HAZARD I: *Software for Fire Hazard Assessment*

NIST Handbook 146, *HAZARD I—Fire Hazard Assessment Method* [1], represents the culmination of a long-term program aimed at placing the prediction of fire outcomes on an objective and scientific basis. In the 1970s, NIST supported Harvard University to develop numerical models that could predict the temperature in a room containing a fire. These early models were difficult to use and interpret; required large, mainframe computers that were available only in academic institutions; and were plagued with long execution times, often interrupted by software crashes. Major pieces of fire physics and most fire chemistry were not well enough understood to be included in the models, so that predictive accuracy was disappointing. As a result, these early models were little more than academic playthings which were seldom put to practical use.

In 1983, NIST's fire program established a goal to develop a tool that could evaluate the role of the fire performance of an individual material or product in the outcome of a specific fire in a specific compartment or group of compartments. The first year of the project was devoted to determining the capabilities needed to accomplish this, and the effort was somewhat daunting. Not only would it be necessary to predict the fire environment in the space resulting from the material or product burning, but it would also require understanding the movement and behavior of occupants and the physiological and psychological effects of exposure to this fire.

Since the project started before the personal computer revolution, the initial plan was to develop the software to run on NIST's mainframe and to equip a "fire simulation laboratory" at NIST with terminals and graphics equipment so that scientists and engineers could learn how to use the software to address practical problems. Once the usefulness of these models were appreciated, the larger engineering firms were expected to invest in the hardware needed to exploit the technology. It was expected that these firms would have the computers to run the software in their own offices by the end of the century.

By 1986 the NIST multi-compartment model, FAST (Fire and Smoke Transport) [2] had been enhanced so that its predictions were credible when applied within specific bounds. NIST's pioneering development of oxygen consumption calorimetry provided a means to measure the rate at which mass and energy were released from a burning item. By expressing a material's fire performance in terms of conserved quantities, it was possible to describe burning behavior for a predictive model. A NIST psychologist was developing a unique evacuation model with embedded behavioral rules derived from interviews with fire victims. Finally, the NIST combustion toxicology program was producing data that showed toxicological effects were primarily from a small number of toxic species.

Also at this time, the personal computer revolution was well underway. It became clear that a computer on every desktop would soon be a reality, so the NIST software was now targeted at that group of users. Efforts were expended on an improved user interface that would both simplify data entry at the front end and provide graphical output support to make the results more understandable and useful at the back end.

The first version of the *HAZARD I* software and documentation [1] was released in 1989. The software was clearly focused on material and product manufacturers as a tool to assess the fire hazards of their products and a means to justify higher costs associated with better performing products. However, the manufacturers were underwhelmed because the methods required skill to apply and were unproven.

Several factors soon began to change perceptions of the potential of *HAZARD I.* There was political pressure to regulate combustion toxicity, with one state actually promulgating a regulation. NIST produced a fire hazard analysis that showed burning rate was much more important as an indicator of fire hazard than toxicity. In addition, a well respected fire protection engineer became interested in learning these new techniques and successfully applied *HAZARD I* to absolve clients of liability in civil litigation involving a fire. This led to additional uses in both civil and criminal litigation and represented the first significant application of modern fire models.

The publication of NIST Handbook 146 was a watershed for NIST in several ways. While NIST had developed and distributed other software products (such as DATAPLOT, a scientific graphing package), *HAZARD I* was an engineering analysis tool that could be used to make (literally) life and death decisions. It contained a broad range of engineering and scientific methodology that needed to be appropriately documented. Documentation consisted of a Technical Reference Guide which underpins the equations and assumptions and explains how they are coded, a set of worked examples, and a

Users' Guide to the software. The product was packaged as a commercial product with printed binders for the manuals, shrink wrapped disks with the software and installation program, and even a printed function key template. This Handbook received special scrutiny on technical, policy, and legal fronts and was the model for most NIST software to follow.

The *HAZARD I* product was distributed under a formal agreement with the National Fire Protection Association (NFPA), a not-for-profit standards organization. They offered for purchase an initial package, upgrades when issued by NIST, and discounts for their members. Over a decade they sold several thousand copies.

One interesting aspect of this development relates to the exclusion of government-developed software from copyright. Since the software is in the public domain, users are legally unencumbered by the cautions in the documentation. A solution was found by including a users' registration card to be signed, dated, and returned in order to qualify for technical support. The signature on the card was below a statement that the signer read and agreed to the limitations in the documentation—thus creating a contractual agreement. Later, a Government Accounting Office study of the copyright policy that applies to government software cited two specific examples of critical government software that should have copyright protection—Grateful Med from the National Library of Medicine and *HAZARD I*. Several legislative proposals on this issue were considered, but never adopted.

By 1990, successes in litigation led the fire protection engineering community to begin to use *HAZARD I* in building design. While building codes prescribed the minimum required fire safety features of buildings, they also contained a provision recognizing alternative approaches that can be shown to provide equivalent protection. Demonstrating this equivalence to regulatory authorities was always the difficult part. Now *HAZARD I* could be used to show equivalence in safety to occupants rather than having to prove that an alternative approach performed the same function.

The acceptance of *HAZARD I* in demonstrating code equivalence led to a global revolution in building codes. It became possible for codes to specify only the desired outcomes in terms of life safety and property protection and to allow any solutions that provided that level of performance. Such performance-based codes had long been discussed, but were impractical until means were available to measure fire safety performance quantitatively. The U.S. building regulatory community began work on a performance code in 1996 that is expected to be published in 2000. As similar codes are developed and adopted in other countries, they are eliminating non-tariff barriers to trade that result from unique test-methods that are being replaced by nearly uniform performance objectives. *HAZARD I* and its components are

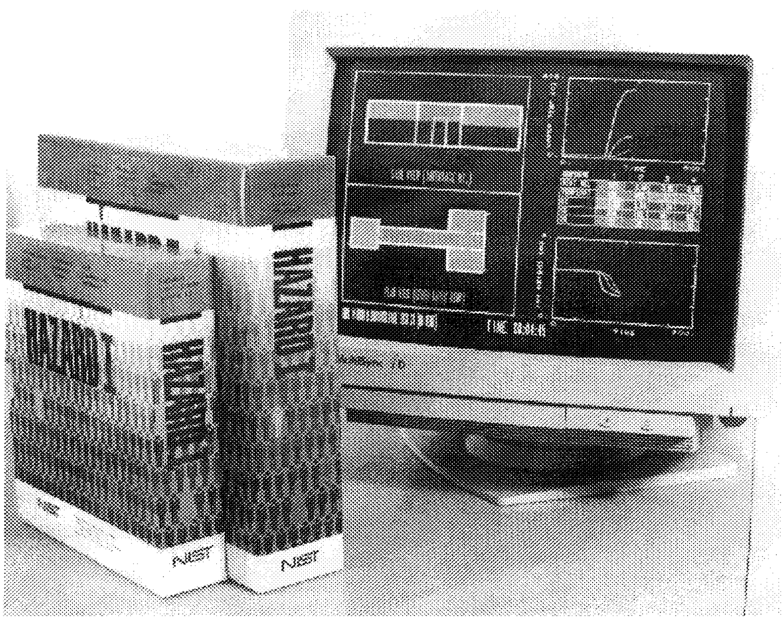

Fig. 1. The *HAZARD I* software and documentation package.

specifically cited in most of these codes and supporting guidelines documents as an acceptable means of demonstrating compliance with the codes.

HAZARD I included several technological advances that were crucial to its acceptance in practice. First, the fire model, FAST, was more robust and easier to use because of a significant investment in the user interface software. There were embedded databases of material properties, and additional references to data were cited. One of the criteria used by the development team was to require as inputs only data that are available and to cite sources for everything. Many other models of the time used engineering estimates that required coefficients to be entered by the user based solely on judgment rather than properties for which measurement methods and handbook values existed.

The equation solver used was carefully selected to work efficiently and seldom failed to converge. The software could be run interactively (with real-time graphics) for exploratory purposes or in batch mode to generate case files or for sensitivity analysis in engineering applications.

The FAST model predictions were compared to a range of full-scale experimental data and these comparisons were published to form a body of verification literature. Further, a suite of test cases stressed the model in different ways to see if it would fail. This test suite was run each time the model was modified. Computer Aided Software Engineering (CASE) tools were used to document changes to the model and to allow changes to be reversed if necessary. Each revision of the software was backward compatible so that users would not have to work excessively to re-run older cases, and the effect of changes was documented. Each of these aspects followed good (commercial) software development practice.

The EXITT (for Exit Time) [3] evacuation model differed from most of its contemporaries in the inclusion of a behavioral module. Other evacuation models of the day had everyone making the correct decisions and, while some allowed for user-selected decision delays, people marched quickly toward the exits. In *HAZARD I,* people investigated the fire until seeing smoke or flame, assisted other family members, or even (children) hid or waited for instructions from an adult. The result was an amazingly realistic sequence of actions and an evacuation process that convinced users and authorities of its applicability.

The toxicology module TENAB (for Tenability) [1] was, and still is, the only attempt to model physiological effects of the inhalation of a mixture of toxic gases. Based on correlations to data from animal exposures, but with an implementation that mimics important physiological interactions, the model produced results that aligned well with actual fire experience. In one case, *HAZARD I* successfully predicted the development of the fire, including a prediction of which occupants successfully escaped and which died, including the location of the bodies and the autopsy results on each. This particular case involved NIST using *HAZARD I* to support a Justice Department attorney to defend the federal government in a wrongful death suit from a fire on a military base. The final analysis indicated no fault by the government, and the day following the deposition of the NIST staff, the plaintiff's counsel offered to settle this $26.5 million suit for $180 thousand.

NIST's pioneering work to develop engineering tools to predict fire performance in buildings, and especially the *HAZARD I* methodology, represented the enabling technology for the move to performance-based building and fire codes which are being adopted globally. The methods and models included in *HAZARD I* are routinely cited in these performance-based codes and in their associated codes of practice, worldwide. These performance methods are reducing the costs of fire safety and are eliminating non-tariff barriers to trade for U.S. companies.

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Bibliography

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