THE ROLE OF FIRE SCIENCE

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ABSTRACT

It is always difficult in a scientific field to identify one particular individual whose contributions above all others stand out as the most significant. However it is without fear of contradiction that I can say that, for the disciplines of Fire Safety Science and Fire Safety Engineering, there is no question that that figure is Philip Thomas. Throughout his long career he has published much of the key seminal scientific research that has provided us with our understanding of fire.

Ranging through his contributions on self-heating, thermal explosion theory, through fire extinction and buoyant diffusion flame theory to the modelling of forest and building fires, his name is dominant in author citation indexes in the field.

Not only his seminal scientific research, but also his vision and leadership of the influential international committees, CIB W14, ISO TC92 and the IAFSS, delivered a new engineering discipline on which modern performance-based building regulation is heavily dependent.

This lecture will explore the progress of one contributory element as its scientific treatment developed from largely observational to analytical and where the digital computer now offers a substantial contribution.

It will consider how far analytical techniques currently available can be applied to the "real world" and what they mean for standards making. Finally it will comment on the various agendas for the delivery of a robust fire engineering capability and their lack of progress.

I use a brief personal account to illustrate the role of fire science in the achievements of today's engineering practice but suggest that the current trend to abandon scientific research is conducted at great risk to the safe implementation of performance-based regulation.

INTRODUCTION

It is a great pleasure and privilege to be invited to give this first Philip Thomas Lecture. I have had the honour of knowing Philip for over thirty years and to have learnt most of what I know from him about fire science and the many philosophical issues surrounding the provision of fire safety.

Isaac Newton is quoted as commenting that if he had seen further than others it was because he was standing on the shoulders of giants. I think it is no exaggeration to claim that all of us who have followed Philip in the field of fire safety science and engineering do so by standing on his broad shoulders. Whether we have seen any further, time will be the judge!

Not only did Philip generate a scientific understanding of so many aspects of fire science but he also provided international vision and leadership as Coordinator of the Fire Commission of the Conseil International du Batiment (CIB W14) from 1974 to 1994 , Chairman of the Technical Committee on Fire Safety of the International Organisation for Standardisation (ISO TC92) from 1976 to 1995, and founder Chairman of the International Association for Fire Safety Science from 1985 to 1991.

Philip has well over one hundred scientific papers and many more reports on so many topics that it is impossible to do justice to the breadth and depth of his work in such a relatively short lecture. For anyone wishing to dig deeper, a good start would be with the two separate collections of of his work [1, 2]. The first from the Fire Research Station is a small selection from his journal publications and the second a complete set of his Fire Research Notes put together for a Symposium in his honour at the University of California in Berkeley in 1980. Although the latter three volumes had only a very limited print run, all of them, and indeed those of his many contemporaries at the Fire Research Station from 1952 to 1978, are now online at the IAFSS website.

This lecture represents a brief personal view of the development of some aspects of fire science and its application during my working life. Looking back, it is clear that extrinsic factors such as political change and fashion have played at least as big a part as scientific progress.

The widespread move away from coal- and oil-fired space heating in dwellings, for example, and the continuing replacement of natural materials with man-made alternatives have had their impact on fire safety. The fashion for lower ceilings in domestic dwellings for reasons of economy of construction and energy conservation has almost certainly led to shorter room flashover times and thus less escape time for building occupants. The need to better insulate buildings can also lead to shorter flashover times depending upon where the insulation medium is located. Inside a cavity wall, it exerts little influence but installed on an inner leaf it is very likely to.

In the past the problems of fire have tended to be considered only as an afterthought at the end of the design process, or even after a tragedy, rather than as one of the determining factors at the conceptual stage. Scientific research has attempted to foresee problems before they occur and has generated advice for use in a wide range of regulatory guidance. It has also delivered a variety of analytical tools that can assist in the provision of fire safe design particularly for novel buildings for which there is no historical record of performance.

Whether fire occurs in a building, aircraft, ship, forest or spacecraft, unless we understand the science of fire it will be difficult to offer properly conceived fire safety protection.

As our understanding improved, fire science has progressed from mainly an observational to an analytical one. Of course a large acceleration to that progress has been facilitated by the development of high speed computational power, the impact of which is now very evident in the widespread application of simulation models in engineering practice.

In this lecture I have chosen to trace one particular aspect of fire science to illustrate the progress that has been made over the recent past and in which some of my own contributions link with Philip's.

This concerns treatments for the turbulent buoyant diffusion flame, characteristic of fire. We now have semi-empirical formulae for describing flame lengths, gas velocities, temperatures and chemical species but the problem still presents a substantial challenge for computer modelling.

BUOYANT DIFFUSION FLAMES

It was the experimental data of Blinov and Khudiakov [3], from the 1950's, for the height of flames from liquid tank fires that raised questions on the relative roles of fuel source momentum and buoyancy head in its determination. It had been argued that the momentum of the fuel gases at the source was the controlling factor for fires as had been shown to be by Hawthorne et al [4] for jet flames. But in natural fires, source velocities are very low and much less than those generated by their own buoyant acceleration.

Philip argued [5] that the rate of fuel supply has a duel significance in determining flame length. On the one hand it controls the initial momentum of the fuel gases leaving the liquid fuel surface and thereby the physical mixing of ambient air into the flame; and on the other it controls the quantity of air required by the chemistry of the fuel's combustion.

He argued that flame height, L, in still air, should be related to the fuel flow rate and a characteristic dimension of the fuel bed by a relationship of the form,

$$\frac{L}{D} = f\left(\frac{V^2}{gD^5}\right)$$

where V is the volume flow rate of fuel and D a horizontal dimension of the fuel bed

He further argued that the form of the function f could be determined from consideration of an entraining surface area of the flame and an averaged air entrainment velocity into that surface (for buoyancy dominated flame systems $\propto L^{1/2}$). For axisymmetric flow then,

$$\frac{L}{D} \propto \left(\frac{V^2}{gD^5}\right)^{\frac{1}{2n+1}} \qquad (1)$$

where n=0, for very short conical flames whose base is the fuel bed and apex the flame "tip",

or n=1, for cylindrical flames and n=2, for truncated conical flames with the smaller diameter at the fuel bed in the limit as though emanating from a point source.

The n=2 case, being independent of fuel bed dimension, gives flame length being simply related to $V^{2/5}$, or in current usage $\dot{Q}^{2/5}$ where $\dot{Q}$ is the rate of heat release of the fire.

From this insight and repeated confirmation of these relationships by many workers a valuable tool emerged for scoping the local hazard posed by fire.

Rasbash et al [6] at about the same time that the Russian work was published presented detailed measurements using cine photography of the velocities of flame tips. These were given in the form of regression equations for velocity dependent mainly on height above the fuel surface. Philip demonstrated that these velocity data were linearly dependent on the theoretical maximum velocity that a parcel of gas at flame temperature could achieve under buoyant acceleration from the fuel bed,

$$v \propto \left(\frac{2g\vartheta_f z}{T_0} \right)^{1/2} \qquad (2)$$

This relationship for gas velocity, v, in the flame enabled the first quantitative estimations of air entrainment into fires (and consequently smoke production rate) to be made. It would also be used along with similar relationships for the non-reacting plume above the flame tip to establish the first, two-layer, zone model for enclosure fires [7]. Philip was the first to propose [8, 9] that the entrainment coefficient for the strong plume should be related to that for the weak plume as

$$\alpha_{strong} = \left(\frac{\rho}{\rho_a} \right)^{1/2} \alpha_{weak}$$

This zone model predated the widespread availability of electronic computers and so results were presented in the form of nomograms calculated by mechanical tabulating machines.

The understanding provided from this analysis was to be exploited very widely for the design of roof venting in industrial units and modern covered shopping arcades.

It was about this time that I joined the Fire Research Station and set about making detailed velocity measurements within the bulk of such flames. I used a technique for measuring the transit time of natural random turbulent fluctuations of different properties transported between two fixed points in the flame. To do this it was necessary to locate the peak in cross-correlation functions of the measured property being transported. Both fine wire thermocouples and Langmuir probes were used for this purpose. Langmuir probes sense natural ionisation within flame sheets passing over the probes and therefore track the motion of the chemical reaction zones within the flame.

The outcome was confirmation of the relationship, equation (2) but with a different constant of proportionality representing now, not the visual flame tips of the Rasbash experiments, but local time-averaged gas velocity in the case of the thermocouple sensors and the local flame sheet velocity in the case of the Langmuir probes. The two sensor types and McCaffrey's pressure probe measurements were in good agreement in the initial "continuous" accelerating region, some 40% of the flame length immediately above the burner surface, but differed, over the upper 60%, with Langmuir probe velocities continuing to accelerate as $z^{1/2}$ but with those measured by thermocouples (and pressure probe) levelling off. This illustrated the relative infrequency of finding a flame sheet in this region and so is why the region became termed "intermittent flaming" (Figure 1).

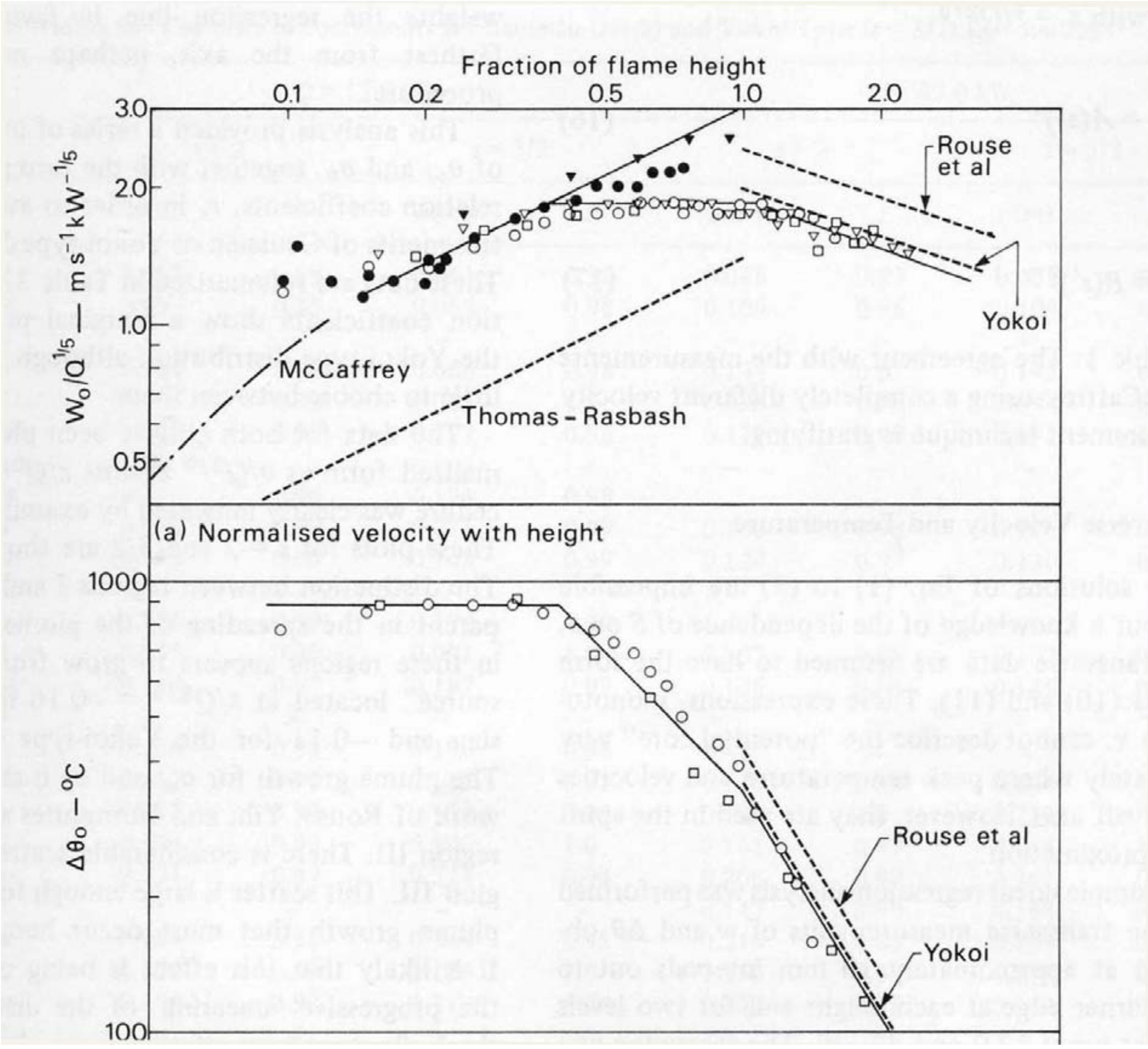

Figure 1. Centreline velocity and gas temperature measured in buoyant diffusion flames; Langmuir probes-solid symbols; thermocouples-open symbols [Cox & Chitty (10)]

Bernard McCaffrey of the US National Bureau of Standards (now NIST) spent a year's secondment at FRS during this period and conducted complimentary measurements on the same experimental rig using the bi-directional pressure probe to measure gas velocity. These formed the basis of his very well known correlations of velocity and gas temperature in such flames [11].

The time-resolved measurements of fluctuating temperature, velocity and flame ionization, e.g. Figure 2, within the flame are only now receiving greater interest for the development of CFD models, especially those employing the large eddy concept.

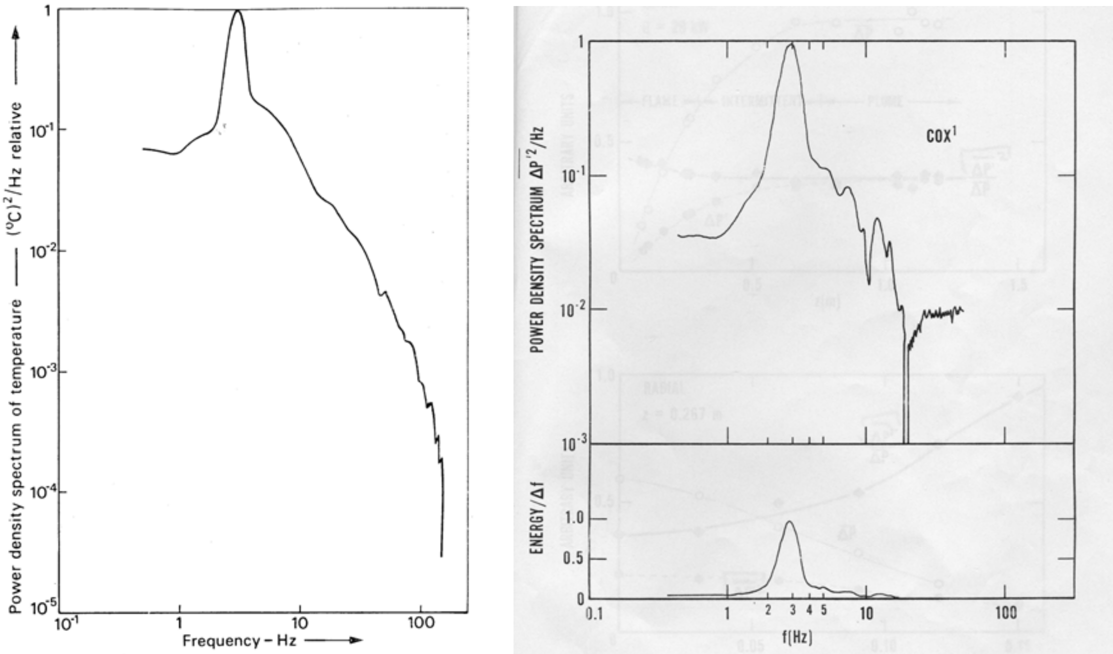

Figure 2. Spectra of thermocouple temperature [Cox (12)] and pressure across a bi-directional probe [McCaffrey (11)] in the buoyant diffusion flame

FIRE MODELLING

At around the same time the FRS CFD models were under development. The original computer code was developed initially at Imperial College by Brian Spalding's team and subsequently with his spin-off company CHAM Ltd. The Initial model (MOSIE) was two dimensional and steady-state and able to exploit at that time only about one thousand grid nodes to span a whole compartment!

Particular attention was directed at whether the technique was viable for use with natural as well as forced convection problems and to develop turbulence modelling for such use. The modifications required to the standard $k{\sim}\varepsilon$ model suggested by this work are still widely used in RANS treatments for turbulent buoyant flow. Successor RANS models, now fully three dimensional and time-dependent utilising at least hundreds of thousands grid nodes, have developed substantially since that time. Figure 3 shows comparisons of predictions of the SOFIE model with the centreline velocity and temperature data for the buoyant diffusion flame shown above.

Figure 4 illustrates early comparisons of JASMINE predictions with the simple room fire data of Steckler et al. The good agreement demonstrates the ability of the model to calculate entrainment into the plume but also extra entrainment resulting from its deflection by the jet of air through the doorway (e.g. Figure 5)

Considerable progress has continued with the addition of sophisticated sub-models for describing turbulence-chemistry, turbulence-radiation interactions and two phase flow. A substantial body of research was sponsored to develop these sub-models by university groups (Imperial, Southampton, Sheffield, Cranfield, Cambridge, Thames Polytechnic) having the specialist capabilities developed primarily in the better-funded field of combustion research.

Just one example is illustrated by Figure 6 which compares measurements of the spectral distribution of thermal radiation from a turbulent buoyant methane diffusion flame with predictions utilising a laminar flamelet treatment for the turbulent-chemistry interaction and a soot production model utilising laminar flame data to describe the luminous contribution.

This approach whilst promising, despite some overprediction requires further development for application to more realistic fuels.

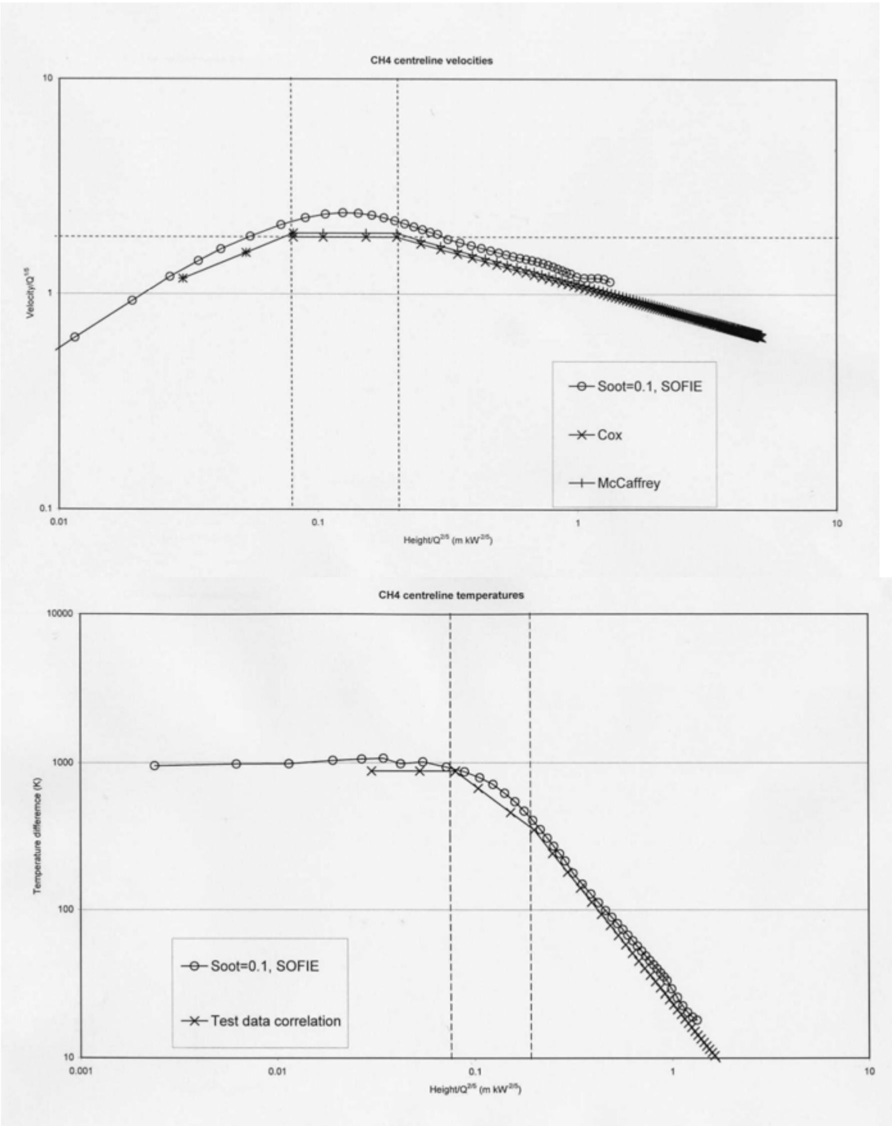

Figure 3. Centreline gas velocity and temperature predictions by SOFIE for the buoyant diffusion flame [Welch (13)]

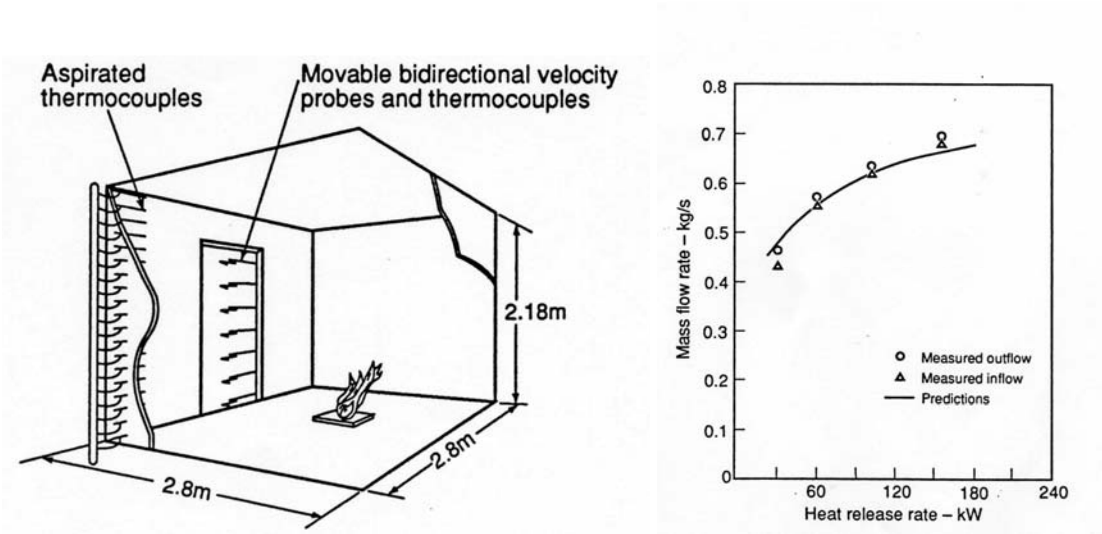

Figure 4. Early comparison of CFD predictions of mass flow rates with measurements [Cox (14)]

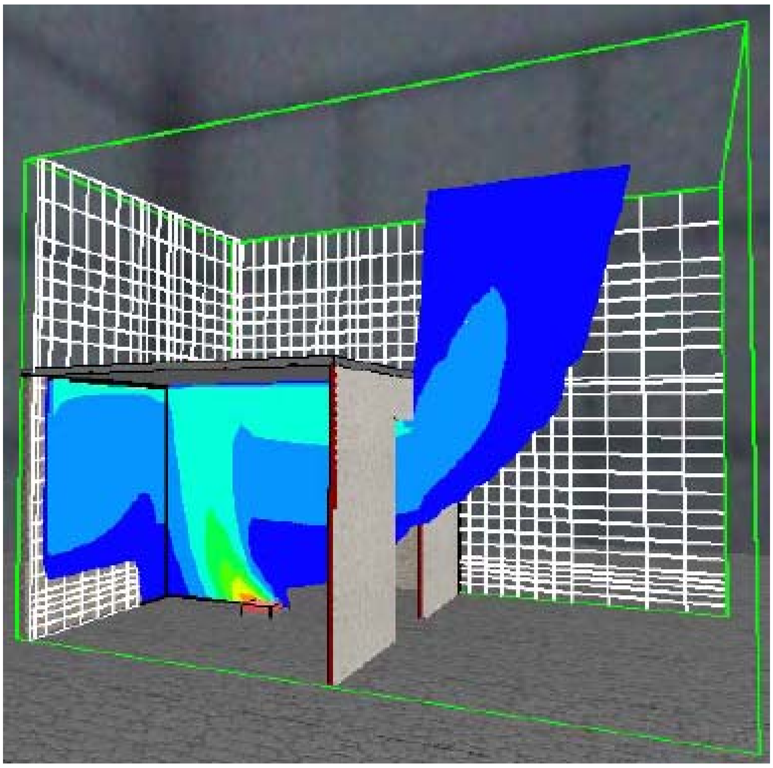

Figure 5. Illustration of plume deflection for centrally located fire

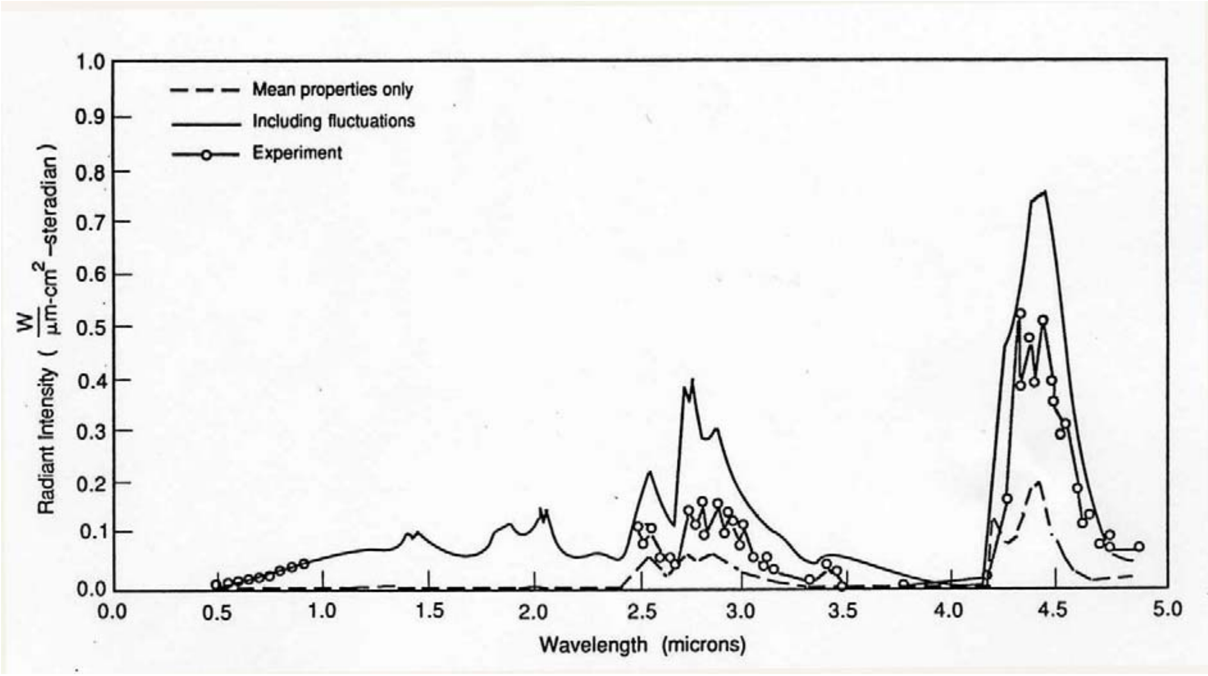

Figure 6. Predicted spectral distribution using laminar flamelet modelling for luminous and non-luminous radiation in the buoyant diffusion flame [Syed et al (15)]

The practical contribution resulting from the modelling research has been seen in a wide variety of engineering and forensic studies. Examples of the former include Stansted, Brussels International and Singapore Changi airport terminal buildings and of the latter include the Kings Cross, Gothenburg disco and Mont Blanc Tunnel fires.

Much fire investigation conducted at the Fire Research Station up to the time of the Kings Cross fire in 1989 tended to be observational, where the conditions conjectured to have occurred at the time of the fire would be reconstructed at full scale in the laboratory in the form of a "build and burn" study (e.g. 1981 Stardust Disco, 1985 Manchester Airport 737).

Modelling played a crucial role in the suggestion of a "trench effect" to explain the mechanism for rapid flame spread on the Piccadilly line escalator at the Kings Cross Underground Station and has recently made a very important contribution to the recent Tribunal on the Mont Blanc Tunnel fire which I will return to.

Now tending to supersede the RANS codes, certainly in terms of numbers of users, has been the development of the FDS large eddy simulation model. This computer code, a result of decades of scientific research and development at the US NIST, has been of great importance recently to the investigation of the collapse of the World Trade Centre towers and is seeing very substantial application by practising fire safety engineers.

Predictions for the centreline data for the buoyant diffusion flame are compared with the measurements in Figure 7.

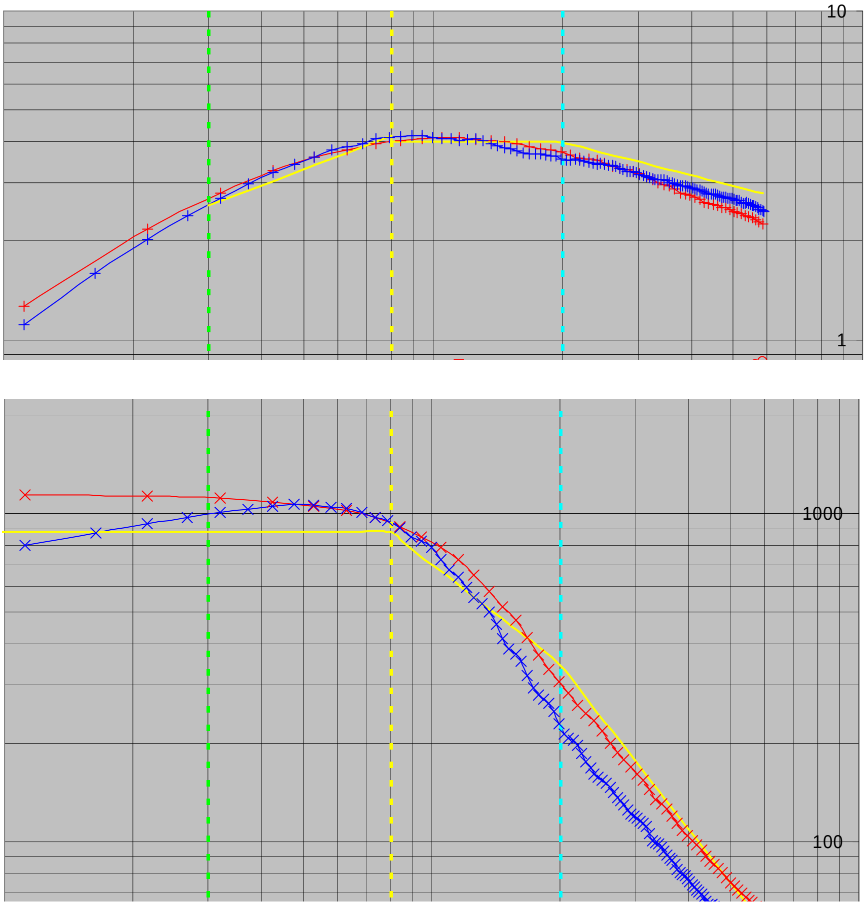

Figure 7. Centreline mean velocity and temperature predictions using FDS [Welch (13)]

As can be seen from figures 3 and 7, both the RANS and LES models predict centreline mean velocities and gas temperatures reasonably well. However there remains something puzzling to me, at least, concerning the coherent eddy shedding evident in the measurements of Figure 2. Although a dominant feature of the physical flow and therefore giving strong support to the large eddy methodology, it is absent in these simulations, Figure 8.

Welch is not alone in not finding it; Wen et al [16] also reported their inability to reproduce it with FDS although they claimed that their own "in house" LES model did. Xin et al [17] more recently, working with FDS, does apparently reproduce it. Whilst this detail may or may not be important for practical engineering application, it vital to a proper understanding of the physics involved. Rajandram's recent study using Direct Numerical Simulation techniques [18] has shed some light on the details of entrainment close to a buoyant source but with the computing resources available could not go down to source Froude numbers representative of natural fire.

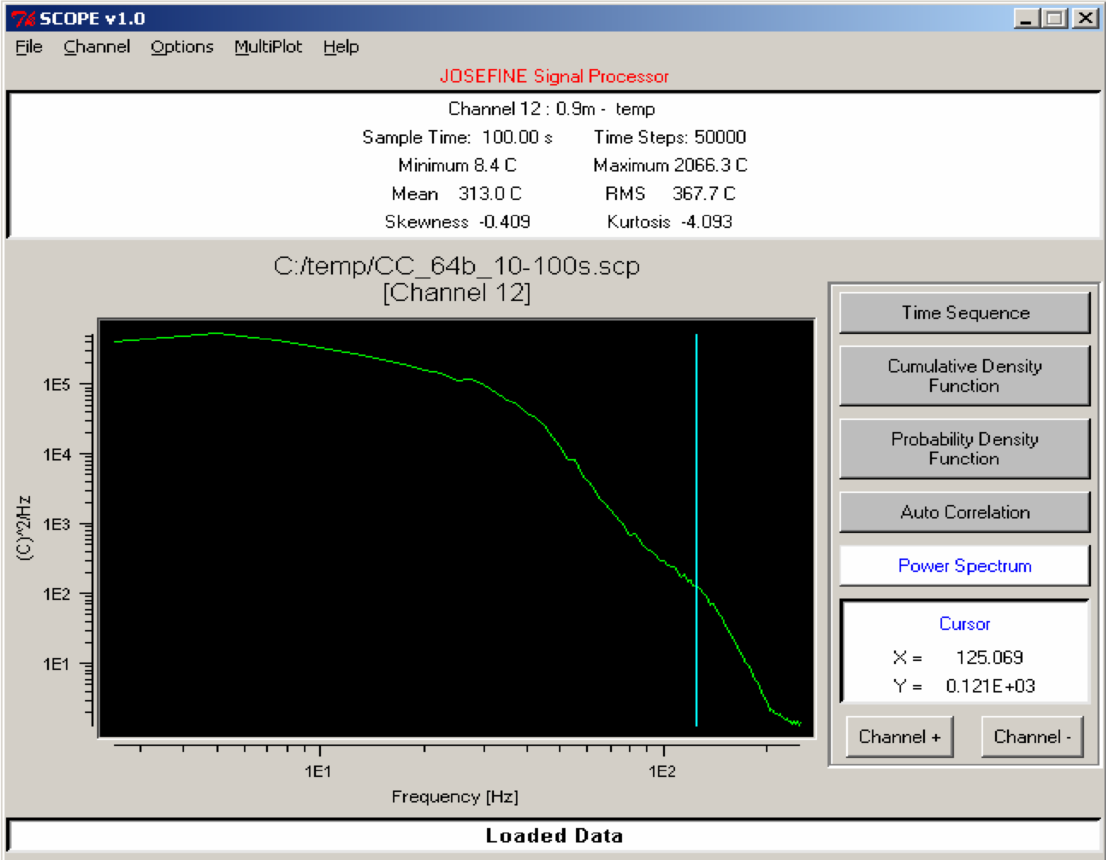

Figure 8. Temperature spectrum determined from transient centreline temperature predictions from FDS [Welch (12)]

The utility of these modelling tools illustrates the progress and practical benefits of scientific research that have been made over the last few decades. Although the potential for their engineering application was recognised at the very early stages of model development, they were heavily dependent on a background of progressive scientific research.

Their development is though far from complete. They have demonstrated their ability for calculating smoke movement problems but require substantial further research if they are to faithfully model fuel pyrolysis, flame spread, soot generation and carbon monoxide yields in "underventilated" fires.

The recent enthusiastic adoption of modelling in fire safety design for simulating smoke movement provides the opportunity to break free from the prescriptive rules of the past and to develop truly innovative designs. However, as with any design tool, there are serious risks if they are misused. There are many examples where users have failed to understand the assumptions implicit in the models and as a consequence produce misleading results. This issue my colleague, Suresh Kumar and I covered in some detail in a Chapter in the 2004 edition of the SFPE handbook of fire protection engineering [19].

In the UK the Office of the Deputy Prime Minister sponsored the development of a proposed Computer Model Performance Assessment Scheme (CoMPAS) to help guide designers, approvers and inspectors on the broader quality assurance issues involved in using models in support of performance based design but as far as I am aware this has still not been openly published. A brief outline is given in reference 20.

There is only so far that deterministic models can go in application to “real-world” problems where many of the required initial and boundary conditions may be unknown or even unknowable. Whilst it is possible to determine the consequences of prescribed “design” fires, the state of art in calculating the development of real fire sources is still limited.

Treatments of the detailed growth and spread of flame under realistic conditions, where complex arrangements of furnishings and building linings are involved, are still not within the compass of our current capabilities. Behaviour such as cracking, bubbling and delamination of products together with influences of installation detail render complete fidelity unachievable in practice.

To illustrate this challenge I will use studies conducted for the 2005 Mont Blanc Tunnel fire Tribunal.

AN ILLUSTRATION OF CURRENT CAPABILITY

RANS modelling was employed along with a physiological “fractional effective dose” model to examine the conditions that occurred on the day of the tragedy that occurred on 24 March 1999 and to suggest whether lives could have been saved with different choices of ventilation strategy by the tunnel operators.

A heavy goods vehicle travelling from France to Italy carrying a refrigerated load of, chiefly, margarine and flour caught fire and came to rest 6.5km into the 11.6km tunnel. Twenty six vehicles travelling in the same direction were trapped behind the fire with the result that 39 people, all but one within 1km of the fire lost their lives.

To be in a position to model this situation we need to recognize that there are things that we know (e.g. dimensions of and gradients within the tunnel, tunnel lining, tunnel ventilation settings, location, dimensions and contents of the vehicle etc etc) and there are things that we don’t know (most importantly the “size” of the fire, how rapidly it grew and, importantly in this case, the external atmospheric pressure difference between the ends of tunnel).

Modelling the detail of fire propagation through the complex arrangement of an assortment of different “fuels” associated with the vehicle is not possible and so many assumptions and approximations were necessary to prescribe a fire source for modelling purposes. Because the fire occurred inside a managed facility with known ventilation settings, video camera and witness observations and records of smoke opacity sensors etc, it was possible to undertake simple “back-of-envelope” calculations to scope the likely fire growth and rates of heat release during the critical period over which conditions became untenable for the victims, Figure 9 (a). These rates of heat release can then be used to estimate mass release rates of the fuel which, of course, is not just one but many (margarine, flour, rubber tyres, diesel fuel, rigid polyurethane trailer insulation, etc etc) and so a “surrogate” had to be used for calculation purposes.

Critical to the fate of the occupants were the ventilation decisions taken on the day, which were known, but also the external atmospheric pressure difference that obtained at the time of the fire between the tunnel ends, 11 km apart. This was known approximately from information supplied by the meteorological authorities but again there was some uncertainty which needed to be encompassed by the modelling. A pre-fire, cold flow simulation was able to reduce this uncertainty by comparing small differences in this boundary condition with the routine anemometer records available from within the tunnel just before the fire.

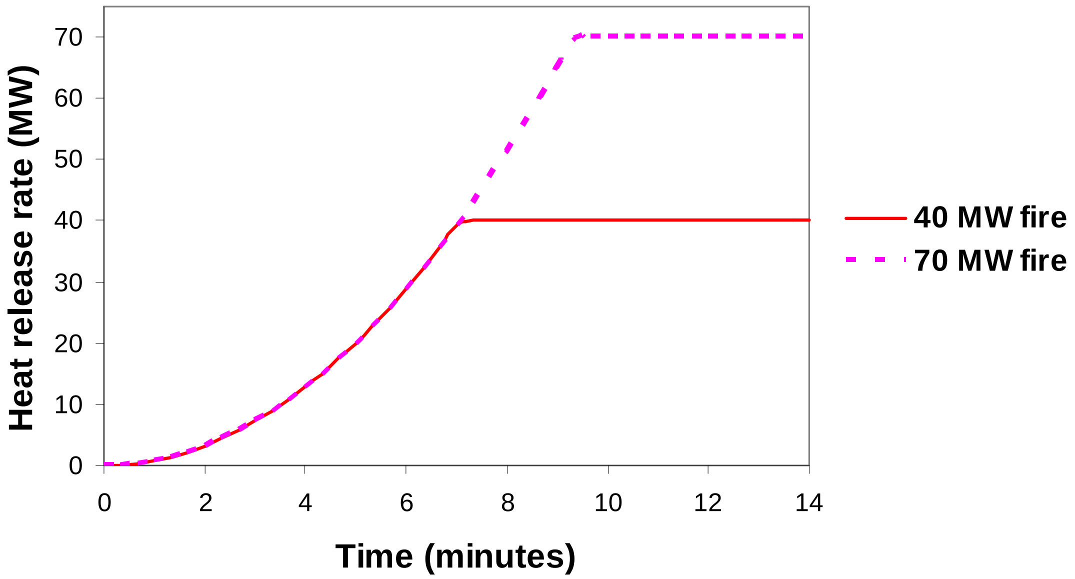

Figure 9 (a). Heat release rate assumptions used guided by witness observation and estimation

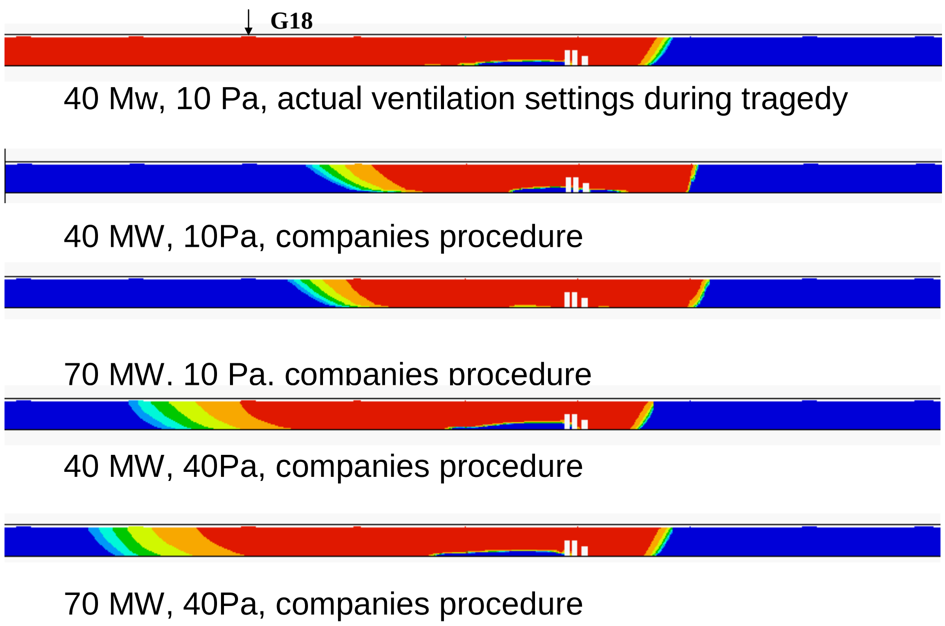

Figure 9 (b). Predictions of carbon monoxide concentration 20 minutes from ignition with different boundary conditions [21]

These are uncertainties in the boundary and initial conditions that cannot be resolved by scientific research. But there are also aspects of the model that are less than adequate because they have received insufficient scientific research and development. The calculation of radiative and convective heat losses to the tunnel boundaries, of local carbon monoxide and smoke concentrations were critical elements for determining the conditions experienced by the tunnel occupants.

The modelling of boundary heat and momentum losses in buoyant stratified flows has received little research attention, whilst a rigorous treatment for the calculation of non-equilibrium products of combustion is still awaited of even the simplest of fuels.

Predictions of breathable gas temperatures, carbon monoxide, visibility and radiant fluxes likely to have been experienced by each of the occupants of vehicles in the tunnel, were assessed with estimates of times of incapacitation and death compared with toxicological data and locations of the remains of the victims given their likely patterns of behaviour. Engineering judgement had to be exercised both to bridge the gaps remaining in fundamental treatments for both the combustion processes and of course human factors.

For this investigation the deterministic models were run many times over to explore the sensitivity of the conclusions drawn to variations in the boundary conditions. It was possible to demonstrate a broad agreement between model predictions and the available evidence and then with that support to be able to suggest what might have happened had the ventilation companies' official procedures been adhered to, Figure 9 (b).

This illustrates both the power of modern simulation capabilities and of its current limitations. Further research will provide greater understanding and capability to such analytical tools but there are some imponderables that can only be addressed by probabilistic approaches. No doubt as the speed of the electronic computer increases further more formal procedures for running deterministic simulations in a probabilistic fashion will become more practicable in the future.

FIRE TESTING AND INTERNATIONAL STANDARDS

The emergence of a mathematical modelling capability has and will have important implications for product fire testing and standardisation. Philip Thomas had been Chairman of ISO TC92 from 1976 until I had the honour to be elected his successor in 1995. During Philip's leadership substantial advances were made in the science of fire and in the capabilities of fire modelling.

The scientific community had been concerned for many years by the weaknesses of the traditional standard fire test methods. The development of a fire modelling capability suggested that a more scientifically based approach to design and assessment was possible, if new fire tests or modifications to existing ones, could produce quantitative data that could be used by models. A key development was made in 1984 when a letter from Philip, as Coordinator of CIB W14, to the Secretary General of ISO explained the view of the full Commission, that there was a need to develop or modify tests with this as its objective. This was a proposal fom the recent CIB workshop on fire modelling suggested particularly by Jim Quintiere. The result was the establishment within TC92 of a new Fire Safety Engineering sub-committee.

The demonstrable success of this sub-committee led ISO in 1995 to charge TC92 with greater responsibilities and a new title. A change was felt necessary to address the needs for standards production in support of the discipline of Fire Safety Engineering. TC92's title was changed from "Fire Tests on Building Materials Components and Structures," which it had been since its formation in 1961, to simply "Fire Safety".

It was understood that new standards would be needed to support Fire Safety Engineering but that any new standards would have a much greater relevance than just the "tests" or the "buildings" of the TC's original title.

Work is still in progress but the long-term strategy of TC92 is to develop new or to modify existing fire tests to provide quantitative data that can be exploited in fire models. The concept is summarised in the schematic representation, Figure 10 [22].

Regrettably the science-based approach was not adopted within the European Union when designing a new test method to support a harmonised approach for the classification of construction products for their reaction-to-fire performance. Because of the urgent political need to ensure that there should be no barriers to trade between member states, and that historical domestic standards would not be accepted across national boundaries, a compromise test method was introduced.

The Single Burning Item test was created. Specified by regulators rather than by scientists, this single intermediate scale test method attempts to provide an assessment of vertical flame spread, rate of heat release, ignitability and issues associated with jointing of materials and the formation of drips.

The disappointing creation of a new test, not based on the principles identified by ISO and CIB, prompted Babraukas's editorial in the Fire Safety Journal [23] with the title "Redefining the value of π in the European Union" lamenting the lack of scientific thinking on display.

Although not satisfying the objectives of the ISO thinking, it does at least utilise the results of modern scientific research to measure rates of heat release. Oxygen-consumption calorimetry [24], the result of research and development in the United States allows rate of heat release to be measured irrespective of the complex mix of flammable material constituting a particular product. A serious weakness of the test is that, although the rate of heat release is measured, it is not related to the area of fuel involved denying its engineering potential.

Unfortunately another political development has also been working against the development of scientifically based test methods. This has been the trend to privatise many of the former national fire research laboratories. The consequence of this for the development of standardised fire testing was nicely summarised by the Chair of the FORUM for International Cooperation on Fire Research, Paul Croce [25]:

"……. As the(se) national labs become privatized/commercialized, the focus of their work will be more on income-producing activities, such as standardized testing, and less on true research. The net result has a dual negative effect: the further erosion of badly needed fundamental research programs and the spread of standardized testing of questionable value for certification."

Why would a privatised laboratory attempt to develop new fire test methods when it can earn income simply by continuing to conduct traditional testing? Generally, material and product producers are content with the status quo, because they know how to address existing tests methods. It is the guardians of safety for the citizen, namely our governments, that have the responsibility to ensure that the testing called upon is appropriate for the assessment of "in-use" performance.

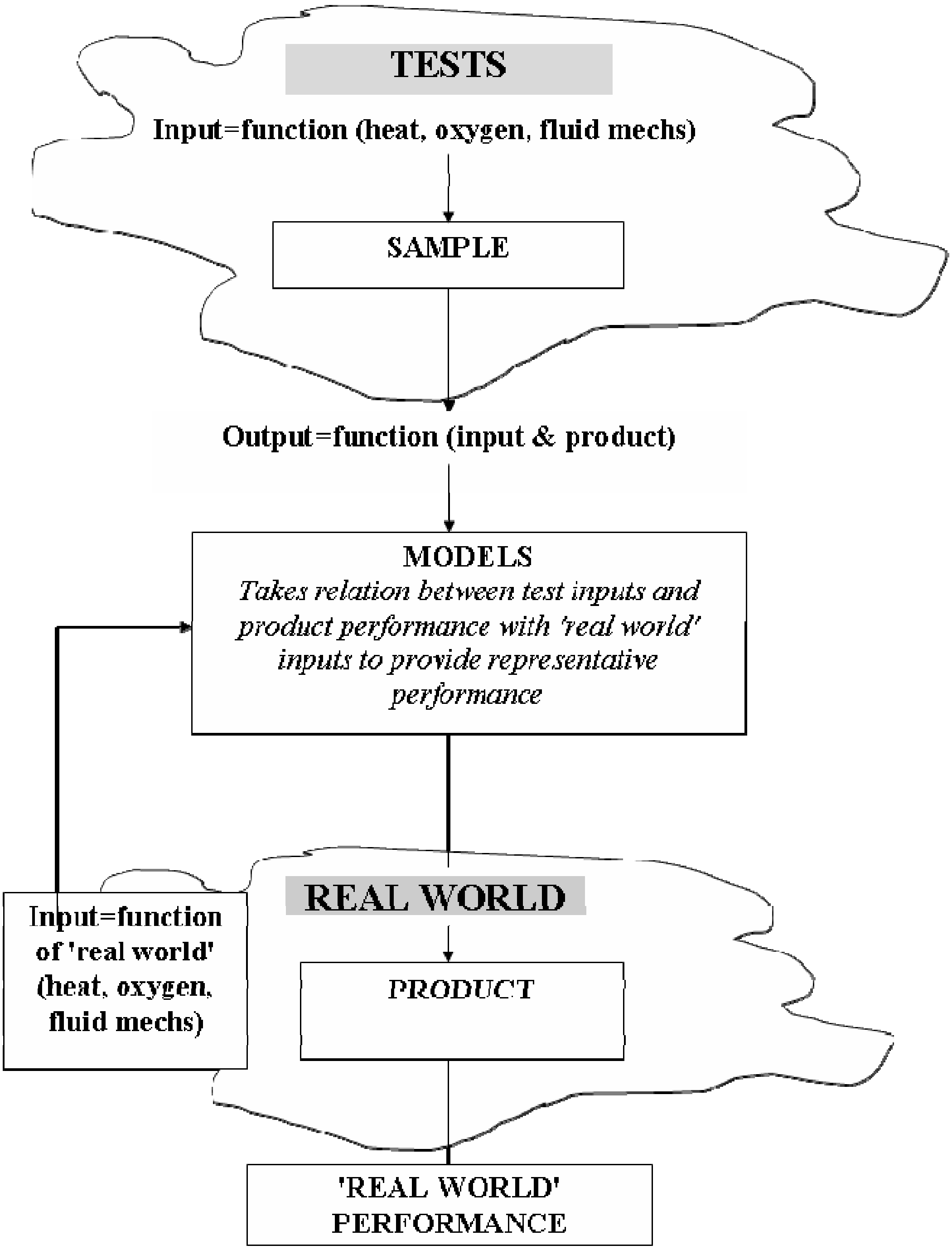

Figure 10. Schematic Showing Proposed Role of Physical Tests and Fire Models in Fire Safety Engineering

A FIRE RESEARCH STRATEGY

Erosion of the science base has been raised repeatedly by the scientific community for many years. Strategic Research programmes have been identified, costed and even agreed by a consensus of stakeholders but ignored.

In 1995 the Construction Sponsorship Directorate of the building ministry of the time, the Department of the Environment (DoE) published "A Research Strategy for the Fire Safety Engineering Design of Buildings"[26]. The advisory panel that developed the year strategy comprised members of the DoE, the Home Office, HSE, Ove Arup, BAA, Loss Prevention Council and the Fire Research Station. Nine areas of scientific research were identified as requiring attention with the objective of:

"……achieve by the year 2005 a scientifically based and fully developed Fire Safety Engineering package (methodology furnished with appropriate calculation methods and data) that can be applied in a cost-effective way to the design and management of buildings………."

This document made no impact and partly as a result of this and other concerns for the lack of strategic thinking, Dougal Drysdale and Dennis Davis wrote, on behalf of the IAFSS and the IFE, to the Chief Scientific Advisor to the Government explaining the problem and calling for action to establish such a research programme [27]. Various initiatives followed, including an Interdepartmental Fire Research Group under the auspices of the Chief Scientist's Office of Science and Technology, a Fire Research Task Group within the Fire Safety Advisory Board of the ODPM, and an EPSRC network, FERN each coming to a similar suggestion [28, 29] but to my knowledge there has been no action taken.

The problem is not confined to the UK although it has been arguably most acute here. Similar discussions have taken place in the US and in the European Union. The US Engineering Foundation suggested a similar strategy early in 2001 [30] but perhaps understandably focus was diverted to understanding the fires at the World Trade Centre and their implications. A Committee of the US National Research Council argued in 2003 [31], however, that these events should not detract from the fundamental fire research needed in support of engineering practice. In the EU, despite similar initiatives [Peters 32, Benefeu 33] there has been no coordinated strategic research.

There is no need to repeat here the detail requiring research effort in areas such as fire growth and spread, structural response and human egress. They are clearly identified in the various documents referenced above and require effort from all the contributory disciplines that go to make up fire safety science.

CONCLUSION

I have chosen a very narrow topic for illustration purposes in this lecture. There are many others that are in urgent need of research. With an increasing reliance on computer models that incorporate current capabilities, it is particularly important that they be challenged by experimental data obtained for this specific purpose and by blind simulation exercises such as that facilitated by CIB W14 in 1998 [34].

I started this lecture by pointing out the influence of political change and fashion on the development of fire safety provision. At the time when Philip Thomas started his career the vital contribution of scientific research to the successes of the second world war were still fresh in the public's memory and although times were initially austere there was a greater appreciation of to the contribution that research can make to all aspects of national life.

The current climate is much more agnostic, meaning that the current practice of fire safety engineering which is so critical for the safe implementation of performance-based building control is heavily dependent upon the scientific research of that earlier period. There are many gaps in that knowledge and areas in urgent need of underpinning scientific research to ensure the safety of the discipline and for innovation in the delivery of safer materials and products.

It is far more efficient to conduct generic research that can be applied to whatever threat appears over the horizon rather than to repeatedly set up short term research programmes to solve the particular whim of the day as has been the habit of recent years. Solutions so obtained are inevitably problem-specific and subject to failure in unforeseen ways.

The growing maturity of fire engineering came at a time of a world-wide political trend to performance-based regulatory reform particularly in the construction sector. The reasoning was based upon deregulation. Allow the responsibility for the fire safety of a structure to be that of the designer not of government. With such a flexible approach design can, when done properly, be more cost effective, innovative and aesthetically pleasing and the costs of regulatory control reduce.

However its safe exploitation is dependent upon an robust foundation of scientific research. There are many areas of fire science that demand our attention but are unsupported. It is essential that these are addressed before fire safety engineering can achieve the maturity of the more traditional engineering disciplines. I fear that it will only be following a tragedy where fire safety engineering practice may have been seen to have been wanting that the need for a strategic programme of scientific research will be recognised again.

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