Preface to the Annotated Bibliography on "Burn Pattern" Questions

The Technical/Scientific Working Group for Fire and Explosions (T/SWGFEX) would like to extend its appreciation to the Research Development Testing & Evaluation Interagency Working Group (RDT&E IWG) for allowing it to participate in their research into the use of burn patterns in the investigation of fires. Before we can provide the annotated bibliography for the questions posed to us, T/SWGFEX would like to clarify its position on the use of burn patterns in the examination of a fire scene.

At this time, "Burn Pattern Analysis" is a misnomer. The examination of the burn patterns following a fire is not a forensic examination and "burn pattern analysis" is not a forensic discipline. "Burn pattern analysis" has not risen to the level where it can be used exclusively as the only determinant of a fire investigation. T/SWGFEX supports the position that burn patterns provide the investigator with information as to "Where the fire's destruction did and did not take place constitutes the fire pattern." [1]

Due to the large number of variables and unknowns which have not yet been conclusively established by scientific research, "burn pattern analysis" cannot be considered as rising to the level where it is a recognized forensic discipline. Existing and planned research is seeking to address and collect data on the many variables that affect the production and appearance of burn patterns within a scene. What has been determined so far is that many of the variables are interconnected and slight variations will change the resulting burn patterns.

> "However, many factors can contribute to the deviation of a fire from normal behavior. Prevailing drafts and winds; secondary fires due to collapsing floors and roofs; the physical arrangement of the burning structure; stairways and elevator shafts; holes in the floor, wall, or roof; and the effects of the firefighter in suppressing the fire are all factors that the knowledgeable fire investigator must consider before determining conclusive findings."[2]

Since this was written, many more parameters that affect the production of burn patterns have been identified. Burn patterns provide data to the fire investigator in order to apply the scientific method to their investigation. The authoritative reference used by competent fire investigators is the National Fire Protection Association 921 "Guide for Fire and Explosion Investigations". In section 6.3.1 the reference offers this disclaimer:

> "The circumstances of every fire are different from every other fire because of the differences in the structures, fuel loads, ignition factors, airflow, ventilation, and many other variables. This discussion, therefore, cannot cover every possible variation in fire patterns and how they come about. The basic principles are covered here, and the investigator should apply them to the particular fire incident under investigation."[3]

It is the goal of current research in burn patterns, fire dynamics, and fire modeling to better characterize the patterns that can be expected to develop under specific circumstances. However duplication of all circumstances from the research setting to actual fire scenes is highly unlikely and the investigator will be left with applying the best data they can obtain to test their hypothesis as to a fire's origin. Burn patterns provide only a portion of the data that must be identified and analyzed by the investigator and are not sufficient in and of themselves to conclude the origin or cause of the fire. After all parameters are considered and current understanding of their effects are applied, the investigator may be able to use them to build their hypothesis as to area of origin, the directionality of the fire, the time for fire development, and the heat generated during the fire. There may be other aspects of the fire suggested by the patterns that are not listed here.

At this time the most commonly used "forensic" discipline intimately connected to fire investigations is the analysis of fire debris for the presence and identity of ignitable liquids. It is based on established scientific principles and is not under scrutiny as a result of the National Academy of Science's 2009 report, "Strengthening Forensic Science: A Path Forward."[4]

1. Kirk's Fire Investigation, 7th edition, DeHaan, J. & Icove, D, Pearson Education, 2012, p258
2. Criminalistics, 10th edition, Saferstein, R., Prentice Hall, 2011, p 362
3. NFPA 921 Guide for Fire and Explosion Investigations, 2011 edition, National Fire Protection Association, Technical Committee on Fire investigations, 2011. Section 6.3.1 p 52.
4. "Strengthening Forensic Science: A Path Forward", a report from the National Academy of Science, 2009

Annotated Bibliography from IWG Questions:

Most of the publications and websites listed below each question apply to all of the questions. These publications are accepted references by the majority of fire investigators throughout the United States. It is important to remember that pattern analysis is not a forensic science, although in interpreting fire patterns the fire investigator must rely on forensic science such as fire dynamics.

> NFPA 1033: Standard for Professional Qualifications for Fire Investigator, 2009 Edition NFPA, 2011, 16 pages, Copyright, National Fire Protection Association
>
> The entire Standard provides guidelines for the Fire Investigator in interpretation of the information (including burn patterns) to determine a fire's cause Sections 4.2.4, 4.6.5 and 4.7.1.
>
> NFPA 921: "Guide for Fire & Explosion Investigations" 2008 Edition
>
> Section 17.4 through Section 17.8, that refers to analyzing the data with discussions regarding fire pattern analysis. The entire chapter 1, NFPA 921, Chapter 8 also applies.

Some annotations are provided for groups of references.

1. What literature exists that describes how basic science in the physics and chemistry of fires is translated into the practice of burn pattern analysis for practitioners?

> Kirk's Fire Investigation, 7/e (5/2011), John D. DeHaan. David J. Icove, Brady / Pearson Education, 2012, 800 pages, ISBN: 978-0-13-508263-8, BK6007
>
> Chapters 3 through 7, Pages 32 - 323, provide an understanding of the basic fundamentals of fire behavior, material characteristics, properties, combustion and the processes of heat transfer, heat release rate, fire propagation, and the assessment that must be applied to give the fire investigator an understanding of how they affect fire growth and patterns.
>
> NFPA 921: Guide For Fire And Explosion Investigations 2011 ed. (3/2011), NFPA, 2011, 357 pages, ISBN: 978-1-6166-5714-7, BN2808
>
> Chapters 4 through 6, pages 17 – 63 provide a detailed overview of basic methodology, basic fire science and fire patterns, the fire effects, the pattern itself, and their analysis. It details information and guidelines to assist the fire investigator in evaluating fire patterns accurately.
>
> Forensic Fire Scene Reconstruction, 2nd ed. (6/2008), David J. Icove and John D. DeHaan, 2009, 527 pages, ISBN: 978-0-13-222857-2, BF9691
>
> Pages 1 – 54 describes a systematic approach to reconstructing fire scenes in which investigators rely on the combined principles of fire protection engineering along with forensic and behavioral science. Using this approach the investigator can more accurately

document a structural fire origin, intensity, growth, direction of travel, and duration as well as the behavior of the occupants.

Enclosure Fire Dynamics, Karlsson, B., Quintiere, J., CRC Press, 2000

A comprehensive discussion of scientific factors affecting the development and progression of a fire in an enclosed space.

2. How long a fire has burned seems to have a big effect on the information that can be inferred from a fire scene. What literature exists that shows how burn time affects the ability to determine source and/or origin?

Kirk's Fire Investigation, 7/e (5/2011), John D. DeHaan. David J. Icove, Brady / Pearson Education, 2012, 800 pages, ISBN: 978-0-13-508263-8, BK6007

Pages 279-282, discuss char depth and char appearance, and what variables affect them. It also discusses how heat penetration is not linear with burn time and the variables that affect heat penetration.

NFPA 921: Guide For Fire And Explosion Investigations 2011 ed. (3/2011), NFPA, 2011, 357 pages, ISBN: 978-1-6166-5714-7, BN2808

Chapter 6, section 6.2.4, pages 43 – 44 provides a detailed overview of char and the rate of wood charring and the variables that affect it.

Chapter 5, pages 20 – 42 provides a guideline of fire science principles. The investigator is made aware of all the factors that that have an effect a burn time line such as the properties of the material burning, the geometry of the enclosure, the ventilation, and several other characteristics.

Forensic Fire Scene Reconstruction, 2nd ed. (6/2008), David J. Icove and John D. DeHaan, 2009, 527 pages, ISBN: 978-0-13-222857-2, BF9691

Pages 55 – 99 describes fire dynamics knowledge as it applies to fire scene reconstruction and analysis is based on the combined disciplines of thermodynamics, chemistry, heat transfer, and fluid mechanics. The growth and development of fires are influenced by a number of variables such as available fuel load, ventilation, and physical configuration of the room. To estimate accurately a fire’s origin, intensity, growth, direction of travel, and duration, investigators must rely on and understand the principles of fire dynamics.

3. What is the literature that describes the key investigative issues that must be considered when performing burn pattern analysis and arson investigation at the crime scene?

Kirk's Fire Investigation, 7/e (5/2011), John D. DeHaan. David J. Icove, Brady / Pearson Education, 2012, 800 pages, ISBN: 978-0-13-508263-8, BK6007

Pages 249-323, provide details of how fire patterns are generated, and what variables occur that can change their direction. On page 321, Analysis and Hypothesis testing is discussed. It emphasizes that the investigator continually observes the totality of indicators and uses the scientific method.

NFPA 921: Guide For Fire And Explosion Investigations 2011 ed. (3/2011), NFPA, 2011, 357 pages, ISBN: 978-1-6166-5714-7, BN2808

Chapter 6, section 6.4, page 63, discusses the process of identifying and interpreting fire patterns. It also states reference to the fire dynamics that is discussed in section 5.10 Compartment Fire Development, pages 38 – 43. This section discusses the rate and pattern of a fire development and its dependences the complex relationships between the burning fuel and the surrounding environment.

Chapters 17 & 18, pages 157 – 174 provides methodology and guidelines for determining origin and cause. The investigator is basically instructed to be aware of the totality of information and data involved in performing an analysis of the fire scene.

Forensic Fire Scene Reconstruction, 2nd ed. (6/2008), David J. Icove and John D. DeHaan, 2009, 527 pages, ISBN: 978-0-13-222857-2, BF9691

Pages 101 – 165 describes the underpinnings of how fire patterns are used by investigators in assessing fire damage and determining a fires origin. Fire patterns are often the only remaining visible evidence after a fire is extinguished. The ability to document and interpret fire pattern damage accurately is a skill of paramount importance to investigators when they are reconstructing fire scenes.

4. What is the literature that describes how fire modeling and fire simulation is used in fire investigations?

Kirk's Fire Investigation, 7/e (5/2011), John D. DeHaan. David J. Icove, Brady / Pearson Education, 2012, 800 pages, ISBN: 978-0-13-508263-8, BK6007

Pages 698-707, provide details of each type of fire modeling such as mathematical, zone, field and other specialized applications. Also detailed are issues involved in choosing the right model for the job and how to evaluate, validate and verify the results. It discusses the critical analysis of a case to ensure the appropriate application of computer modeling can best be approached.

Forensic Fire Scene Reconstruction, 2nd ed. (6/2008), David J. Icove and John D. DeHaan, 2009, 527 pages, ISBN: 978-0-13-222857-2, BF9691

Pages 272-304, provides an overview of all types of fire models and describes what each model can provide for each type of testing. It also describes what the realistic and reliable results are of a fire model. Several fire modeling case studies are provided to the reader to provide examples of their use and how they were applied.

NFPA 921: Guide For Fire And Explosion Investigations 2011 ed. (3/2011), NFPA, 2011, 357 pages, ISBN: 978-1-6166-5714-7, BN2808

Pages 176 – 184, provide guidance on Failure Analysis and Analytical Tools. This section covers many items including developing time lines, system analysis, mathematical modeling, zone & field models, and fire testing guidelines. Also included are guidelines for test methods, limitations, type of required data on materials.

"The Dalmarnock Fire Tests: Experiments and Modelling", (Editors) G. Rein, C. Abecassis Empis & R.Carvel, University of Edinburgh, November 2007. ISBN 978-0-9557497-0-4., G. Rein, J.L. Torero, W. Jahn, et al., Round-Robin Study of a priori Modeling Predictions of The Dalmarnock Fire Test One, Fire Safety Journal 44 (4), pp. 590-602.

The Dalmarnock tests comprise a set of fire experiments conducted in a real high-rise building in July 2006. The two main tests took place in identical flats, Test One allowing the fire to develop freely to post-flashover conditions while Test Two incorporated sensor-informed ventilation management. The test compartments were furnished with regular living room/office items and fully instrumented with high sensor densities. The furniture and objects acting as fuel were arranged to provide conditions that favor repeatability. A full description of the set up of the tests, including fire monitoring sensors, is provided. Focus is on the larger Test One fire for which the major events are reported together with a thorough characterization of the fire using sensor information. The main aim of the experiments was to collect a comprehensive set of data from a realistic fire scenario that had a resolution compatible with the output of field models. The characterization of Test One provides a platform with potential for analytical and computational fire model validation.

"Comparison of FPETool:FIRE SIMULATOR With Data From Full Scale Experiments". (1586 K), Vettori, R. L.; Madrzykowski, D. NISTIR 6470; 73 p. February 2000.

A comparison of the compartment zone fire model FPETool:FIRE SIMULATOR is made with data from three different full scale experimental compartment fire studies. These three studies represent a variation of room geometry, ventilation factors, thermal physical properties, fuels, fire geometry and fire growth. Depending on the experimental data presented, comparisons were made for the following parameters, ceiling jet velocity, ceiling jet temperature, upper layer depth, detector link temperature, time to sprinkler activation, and heat release rate at time of sprinkler activation. Results for predicted sprinkler activation times ranged from 74% to 159% of measured times depending on the RTI chosen for the sprinkler, characteristics of the fire, and fire growth rate. All predicted ceiling jet velocities differed by approximately a factor of two from measured values. Generally, upper layer depth predictions were good only for situations where there was not a large vent from the room. For the full scale experiment conducted in a large room with a high ceiling, predicted link and ceiling jet temperatures had better agreement with measured values if consideration was given to the time required for the transport of the products of combustion from the fire to the link. For experiments which had varying fire growth rates predictions for upper layer temperature increase were better for experiments with the slower fire growth rates.

“Cook County Administration Building Fire, 69 West Washington, Chicago, Illinois, October 17, 2003: Heat Release Rate Experiments and FDS Simulations”. (8551 K) Madrzykowski, D.; Walton, W. D. NIST SP 1021; NIST Special Publication 1021; 489 p. July 2004.

On October 17, 2003, in the Cook County Administration Building, 69 West Washington, Chicago, Illinois, a fire resulted in six fatalities and several injuries. In response to a request from the Governor of Illinois, the National Institute of Standards and Technology (NIST) agreed to provide technical assistance to the Governor's review team headed by James Lee Witt. NIST's focus was the simulation of the fire using the Fire Dynamic Simulator (FDS) and visualizations using Smokeview to provide insight into the fire growth and smoke movement. A team from NIST visited the fire scene to collect data for the model including; building dimensions, floor plan, door and window locations, materials of construction and furnishing, and fuels. In addition, information collected by the Governor's team on fire service operations and building systems was used to develop the fire timeline. The NIST team also documented the fire damage in order to compare fire model predictions with the observed physical damage. Exemplar interior finish materials and furnishings from the fire floor, but undamaged by flames, were obtained for use in laboratory scale heat release rate experiments. Laboratory scale data for rate of heat release was necessary for the fire model input and comparison to fire model results. This report documents the furnishings, the experiments conducted, and the results of those experiments. This report also explains the development of a computational simulation and the result of those simulations. The NIST simulation started with a small, flaming fire in the storage room and ended with the start of fire suppression activities by the fire department, 16 min 30 s later. The FDS simulations provide insight into the fire development in Suite 1240. The simulations examine the impact of the spread of smoke into the southeast stairway with and without a functioning smoke exhaust shaft. Another simulation examined the impact of automatic fire suppression sprinklers. The FDS simulation suggested that had automatic sprinklers been present in the storage room where the fire is believed to have originated, they would have controlled the fire and limited the fire spread to the room of fire origin.

“Fire Research: Providing New Tools for Fire Investigation. Fire and Arson Investigator”, Vol. 52, No. 4, 43-46, July 2002. Madrzykowski, D.

“Fire Spread Through a Room With Polyurethane Foam Covered Walls. Volume 2”; Interflam 2004. (Interflam '04). International Interflam Conference, 10th Proceedings. Volume 2. July 5-7, 2004. Organized by Interscience Communications Ltd. in association with National Institute of Standards and Technology, Building Research Establishment; National Fire Protection Association; Society of Fire Protection Engineers; and Swedish National Testing and Research Institute, Edinburgh, Scotland, Interscience Communications Ltd., London, England, 1127-1138 pp, 2004. Madrzykowski, D.; Bryner, N. P.; Grosshandler, W. L.; Stroup, D. W.

Flammable and Combustible Liquid Spill/Burn Patterns. NIJ Report 604-00; NCJ 186634; 71 p. March 2001. Putorti, A. D., Jr.; McElroy, J. A.; Madrzykowski, D.

“Future of Fire Investigation”. Fire Chief, Vol. 44, No. 10, 44-45,48-50, October 2000. Madrzykowski, D.

“Modeling Smoke Flow in Corridors. National Institute of Standards and Technology (NIST) and Society of Fire Protection Engineers (SFPE)”. International Conference on Fire Research and Engineering (ICFRE). Proceedings. September 10-15, 1995, Orlando, FL, SFPE, Boston, MA, Lund, D. P.; Angell, E. A., Editor(s)(s), 377-382 pp, 1995. Stroup, D. W.; Madrzykowski, D.

“NIST Station Nightclub Fire Investigation: Physical Simulation of the Fire”. Fire Protection Engineering, No. 31, 34-36,38,40,42,44,46, Summer 2006. Madrzykowski, D.; Bryner, N. P.; Kerber, S.

“Reconstructing the Station Nightclub Fire: Computer Modeling of the Fire Growth and Spread. Volume 2”; Interflam 2007. (Interflam '07). International Interflam Conference, 11th Proceedings. Volume 2. September 3-5, 2007, London, England, 1181-1192 pp, 2007. Bryner, N. P.; Madrzykowski, D.; Grosshandler, W. L.

“Reconstructing the Station Nightclub Fire: Materials Testing and Small-Scale Experiments. Volume 2”; Interflam 2007. (Interflam '07). International Interflam Conference, 11th Proceedings. Volume 2. September 3-5, 2007, London, England, 1549-1554 pp, 2007. Bryner, N. P.; Madrzykowski, D.; Grosshandler, W. L.

“Report of the Technical Investigation of The Station Nightclub Fire: Appendices. Volume 2”. NIST NCSTAR 2: Volume 2; 414 p. June 2005., Grosshandler, W. L.; Bryner, N. P.; Madrzykowski, D.; Kuntz, K.

“Report of the Technical Investigation of The Station Nightclub Fire. Volume 1”. NIST NCSTAR 2: Volume 1; 246 p. June 2005., Grosshandler, W. L.; Bryner, N. P.; Madrzykowski, D.; Kuntz, K.

“SFPE Engineering Task Group on Computer Model Evaluations: Status Report – DETACT”., Fire Research and Engineering, Second (2nd) International Conference. (ICFRE2). Proceedings. ABSTRACTS ONLY. National Institute of Standards and Technology and Society of Fire Protection Engineers. August 10-15, 1997, Gaithersburg, MD, Slaughter, K. C., Editor(s), 106-106 pp, 1997., Madrzykowski, D.

“Simulation of the Dynamics of a Fire in a One-Story Restaurant, Texas, February 14, 2000”., NISTIR 6923; 27 p. October 2002., Vettori, R. L.; Madrzykowski, D.; Walton, W. D.

“Simulation of the Dynamics of a Fire in a Two-Story Duplex, Iowa, December 22, 1999”.
NISTIR 6854; 28 p. January 2002., Madrzykowski, D.; Forney, G. P.; Walton, W. D.

“Simulation of the Dynamics of the Fire at 3146 Cherry Road NE, Washington, DC, May 30”, 1999. NISTIR 6510; April 2000. Madrzykowski, D.; Vettori, R. L.

“State-of-the-Art Research Is the Future of Fire Investigation”. SIU Awareness, Vol. 15, No. 1, 18-23, March 2001. Madrzykowski, D.

“Understanding Fire and Smoke Flow Through Modeling and Visualization”. IEEE Computer Graphics and Applications, Vol. 23, No. 4, 6-13, July/August 2003. Forney, G. P.; Madrzykowski, D.; McGrattan, K. B.; Sheppard, L.

“Modeling on Temperature and Ventilation Induced by a Model Fire in a Tall and Narrow Atrium Space”. NISTIR 6030; June 1997.U.S./Japan Government Cooperative Program on Natural Resources (UJNR). Fire Research and Safety. 13th Joint Panel Meeting. Volume 2. March 13-20, 1996, Gaithersburg, MD, Beall, K. A., Editor(s), 31-39 pp, 1997. Satoh, H.; Sugawa, O.; Kurioka, H.

“Behavior of Charring Materials in Simulated Fire Environments”. Final Project Report. 1990-1992., Suuberg, E. M.; Milosavljevic, I.; Lilly, W. D., NIST GCR 94-645; 651 p. June 1994.

The focus of this study was the behavior of thick charring solids in fire situations. Clearly one of the most important parameters governing the fire phenomenon is the rate of release of combustible volatiles into the gas phase, in which they actually burn. Over the years, fire researchers have learned how to model the processes in the gas phase, so that the rate of heat feedback to the solid surface can be reasonably well predicted. Likewise, there exists the ability to model the heat transfer processes at the solid surface and within the solid itself. Finally, there is a large literature on the laboratory-scale pyrolysis of various charring polymers. It might appear that predicting the course of the fire would involve carefully coupling these different models together. There have unfortunately not been any successful demonstrations of the ability to do this, though in broad stroke, some models capture the key features of the processes. This study was concerned with the possibility that the inability to come to complete closure on the charring polymer fire problem might derive from difficulties in applying laboratory scale kinetics to actual fire conditions. Specifically, we were concerned about how well small scale laboratory experiments used to derive the kinetics of pyrolysis could be used to predict the behavior of charring solids in fire situations

“Burning Rate Model for Charring Materials.” Anderson, G. W. NIST GCR 97-725; 93 p. August 1997.

A one dimensional model has been developed to describe the processes involved in the transient pyrolysis of a semi-infinite charring material subjected to a constant radiant heat flux. Material properties are assumed constant with respect to temperature and time. The model tracks the char layer growth, thermal penetration depth, surface temperature and mass loss rate. A review of the physical phenomena involved in charring pyrolysis is presented and the relevant phenomena included in the model. the integral method is described, and an example for constant surface heat flux is solved. The derivation of the model divides the material into three regions: char layer, vaporization plane, and virgin material and the equations of conservation of mass and energy are applied to each region using the integral approximation with polynomial temperature profiles. The resulting coupled, nonlinear, autonomous system of three different equations and one algebraic equation is suitably nondimensionalized and solved using Mathematics (tm) software. The results generated by the model are compared to existing models and, a method by which effective properties for use in the model might be deduced from experimental data is suggested.

"Effect of Sample Size on the Heat Release Rate of Charring Materials." Ritchie, S. J.; Steckler, K. D.; Hamins, A.; Cleary, T. G.; Yang, J. C.; Kashiwagi, T. International Association for Fire Safety Science. Fire Safety Science. Proceedings. Fifth (5th) International Symposium. March 3-7, 1997, Melbourne, Australia, Intl. Assoc. for Fire Safety Science, Boston, MA, Hasemi, Y., Editor(s), 177-188 pp, 1997 .

The burning of a horizontal wood slab situated atop an insulating substrate was modeled using three coupled submodels for the gas-phase, wood, and substrate processes. A global analytical model was used to determine the radiative and convective heat feedback from the gas-phase combustion to the wood surface. The char-forming wood model was a one-dimensional numerical computation of the density change as a function of position and time. The backside boundary condition of the wood was treated as conductive heat loss into a substrate material modeled by the heat conduction equation. The condensed-phase model results were tested by exposing Douglas Fir samples to an external flux in a nitrogen environment (no combustion). Heat release rate calculations are compared to experimental results for Douglas Fir samples of 0.1 m and 0.6 m diameter. Both theory and experiments show that, for the conditions studied, the heat release rate is nearly independent of the specimen diameter except for the initial peak and the affect of this peak on the first portion of the quasi-steady settling period. Model predictions also indicate that the second peak, which follows the settling period, is very sensitive to the thickness of the insulating substrate.

"CFAST: Consolidated Model of Fire Growth and Smoke Transport (Version 6)". Technical Reference Guide. NIST SP 1026; NIST Special Publication 1026; Version 6; 117 p. April 2009 (Revision)., Jones, W. W.; Peacock, R. D.; Forney, G. P.; Reneke, P. A.

CFAST is a two-zone fire model used to calculate the evolving distribution of smoke, fire gases and temperature throughout compartments of a constructed facility during a fire. In CFAST, each compartment is divided into two gas layers. The modeling equations used in CFAST take the mathematical form of an initial value problem for a system of ordinary differential equations (ODEs). These equations are derived using the conservation of mass, the conservation of energy (equivalently the first law of thermodynamics), the ideal gas law and relations for density and internal energy. These equations predict as functions of time quantities such as pressure, layer height and temperatures given the accumulation of mass and enthalpy in the two layers. The CFAST model then consists of a set of ODEs to compute the environment in each compartment and a collection of algorithms to compute the mass and enthalpy source terms required by the ODEs. In general, this document provides the technical documentation for CFAST along with significant information on validation of the model. It follows the ASTM E1355 guide for model assessment. The guide provides several areas of evaluation: (*) Model and scenarios definition, (*) Theoretical basis for the model, (*) Mathematical and numerical robustness, (*) Model sensitivity and (*) Model Evaluation.

"Comparison of CFAST Predictions to USCG Real-Scale Fire Tests." NISTIR 6446; 16 p. January 2000.Journal of Fire Protection Engineering, Vol. 11, No. 1, 43-68, February 2001. Reneke, P. A.; Peatross, M. J.; Jones, W. W.; Beyler, C. L.; Richards, R.

The zone model CFAST was used to make predictions of single room pre-flashover tire tests conducted in a steel enclosure. These results were then compared with previously published measurements obtained in fire tests. Tests included diesel pool fires, polyurethane slab fires, and wood crib fires. Half of these tests used natural ventilation (window, 1/4 door, and full door) while the remaining tests used forced ventilation (0.25 m3/s, 0.38 m3/s, and 0.61 m3/s). With the exception of heat release rates, all CFAST inputs were selected without knowledge of the experimental results. Key variables compared include the upper layer temperature, the hot layer interface location, and ceiling temperatures. Overall, predictions made by CFAST were in good agreement with the data. There was a general tendency to over predict both the hot gas layer temperature and the boundary surface temperature which may be due to under prediction of boundary heat losses. Experimental results showed that heat release rates varied with ventilation configurations by as much as a factor of 3. This observation indicates that the wide practice of using free bum heat release rate data in compartment fire predictions can result in over prediction of compartment fire conditions.

"Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications". Volume 5. Consolidated Fire Growth and Smoke Transport Model (CFAST). (4779 K) Peacock, R. D.; Reneke, P. A. NUREG-1824; EPRI 1011999; Volume 5; 206 p. May 2007.

As the use of fire modeling tools increases in support of day-to-day nuclear power plant (NPP) applications including fire risk studies, the importance of verification and validation (V&V) studies for these tools also increases. V&V studies provide the fire modeling analysts increased confidence in applying analytical tools by quantifying and discussing the performance of the given model in predicting the fire conditions measured in a particular experiment. The underlying assumptions, capabilities, and limitations of the model are discussed and evaluated as part of the V&V study. The main objective of this volume is to document a V&V study for the Consolidated Fire Growth and Smoke Transport (CFAST) zone model. As such, this report describes the equations that constitute the model, the physical bases for those equations, and an evaluation of the sensitivity and predictive capability of the model. CFAST is a two-zone fire model capable of predicting the fire-induced environmental conditions as a function of time for single- or multi-compartment scenarios. Toward that end, the CFAST software calculates the temperature and evolving distribution of smoke and fire gases throughout a building during a user-prescribed fire. The model was developed, and is maintained, by the Fire Research Division of the National Institute of Standards and Technology (NIST), which officially released the latest version of the CFAST model in 2004.

"Adiabatic Surface Temperature for Calculating Heat Transfer to Fire Exposed Structures", Wickstrom, U.; Duthinh, D.; McGrattan, K. B. Volume 2; Interflam 2007. (Interflam '07). International Interflam Conference, 11th Proceedings. Volume 2. September 3-5, 2007, London, England, 943-953 pp, 2007.

A basic and common understanding of heat transfer to solids is very important for the advancement of fire safety engineering in areas such as the prediction of the temperature and load bearing capacity of structural components as well as the burning behaviour of real materials. However, because researchers and test standard developers have different ways of expressing and measuring the various forms of convective and radiative heat flux, confusion often arises. This paper is intended to address this issue. The new concept of adiabatic surface temperature is introduced as a practical means to express the thermal exposure of a surface. The concept is particularly useful when calculating temperatures in fire exposed structures, as is shown in this paper. It can be used successfully when the exposure conditions are obtained either from a fire model or directly from measurements. In the latter case, the so called plate thermometer (PT), defined in the fire resistance standards ISO 834 or EN 1363-1, may be employed. This implies that the temperature of structural components tested according to these standards may be predicted using the plate thermometer measurements which are inherently designed to follow specified time-temperature curves.

"Application of CFD Modeling to Room Fire Growth on Walls", Liang, K. M.; Ma, T.; Quintiere, J. G.; Rouson, D. NIST GCR 03-849; 86 p. April 2003.

An evaluation of the NIST FDS model was conducted with particular attention for its use in predicting flame spread on surfaces. Over the course of this investigation the computational model changed from combustion depicted by particles to a mixture fraction based combustion model. The study pertains to version 2.0 released on December 4, 2001. Three aspects were considered in the study. First, we studied the evaluation of the code to predict a combusting plume. Second, the code was applied to a fire plume adjacent to a vertical wall, and then flame spread on the wall. Third, a complementary investigation of an improved algorithm for convective heat transfer at a surface was developed. The first two studies resulted in M.S. theses. Damian Rouson of CCNY performed the third study. The thesis by Ma on the axi-symmetric plume was previously transmitted and will not be included here. However, a recently accepted paper, based on the thesis with updated results is included. The general conclusions are that the FDS code is very good for computing the fluid dynamics, entrainment and flame height. The temperature in the combustion region appears to be over-estimated at the base of the geometry considered, and any related heat flux is consequently over-predicted. The temperature results are grid dependent. A computation of flame spread on vertical PMMA gave mixed results. The code was benchmarked against fire plume correlations after a review of the literature to obtain the most general results. Most of the experimental correlations have some deficiencies, and should be improved. Particular attention needs to be given to temperature measurements in the flame since these are generally under-estimated due to radiation error. The wall heat flux and flame spread comparisons were made against data we viewed as quality data. The algorithm developed by Rouson is based on the theoretical formulation by Howard Baum, and has not been tested in the FDS code.

"Assessment of Correlations Between Laboratory and Full-Scale Experiments for the FAA Aircraft Fire Safety Program. Part 4. Flammability Test", Quintiere, J. G. NBSIR 82-2525; DOT/FAA/CT-82/101; 21 p. July 1982.

A review is made of studies in which full-scale fire growth was compared with laboratory test data on materials. Both room and corridor fires are included in which primarily interior lining materials have been the combustible element. The studies include standard test methods and other laboratory devices used in the United States and other countries. An effort was made to intercompare experimental results in a common basis. For example, maximum room temperature data are compared with ASTM E-84 flame spread classifications for several full-scale test which involved nearly the same room geometries and same fuel arrangements.

"Basis for Using Fire Modeling With 1-D Thermal Analyses of Barriers/Partitions to Simulate 2-D and 3-D Barrier/Partition Structural Performance in Real Fires", Cooper, L. Y.; Franssen, J. M. NISTIR 6170; 22 p. September 1998. Fire Safety Journal, Vol. 33, No. 2, 115-128, September 1999.

Computer fire models for simulating compartment fire environments typically require a mathematical formulation that couples the thermal response of the gases that fill the compartment and the thermal response of compartment barriers and partitions. The fire environment characteristics calculated by such models can be used to provide input, via thermal boundary conditions, to an uncoupled thermal-structural computer model for simulating and evaluating the combined thermal/structural performance of the barriers/partitions. The objective of such a combined analysis would be to determine, through analysis, the structural fire resistance of a barrier/partition design.

"Burning Behavior in a Poorly-Ventilated Compartment Fire--Ghosting Fire", Sugawa, O.; Kawagoe, K.; Oka, Y. NISTIR 4449; U.S./Japan Government Cooperative Program on Natural Resources (UJNR). Fire Research and Safety. 11th Joint Panel Meeting. October 19-24, 1989, Berkeley, CA, Jason, N. H.; Cramer, D. M., Editor(s)(s), 163-172 pp, 1990.

“Calculating Flows Through Vertical Vents in Zone Fire Models Under Conditions of Arbitrary Cross-Vent Pressure Difference”, Cooper, L. Y. NBSIR 88-3732; 16 p. May 1988.

In typical compartment fire scenarios, ratios of cross-vent absolute pressures are close to 1. When such is the case, algorithms are available to predict the resulting cross-vent room-to-room flows. There are, however, important situations where this pressure condition does not prevail, for example, in fire scenarios involving relatively small penetrations in otherwise hermetically-sealed compartments of fire origin. It is important for a versatile compartment fire model have a capability of predicting vent flows for the entire range of possible cross-vent pressure conditions. This paper develops a unified analytic description for flows through vertical vents between pairs of two-layer room fire environments under conditions of arbitrary cross-vent pressure difference. The analysis, which takes advantage of generally useful modeling approximations, leads to a concise result which is not significantly more complicated than the result for simple, low-pressure-difference cases.

“Carbon Monoxide Levels in Structure Fires: Effects of Wood in the Upper Layer of a Post-Flashover Compartment Fire”, Lattimer, B. Y.; Vandsburger, U.; Roby, R. J. Fire Technology, Vol. 34, No. 4, 325-355, November 1998.

This experimental study was performed to determine the effects of wood pyrolyzing in a high-temperature, vitiated compartment upper layer on the environment inside the compartment and an adjacent hallway. This was done by comparing species concentrations and temperature measurements from tests with and without wood in the compartment upper layer. Experiments were performed with a window-type opening and a door-type opening between the compartment and the hallway. In these tests, the wood in the compartment upper layer caused CO concentrations inside the compartment to increase, on average, to 10.1% dry, which is approximately 3 times higher than levels measured without wood in the upper layer. Down the hallway 3.6 m from the compartment with wood in the upper layer, CO concentrations were measured to be as high as 2.5% dry. The use of the global equivalence ratio concept to predict species formation in a compartment was explored for situations where wood or other fuels pyrolyze in a vitiated upper layer at a high temperature.

“Carbon Monoxide Production in Compartment Fires: Full-Scale Enclosure Burns”, NISTIR 5499; September 1994.National Institute of Standards and Technology. Annual Conference on Fire Research: Book of Abstracts. October 17-20, 1994, Gaithersburg, MD, 53-54 pp, 1994.Bryner, N. P.; Johnsson, E. L.; Pitts, W. M.

Recent studies attribute a large percentage of fire injuries and deaths to the generation of carbon monoxide (CO) and indicate that in roughly two-thirds of the fire deaths the fire victims have fatal or incapacitating levels of carboxyhemoglobin in their blood. A series of natural-gas fires within reduced- and full-scale rooms have been designed to improve the understanding of and to develop a predictive capability for CO formation in compartment fires. The findings will be used in realistic fire models and in the development of strategies for reducing the number of deaths attributed to carbon monoxide.

“Characteristics of Fire Scenarios in Which Sublethal Effects of Smoke Are Important”, Peacock, R. D.; Averill, J. D.; Reneke, P. A.; Jones, W. W. Fire Technology, Vol. 40, No. 2, 127-147, April 2004.

A number of simulations were performed using the CFAST zone fire model to predict the relative times at which smoke inhalation and heat exposure would result in incapacitation. Fires in three building types were modeled: a ranch house, a hotel, and an office building. Gas species yields and rates of heat release for these design fires were derived from a review of real-scale fire test data. The incapacitation equations were taken from draft 14 of ISO document 13571. Sublethal effects of smoke were deemed important when incapacitation from smoke inhalation occurred before harm from thermal effects occurred. Real-scale HCl yield data were incorporated as available; the modeling indicated that the yield would need to be 5 to 10 times higher for incapacitation from HCl to precede incapacitation from narcotic gases, including CO COd2, HCN and reduce O2. The results suggest that occupancies in which sublethal effects from open fires could affect escape and survival include multi-room residences, medical facilities, schools, and correctional facilities. In addition, fires originating in concealed spaces in any occupancy pose such a threat. Sublethal effects of smoke are not likely to be of prime concern for open fires in single- or two-compartment occupancies (e.g., small apartments and transportation vehicles) themselves, although sublethal effects may be important in adjacent spaces; buildings with high ceilings and large rooms (e.g., warehouses, mercantile); and occupancies in which fires will be detected promptly and from which escape or rescue will occur within a few minutes

“Comparison Between Observed and Simulated Flame Structures in Poorly Ventilated Compartment Fires”, Hu, Z.; Utiskul, Y.; Quintiere, J. G.; Trouve, A. Fire Safety Science. Proceedings. Eighth (8th) International Symposium. International Association for Fire Safety Science (IAFSS). September 18-23, 2005, Beijing, China, Intl. Assoc. for Fire Safety Science, Boston, MA, Gottuk, D. T.; Lattimer, B. Y., Editor(s), 1193-1204 p., 2005.

This study is aimed at characterizing the dynamics of compartment fires under poorly ventilated conditions. The study considers four cases that correspond to different values of the fire room global equivalence ratio and are representative of strikingly different flame behaviors. The study is based on a detailed comparison between experimental and computational data. The numerical simulations are performed with the Fire Dynamics Simulator (FDS) developed by the National Institute of Standards and Technology, USA. The comparative tests serve to evaluate the general ability of FDS to describe the transition from over- to under-ventilated fire conditions, as well as the transition from extinction-free conditions to conditions in which the flame experiences partial or total quenching.

"Comparison of CFAST and FDS for Fire Simulation With the HDR T51 and T52 Tests", Floyd, J. E. NISTIR 6866; 111 p. March 2002.

This work uses three methods: hand calculations, a zone model (CFAST), and a computational fluid dynamics code (FDS), to examine two fire tests from the HDR facility, a decommissioned reactor containment building in Germany. The two tests, T51.23 and T52.14, used different fuels, propane gas and a hydrocarbon solvent, and occurred in two quite differeny locations, low in the containment and just below the containment operating deck, respectively.

"Experiments and Modeling of Multiple Workstations Burning in a Compartment. Federal Building and Fire Safety Investigation of the World Trade Center Disaster". NIST NCSTAR 1-5B; 352 p. September 2005. Hamins, A.; Maranghides, A.; McGrattan, K. B.; Johnsson, E. L.; Ohlemiller, T. J.; Donnelly, M. K.; Yang, J. C.; Mulholland, G. W.; Prasad, K. R.; Kukuck, S. R.; Anleitner, R. L.; McAllister, T. P. NIST NCSTAR 1-5B; 352 p. September 2005.

Reconstructing the fires and their impact on structural components in the World Trade Center (WTC) buildings on September 11, 2001, requires extensive use of computational models. For the use of such models to be a viable investigative tool, it is essential to know the accuracy with which they capture the physical phenomena of the fires and the concurrent heat transfer to the building structure. This report documents a series of large-scale experiments that was conducted in the National Institute of Standards and Technology (NIST) Large Fire Laboratory from March 10 to March 26, 2003. The experiments represent one phase of an effort to ascertain the validity of the models for the NIST WTC Investigation. The objective of the experiments was to assess the accuracy with which (1) the NIST Fire Dynamics Simulator (FDS) fire model predicts the thermal environment in a burning compartment and (2) the NIST Fire Structure Interface (FSI) model in combination with the ANSYS finite-element model predicts the temperature rise of structural steel components in a burning compartment. The experiments also had the potential to improve input parameters in the modeling, if appropriate, and, in general, help to increase understanding of the sequence of events that occurred in the WTC tower fires. Within a steel-frame compartment (3 m by 7 m by 4 m) lined with calcium silicate board were placed four steel components: two trusses, one thin-walled column, and a rod. The components either were uninsulated or had fibrous sprayed fire-resistive material (SFRM) applied; two thicknesses were tested. The 2 MW and 3 MW fires were generated using liquid hydrocarbon fuels introduced by a two-nozzle spray burner onto a by 2 m pan. The fuels were a commercial blend of heptane isomers and a mixture of the heptane blend with toluene. Six experiments were conducted.

"Measurements of Heat and Combustion Products in Reduced-Scale Ventilation-Limited Compartment Fires", Bundy, M.; Hamins, A.; Johnsson, E. L.; Kim, S. C.; Ko, G. W.; Lenhert, D. B. NIST Technical Note 1483; NIST TN 1483; 154 p. July 2007

A series of new reduced-scale compartment fire experiments were conducted, which included local measurements of temperature and species composition. The measurements are unique to the compartment fire literature. By design, the experiments provided a comprehensive and quantitative assessment of major and minor carbonaceous gaseous species and soot at two locations in the upper layer of fire in a 2/5 scale International Organization for Standards (ISO) 9705 room. The enclosure defined in the international standard ISO 9705 "Full-scale room test for surface products" is an important structure in which to conduct fire research. Many dozens of research projects and journal articles have focused on this enclosure and the standard describing its use. It is a common reference point for studies of many fire-related phenomena as well as fire modeling efforts. While some previous studies have considered the mixture fraction to analyze experimental compartment fire data, few have considered minor hydrocarbon species and none have considered soot. In tandem, accurate measurements of temperature at these same locations allowed analysis of thermal effects on species concentrations. A wide range of fuel types were considered, including aliphatic hydrocarbons (natural gas and heptane), aromatic hydrocarbons (toluene and polystyrene) and alcohols (methanol and ethanol). Field models, such as the National Institute of Standards and Technology (NIST) Fire Dynamics Simulator (FDS), are widely used by fire protection engineers to predict fire growth and smoke transport for practical engineering applications. Field models numerically solve the conservation equations of mass, momentum and energy that govern low-speed, thermally-driven flows with an emphasis on smoke and heat transport from fires. All field models have strengths and weaknesses. Among the various assumptions used in the development of previous versions of FDS, all chemical species were tied to the mixture fraction state relations. A single mixture fraction variable cannot be used for the prediction of carbon monoxide and soot, and the yield of these species was prescribed in FDS 4, rather than predicted. In fact, the yield of these species is usually not constant, but a complex function of their time-temperature history. In practice, an engineer using FDS 4 would choose combustion product yields directly from literature values for well-ventilated burning, using data from a bench-scale apparatus. Using this approach, the carbon monoxide (CO) volume fraction for pool fire burning in an under-ventilated compartment can be underestimated by as much as a factor of ten. A new version of FDS (version 5) is currently being tested which implements a predictive model of CO production. The experimental results provided in this report are the first step of a long-term NIST project to generate the data necessary to test our understanding of fire phenomena in enclosures and to guide the development and validation of field models by providing high quality experimental data. The experimental plan was designed in cooperation with developers of the NIST FDS model to assure that the measurements would be of maximum value. Advanced development of FDS and other field models is extremely important, since it will lead to improved accuracy in the prediction of underventilated burning, typical of fire conditions that occur in structures. Improving models for under-ventilated burning will foster improved prediction of important life safety and fire dynamic phenomena, including fire spread, backdraft, flashover, and egress (involving the presence of toxic gases and smoke), which are critically important for application of fire models for fire safety. In summary, the main objective of this project is to provide an improved understanding of the physics, chemistry, and structure of underventilated compartment fires, and to provide experimental measurements to guide the development of fire chemistry sub-models.

"Numerical Modeling of Pool Fires Using LES and Finite Volume Method for Radiation. Fire Safety Science", Proceedings. Seventh (7th) International Symposium. International Association for Fire Safety Science (IAFSS). June 16-21, 2003, Worcester, MA, Intl. Assoc. for Fire Safety Science, Boston, MA, Evans, D. D., Editor(s), 383-394 pp, 2003. Hostikka, S.; McGrattan, K. B.; Hamins, A.

The thermal environment in small and moderate-scale pool flames is studied by Large Eddy Simulation and the Finite Volume Method for radiative transport. The spectral dependence of the local absorption coefficient is represented using a simple wide band model. The predicted radiative heat fluxes from methane/natural gas flames as well as methane pool burning rates and flame temperatures are compared with measurements. The model can qualitatively predict the pool size dependence of the burning rate, but the accuracy of the radiation predictions is strongly affected by even small errors in prediction of the gas phase temperature

"Program for the Study of Fire Patterns", Shanley, J. H., Jr.; Kennedy, P. M. NISTIR 5904; October 1996. National Institute of Standards and Technology. Annual Conference on Fire Research: Book of Abstracts. October 28-31, 1996, Gaithersburg, MD, 149-150 pp, 1996.

5. What is the literature that describes the differences in proficiency between certified fire investigators and non-certified fire investigators?

We are unaware of any study or data relating to the proficiency between certified and non-certified fire investigators.

6. What is the literature that describes any studies conducted in which the "data" that are collected from the scene (photos, chemical testing results, witness interviews, etc) is then interpreted by different fire investigators to see if the same conclusion is obtained?

We are unaware of any study or data relating to the comparison of collected scene data between different investigators. The use of only photos, chemical testing results, witness interviews, etc… is not an optimum investigative method. Physical examination of a site is necessary for a full investigation, but may not be possible after the fact and after time has passed. A study may be possible by using the results from the Forensic Evidence Collection class (R214) taught at the National Fire Academy in Emmitsburg, MD. In that class the participants are divided into teams and provided a "cold case" containing only photographs, forensic laboratory reports, interviews, and documents. They must then examine the items provided to derive an answer as to whether the case is arson or not. There are 24 scenarios used by the classes since 2009 (with 4 to 6 classes per year and 4 to 6 scenarios used per class). It may be possible to review the past classes and see if teams assigned the same scenarios were able to come to the same determinations. If a study of these results is not possible, the construction of the scenarios may provide a model for creation of a study.

7. Some aspects of fire debris investigations appear to be measurable (i.e. burn thickness in wood, location of origin, etc.). What literature exists that describes how reproducible these effects are? An example might be a study that burned ten 2x4 boards for 5 minutes, another ten for 7 minutes and another ten for 15 minutes, then documented the results.

"The Mythology of Arson Investigation", John J. Lentini, CFEI, F-ABC, available at: http://firescientist.com/Documents/The%20Mythology%20of%20Arson%20Investigation.pdf

"…progress in fire investigation is held back by the burden of an entrenched mythology. Despite the fact that it has been fifteen years since NFPA 921 was first published, some fire investigators still rely on "misconceptions" about the meaning of various fire effects and fire patterns." This reference explores the development and promulgation of the myths and how they are being weeded out.

8. What is the literature that describes an acceptable conclusion for an investigator to be considered correct? For example, is general directionality sufficient or is determining the specific distance from an ignition source expected?

Kirk's Fire Investigation, 7/e (5/2011), John D. DeHaan. David J. Icove, Brady / Pearson Education, 2012, 800 pages, ISBN: 978-0-13-508263-8, BK6007

Pages 249-323, provide details of how fire patterns are generated, and what variables occur that can change their direction. On page 321, Analysis and Hypothesis testing is discussed. It emphasizes that the investigator continually observes the totality of indicators and uses the scientific method.

NFPA 921: Guide For Fire And Explosion Investigations 2011 ed. (3/2011), NFPA, 2011, 357 pages, ISBN: 978-1-6166-5714-7, BN2808

Chapter 6, section 6.4, page 63, discusses the process of identifying and interpreting fire patterns. It also states reference to the fire dynamics that is discussed in section 5.10 Compartment Fire Development, pages 38 – 43. This section discusses the rate and pattern of a fire development and its dependences the complex relationships between the burning fuel and the surrounding environment.

Chapters 17 & 18, pages 157 – 174 provides methodology and guidelines for determining origin and cause. The investigator is basically instructed to be aware of the totality of information and data involved in performing an analysis of the fire scene.

Forensic Fire Scene Reconstruction, 2nd ed. (6/2008), David J. Icove and John D. DeHaan, 2009, 527 pages, ISBN: 978-0-13-222857-2, BF9691

Pages 101 – 165 describes the underpinnings of how fire patterns are used by investigators in assessing fire damage and determining a fire's origin. Fire patterns are often the only remaining visible evidence after a fire is extinguished. The ability to document and interpret fire pattern damage accurately is a skill of paramount importance to investigators when they are reconstructing fire scenes.

"Advanced Fire Pattern Research Project: Single Fuel Package Fire Pattern Study," International Symposium on Fire Investigation Science and Technology (ISFI 2006), Hicks, W., Gorbett, G.E., Kennedy, P.M., Hopkins, R.L., and Abney, W.M., 2006. Cincinnati, OH, June 26-28, 2006.

This study showed that when the 5 controllable factors (heat release rate, ventilation, witness surface characteristics, intersecting surfaces, and fuel packages proximity) are limited, a similar, duplicate staged pattern occurs. Although recreating the exact conditions present on a fire scene, including: obtaining the same fuel package and achieving exact duplication of the conditions present at the time of the fire would be difficult, this study illustrates that the evolution of flame zone pattern phases that a fuel package goes through during a fire are valid, and have now been tested in a controlled environment. By controlling the air movement (not Oxygen concentration) these researchers were able to limit any air movement effects on pattern production.

"Improving the Understanding Of Post-Flashover Fire Behavior", Carman, S., Proceedings of the 3rd International Symposium on Fire Investigations, Science and Technology (ISFI), Cincinnati, OH, May 19-21, 2008, available at:
http://carmanfireinvestigations.com/Publications_files/Improving%20the%20Understanding%20of%20Post%20Flashover%20Fire%20Behavior.pdf

The presentation offers an approach for enhancing investigators' understanding of post-flashover fire behavior through use of standard fire dynamics instruction combined with the graphic output of the computer programs, Fire Dynamics Simulator and Smokeview. Such training offers students a visual introduction to the nuances of ventilation-limited burning. It also introduces the use of computer models in hypothesis-testing as part of an investigative methodology.

"Progressive Burn Pattern Development In Post-Flashover Fires", Carman, S., Proceedings of the Conference on Fire and Materials, 2009, San Francisco, California, available at:
http://carmanfireinvestigations.com/Publications_files/Progressive%20Burn%20Pattern%20Development%20in%20Post-Flashover%20Fires.pdf

Report of tests used to evaluate burn pattern development in fully involved, ventilation-controlled fires with similar physical layouts, furnishings and ignition scenarios. The principle variable between the tests was time of exposure to full fire involvement. Analyses of heat flux, temperature and gas concentration data as well as examination of burn patterns were conducted to better understand the various mechanisms involved. Information from the tests was also used as the basis of a new Internet-based training module on Post-Flashover Fires at the training site, *CFITrainer.net.*

“’Clean Burn’ Fire Patterns – A New Perspective for Interpretation”, Carman, S., available at: http://carmanfireinvestigations.com/Publications_files/Clean%20Burn%20Fire%20Patterns.pdf

Persistence of clean burn patterns is examined. The author’s initial hypothesis is that the mechanism for clean-burn pattern development may be different than the popular notion of combustion of previously deposited soot. The patterns may be due in part to high thermal gradients on surfaces preventing localized deposition from occurring. A better understanding of such mechanisms may improve the interpretation of such patterns, particularly in relation to identifying aspects related to the timing of their creation.

“Investigation of An Elevated Fire - Perspectives on the ‘Z-Factor’”, Carman, S., available at: http://carmanfireinvestigations.com/Publications_files/Investigation%20of%20an%20Elevated%20Fire%20-%20Perspectives%20on%20the%20%27Z-factor%27.pdf

Describes the use of full scale and computer fire models to examine various hypotheses of burning behavior caused by variations in the “z” factor (a fire’s base height). A particular case study is presented with a recap of the subsequent analyses related specifically to effects on fire behavior from an elevated fire.

“A Comparison between Observed and Simulated Flame Structures in Poorly Ventilated Compartment Fires”, Hu, Z., Utiskul, Y., Quintiere, J. G., and Trouve, A., Fire Safety Science–Proceedings Of The Eighth International Symposium, Pp. 1193-1204, Copyright © 2005 International Association For Fire Safety Science

The study characterizes the dynamics of compartment fires under poorly ventilated conditions. It examines four cases that correspond to different values of the fire room global equivalence ratio representative of different flame behaviors. The authors provide a detailed comparison between experimental and computational data.

“Full Scale Room Burn Pattern Study”, NIJ Report 601-97, NCJ 169281, 1997, by A. D. Putorti Jr (62 pages)

Rooms with features resembling typical residential bedrooms were constructed. Each room had a single open doorway, with a door that was completely open during the experiments, and each room was fitted with one double-hung window. While the layout of each room was nearly identical, room location inside the burn tower varied. Experiments involved chair ignition fires and gasoline spill fires. Conditions of room contents and building components were examined after fire experiments, and photographs were taken. Results showed good agreement between experiments with the same method of ignition. In addition, times to events such as window breakage and transition to flashover were similar. Comparisons of room conditions and furnishings after experiments revealed the following similarities: sagging of bed springs and bed frames, protection of room surfaces by furniture, presence of deformed light bulbs, more severe burning of floor surfaces near room centers than near room edges, and presence of areas burned clean of soot. Comparisons also revealed differences related to severity of burning and pattern types and locations. Further experiments are recommended to understand conditions present in fire rooms and the impact of fire ignition method on indicator formation.

"Flammable and Combustible Liquid Spill/Burn Patterns." NIJ Report 604-00; NCJ 186634; 71 p. March 2001. Putorti, A. D., Jr.; McElroy, J. A.; Madrzykowski, D.

This report provides a means for fire investigators to predict the quantity of spilled gasoline necessary to produce a fire pattern of a particular size on various types of commonly used flooring materials.

"USFA Fire Burn Pattern Tests", Federal Emergency Management Agency, United State's Fire Administration, Shanley, J. et.al., 1997

Confirmation of the concepts, investigative systems, dynamics of pattern production, and patterns analysis described in NFPA 921, Guide for Fire and Explosion Investigations

ASTM E603 - 07 Standard Guide for Room Fire Experiments , American Society for Testing and Materials, 2007

The Standard addresses the means for conducting full-scale fire experiments in order to evaluate the fire-test-response characteristics of materials, products, or assemblies under actual fire conditions. It allows users to obtain fire-test-response characteristics of materials, products, or assemblies, which are useful data for describing or appraising their fire performance under actual fire conditions.

ASTM E678 - 07 Standard Practice for Evaluation of Scientific or Technical Data, American Society for Testing and Materials, 2007

This establishes criteria for evaluating scientific and technical data, and other relevant considerations, which constitute acceptable bases for forming scientific or technical expert opinions. The standard recommends generally acceptable professional practices.

"Fire Pattern Repeatability: A Laboratory Study on Gypsum Wallboard", NCJ 234312, September 2010, by Daniel Madrzykowski, Charles Fleischmann Ph.D. (12 pages)

In 2009, the National Research Council (U.S) published a report identifying the research needs of the forensic science community. In the field of fire investigation, one of the specific needs identified was research on the natural variability of burn patterns. The National Institute of Standards and Technology (NIST) is conducting a multi-year study, with the support of the National Institute of Justice (NIJ) and the NIST Office of Law Enforcement Standards (OLES), to examine the repeatability of burn patterns. The primary objective of the study is assessing the repeatability of burn patterns on gypsum board exposed to a range of source fires.

"Fire Pattern Persistence and Predictability In Pre And Post Flashover Compartment Fires", Hopkins, R. L., Gorbett, G., Kennedy, P., Proceedings of the 3rd International Symposium on Fire Investigations, Science and Technology (ISFI), Cincinnati, OH, May 19-21, 2008, available at:
http://tracefireandsafety.com/FireInvestigationResearch/ISFIPatternPersistance-F1-08.pdf

This study provides a considerable amount of data concerning fire pattern development and evolution during fire growth and spread. Specifically, the 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.

"Fire Pattern Persistence and Predictability on Interior Finish and Construction Materials During Pre and Post Flashover Compartment Fires" Hopkins, R. L., Gorbett, G., Kennedy, P., Proceedings of the 10th International Meeting on Fire and Materials - 2007, San Francisco, CA, 29th - 31st January 2007, available at:
http://www.kennedy-fire.com/PDFs/FirePatternsPersistance.pdf

Report of test burns to demonstrate 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.

"Full-Scale Room Burn Pattern Study", Hicks, W., Hopkins, R. L., Gorbett, G., Kennedy, P., Kennedy, K., International Symposium on Fire Investigation Science and Technology, ISFI 2006, Cincinnati, OH, June 26-28, 2006, available at:
http://tracefireandsafety.com/FireInvestigationResearch/FullScaleRoomBurnPatternGorbett.pdf

This report describe tests that demonstrate a remarkable resemblance of patterns in minimal variable testing methods. Patterns persistence through flashover and full room involvement was observed, as well as the reproducibility of specific fire patterns, heat and flame vector analysis results, and depth of calcination measurements. In addition, several ancillary fire effects, fire patterns, and post-fire analysis issues were successfully examined.

"Hourglass" Burn Patterns: A Scientific Explanation For Their Formation", Icove, D., DeHaan, J., International Symposium on Fire Investigation Science and Technology, ISFI 2006, Cincinnati, OH, June 26-28, 2006, available at:
http://tracefireandsafety.com/FireInvestigationResearch/IcoveDeHaanHourglass-06.pdf

Both fire testing and mathematical analysis by the authors show that the formation of "hourglass" burn patterns is a direct function of the fire plume's virtual origin, which is mathematically tied to the heat release rate and surface area of the fuel package. Several examples are provided along with engineering calculations.

Scientific Protocols for Fire Investigation, Lentini, J., CRC Press-Taylor and Francis, 2006

Sections 3.8 and 4.12 describe the development of fire patterns and proper methodology for forming hypotheses for the cause of a fire.

NFPA 1033: Standard for Professional Qualifications for Fire Investigator, 2009 Edition NFPA, 2011, 16 pages, Copyright, National Fire Protection Association

Guidelines are provided for the Fire Investigator in interpretation of the information (including burn patterns) to determine a fire's cause Sections 4.2.4, 4.6.5, and 4.7.1.

9. What is the literature that describes the types of measurement uncertainty involved with data collection and interpretation for burn pattern analysis and arson investigations?

"Progressive Burn Pattern Development In Post-Flashover Fires", Carman, S., available at: http://carmanfireinvestigations.com/Publications_files/Progressive%20Burn%20Pattern%20Development%20in%20Post-Flashover%20Fires.pdf

Reports the results and percentages of correct evaluations by investigators at controlled test fires and presents suggestions for improving the training of investigators so as to improve their abilities to correctly interpret fire patterns.

"Flammable and Combustible Liquid Spill/Burn Patterns." NIJ Report 604-00; NCJ 186634; 71 p. March 2001. Putorti, A. D., Jr.; McElroy, J. A.; Madrzykowski, D.

This report discusses the uncertainties in measurements made during the experiments.

"Estimates of the Uncertainty of Radiative Heat Flux Calculated from Total Heat Flux Measurements", Bryant, R., Johnsson, E., Ohlemiller, T., Womeldorf, C., Interflam '01, International Fire Science and Engineering Conference, 9th. Proceedings September 17-19, 2001, Edinburgh, Scottland

Specific to uncertainty measurement calculations related to heat flux which is a factor in the production of burn patterns.

NFPA 921, "Guide for Fire & Explosion Investigations" 2008 Edition

Section 17.4 through Section 17.8, that refers to analyzing the data with discussions regarding fire pattern analysis. The entire chapter 1, NFPA 921, Chapter 8 also applies.

10. What literature exists that describes error rates for any aspects of fire investigation including burn pattern interpretation error. This includes literature describing statistics about consistency of conclusions among experienced investigators for the same case?

"Progressive Burn Pattern Development In Post-Flashover Fires", Carman, S., available at: http://carmanfireinvestigations.com/Publications_files/Progressive%20Burn%20Pattern%20Development%20in%20Post-Flashover%20Fires.pdf

Reports the results and percentages of correct evaluations by investigators at controlled test fires and presents suggestions for improving the training of investigators so as to improve their abilities to correctly interpret fire patterns.

"Heat Release Rate: Precision", Babrauskas, V., Fire Science and technology, Inc., available at: http://www.doctorfire.com/precision.html

Discussion of precision and rates of error in determining the heat release rate for various heat release rate test methods. Heat release rates are an important component in understanding the development of fire patterns, fire dynamics, and fire modeling.

The following comment applies to all the cited literature and web resources below:

Burn patterns would be subjective by the author. Any error rate rests on the investigator's ability to look at the total data surrounding the analysis of any burn patterns.

Website at: http://www.interfire.org/ Fire Scene Investigation: The Daubert Challenge by Guy E. Burnette, Jr., Esquire and Fire Investigation Myth understandings *Examining Long-Held Truths About Fire Dynamics, Physical Indicators of Incendiary Fires, and Fire Investigation Techniques* By Cathleen E. Corbitt-Dipierro

Forensic Fire Scene Reconstruction, 2nd ed. (6/2008), David J. Icove and John D. DeHaan, 2009, 527 pages, ISBN: 978-0-13-222857-2, BF9691

Kirk's Fire Investigation, 7/e (5/2011), John D. DeHaan. David J. Icove, Brady / Pearson Education, 2012, 800 pages, ISBN: 978-0-13-508263-8, BK6007

NFPA 921: Guide For Fire And Explosion Investigations 2011 ed. (3/2011), NFPA, 2011, 357 pages, ISBN: 978-1-6166-5714-7, BN2808

11. What is the literature that describes studies that compare the amount of experience fire investigators may have versus how it affects their conclusions?

Forensic Fire Scene Reconstruction, 2nd ed. (6/2008), David J. Icove and John D. DeHaan, 2009, 527 pages, ISBN: 978-0-13-222857-2, BF9691 , Chapter 1, page 1.

"To be effective, these expert opinions must be able to pass the eventual scrutiny of cross examination during peer review, sworn depositions, Daubert hearings and courtroom testimony. Recent court decisions place more weight on expert forensic testimony based on scientific, rather than merely experience-based knowledge."

Kirk's Fire Investigation, 7/e (5/2011), John D. DeHaan. David J. Icove, Brady / Pearson Education, 2012, 800 pages, ISBN: 978-0-13-508263-8, BK6007, Chapter 1, page 7

"It means to apply the scientific method of logical enquiry to the investigation."

NFPA 921: Guide For Fire And Explosion Investigations 2011 ed. (3/2011), NFPA, 2011, 357 pages, ISBN: 978-1-6166-5714-7, BN2808 Section 17.4 through Section 17.8, that refers to analyzing the data with discussions regarding fire pattern analysis. The entire chapter, NFPA 921, Chapter 8 also applies.

"Analysis of the data is based on knowledge, training, and experience and expertise of the individual doing the analysis."

12. What is the literature describing any quality assurance/controls used in the cognitive evaluation of physical evidence at the scene to generate a fire investigator's conclusion?

NFPA 921, "Guide for Fire & Explosion Investigations" 2011 Edition, Section 17.4 through Section 17.8, that refers to analyzing the data with discussions regarding fire pattern analysis. The entire chapter 1, NFPA 921, Chapter 8 also applies.

"An investigator should read and understand the concepts of fire effects, fire dynamics, and fire pattern development----. This knowledge is essential in the analysis of a scene to determine the origin of a fire"

NFPA 921, "Guide for Fire & Explosion Investigations" 2011 Edition, Chapter 4, Basic Methodology

"The systematic approach recommended is that of the scientific method, which is used in the physical sciences."

NFPA 921, "Guide for Fire & Explosion Investigations" 2011 Edition, Chapter 16, Physical Evidence

"The fire investigator should be thoroughly familiar with recommended and accepted methods of processing such evidence."

13. What is the literature on databases available to standardize interpretations of fire patterns/damage at scenes and support fire investigators' conclusions?

We are unaware of any study or data relating to standardized interpretations of fire patterns/damage at scenes that support fire investigator's conclusions.

14. What literature exists that describes studies on understanding how cognitive bias may impact burn pattern analysis and arson investigations?

While we are unaware of any studies on understanding how cognitive bias may impact burn pattern analysis and arson investigations, the following paper references how that bias may be perpetuated.

"The Mythology of Arson Investigation", John J. Lentini, CFEI, F-ABC, available at: http://firescientist.com/Documents/The%20Mythology%20of%20Arson%20Investigation.pdf

15. What databases are most needed in the field of burn pattern analysis and arson investigation? (Note- this question does not require a list of references, it is for informational purposes only.)

In 2008, the National Center for Forensic Science prepared a report for the National Institute of Justice (available at 2007-2008 National Needs Assessment for the Near and Long Term Future of Fire Debris and Explosives Analysis and Investigation) which included a survey of investigators and scientists as to what was needed to improve investigations and analytical procedures in fires and explosions. The analysis of the survey results indicated that databases were needed and novel investigative tools needed to be developed. Specific information as to the databases are found within the report:

F. *Access to Existing Federal Databases and Information on Fire and Explosives Issues and Materials*

1. Needs and Problems Identified

a. Federal agencies, particularly the Federal Bureau of Investigations (FBI, http://www.fbi.gov), the Bureau of Alcohol, Tobacco, Firearms, and Explosives (BATFE, http://www.atf.treas.gov), and the United States Fire Administration (USFA, http://www.usfa.dhs.gov), have and maintain various databases and reference material collections on fires and explosions.

b. Local and state agencies desire access to these databases in order to be able to cross-reference the items they find in casework with the larger reference collection of the federal agencies. They can take the data they develop on the composition of various materials and compare their results to the federal reference materials. The issue is that more often than not, these databases and materials are not accessible to the local and State agencies. In some instances the databases and materials are available, but not through a single resource.

G. Fire and Explosion Computer Modeling

1. Needs and Problems Identified

a. Computer fire modeling has improved significantly since its inception. Its key limitation has always been the ability of the program to factor in all the various parameters and the accuracy of the parameters. Many of the references needed (e.g., heat flux, specific gravity, thermal inertia, heat transfer rate, etc.) may exist in various resources. They need to be accumulated into a single source. For many materials, this data does not exist.

b. Obtaining this data is beyond the budget and capabilities of most state or local agencies. Federal agencies such as the BATFE Fire Research Laboratory and the National Institute of Science and Technology (NIST, http://www.nist.gov) may have the equipment and laboratory space, but may need additional personnel and access to the materials themselves. Essentially what is needed is a facility with a cone calorimeter to burn items such as different brands and types of chairs, sofas, clothing, mattresses, tables, furnishings, etc.). Once the data is collected, it would be entered into a searchable database. This would allow investigators performing computer fire modeling to have access to more data to estimate the fuel load and model the fire.

c. Once the data from reference materials are available, the parameters specific to a scene must be input. Scene mapping tools, which could automatically input the data at the scene, may permit on-scene modeling, which would allow investigators to assess the validity of their observations and information from interrogations. If this was possible while on-scene, it would allow the investigator to acquire more precise and accurate information from which a scientifically based conclusion may be drawn.

d. Similar modeling programs and research has not been completed for the dynamics of an explosion. Basic research and modification of some fire modeling software may be possible. If it can be developed this would prove to be an advance for the timeliness and accuracy of post-blast investigations.

In support of this finding in the report, a recent communication from an investigator who is a member of T/SWGFEX adds his observations on the creation of a comprehensive database:

"… having a comprehensive database of all materials along with their physical properties. The investigator can then determine how a given material will ignite, burn and what might the heat release rate (energy) be for a given amount. Note: a recent grant was issued to the University of Maryland and the National Center for

Forensic Science. Many materials are listed in the database available at http://firebid.umd.edu/burning-item-database.php. More materials need to be added and the database needs to be made available to all investigators. In addition, as more materials and furnishings are manufactured, the data needs to be provided to the database. At a minimum, the data should consist of the following properties; heat release rate, thermal inertia, density, thermal conductivity, specific heat, mass burning rate and effective heat of combustion."

Relevant Survey Response Discussions:

Skipping to **Question 67**, 72.8% of respondents think they would benefit by having access to a national/international database of certified accelerant detection canine teams.

16. What new technologies and areas of research should be pursued with regard to burn pattern analysis and arson investigation? (Note- this question does not require a list of references, it is for informational purposes only.)

In 2008, the National Center for Forensic Science prepared a report for the National Institute of Justice (available at 2007-2008 National Needs Assessment for the Near and Long Term Future of Fire Debris and Explosives Analysis and Investigation) which included a survey of investigators and scientists as to what was needed to improve investigations and analytical procedures in fires and explosions. The analysis of the survey results indicated that new technologies and research projects were needed. Specific information as to the new technologies and research are found within the report:

A. *Technology Transfer and Development of New Instrumentation for Field and Laboratory Detection and Analysis of Ignitable liquids and Explosives*

1. Needs and Problems Identified

f. The specific areas of interest described in the survey instrument and between planning panel members are:

6) Continue development of field portable (hand-held) instruments for field analysis of explosives, explosive residues and components, and ignitable liquids. Standardize development of new methods and techniques for field analysis using existing hand-held instrumentation. Candidates in limited use or with significant potential for this type of development include: Raman Spectroscopy; X-Ray Florescence; Micro Cantilever Sensors; Ion Mobility Spectroscopy; Differential Mobility Spectroscopy, Chemiluminescent Detection (EGIS); and GC/MS.

8) Develop, test, and validate tools for investigators at a scene such as an affordable hand-held x-ray unit that could allow investigators to "see" the interior of melted and deformed items. Another

example is the development of instruments and tools for scene documentation and laser mapping using GPS markers with the capability of having the data automatically downloaded into computer modeling software (FDS for Fire modeling).

9) Development, testing, and validation of scene “toolboxes” and training kits along the line of the Israeli or Australian models which allow their field agents to process the scene quickly and efficiently.

B. Fire Dynamics

1. Needs and Problems Identified

a. Much has been done to develop our understanding of the dynamics of a fire scene. A training program has been developed by NCFS and the United States Fire Academy (USFA) offers a two-week class on the subject.

b. While there is some information, research, and references on the dynamics of an explosion or the logistics of a post-blast scene, there is currently no comprehensive program describing the dynamics of an explosion scene.

Recent communications from active investigators who are aware of the need to augment the scientific aspects of arson investigation suggests that further testing needs to be available to determine the amount of heat flux levels, distance, and times required to create various burn patterns. This would assist the investigator in understanding what the pattern means. It also would provide further information to Babrauskas' literature on "Will the second item ignite"? This is commonly known as the “One Meter Rule” and relates to the proximity between combustibles in a room and there likelihood of ignition.

Burn Patterns as a Forensic Discipline

In 2009, the National Academy of Science issued its report on forensic science in general and specifically on forensic science applied to scene investigations, “Strengthening Forensic Science: A Path Forward”. Among the criticisms and recommendations was that the scientific basis of investigations must be improved and the qualifications of investigators must incorporate additional training in scientific principles. Specifically the report was very critical of fire investigations, calling into question the basic components for fire scene investigation (burn patterns, basic chemistry and physics, fire dynamics, “forensic” markers in a fire, uncertainty measurements, error rates, etc…)

In the NAS Report, the coverage of fire investigation is brief, but has been interpreted by many to be more involved. The key criticism is in interpretation of burn patterns and the apparent lack of research in that area. This resulted from some of the testimony that was not balanced by the fact that most of the issues and limitations had already been addressed by NFPA 921. Fire and explosion evidence is covered in pages 170 to 173 with the conclusion at the top of 173:

> “By contrast, much more research is needed on the natural variability of burn patterns and damage characteristics and how they are affected by the presence of various accelerants. Despite the paucity of research, some arson investigators continue to make determinations about whether or not a particular fire was set. However, according to testimony presented to the committee, many of the rules of thumb that are typically assumed to indicate that an accelerant was used (e.g. “alligatoring” of wood,a specific char patterns) have been shown not to be true. Experiments should be designed to put arson investigations on a more solid scientific footing.”

The document generally suggests other improvements to other types of evidence requiring subjective interpretation of patterns. This seems to be the source for including “burn pattern analysis” among the truly “forensic” disciplines which need improvements in pattern analysis.

> “Few forensic science methods have developed adequate measures of the accuracy of inferences made by forensic scientists. All results for every forensic science method should indicate the uncertainty in the measurements that are made, and studies must be conducted that enable the estimation of those values.” (p184)

> “There is a critical need in most fields of forensic science to raise the standards for reporting and testifying about the results of investigations. For example, many terms are used by forensic examiners in reports and in court testimony to describe findings, conclusions, and the degrees of association between evidentiary material (e.g., hairs, fingerprints, fibers) and particular people or objects. Such terms include but are not limited to “match,” “consistent with,” “identical,” “similar in all respects tested,” and “cannot be excluded as the source of.” The use of such terms can have a profound effect on how the trier of fact in a criminal or civil matter perceives and evaluates evidence.” (p 185)

The interpretation of burn patterns has been erroneously moved into a “forensic” capacity as others have interpreted the NAS report to try to apply the same requirements on fire investigations as are applied in the laboratory. The resources we provide will hopefully negate that assumption. While burn pattern interpretation is based on application of the scientific method, it is not a discipline of forensic science. Interpretation of burn patterns is not at the same level as such disciplines as fire debris/ignitable liquid analysis, toolmarks, or DNA.

> “The forensic science disciplines need to develop rigorous protocols for performing subjective interpretations, and they must pursue equally rigorous research and evaluation programs. The development of such research programs can benefit significantly from work in other areas, notably from the large body of research that is available on the evaluation of observer performance in diagnostic medicine and from the findings of cognitive psychology on the potential for bias and error in human observers.” (p188)

Burn patterns only repeat themselves in controlled fire experiments where the many variables that affect the patterns in typical structure fires are limited to the particular test conducted. Throughout the reference material provided, the investigator learns about these variables and how they affect the various conditions that exist in a typical structure fire. With this knowledge the investigator can develop a reasonable hypothesis as to how the burn pattern developed, what it means, its relation to the fire’s timeline, the fire’s origin and how it fits in the totality of the fire investigation.

While it is not a forensic discipline, the use of burn patterns by investigators and the potential for misinterpretation of indicators without a proper factoring of all parameters indicates that it is an area that needs additional research. T/SWGFEX with the support of the National Center for Forensic Science (NCFS) as well as other institutions have made application to the National Institute of Justice to conduct basic and applied research into the development of fire patterns and the creation of databases of information that could be made public. It is our hope that the RDT&E IWG recommendations will open up the availability for funding to extend the research in this valuable area.

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