases, toxic materials are discovered during the subsequent investigations or the reconstruction of the facility, by which time any exposure to the initial investigators has occurred. There is a need to undertake research that can best inform the investigator of the dangers and the precautions needed without imposing unneeded hindrance to the processing of the on-site portions of the investigation.

j) Other Research Needs

Complete lists of the research needs identified in this study are contained in the appendices to this report. The three lists developed during the Conference and in the pre-Conference surveys list over 80 subjects that one or more participants felt important and worthy of scientific investigation. The eight listed above were those most commonly called for or given a high preference by the conferees. Other research that the conferees indicated as having a high level of need include the following:

(1) Spontaneous ignition and self heating;

(2) Smoldering and the transition from smoldering to flaming combustion;

(3) Improved recovery and identification of flammable liquids;

(4) Fire spread analysis in support of origin determination including the impacts of fully developed (i.e., flashed over) fires and extinguishment;

(5) Glass breakage by fire and how such breakage impacts ventilation and other factors;

(6) Incendiary devices/mechanisms - What can they ignite and what are the signatures of such devices after a fire?

(7) The use of building systems (smoke detectors, security systems, sprinklers, HVAC, etc.) as diagnostic methods for cause, origin and spread;

(8) Human factors • Human behavior ranges of normal response to indications of fire. Also the level of confidence that can be given to human recollection of fire events. The development of improved interviewing techniques;

(9) Failure modes and discovery of evidence of failure in gas, electric, oil, coal, and other appliances;

(10) Impact of time since incident and exposure on evidence;

(11) Methods of smoke movement through buildings and the use of smoke stains and deposits to trace smoke movement and identify source materials; and

(12) Validation of scaling laws and procedures for the use of scale models in fire investigation and analysis.

5.2.2 Training and Education Needs

There is a recognized need to train fire investigators. The CFI programs are run by ATF; the International Association of Arson Investigators (IAAI) and the National Association of Fire Investigators (NAFI) attest to this. The general educational theme in the Conference was that there is an important need to continually upgrade the knowledge of the practicing fire investigators in both the current state of knowledge and in new knowledge as it emerges.

The appendices to this report include the complete listings produced by the Conference and those suggested in the pre-Conference surveys. Specific training and education needs considered high priority by the Conference include the following:

a) Training in the proper reading and meaning of fire patterns, residue, and other indicators;

b) Development of methods and means for training the trainers. Use the facilities and capabilities to become a major source in development of the subject matter being taught in fire investigation training throughout the nation;

c) Training in the proper use, limitations, and application of fire models and other computational procedures to fire investigation problems;

d) Production of scientific publications in a more simplified matter;

e) Provision of scholarships or fellowships to increase ATF investigator knowledge of more complicated theories and concepts;

f) Production of training dissemination methods by which existing information, test methods, data and theory can be brought to the investigators. Include a program of timely technology transfer on properties of materials to the investigator as soon as possible after those properties become known;

g) Development and promulgation of a protocol for data collection at a scene that is needed by the testing/research lab in order to successfully provide testing that can support a case;

h) Providing regular training and a continuing program of competence certification for laboratory personnel/analysts;

i) Training in the development of audio-visual and other demonstrative evidence;

j) Development of training to instruct those conducting tests in the field of methods that can produce credible and reproducible data;

k) Holding of an annual technical meeting for data dissemination and reporting of ongoing projects; and

l) Production of informative publications and newsletters.

5.2.3 Data Repository Needs

The general consensus of the Conference was that a repository (i.e., library) is an essential need. There is a need that the library be complete in its collection of work produced by ATF and as extensive as possible in other work bearing on the science of fire investigation. It was also considered important that the access to the resource be as open as possible to all qualified persons and that it be accessible through remote access points such as on the Internet and CD-ROM releases. A close cooperative relationship with the Fire Research Information Service (FRIS) at the National Institute of Standards and Technology (NIST) to supplement and extend each other was recommended.

The appendices to this report include the complete listings produced by the Conference and those suggested in the pre-Conference surveys. Specific repository needs listed by the Conference include the following:

(1) A searchable data base of the information gathered by the Center on the burning rates of materials and assemblies, the thermophysical properties of materials, ignition temperatures, and other data needed to use scientifically based models and other computational approaches to analyze fire incidents.

(2) Videos, reports, test data, etc. of the research and testing done at the F.I.R.E. Center and make that material available through CD-ROM, Internet, or conventional means.

(3) Means by which information can become available to both restricted and public personnel based on the sensitivity and appropriateness of the material. The maximum possible level of openness was urged.

(4) A library of exemplars that can aid in the determination of the fuels that were consumed in the fire include coverage of information such as

(a) The most common pieces of furniture involved in the ignition and spread of a fire?

(b) The individual components of different pieces of furniture or other

objects that could be identified from a fire scene (nuts, bolts, springs, etc.)?

(5) Information on the performance of different products/systems and the various modes of failure associated with them.

(6) Documentation on the differences between the expected and observed performance of those products or systems.

5.3 Role for the ATF F.I.R.E. Center

The Conference felt that all of the listed needs are appropriate for the F.I.R.E. Center. It is essential that the Center have scientific credibility in all of its work and conduct its tasks in a manner that is unbiased and scientifically competent. In conducting the work of the Center, the Conference recommends that

1. Center serve as a model for state and local agencies as well as being an international model.
2. Partners include all investigators, private and public.
3. Center be knowledge-based and scientifically creditable and neutral.
4. Center be an "open," facility and a center of excellence for fire investigation. The Center should be visitor friendly including exhibits etc. for the general public.
5. Center investigations go beyond cause and origin to include cause of the loss.
6. If possible, the F.I.R.E. Center should fund outside research work (e.g., academia and others). The NIST fire grants program is a model.
7. The Center evaluate existing "knowledge" as is now being disseminated in the fire investigation and analysis. One conferee recommended that the starting point for such evaluation could be the scientific bases for the statements in NFPA Standard 921, "Guide for Fire and Explosion Investigation," *Kirk's Fire Investigation* (Fourth Edition), and the course material of the fire investigation course at the National Fire Academy.
8. The Center provide a focus/center for knowledge dissemination. A research/teaching hospital is a model for the Center: teaching, research, and clinical work.
9. The Center include attorneys in educational goals/knowledge transfer.
10. The Center use fire incident reconstruction as a tool, not only to appraise

individual cases, but also to proof test models and other analytical analysis methods. Fire incident reconstruction should also be used to determine where additional research is needed. Whenever possible the incident should be analytically evaluated prior to the test and the predicted results compared to the test results measured in the incident reconstruction tests. Fire incident reconstruction tests should also be used to validate the effectiveness of small scale tests and the data base of material properties.

5.3.1 Comments on the Strategic Goals

The statement of Strategic Goals proposed by ATF for the F.I.R.E. Center are presented in Section 1.1, above. It is expected that these goals as finally solidified will guide the Center in what it does and how it does it. The following suggestions related to the goals.

a) The references to prosecution and prosecutorial should be changed to a language that expresses a more neutral view.

b) Include in the goals reference to training, education and witness statements.

A possible revised statement of Strategic Goals is as follows:

· *Conduct essential fire related research that validates fire scene indicators, improves fire evidence analysis, and the taking and analysis of witness statements.*

· *Support fire investigations (criminal and civil) and the identification of potential crimes.*

· *Develop better procedures for investigation, analysis, and the rendering of opinions that integrate the assets of ATF and its partners to raise the quality and expertise of fire investigation and analysis.*

· *Provide a repository of fire investigative research data and disseminate the knowledge gathered to improve public safety.*

· *Advance the training and education of those involved in fire investigation.*

5.4 Tests and Facilities Needed at the ATF F.I.R.E. Center

In the discussions, it was determined that the F.I.R.E. Center should provide a wide range of potential tests. These potential tests range from small scale fire tests to very large fire tests. The one overriding factor that was expressed was that the facility must be very flexible in terms of its capabilities since the exact nature of future work is not well defined.

The small scale portion of the facility will require laboratories that will provide for equipment/testing such as the following:

- Cone calorimeter,
- LIFT apparatus,
- Bench-top types of fire tests (limited size and intensity), and
- Chemical analysis, such as wet chemistry, GC, or mass spectrometer.

As with any small scale laboratory, the appropriate types of fume hoods, chemical hoods, water, gas, benches, etc. will be required in the facility. Material/chemical analysis is needed to support the fire testing. It may be more appropriate for the materials analysis laboratory to be located in the main laboratory.

An additional small scale laboratory was suggested for electrical testing. This laboratory will be unique to the evaluation of the potential for electrical items, wiring, etc. to initiate a fire event. This laboratory will require extensive and specialized electrical requirements.

The full scale test laboratories are the most important feature of the facility. In these laboratories, fire tests from the size of a trash can fire to full-room burnout tests will be performed. The primary equipment to be used in these laboratories will be hood/exhaust systems that will allow for the measurement of Heat Release Rates (HRR). The design and size of the hood systems will dictate the capability of the system to make accurate measurements. For example, a very large hood system will have difficulty accurately measuring the HRR of a small fire. Based on the potential uses of the facility, several hood/exhaust systems will be required:

- Very large hood system (10 - 20 MW HRR maximum),
- Intermediate size hood system (~0 - 5 MW HRR), and

- Small size hood system (0 - 500 kW HRR).

This range of hood/exhaust systems will allow for an excellent range of capabilities. Very small fires as well as very large fires can be studied and analyzed. The size of the hood system, along with the attendant fire size that will be performed under the hood, will dictate the size of the test room(s). The very large hood will require a very large area due to the size of the potential fire and its radiant heat effects on surrounding items as well as its requirements for combustion make-up air. The smaller hood systems will require less floor area, but will still require appropriate space for combustion make-up air.

It was also decided that the various sizes of hoods should be separated from each other so that multiple testing or setups can be performed. This requirement will dictate the use of separate test cells for each hood system.

As with any fire test laboratory, significant ancillary spaces will be required:

- Storage areas,
- Materials handling and staging areas,
- Instrumentation room(s),
- Control room area,
- Conditioning room(s),
- Observation room(s),
- Specialized storage such as evidence areas,
- Computer modeling/graphics room, and
- Loading dock area.

Besides the above mentioned ancillary areas, areas for the general conduct of business will also be required. These areas include but are not limited to the following:

- Reception area;
- Offices for use by engineers, administrative personnel, etc.;
- Classroom areas;
- Locker/shower area;
- Break room area; and
- Library area.

It is anticipated that due to the location of the facility, environmental concerns must be addressed. The primary concerns will be the smoke and combustion by-products due to the fires as well as water runoff. The smoke and combustion by-products will have to be processed via an appropriate treatment apparatus such that the range of potential fires can be accommodated. The use of floor drains and impoundment will initially capture waste runoff, and additional treatment and/or removal may be required.

Overall, the facility must be designed such that all of the above listed test and support areas are provided in a manner which will allow for maximum flexibility with regards to testing, timeliness, and good laboratory practices.

The types of test fixtures and equipment that are proposed for this facility will necessitate a broad range of appropriate instrumentation for use in measuring the various fire parameters that are envisioned. Generally, this type of equipment is in use today, such as thermocouples, heat flux meters, load cells, combustion gas analyzers, etc. Depending on the potential testing, some specialized instrumentation may also be required. It will be imperative that all types of instrumentation be keep in a usable and calibrated condition. The measurements from a fire test are only as good as the instruments used to take the measurements. As such, a stringent calibration system must be in place and enforced.

Significant additional equipment will be required for the safe operation of the facility:

- Water supplies for extinguishment of fires (including deluge guns),
- Fire pump and water storage facility for test purposes,
- Outside storage areas, and
- Combustion make-up air systems

The above listed test apparatuses and test facilities are conceptual in nature and are based on the Conference attendees' experience and potential uses for the lab. This listing, while general in nature, provides a basic framework for the design of the lab and its facilities. The next phase of this program will take this conceptual information and provide specific details for the design

and layout of the fire test laboratory.

As discussed, the Conference attendees provided a very wide range of capabilities for the F.I.R.E. Center. The inclusion of these types of facilities will provide a significant capability for not just ATF, but also the fire community as a whole.

5.5 Staffing Needs of the ATF F.I.R.E. Center

5.5.1 Immediate Needs

The Conference urged ATF to quickly bring on-board selected key personnel for staffing the Center. Those considered most important include the following:

(1) Laboratory Director,

(2) Top Scientist,

(3) Top Technician,

(4) Education Specialist (to manage training development),

(5) Information Specialist (to manage repository development), and

(6) One or more experienced ATF CFIs.

It was suggested that an interim F.I.R.E. Center facility be established with sufficient facilities to conduct at least limited fire phenomena investigations and fire incident reconstruction tests.

It is possible that an arrangement could be made with the Building and Fire Research Laboratory at NIST or other established organization for the initial team to be accommodated as visiting scientists. During the interim period between establishment and the dedication of the F.I.R.E. Center facility, this team can be both conducting research and tests and gaining important experience in the specifics of fire tests and the special needs of ATF and the

rest of the fire investigation community. This would also permit establishment of the F.I.R.E. Center and the commencement of beneficial work while the facilities are under construction.

The early staffing and establishment of the Center would also allow the future senior staff of the Center to become part of both the fire research and fire investigation communities. During this interim, in addition to starting on research projects, the staff will be able to spend time in the field with ATF CFIs to better understand their problems, strengths, and needs. There will also be time to meet with other laboratories, attend and possibility present at fire research conferences, and evaluate the techniques and approaches used by others in the fire research fields.

Of great importance will be the ability to better understand the talents that will be needed at the Center and actually hire some critical persons to add to the Center staff during the interim period. This preparation and staff development will help ensure that the Center is a viable operation as soon as the facility is complete.

The benefits of initiating an interim F.I.R.E. Center as early as possible include the following:

- Early recruiting, selecting and hiring will ensure that key personnel are in place when needed;
- The existing need for fire research and ATF case support can be addressed;
- Practical experience gained working ATF cases before the Center is complete can be integrated into the Center's design;
- Key F.I.R.E. Center staff will be able to participate in the design of the facility and the development of operational protocols;
- Staff participation in the fire research and fire investigation communities will enhance the Center's credibility when the facility is operational;
- Programmatic development in testing, research, and education can begin which will help maximize the Center's potential when the facility is operational;
- Test protocols and work flow procedures can be in place when the Center opens; and

- Participation in the broader fire research community will establish ATF’s fire investigation research role.

5.5.2 Full Staffing for the Center

The estimation of staffing needs was developed with major input from the conferees who are active leaders in fire research facilities, education, and library operation. The estimated staff size ranged from a bare bones minimum of about 30 persons to a fully staffed facility of about 60. At the bare bones level, the Center will experience difficulty responding to the needs of the field in terms of designing and conducting tests within the time scale needed to match the development of cases. Any time a scientist is called to be an expert witness will detract from the scientific and testing effort. This will significantly hinder the Center's ability to service the fire investigation community. The more nearly the Center staffing can reach the higher level, the better its mission can be accomplished.

The types of personnel to be considered for fully adequate staffing would include the following:

a) Laboratory Director;

b) Top Scientist;

c) Top Technician;

d) Information and Education Specialist;

e) Administrative support (budget, personnel, purchasing);

f) Clerical and secretarial support;

g) Information Resources (electronic, library);

h) Audio/visual (about 4 persons);

i) Approximately 12 engineers with research potentials (Masters and Ph.D. levels)

in the following disciplines:

- Fire protection,
- Chemical or mechanical (fluid mechanics and heat transfer backgrounds),
- Electrical,
- Materials, and
- Metallurgy;

j) 16 technicians with vocational training;

k) A minimum of two computer scientists;

l) Education/training coordinator;

m) Up to 6 visiting scientists;

n) 6 CFIs from various jurisdictions;

o) Contractors – building maintenance/pollution control custodial; and

p) Safety officer/Loss control specialist.

This was last updated on September 21, 1999