Journal of the National Academy of Forensic Engineers®

NATIONAL ACADEMY OF FORENSIC ENGINEERS

http://www.nafe.org

ISSN: 2379-3252

Vol. 38 No. 1 June 2021

Computer Fire Modeling and the Law: Application to Forensic Fire Engineering Investigations

By David J. Icove, PhD, PE, DFE (NAFE 899F) and Thomas R. May, MS, JD

Abstract

Computer fire modeling can be a two-edged tool in forensic fire engineering investigations. Professional standards of care recommend that fire modeling's primary use is in examining multiple hypotheses for a fire as opposed to determining its origin. This paper covers the current acceptable benefits of computer fire models, historical and pending legal case law, and methods to use modeling results within expert reports and testimony. Particular issues reviewed are the use of animations versus simulations, evidentiary guidelines, and authentication using verification and validation studies.

Keywords

Fire modeling, forensic fire engineering investigation, Frye and Daubert challenge, animations, simulations, verification and validation (V&V), admissibility of evidence, expert reports, expert testimony

Introduction

Computer fire modeling is now commonplace in support of complex forensic fire and explosion investigations involving fatalities and significant monetary losses, although models have existed since the 1960s[1]. Fire modeling initially centered on explaining, verifying, and validating the physical phenomena of fires.

Fire scientists and forensic engineers are using open source programs developed by the National Institute of Standards and Technology (NIST), which have undergone verification and validation (V&V) by the U.S. Nuclear Regulatory Commission (NRC). These scientists and engineers have pushed the acceptability and application of fire modeling out of laboratory conditions and into the world of forensic fire scene reconstruction[2-9]. Early successes of fire modeling in the field of fire litigation and reconstruction led the way to define its usefulness[10-12]. In addition, selected peer-reviewed references further underscore its application[12-14].

Computer fire models constitute independent scientific evidence (e.g., scientific tests) under legal rules to simulate or reconstruct a fire event, draw inferences from existing information, and analyze complex mathematically driven theories. Therefore, the evidentiary standards and rules of admissibility for scientific computer-generated displays ultimately determine whether increasingly complex expert testimony and visual illustrations will be presented to fact finders. Although the rules in state and federal courts do not specifically address computer-generated displays' admissibility, the existing rules are adequately flexible to provide sufficient management of the ever-developing cases and controversies.

It is imperative for any advocate of computer fire modeling to comprehend and remain current regarding the legal rules implicated in the admission or exclusion of scientific evidence at administrative hearings and trials. After all, an unfavorable evidentiary ruling involving essential case facts is a lost opportunity to narrate a hypothesis at a minimum and could potentially have the adverse effect of changing the case result in its entirety.

Selection/Application of Computer Fire Models

Computer fire modeling (particularly of structures) can render a wide range of acceptable uses — mainly when used in forensic fire scene reconstructions. However, in choosing the "right tool for the job," the user must have insight into the model's purpose and bounded conditions[15].

Fire models are not limited solely to forensic engineering applications. Early work at NIST[16] defined the various broader areas that fire modeling can be applied,

David Icove, PhD, PE, DFE, PO Box 1348, Knoxville, TN 37901-1348, (865) 693-4361, icove@utk.edu
DOI: 10.51501/jotnafe.v38i1.167

which include, but are not limited to:

- Avoiding repetitious full-scale fire testing;
- Establishing flammability of materials;
- Helping designers and architects increase the flexibility and reliability of performance-based fire codes;
- Identifying needed fire research;
- Assisting in fire investigations and litigation.

Fire modeling in forensic cases can assist in extending the interpretation of existing data, incorporating peer-reviewed historical findings, and evaluating the incapacitating impact of byproducts of combustion on humans[14,17]. However, the proper fire model's selection and use is the decision of the forensic engineer or investigator[15]. The following available classes of fire models are recognized for use by fire investigators[1] who perform a wide range of calculations:

- *Spreadsheet* — Calculates mathematical solutions for interpretations of actual case data[5,18-20];
- *Zone* — Calculates the fire environment through two homogeneous zones[7,21-25];
- *Field* — Calculates the fire environment by solving conservation equations, usually using finite-element mathematics[9,14,26-36];
- *Post-flashover* — Calculates time-temperature history for energy, mass, and species and is useful in evaluating structural integrity in fire exposure[37-39];
- *Fire protection performance* — Calculates sprinkler and detector response times for specific fire exposures based on the response time index[34,40-44];
- *Thermal and structural response* — Calculates the structural fire endurance of a building using finite-element calculations[45-57];
- *Smoke movement* — Calculates the dispersion of smoke and gaseous species[21,58-70];
- *Egress* — Calculates the evacuation times using stochastic modeling using smoke conditions, occupants, and egress variables[71-76].

The atypical/uncommon use of two or more computer fire models by an investigator, such as a first-order calculation followed by a more accurate model, may help the expert self-peer-review the bounds of a fire scenario. This methodology can be accomplished by first approaching the fire scenario using a spreadsheet calculation of first-order relationships followed by a zone and even a field model.

Peer-reviewed findings[77] show that when applying the multiple model approach in three different apartment fire scenarios, the reported results were in relatively good agreement, particularly in the early stages of the fire. Using simpler models is cost-effective, less time-consuming, and can confirm the order of magnitude of the results from more complex models.

Finally, engineering guidelines and standards exist for selecting, applying, and determining computer fire models' accuracy through exhaustive reviews and testing. The Society of Fire Protection Engineers publishes guidelines[78-80] along with ASTM International[81-84]. The National Fire Protection Association NFPA 921's *Guide to Fire and Explosion Investigations*[85] Chapter 22 on "Failure Analysis and Analytical Tools" devotes an entire section to the guidance for the use of fire models along with their limitations in forensic fire investigations. Understanding, applying, and referencing these standards enhance the benefits derived from the investigator's application to forensic cases, support their conclusions, and subsequently can be upheld during scrutiny in expert challenges in court.

Challenges to the Use of Computer Fire Modeling in Forensic Fire Investigations

V&V is a formal process of establishing acceptable uses, suitability, and limitations of fire models. Verification determines that a model correctly represents the developer's conceptual description. Validation determines that a model is a suitable representation consistent with scientific evidence of the real world and is capable of reproducing phenomena of interest[3].

What concerns both expert witnesses and the courts is the reliability of computer fire models to predict the fires' common features accurately. These features include upper-layer temperatures and heat fluxes, generation of toxic byproducts of combustion, and activation of smoke alarms, heat detectors, and sprinkler systems. For example, NRC's V&V studies compare actual fire test results

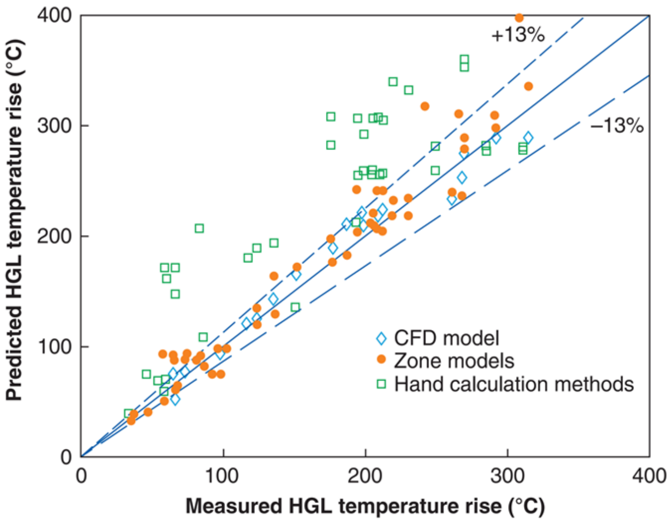

Figure 1
NRC verification and validation studies showing the comparison of hot gas layer (HGL) temperatures measured in full-scale tests compared with predictions of hand calculations, zone models, and FDS models. A predicted +/-13% variability range is included. Note that the hand calculations tended to overpredict layer temperatures, whereas both zone and field model predictions were generally within variability limits.

and predictions of hand calculations, zone models, and field models. As shown in **Figure 1**, when the models are applied correctly to fires that are in their incipient stage of development and pre-flashover, there is general agreement among them and the variability of real-world fires.

Mathematical, experimental, physical, structural, computational, and input/output uncertainties are an unfortunate reality when choosing which computer fire models to apply. To maintain the trustworthiness of computer fire modeling, the users of this technology are challenged to: (a) mitigate error by ensuring the use of quality input data; (b) quantify and articulate uncertainties that can inherently plague the underlying calculations; and (c) ensure that quality expert judgment is used when introducing and utilizing computer fire modeling as evidence during testimony and trials.

The United States Nuclear Regulatory Commission (NRC) has written a 2,000+ page series of V&V manuals to analyze various computer fire models. These documents contain voluminous materials on computer fire modeling uncertainties that are inherent in the models. Also, manuals accompanying the computer software contain disclaimers that can be used to attack even the most attentive practitioner.

Use of Animations Vs. Simulations

Anytime computer-generated materials are entered into evidence, whether in an expert report, a hearing, or a courtroom proceeding, the report's admission will likely be scrutinized. Computer-generated exhibits typically fall into two general categories: animations or simulations. An animation is an artificially created continuation of events, while a simulation determines the missing components or data that led up to the event[86].

Animations

Reconstructions using fire modeling often involve the computer-generated approach. Suggested definitions by Morande[87] propose that animation should be viewed as merely a computer-generated set of snapshots used to guide and illustrate a witness's testimony. The key here is that animations are precisely that — interpretations of what a witness perceives to be an incident's outcome.

It is important to note that the animation alone needs a qualified expert to draw conclusions and generate opinions derived from this computer-generated animation. For example, an experienced radiologist would interpret x-rays or computed tomography (C.T.) scans. Although an animation is not substantive evidence, its use at trial is governed by the Rules of Evidence.

Animations are demonstrative aids that are used to illustrate and support a witness's testimony and opinion. Testimony is utilized to recreate the event; an animation has secondary relevance to the issues and does not depend on the proper use of scientific rules. Animations are admissible in a court of law if they supplement a witness's verbal description of the transpired event, clarify some issue in the case, and are more probative than prejudicial.

Simulations

Morande[87] defines that a simulation is computer-generated substantive evidence. A simulation creates a series of scaled diagrams strung together to produce what appears to be a moving image. For example, NIST's CFAST and FDS computer models generate data interpreted by a program known as Smokeview[88]. This visual data consists of a combined series of frames that (in rapid sequence) produce a movie.

However, the Smokeview visualization of each data frame is associated with a specific predicted time by FDS in the fire event. The data frames can be played back at a single rapid, real-time, or slow-motion rate. What sets these approaches apart is that a simulation utilizes one or more programs, which, after inputting data, use scientific formulas to produce conclusions based on that data regarding issues material to the trial. The results produced by a simulation's programming are equivalent to the opinions reached by an expert witness.

Figure 2 illustrates how a fire pattern analysis of an existing fire scene can use image pattern recognition and a generic first-order algorithm describing fire dynamics (fuel package, virtual origin, fire plume, ceiling jet) complemented with an actual FDS fire model simulation showing heat flux exposure to interior surfaces.

Subsequently, when computer-generated simulations are offered into evidence, it is admissible if both its reliability and general acceptance into the scientific community are established. The reliability of fire modeling software is generally of high quality.

Evidence law is in flux with regard to foundational evidentiary issues associated with computer-generated animations and simulations. The initial inquiry involves distinguishing between animations and simulations.

Simulations are substantive evidence based upon scientific and physical principles rather than merely illustrative testimonial aids[87]. Data input and analysis supplants eyewitness testimony in an attempt to recreate an event to arrive at factual determinations that have independent evidentiary value. When simulations are used, fact finders are asked to rely upon mathematical calculations, computer processes, and expert scientific assumptions; in essence, the computer becomes a second witness[87].

When computer-generated evidence supplies missing information to prove a disputed material fact, assist an expert in forming an opinion, or test an expert's hypothesis, more rigorous assessments of reliability and validity are necessary before the authentication and admissibility of the proposed computer fire model can take place[85].

Admissibility of Computer Fire Models

Authentication of the Computer Fire Model

When considering the introduction of a computer fire model in ligation, authentication of evidence is a prerequisite to its admissibility. The Rule of Evidence 901 deals with this issue, stating:

(a) In General. To satisfy the requirement of authenticating or identifying an item of evidence, the proponent must produce evidence sufficient to support a finding that the item is what the proponent claims it is.

(b) Examples

(1) Testimony of a Witness with Knowledge. Testimony that an item is what it is claimed

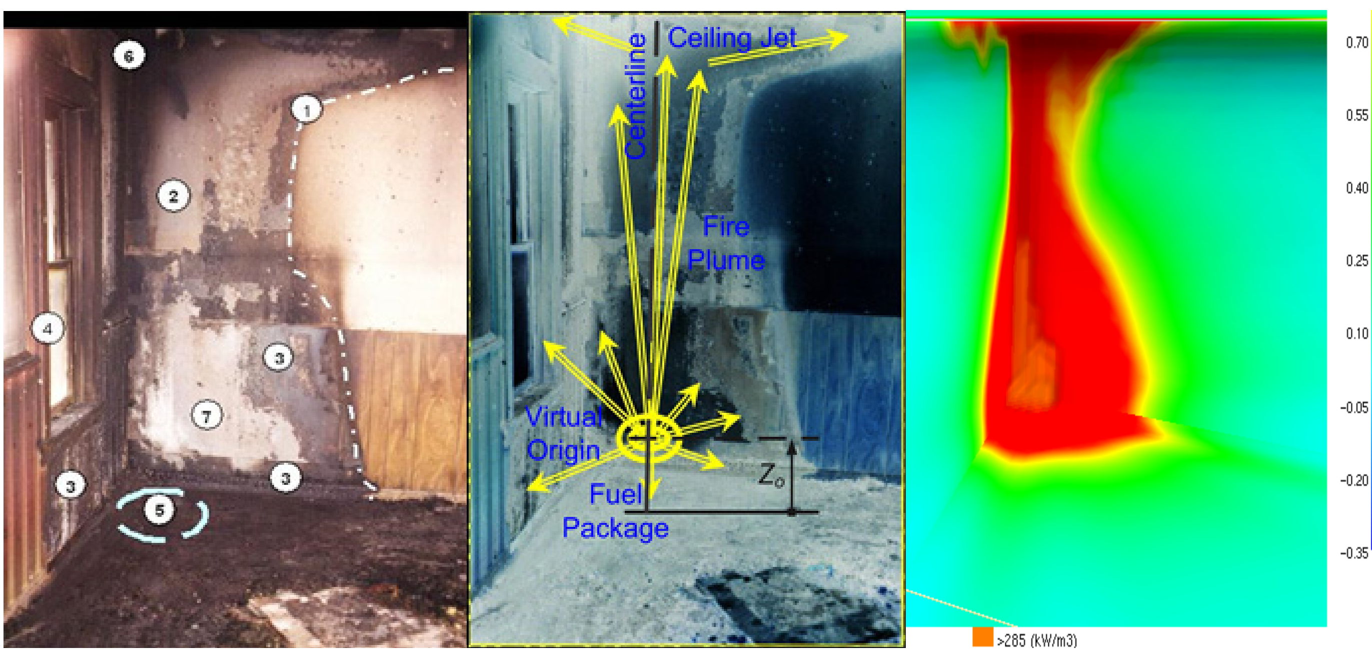

Figure 2

Example fire pattern analysis using (a) fire pattern indicators, (b) image pattern recognition and a generic algorithm describing fire dynamics (fuel package, virtual origin, fire plume, ceiling jet), and (c) an actual FDS fire model simulation showing heat flux exposure to interior surfaces. Courtesy: DJ Icove, University of Tennessee.

to be * * *.

(2) Evidence About a Process or System. Evidence describing a process or system and showing that it produces an accurate result.

Whether or not a result can be verified by another means can affect the ability to authenticate it. "Fire modeling can normally be considered as the prediction of fire characteristics by the use of a mathematical method which is expressed as a computer program[11]."

Admissibility of Evidence

There exists as a general rule, for evidence to be admissible in a court of law, the proposed exhibit:

(a) must be relevant (e.g., tend to prove or disprove a fact that is of consequence in the case);

(b) must have probative value that is not substantially outweighed by unfair prejudice, must not mislead or confuse the jury, be a waste of time or needlessly cumulative;

(c) must be authenticated (e.g., proven to be genuine and what it is purported to be);

(d) must not be hearsay or fall within an exception to hearsay;

(e) must constitute the "best evidence";

(f) if offered as an opinion, must conform to the attendant lay or expert rules;

(g) if offered as scientific evidence, then must meet the standards for admission;

(h) if offered as demonstrative evidence, must be relevant, material, and competent; and

(i) must not violate any other rule of evidence[86].

In a nutshell, evidentiary rules require a judge to determine if the expert is qualified, if their opinion is relevant and reliable, and if the proposed testimony will assist the factf inder.

Laying a Foundation for the Admission of Computer-Generated Evidence

The proponent of a computer fire model must clear two legal hurdles before the computer-generated exhibit is admitted into evidence: A foundation must be laid that is based upon what the advocate is attempting to prove (e.g., simulation or animation), and the model must negotiate a balancing test (Rule 403) to demonstrate that the evidence is more probative than prejudicial.

The testifying expert's qualifications must demonstrate that she: is qualified in the specific field of computer fire modeling and is qualified in the technique of generating a computer simulation or animation based on specific input data[89].

Computer fire models must satisfy the Daubert factors (testing, peer review, error rates, acceptability in the relevant scientific community) or any other applicable test in the jurisdiction[85]. In addition, the underlying mathematical model will be scrutinized to ensure that: (a) the chosen factors are correctly measured; (b) the selected factors are relevant and inclusive; (c) the underlying mathematical formulae and simplification procedures are appropriate; (d) the numerical tools were accurately applied; and (e) the problem was adequately translated into the model[1].

After this, foundation testimony will be required to confirm: (a) the reliability of the data underlying the computer-generated evidence; (b) the authentication of the computer equipment and the principles used in the software program; (c) the integrity and security of the computer system; and (d) the security of the output[1,83,85,89].

A computer fire modeling expert should expect questions in reference to:

- Details about how the animation/simulation was generated,
- What information was used in creating the computer-generated evidence,
- How the information used was collected,
- The appropriateness of the mathematical model,
- How the computer fire modeling program accurately processes the input information,
- The specific methodology employed,
- The facts and evidence on which their opinion is based and relied upon in reaching conclusions,

- How their expert judgment relates to the available physical evidence, and

- Any technical or scientific assumptions that have been made[80,85,89,90].

Admissibility of Demonstrative Vs. Substantive Evidence

Computer fire models may be admitted into a court of law as demonstrative or substantive evidence. Demonstrative evidence has no probative value standing alone, but merely serves as a visual aid to help the fact finder (e.g., jury) in comprehending the verbal testimony of a witness. This type of evidence is tethered to other material testimony in order to be relevant and is admissible to the same extent as the associated testimony[86].

Demonstrative evidence, such as graphics, charts, diagrams, and models, are generally admissible if the item constitutes a "fair representation" of the evidence it purports to represent[91]. In general, if a computer-generated presentation meets the requirements of the rules of evidence — and does not exceed the scope of the evidence it is intended to explain or clarify — it can be admitted at trial as a demonstrative exhibit.

Conversely, substantive evidence is defined as "that which is offered to establish the truth of a matter to be determined by the trier of fact[92]." This type of evidence has independent evidentiary value and is offered to prove a crucial fact at issue in the litigation. "Computer-generated simulations used as substantive evidence or as the basis for expert testimony regarding matters of substantive proof must have been generated from computer programs that are generally accepted by the appropriate community of scientists to be valid for the purposes at issue in the case[92]."

A note of interest: Even though a computer fire model could be inadmissible as substantive evidence due to not being properly authenticated, a jury may be allowed to view the simulation during the course of expert witnesses' testimony at trial, solely as a demonstrative exhibit.

Rule 403 and the Exclusion of Relevant Evidence

Rule 403 is sometimes utilized to exclude relevant evidence that may nevertheless pose a danger of diverting jurors with inequitable considerations that could impair the reaching of a rational decision based solely on relevant facts. In most legal settings, however, the Rule favors the admission and not the exclusion of evidence.

> Rule 403. Excluding Relevant Evidence for Prejudice, Confusion, Waste of Time, or Other Reasons
>
> The court may exclude relevant evidence if its probative value is *substantially* outweighed by a danger of one or more of the following: unfair prejudice, confusing the issues, misleading the jury, undue delay, wasting time, or needlessly presenting cumulative evidence (*emphasis added*).

Reasons for excluding computer fire models include:

- Susceptibility to and ease of manipulation,

- Convincing impact (e.g., seeing is believing, CSI effect),

- Confusion of the jury,

- A disadvantage to opponents who cannot afford to create computer fire models, unjustifiable reliance of jurors due to familiarity with computers, and/or

- A belief that the animation/simulation is an actual recreation of the event[92].

Admissibility of Expert Testimony

Admissibility and Rule of Evidence 702

The admission of computer fire models into evidence requires the testimony of an expert and is therefore governed by Daubert and Rule of Evidence 702 — Testimony by Expert Witnesses:

> A witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if:
>
> (a) the expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue;
>
> (b) the testimony is based on sufficient facts or data;
>
> (c) the testimony is the product of reliable principles and methods; and
>
> (d) the expert has reliably applied the principles and methods to the facts of the case.

The Frye Standard and Admissibility

The Frye standard is a "general acceptance" test that is utilized to determine the admissibility of scientific evidence[93]. Expert opinions that are based on a scientific technique are only admissible when the technique is widely used and generally accepted as reliable in the relevant scientific community. The reliability of the conclusion is not at issue with Frye — only the reliability of the methodology[93]. In a nutshell, head counting in the relevant scientific community is utilized to determine if the methods or principles used to produce the conclusion is generally accepted. In its tally, courts often consider scholarly articles, journals, and affidavits to gauge the state of knowledge in the appropriate community of scientific experts[94].

The Frye test was conceived to keep unproven junk science out of the courtroom. However, the test also prevented the introduction of novel and innovative scientific techniques and inhibited courts from receiving beneficial cutting-edge scientific evidence[87]. In 1993, many courts replaced the Frye test with the Daubert factors test, a more flexible standard entailing the contemplation of a variety of factors[95].

Daubert Factors and Admissibility

Daubert utilizes the Frye "general acceptance" test as only one factor in consideration of the reliability and admissibility of scientific evidence. While Frye offers some protection by ensuring that scientific theories are generally accepted in the scientific community, Daubert offers added protection because it applies more criteria to determine whether the proffered evidence is the consequence of reliable methodology. In fact, scientific evidence can be validated in court even before it has generally been accepted in the scientific community.

The four (core) non-exhaustive Daubert criteria[96] for evaluating the admissibility of expert testimony are:

1. Whether the methods upon which the testimony is based are centered upon a testable hypothesis;

2. The known or potential rate of error associated with the method;

3. Whether the method has been subject to peer review; and

4. Whether the method is generally accepted in the relevant scientific community.

Expert witnesses should prepare to address with specificity the above criteria explicitly mentioned in Daubert and discuss how the criterion is satisfied and, when appropriate, why the factor is not relevant or does not apply.

The understanding, explanation, or application of Daubert factors to scientific evidence is evolving and, as a result, erroneous explanations and applications (e.g., methodology, peer review) routinely appear in published and unpublished opinions. As a result, admissibility analyses are not a predictable endeavor.

Daubert challenges usually arise soon after an expert submits a report and a deposition has been taken. However, if an in limine motion challenging an expert's qualifications and/or proposed testimony is denied during the pretrial phase, an expert has been afforded a window into opposing counsel's likely approach to cross-examination at trial. Beware: Challenges may also be raised in the first instance on voir dire or during cross-examination.

Historical Legal Cases on Computer Fire Modeling

Two prevailing historical court cases help define and illustrate how expert weathers the acceptance and rejection of computer fire modeling. In both cases, experienced expert witnesses professionally presented their findings, yet the courts came to separate conclusions regarding the admissibility of their fire modeling. One overriding premise in these cases was how effectively peer-reviewed findings and reliance on V&V studies were introduced, along with documentation on the general acceptance of fire modeling in the field of fire investigation.

The following are brief summaries of the two cases[97]:

Turner v. Liberty Mutual Fire Insurance Company. Turner v. Liberty Mut. Fire Ins. Co., 2007 WL 2428035 (N.D. Ohio)]. In this case, a trial court held that the National Institute of Standards and Technology (NIST) Fire Dynamics Simulator (FDS, Version 4.0) computer simulation proffered by the defendant's expert satisfied the Daubert reliability test[98] governing expert testimony.

In the analysis of the Turner case, the plaintiff allegedly left his home to run errands, and shortly thereafter, the structure was "fully engulfed in flames." Photos taken by a passerby captured the progression of the fire at the incipient stage until total destruction had occurred. Public as well as private fire investigators classified the fire as undetermined. After this, an expert was employed by the defendant to conduct an "evaluation involving an analysis of the progression of the fire." The expert utilized computer fire modeling to reach the conclusion that the fire was "incendiary and accelerated."

The plaintiff filed suit for breach of contract and bad faith after his insurance claim was denied, and subsequently moved to exclude the testimony of the computer fire modeling expert.

In its analysis, the court ruled that the computer simulation was reliable and admitted it into evidence because:

(a) the software had been tested ("a number of small- and large-scale experiments [had been conducted to validate FDS" e.g. "S*eptember 2005 Computer Simulation of the Fires in the World Trade Center Towers Abstract*");

(b) "[t]he software has been adequately subject to peer review and publication" ("NIST Special Publication 1018's acknowledgment section includes three pages of peer reviews and contributions while its bibliography lists 152 sources from which the technical data has been drawn");

(c) known software error rates could appropriately be addressed during cross-examination ("NIST FDS cautions that two components of its calculations — flow velocities and temperatures — have error rates of 5% to 20%. However, plaintiff notes the 5% to 20% figure does not represent an overall error rate");

(d) "computer simulation methodology is 'generally accepted' by the 'relevant scientific community'" (citing NFPA 921 and "its use in three recent nationally recognized fires: the World Trade Center collapse, the Rhode Island nightclub fire, and the South Carolina sofa store fire").

In *Santos v. State Farm Fire & Cas. Co.*, 28 Misc. 3d 1078, 905 N.Y.S.2d 497 (Sup. Ct. 2010), the general acceptance of computer fire modeling for use in determining fire origin and causation was at issue in New York, a Frye state.

The plaintiff contended that the engineering expert's proposed computer fire model was unsuited for and not generally utilized to determine fire origin and causation. The plaintiff's fire investigation expert opined that computer fire modeling is not generally accepted as an investigative tool in the fire investigation community due to speculation related to building construction and materials used — and also that the computer fire model could not be used to determine fire causation.

The opposing expert, a professor with a PhD in chemistry, testified that: (a) "the underlying equations and laws of physics [related to computer fire modeling] have been generally accepted in the fire science community;" (b) "fire modeling of fire dynamics is not a new science;" (c) his testimony was not to "state the cause and origin of the fire but rather to apply the computer dynamics to see how the fire would spread;" (d) "the results of the fire modeling established that there was a timeline that matched a particular origin of the fire, that the damage in the building corresponded to the results of the modeling, and that the determination of fire dynamics in that particular theory [the timeline] is generally accepted for that purpose;" (e) and"[t]he computer fire modeling essentially verified the hypothesis as to the ignition source or cause of the fire [and is] "never * * * accepted for determining the origin of the fire [but can help in determining the cause]."

The court's analysis led to exclusion of the computer fire model because:

(a) "[w]hile computer fire modeling may be generally accepted in the scientific community for predicting the course of fires given a particular set of circumstances and, therefore, useful in fire prevention and safety, [the expert] has not demonstrated its general acceptance in fire investigation;"

(b) [f]ire modeling carries with it a 15% to 20% margin for error assuming all conditions are correct but could be as high as 80 percent depending upon the real conditions [and the expert] acknowledged that there could be a difference between the material represented in a table and the actual material at the fire scene;"

(c) the regulatory agencies that utilize computer fire modeling (the Department of Energy and Nuclear Regulation Commission, the Department of Defense, the Department of Agriculture and ATF) "are involved in risk assessment as opposed to fire investigation based on scientific standards;"

(d) "[t]hese models in general are designed to start with the ignition of a fire under preset conditions and predict the time factors and conditions of growth and sometimes decay. They are not designed to recreate a particular fire by working backward from a set of final observations to determine what the starting or even intermediate conditions were."

Preparing for Challenges to Your Use of Computer Fire Models in Forensic Fire Investigations

Rule 26 Expert Witness Reports

In court cases, the best method to reduce the successful challenge of your use of computer fire modeling in forensic investigations is in the preparation of a comprehensive written report.

A "written report prepared and signed by the witness" is a prerequisite to expert witness testimony[99]. Courts will utilize the report, in part, to consider Rule 702 and Daubert issues to determine relevancy, reliability, and qualifications. In theory, an expert witness is only allowed to testify to the facts and opinions contained in the expert witnesses' report[100].

An expert report must contain:

(a) A complete statement of all opinions the witness will express and the basis and reasons for them;

(b) The facts or data considered by the witness in forming them;

(c) Any exhibits that will be used to summarize or support them;

(d) The witness's qualifications, including a list of all publications authored in the previous 10 years;

(e) A list of all other cases in which, during the previous 4 years, the witness testified as an expert at trial or by deposition; and

(f) A statement of the compensation to be paid for the study and testimony in the case[101].

Failure to provide all of the information required by Rule can lead to preclusion as an expert. Conformity with Rule 26 facilitates Rule 702 admissibility if the expert witness report contains, at a minimum: (a) facts and data utilized to reach opinions held; (b) a thorough explanation of methodologies used; and (c) authoritative bases relied upon. Rule 26 also requires post-report disclosures of information in the report that is unfinished or requires supplementation. Changes that should have been included in the initial report are prohibited[102]. Beware: Opposing counsel's cross-examination may pose hypothetical questions based upon the facts not contained within the expert witness report.

Summary and Conclusions

Computer fire modeling can be a valuable tool in forensic fire engineering investigations. The forensic engineer or knowledgeable investigator must implement professional standards of care within their expert reports and testimony to ensure that the model exhaustively examines multiple hypotheses for a fire or explosion as well as address error rates. Based upon the current acceptable uses of computer fire models, experts must be prepared to contemplate the underpinnings of historical and pending legal case law, as well as methods to impart the results of modeling into expert reports and testimony. Experts should also be aware of the particular issues regarding the use of animations versus simulations, evidentiary guidelines, and authentication using verification and validation studies.

References

1. Icove DJ, Haynes GA: Kirk's Fire Investigation, Eighth edn. Ny, Ny: Pearson; 2018.

2. Mitler HE, Rockett JA: Users' Guide to FIRST, a Comprehensive Single-Room Fire Model. In. Gaithersburg, MD: National Bureau of Standards; 1987: 138.

3. Salley MH, Kassawar RP: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications: Main Report. In., vol. 1, NUREG-1824 edn. Washington, DC: U.S. Nuclear Regulatory Commission; 2007.

4. Salley MH, Kassawar RP: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications: Experimental Uncertainty In., vol. 2, NUREG-1824 edn. Washington, DC: U.S. Nuclear Regulatory Commission; 2007.

5. Salley MH, Kassawar RP: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications: Fire Dynamics Tools (FDTS). In., vol. 3, NUREG-1824 edn. Washington, DC: U.S. Nuclear Regulatory Commission; 2007.

6. Salley MH, Kassawar RP: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications: Fire-Induced

Vulnerability Evaluation (FIVE-Rev1). In., vol. 4, NUREG-1824 edn. Washington, DC: U.S. Nuclear Regulatory Commission; 2007.

7. Salley MH, Kassawar RP: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications: Consolidated Fire Growth and Smoke Transport Model (CFAST). In., vol. 5, NUREG-1824 edn. Washington, DC: U.S. Nuclear Regulatory Commission; 2007.

8. Salley MH, Kassawar RP: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications: MAGIC In., vol. 6, NUREG-1824 edn. Washington, DC: U.S. Nuclear Regulatory Commission; 2007.

9. Salley MH, Kassawar RP: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications: Fire Dynamics Simulator (FDS) In., vol. 7, NUREG-1824 edn. Washington, DC: U.S. Nuclear Regulatory Commission; 2007.

10. Bukowski RW, Spetzler RC: Analysis of the Happyland social club fire with HAZARD I. Journal of Fire Protection Engineering 1992, 4(4):117-130.

11. Babrauskas V: Fire Modeling Tools for FSE: Are They Good Enough? Journal of Fire Protection Engineering 1996, 8(2):87-96.

12. DeWitt WE, Goff DW: Forensic Engineering Assessment of FAST and FASTLite Fire Modeling Software. National Academy of Forensic Engineers 2000:9-19.

13. Emmons HW: Why fire model? The MGM fire and toxicity testing. Fire Safety Journal 1988, 13(2–3):77-85.

14. Christensen AM, Icove DJ: The application of NIST's fire dynamics simulator to the investigation of carbon monoxide exposure in the deaths of three Pittsburgh fire fighters. Journal of Forensic Sciences 2004, 49(1):104-107.

15. Mowrer FW: The Right Tool for the Job. SFPE Fire Protection Engineering Magazine 2002, 13(Winter):39-45.

16. Mitler HE: Mathematical modeling of enclosure fires. In. Gaithersburg, MD: National Institute of Standards and Technology; 1991.

17. Nelson HE, Tu K-M: Engineering analysis of the fire development in the Hillhaven Nursing Home fire, October 5, 1989: National Institute of Standards and Technology, Building and Fire Research Laboratory; 1991.

18. Mowrer FW: Spreadsheet Templates for Fire Dynamics Calculations. In. College Park, MD: University of Maryland; 2003: 91.

19. Iqbal N, Salley MH: Fire Dynamics Tools (FDTs): Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program. Washington, DC; 2004.

20. Peacock RD, Reneke PA, Bukowski RW, Babrauskas V: Defining Flashover for Fire Hazard Calculations. Fire Safety Journal 1999, 32(4):331-345.

21. Bailey JL, Forney GP, Tatem PA, Jones WW: Development and Validation of Corridor Flow Submodel for CFAST. Journal of Fire Protection Engineering 2002, 12(3):139-161.

22. Hoover JB: Application of the CFAST Zone Model to Ships — Fire Specification Parameters. Journal of Fire Protection Engineering 2008, 18(3):199-222.

23. Jones WW, Peacock RD, Forney GP, Reneke PA: CFAST – Consolidated Model of Fire Growth and Smoke Transport (Version 6) Technical Reference Guide. In. Edited by Fire Research Division BaFRL, NIST Special Publication 1026 edn. Gaithersburg, Maryland: National Institute of Standards and Technology; 2009.

24. Lee Y-H, Kim J-H, Yang J-E: Application of the CFAST zone model to the Fire PSA. Nuclear Engineering and Design 2010, 240(10):3571-3576.

25. Peacock RD, McGrattan K, Klein B, Jones WW, Reneke PA: CFAST – Consolidated Model of Fire Growth and Smoke Transport (Version 6) Software Development and Model Evaluation Guide. In. Edited by Fire Research Division BaFRL.

Gaithersburg, Maryland: National Institute of Standards and Technology; 2008.

26. Chen CJ, Hsieh WD, Hu WC, Lai CM, Lin TH: Experimental investigation and numerical simulation of a furnished office fire. Building and Environment 2010, 45(12):2735-2742.

27. Cheong MK, Spearpoint MJ, Fleischmann CM: Calibrating an FDS Simulation of Goods-vehicle Fire Growth in a Tunnel Using the Runehamar Experiment. Journal of Fire Protection Engineering 2009, 19(3):177-196.

28. Rinne T, Hietaniemi J, Hostikka S: Experimental validation of the FDS simulations of smoke and toxic gas concentrations. VTT, Finland 2007.

29. Jahn W, Rein G, Torero JL: A posteriori modelling of the growth phase of Dalmarnock Fire Test One. Building and Environment 2011, 46(5):1065-1073.

30. Lan X, Liang P, Long XF: Experimental Investigation and Numerical Simulation of Road Tunnel Fire. Prog Safety Sci Tech 2008, 7:673-678.

31. Lock A, Bundy M, Johnsson EL, Hamins A, Ko GH, Hwang C, Fuss P, Harris Jr RH: Experimental Study of the Effects of Fuel Type, Fuel Distribution and Vent Size on Full-Scale Underventilated Compartment Fires in an ISO 9705 Room. In. Gaithersburg, MD: National Institute of Standards and Technology; 2008: 168.

32. Ma TG, Quintiere JG: Numerical simulation of axi-symmetric fire plumes: accuracy and limitations. Fire Safety Journal 2003, 38(5):467-492.

33. Madrzykowski D, Vettori RL: Simulation of the Dynamics of the Fire at 3146 Cherry Road NE, Washington, DC, May 30, 1999. In: NISTIR 6510. Gaithersburg, MD: National Institute of Standards and Technology, Center for Fire Research; 2000.

34. Madrzykowski D, Walton WD: Cook County Administration Building Fire, October 17, 2003. In: NIST SP 1021. Gaithersburg, MD: National Institute of Standards and Technology; 2004.

35. McGill D: Fire Dynamics Simulator, FDS 683, Participants' Handbook. . In. Edited by School of Fire Protection SC. Toronto, Ontario, Canada; 2003.

36. McGrattan K, Hostikka S, McDermott R, Floyd J, Weinschenk C, Overholt K: Fire Dynamics Simulator User's Guide. In. Gaithersburg, MD: National Institute of Standards and Technology; 2014: 268.

37. Babrauskas V: COMPF: A Program for Calculating Post-Flashover Fire Temperatures. In. Berkeley, CA: Fire Research Group, University of California, Berkeley; 1975.

38. Babrauskas V, Peacock RD, Reneke PA: Defining Flashover for Fire Hazard Calculations: Part II. Fire Safety Journal 2003, 38:613-622.

39. Nelson HE: Fire Growth Analysis of the Fire of March 20, 1990, Pulaski Building, 20 Massachusetts Avenue, NW, Washington, D.C. In: NISTIR 4489. Gaithersburg, MD: National Institute of Standards and Technology, Center for Fire Research; 1994: 51.

40. Evans DD: Sprinkler fire suppression algorithm for HAZARD: U.S. Department of Commerce, National Institute of Standards and Technology; 1993.

41. Grosshandler WL, Bryner NP, Madrzykowski D, Kuntz KJ: Report of the Technical Investigation of the Station Nightclub Fire. In: NIST NCSTAR 2. vol. 1. Gaithersburg, MD: National Institute of Standards and Technology; 2005.

42. Alpert R: Calculation of Response Time of Ceiling-Mounted Fire Detectors. Fire Technology 1972, 8(3):181-195.

43. Evans D, Stroup D: Methods to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings. Fire Technology 1986, 22(1):54-65.

44. Milke JA, Hulcher ME, Worrell CL, Gottuk DT, Williams FW: Investigation of multi-sensor algorithms for fire detection. Fire Technology 2003, 39(4):363-382.

45. Babrauskas V: Charring Rate of Wood as a Tool for Fire Investigations. Fire Safety Journal 2005, 40(6):528-554.

46. Bai Y, Hugi E, Ludwig C, Keller T: Fire Performance of Water-Cooled GFRP Columns. I: Fire Endurance Investigation. J Compos Constr 2011, 15(3):404-412.

47. Chowdhury EU, Bisby LA, Green MF, Kodur VKR: Investigation of insulated FRP-wrapped reinforced concrete columns in fire. Fire Safety Journal 2007, 42(6-7):452-460.

48. Malanga R: Fire endurance of lightweight wood trusses in building construction. Fire Technology 1995, 31(1):44-61.

49. Palmieri A, Matthys S, Taerwe L: Experimental investigation on fire endurance of insulated concrete beams strengthened with near surface mounted FRP bar reinforcement. Composites Part B: Engineering 2012, 43(3):885-895.

50. Richardson LR: Thoughts and observations on fire-endurance tests of wood-frame assemblies protected by gypsum board. Fire and Materials 2001, 25(6):223-239.

51. Vytenis B: Charring rate of wood as a tool for fire investigations. Fire Safety Journal 2005, 40(6):528-554.

52. Ali F, Nadjai A, Choi S: Numerical and experimental investigation of the behavior of high strength concrete columns in fire. Eng Struct 2010, 32(5):1236-1243.

53. Ariyanayagam A, Mahendran M: Development of realistic design fire time-temperature curves for the testing of cold-formed steel wall systems. Front Struct Civ Eng 2014:1-21.

54. Buchanan AH: Structural Design for Fire Safety. Chichester, England; New York: Wiley; 2001.

55. Cyriax GR: An Investigation of Structural Damage by Fire - Reply. Concrete 1970, 4(5):174-&.

56. Izydorek MS, Zeeveld PA, Samuels MD, Smyser JP: Structural Stability of Engineered Lumber in Fire Conditions. In. Edited by Gandhi PD, Backstrom B. Northbrook, IL: Underwriters Laboratories; 2009: 95.

57. Perricone J, Wang M, Quintiere J: Scale Modeling of the Transient Thermal Response of Insulated Structural Frames Exposed to Fire. Fire Technology 2007, 44(2):113-136.

58. Baker R: Smoke generation inside a burning cigarette: Modifying combustion to develop cigarettes that may be less hazardous to health. Progress in Energy and Combustion Science 2006, 32(4):373-385.

59. Baker RR, Robinson DP: Semi-theoretical model for the prediction of smoke deliveries. In: Harare, Zimbabwe: Proceedings of CORESTA Congress. Smoke and Technology Groups; 1994: 63-72.

60. Barillo DJ, Brigham PA, Kayden DA, Heck RT, McManus AT: The fire-safe cigarette: a burn prevention tool. J Burn Care Rehabil 2000, 21(2):162-164; discussion 164-170.

61. Delichatsios M: Tenability conditions and filling times for fires in large spaces. Fire Safety Journal 2004, 39(8):643-662.

62. Fu Z, Hadjisophocleous G: A two-zone fire growth and smoke movement model for multicompartment buildings. Fire Safety Journal 2000, 34(3):257-285.

63. Levin BC, Kuligowski ED: Toxicology of Fire and Smoke. In: Inhalation Toxicology. Edited by Salem H, Katz SA. Boca Raton, FL: CRC Press (Taylor and Francis Group); 2005: 205-228.

64. Lin C-C, Wang L: Forecasting smoke transport during compartment fires using a data assimilation model. Journal of Fire Sciences 2015, 33(1):3-21.

65. Lin CS, Yu CC, Wang SC: Numerical Investigation of Fire Dynamic Behavior for a Commercial Building Basement. Advanced Materials Research 2012, 594-597:2213-2218.

66. Jones WW, Quintiere JG: Prediction of Corridor Smoke Filling by Zone Models. Combustion Science and Technology 1984, 35(5-6):239-253.

67. Muhasilovic M, Duhovnik J: CFD-Based Investigation of the Response of Mechanical Ventilation in the Case of Tunnel-Fire. Stroj Vestn-J Mech E 2012, 58(3):183-190.

68. Mulholland GW: Smoke Production and Properties. In: SFPE Handbook of Fire Protection Engineering, 4th Edition. Edited by DiNenno PJ. Quincy, MA: National Fire Protection Association; 2008: Part 2, Chapter 13, 12-297.

69. NAS: Smoke and Toxicity, vol. 3. Washington, DC: The National Academies Press; 1978.

70. NAS: Flammability, Smoke, Toxicity, and Corrosive Gases of Electric Cable Materials. Washington, DC: The National Academies Press; 1978.

71. Jensen G: Wayfinding in heavy smoke: Decisive factors and safety products: Findings related to full-scale tests. IGPAS, . In.: InterConsult Group ICG; 1998.

72. Stewart RD, Newton PE, Hosko MJ, Peterson JE: Effect of Carbon Monoxide on Time Perception. Archives of Environmental Health: An International Journal 1973, 27(3):155-160.

73. Till RC: Timed egress requirements for transit and passenger rail station evacuation as described in NFPA 130. Ashrae Tran 2006, 112:246-250.

74. Yakush SE: Uncertainty of Tenability Times in Multiroom Building Fires. Combustion Science and Technology 2012, 184(7-8):1080-1092.

75. Jin T: Visibility Through Fire Smoke--Part 5, Allowable Smoke Density for Escape from Fire. In: Report No 42. Fire Research Institute of Japan; 1976: p. 12.

76. Jin T, Yamada T: Irritating Effects of Fire Smoke on Visibility. Fire Science and Technology 1985, 5(1):79-90.

77. Rein G, Bar-Ilan A, Fernandez-Pello AC, Alvares N: A Comparison of Three Models for the Simulation of Accidental Fires Journal of Fire Protection Engineering 2006, 16(3):183-209.

78. SFPE: Fires-T3: A Guide for Practicing Engineers. In. Edited by Models STGoDoC. Bethesda, MD: Society of Fire Protection Engineers; 1995.

79. SFPE: SFPE engineering guide—The Evaluation of the Computer Model DETECT-QS. Bethesda, MD: Society of Fire Protection Engineers; 2002.

80. SFPE: Guidelines for Substantiating a Fire Model for a Given Application. Society of Fire Protection Engineers, Bethesda, Maryland 2011.

81. ASTM-E1355: ASTM E1355 - 12 Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models. In: ASTM International Subcommittee E0533 on Fire Safety Engineering. 2012.

82. ASTM-E1472: ASTM E1472-07 Standard Guide for Documenting Computer Software for Fire Models (Withdrawn 2011). In: ASTM International Subcommittee E0533 on Fire Safety Engineering. 2007.

83. ASTM-E1591: ASTM E1591 - 20 Standard Guide for Obtaining Data for Deterministic Fire Models. In: ASTM International Subcommittee E0533 on Fire Safety Engineering. 2020.

84. ASTM-E1895: ASTM E1895 - 07 Standard Guide for Determining Uses and Limitations of Deterministic Fire Models (Withdrawn 2011). In: ASTM International Subcommittee E0533 on Fire Safety Engineering. 2007.

85. NFPA-921: NFPA 921 - Guide for Fire and Explosion Investigations, 2014 edn. Quincy, MA: National Fire Protection Association; 2017.

86. Lipson AS: Is it Admissible?: LexisNexis; 2017.

87. Morande DA: A Class of Their Own: Model Procedural Rules and Evidentiary Evaluation of Computer-Generated "Animations". University of Miami Law Review 2007, 61:1069-1135.

88. Forney GP: Smokeview (Version 5) - A Tool for Visualizing Fire Dynamics Simulation Data: Volume I: User's Guide. In. Gaithersburg, MD: National Institute of Standards and Technology; 2010.

89. NFPA-1033: NFPA 1033--Standard for Professional Qualifications for Fire Investigator. In. Quincy, MA: National Fire Protection Association; 2014.

90. Icove DJ, Crisman HJ: Application of pattern recognition in arson investigation. Fire technology 1975, 11(1):35-41.

91. Morales LI, Canales DA: Discoverability and Admissibility of Electronic Evidence. Advocate 2017, 79.

92. Webster V, Bourn III FE: The Use of Computer-Generated Animations and Simulations at Trial. Def Counsel J 2016, 83:439.

93. Imwinkelried EJ: The Best Insurance Against Miscarriages of Justice Caused by Junk Science: An Admissibility Test That Is Scientifically and Legally Sound. 2017.

94. Easton SD: Yer Outta Here-A Framework for Analyzing the Potential Exclusion of Expert Testimony under the Federal Rules of Evidence. U Rich L Rev 1998, 32:1.

95. Beyea J, Berger D: Scientific Misconceptions among "Daubert" Gatekeepers: The Need for Reform of Expert Review Procedures. Law and Contemporary Problems 2001, 64(2/3):327-372.

96. Daubert v. Merrell Dow Pharmaceuticals, Inc. In: F 3d. vol. 43: Court of Appeals, 9th Circuit; 1995: 1311.

97. See cases: Turner v. Liberty Mutual Fire Insurance Co. In.: Dist. Court, ND Ohio; 2007 and Santos v. State Farm Fire & Cas. Co., 28 Misc. 3d 1078, 905 N.Y.S.2d 497 (Sup. Ct. 2010) .

98. Kesan JP: Critical Examination of the Post-Daubert Scientific Evidence Landscape. Food and Drug Law Journal 1997, 52:225-251.

99. Mickus L: Discovery of Work Product Disclosed to a Testifying Expert Under the 1993 Amendments to the Federal Rules of Civil Procedure. Creighton L Rev 1993, 27:773.

100. Krafka C, Dunn MA, Johnson MT, Cecil JS, Miletich D: Judge and attorney experiences, practices, and concerns regarding expert testimony in federal civil trials. Psychology, Public Policy, and Law 2002, 8(3):309.

101. Zeigler JH, Geer JD: Recent Decisions on the FRCP Rule 26 Amendments Pertaining to Experts in Products Liability Cases. Defense Counsel Journal 2013, 80(1):59.

102. Wells D: In brief: Law 101: Legal guide for the forensic expert. NIJ Journal 2012(269):24-25.