

# The International Bushfire Research Conference 2008

incorporating **The 15<sup>th</sup> Annual AFAC Conference**



The Adelaide Convention Centre, Australia Monday 1 - Wednesday 3 September 2008

Title: **Scenario Analysis in Fire Engineering of Major Projects**

Author: P. F. Johnson, D. Boverman, C. E. Johnson

**Disclaimer:** This paper represents the views of the author and does not necessarily reflect the views of AFAC, Bushfire CRC or an individual AFAC member agency, nor indicate a commitment to a particular course of action.

The information is provided solely on the basis that readers will be responsible for making their own assessment of topics discussed herein.



# Scenario Analysis in Fire Engineering of Major Projects

P. F. Johnson<sup>1</sup> , D. Boverman<sup>2</sup> , C. E. Johnson<sup>3</sup>

*1 Fire Engineering, Arup, Melbourne, VIC, Australia*

*2 Fire Safety Division, NSW Fire Brigade, Sydney, NSW, Australia*

*3 Psychology, LaTrobe University, Melbourne, VIC, Australia*

## ABSTRACT

Many countries now permit the use of a performance based approach to fire safety design for major construction projects such as high rise buildings, road and rail tunnels, and airports.

The most significant input to a fire engineering analysis is the choice of fire scenarios and related design fires, since they underpin the ensuing fire safety design and its authority approval. Underplaying the design fires could result in inadequate protection and the unacceptable possibility of major fire incidents; being too conservative and design requirements could become unrealistic, unachievable, and uneconomic.

CRC research in Australia on the use of worst case scenarios for bushfire incident control is now providing some ideas for better building fire engineering. The risk approach in industrial fire protection is also assisting in developing guidance on an improved methodology for design fires for major construction projects.

Key to this improved, systematic approach is a more structured identification of all credible fire scenarios and their classification into those for standard design, those for testing design beyond standard limits, and those which are extreme events and beyond design. Further consideration of the required expertise amongst those involved in scenario planning is also an issue.

This fire scenario technique has been trialled on a major road tunnel project, and is being considered for a national standard. The hope is that the approach will gain broad fire community acceptance and incorporation in fire engineering guidelines or codes of practice.

This approach should allow a more structured, consultative process between design teams, certifiers and fire authorities and lead to more robust designs of major projects in Australia and internationally, and achieving design fire safety levels commensurate with community expectation.

## INTRODUCTION

Australia is one of a number of countries that has introduced a performance based building code that encourages the use of fire safety engineering analysis to support Alternative Solutions for building and infrastructure design.

As a result, fire safety engineers are involved in a wide range of projects from office, residential and retail buildings to more complex infrastructure projects such as stadia, rail stations, airports and road tunnels.

Some projects subject to fire engineering analysis involve minor deviations from the more traditional prescriptive or Deemed-To-Satisfy (DTS) solutions offered by the code. Typical

accepted solutions might involve extended travel distances or minor reductions to fire resistance levels, which are substantiated by appropriate fire modelling and/or qualitative arguments.

Other building projects might involve more radical or innovative fire safety design, including:

- Use of single stairs in lieu of two stairs in a DTS solution.
- Very large compartment sizes.
- Use of unprotected steel structure or significantly reduced fire resistance levels (FRLs).
- Passive protection measures rather than automatic sprinklers specified in a DTS solution.

In these cases, the designs may be far from the “norm” and establishing the adequate safety represents more of a challenge.

These concepts of larger compartmentation, unprotected structure, partial or no sprinklers are also often seen along with large populations in sports stadia, airport, rail station complexes and other infrastructure projects.

In the fire safety engineering of all these projects where the DTS solutions are not followed, the most significant input to the supporting fire safety engineering analysis is the choice of fire scenarios and related design fires used for analysis. Those scenarios and design fires underpin the analysis and fire safety design and its approval by the relevant authorities.

If the appropriate fire scenarios are not identified and the right design fires not used, then the fire safety design could be fundamentally flawed. Underplaying the design fires could result in inadequate protection and the unacceptable possibility of major fire incidents and/or loss of life; being too conservative could lead to overly onerous design requirements which make a building design totally unachievable or uneconomic.

The question is how do we get the right balance and help the designers get the right solution that offers an adequate level of fire safety that meets the Performance Requirements of the Building Code of Australia (BCA)?

This paper examines decision making techniques used in other fields of fire safety to suggest a new approach to fire safety analysis and design that is being trialled on major projects. The hope is that this new approach will yield a nationally agreed methodology for development of fire scenarios and design fires which will underpin more robust fire safety solutions, particularly for highly innovative buildings or major infrastructure projects.

## **FIRE SCENARIO DEVELOPMENT**

Fundamental to the process of fire safety engineering is the proper evaluation of fire hazards and the resulting developments of fire scenarios. These are then translated into design fires which provide the “load” in any fire engineering analysis and fire risk evaluation. This could be argued as the most critical part of the overall process embodied in the International Fire Engineering Guidelines<sup>[1]</sup> or their equivalents in other countries such as the SFPE Performance Based Fire Protection – Analysis and Design of Buildings<sup>[2]</sup> used in the US.

These key steps of hazard analysis and fire scenarios/design fire development form critical elements of Fire Engineering Brief (FEB) report which is the first part and forms the needed basis of any fire safety design.

In fire safety engineering for the built environment it would seem that the process of hazard analysis, development of fire scenarios and choice of design fires for fire engineering calculations are somewhat problematic. This message comes through strongly in research articles by Bukowski<sup>[3]</sup>, Koffel<sup>[4]</sup> and Meacham<sup>[5]</sup>, despite fire engineering guidelines stressing their importance. This is further supported by wide discrepancies that have been observed for scenarios and design fires adopted for similar issues (AFAC reviewing agencies).

A review by Johnson<sup>[6]</sup> highlighted that part of the problem may stem from the lack of clarity in many guidelines documents on matters of:

- Definition of what constitutes “worst credible scenario”.
- How to address issues of redundancy and uncertainty.
- Very limited direction on safety factors and sensitivity analysis.
- No proper consideration of “high challenge fires” or extreme events.

The failure of the fire safety engineering community to grasp the importance of these elements of the fire engineering process has prompted some such as Meacham<sup>[5]</sup> to recommend that design fires in building regulations be prescribed. To some extent this has occurred in NFPA 5000<sup>[7]</sup> and it is understood that this approach is being considered by building regulators in New Zealand and Australia.

The problem is the same as applying generic prescriptive building code requirements to individual, special or innovative building designs. It just does not work, and variations or modifications need to be made to code requirements as has always been the case for building codes prior to BCA 96<sup>[8]</sup>.

A more productive approach would seem to be to develop a robust methodology for the development of fire scenarios and design fires that could be agreed by the fire engineering profession, regulators and certifiers and used on all projects. This could be enshrined in guidelines documents and codes of practice and become the way of improving fire engineered design solutions.

## **CRC RESEARCH**

The development of new approaches or methodologies to addressing industry problems often benefit from examination of research or practice in different or related fields. This is the case here.

The Co-operative Research Centre (CRC) on Bushfire Research is currently sponsoring research into use of worse case scenarios in decision making by fire fighters and incident controllers in bushfire fighting<sup>[9]</sup>.

This research in turn is relying upon a field of psychology called naturalistic decision making that offers considerable insight into dealing with low probability, high consequence events which might be one way of describing “worst case scenarios”. These are rare events often unlikely to have been previously experienced by those responsible for the decisions.

Research by Klein<sup>[10]</sup> has indicated that decision makers in bushfire settings regularly perform well under complex and hazardous conditions, particularly when events develop along familiar lines. However, he suggests that a lack of experience with worst case scenarios could impair the

ability to identify major unexpected catastrophes, unless decision makers are made aware or given tools or training to recognise their extreme events.

This CRC research<sup>[9]</sup> further suggests that considering worse case scenarios is not about planning for every possibility; it is the ability to see, admit, process and consider possibilities with very serious outcomes. Clarke<sup>[11]</sup> has argued that decision makers should be planning better for disasters and extreme events, as unexpected catastrophes are starting to occur far too often. Clarke suggests unexpected events must be considered and outcomes imagined, ensuring appropriate risk assessment and better decision making.

The recent reports on the major bushfires in the ACT<sup>[12]</sup> and South Australia<sup>[13]</sup> have similarly highlighted the fact that a lack of full consideration of “worst case scenarios” may have contributed to less than favourable outcomes in these events.

The implications for building fire safety design are that a failure to properly consider worst case scenarios could lead to inadequate designs and in the extreme, disastrous outcomes in fire situations.

Another important issue is the suggestion that experienced decision makers generally perform well in more familiar situations but even experts do not perform well when the tasks depart from the expert’s familiar tasks<sup>[14]</sup>. This suggests in fire engineering that where designs are close to the DTS provisions (i.e. the “norm”), most fire engineers and certifiers should be able to make reasonable judgments about fire scenarios, design fires, acceptance criteria and overall analysis, assuming they have an appreciation of the associated scenarios and the levels of performance intended. However, it equally suggests that more innovative building designs far from the DTS provisions or for highly complex infrastructure projects, fire engineers should involve a wider range of specialists who can contribute their expertise and make sure all fire scenarios are properly identified and evaluated.

## **INDUSTRIAL FIRE PROTECTION**

The field of industrial fire protection generally uses a much more structured methodology in the development of fire and explosion scenarios. These scenarios are typically utilised in quantitative risk assessment (QRA) and result from a very thorough evaluation of process design, hazard analysis, scenario development and risk analysis, examining both frequency and consequences of all critical scenarios.

Practitioners in this field use a wide range of techniques such as “What if” analysis, HAZOP, Failure Mode and Effects Analysis, and other methodologies to uncover all scenarios which could lead to disastrous outcomes.

Barry<sup>[15]</sup> has written extensively on these approaches and has highlighted a form of analysis which is based on three groups of moderate-high risk fire hazard scenarios, namely:

- Design basis events.
- High challenge events.
- Worst case events.

He indicates that the high challenge events are those which may require additional protection measures, and worst case events, while not used for design still should be considered to make sure they are scenarios of very low, remote possibility.

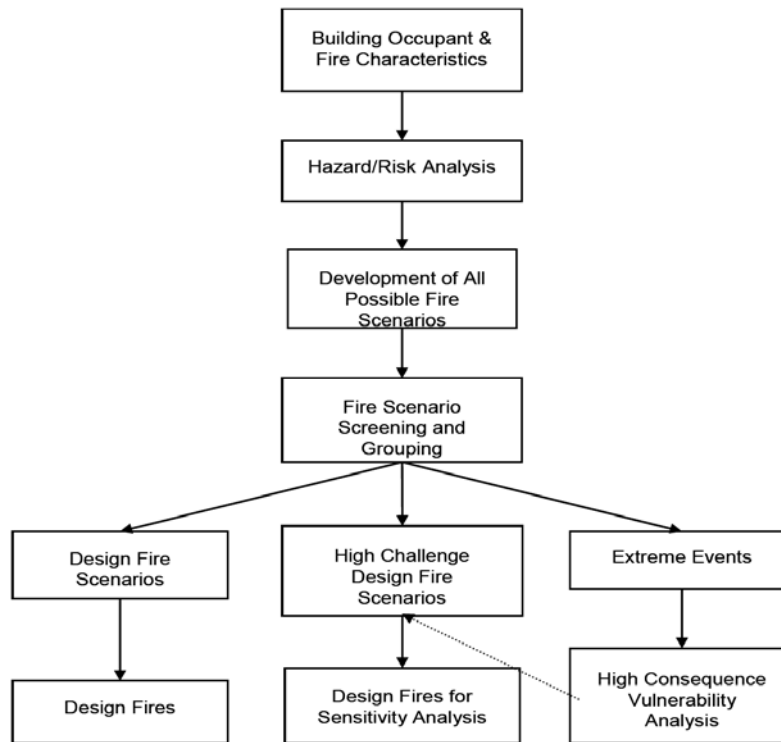
Translated into building and infrastructure fire safety design, such worst case events or extreme events could be a major terrorist bomb leading to a fire in commercial building or the BLEVE of an LPG tanker in road tunnel. While we may not be able to design fire protection systems to economically protect occupants from such events, they are scenarios which must be recognised, considered and mitigated against through other means, such as security provisions, or prevention techniques.

**FIRE SCENARIO FRAMEWORK**

Consideration of what we can learn from other fields, and as development of our own FEB process in fire engineering, the analysis of all possible fire hazards leads to the development of three groups of fire scenarios, viz:

- Design fires
- High challenge fires (for sensitivity testing)
- Extreme events (scenarios beyond design)

This framework is set out in Figure 1 below.



**Figure 1: Fire Scenario and Design Fire Framework**

A key element of this framework is the proper analysis of fire hazards as the forerunner to scenario development. Often such hazard analysis is very superficial in fire engineering reports and this is an area where fire engineering guidelines could be strengthened. In particular fire engineers should examine:

- Cause and origin of fires in the particular building occupancy being designed.
- Data on first item ignited and the likelihood of spread.
- The impacts of geometry on fire development and spread through radiation feedback from walls and ceilings/roofs.
- Frequency and consequences of fires and initiating events for the particular occupancy.

There are many good sources of this data which include:

- SFPE Handbook of Fire Protection Engineering<sup>[16]</sup>
- PD7974 – Application of Fire Safety Engineering Principles to Fire Safety Design of Buildings<sup>[17]</sup>
  - Part 6: Human factors
  - Part 7: Probabilistic risk assessment
- Factory Mutual- Data Sheets<sup>[18]</sup>
- NFPA Fire Protection Handbook<sup>[19]</sup>

More recently we have seen the publication of preliminary statistical data for fires in buildings published in the FPAA Fire Journal based on the AFAC National Incident Database<sup>[20]</sup>.

The next step after hazard analysis is to determine the three sets of fire scenarios from which design fires are going to be developed. These need agreement of all the relevant stakeholders, and will vary from one project to another but the three categories might typically be:

- Design fires – reasonable fire growth rates, assuming all fire protection systems are operating satisfactory and with a substantial safety factor (ASET/RSET > 1.5 or 2.0 for example)
- High challenge fires – higher growth rates, peak populations, failure of one fire protection system (e.g. sprinkler or smoke control), fire ignition in a particularly onerous location (e.g. single stair) – in this case the safety factor for ASET/RSET might be reduced.
- Extreme events – scenarios not for analysis or design such as major arson with multiple ignition sites, terrorist bomb attacks, aircraft collision leading to fire (although the likelihood and investigation for these events needs to be considered and agreement reached and documented on methods of mitigation).

One particular aspect of scenario development requires particular attention and that is the location of fire ignition relative to building design. There are some buildings where the occupants may be particularly vulnerable to fires in one location but not another. For example, in a low rise, single stair office building, a fast growing fire may represent a bigger threat if located close to the single exit door than if it is located in the far corner of the office floor. Similarly a fire in a retail unit close to a passage discharging occupants from an internal stair to the outside of a building may be a more hazardous location rather than the same fire in an individual office on an upper floor.

Another key aspect of this scenario development is who is involved in the identification of hazards and the development of fires for analysis. This goes back to the issues of the distance the fire design is from the “norm” and the experience and expertise of the fire safety engineer, certifier, fire authority and others in the review process.

The approach has to be cost effective and timely in terms of project delivery and approval. For designs with solutions close to the DTS provisions, it could be agreed that an experienced fire safety engineer and certifier, consulting with the appropriate fire authorities on relevant matters, should arrive at an acceptable fire engineered solution that meets the Performance Requirements of the BCA.

The number of fire scenarios to be considered might be relatively low, and the identification of the three groups of scenarios and design fires relatively straightforward.

On the other hand, design solutions far from the norm, e.g. unprotected steel structures, single stair high rise buildings, major airport terminal buildings etc, would seem to demand a much more thorough consideration of hazards and fire scenarios. It also suggest the involvement of a wider team of specialists, in some cases facilitated by a very experienced fire safety engineer or external hazard/risk facilitator, to ensure all potential major consequence scenarios are uncovered.

This is where fire authorities experienced in major fire incidents and fire fighting can throw particular light on reasons for fire growth and the likelihood of serious consequences. Often these projects will demand independent peer review or reviews, just as proof engineers and independent verifier work in other fields of engineering such as structural design.

To think that inexperienced fire safety engineers and/or certifiers can develop complex and highly innovative designs in isolation is to create unnecessary risk to building occupants and communities which other fields of engineering and design would regard as unacceptable.

## **FRAMEWORK APPLICATION**

This framework has been used as the basis for discussion of fire scenarios and design fires on at least one road tunnel project in Australia, and is now proposed for other projects. Some details of this approach are included in a recent SFPE conference paper presented in New Zealand<sup>[21]</sup>.

Such an approach is also being considered by Standards Australia Committee FP-023 involved in preparing a standard for tunnels in Australia/NZ.

In this case, the high challenge fires for road tunnels may involve scenarios such as:

- Congested traffic situations.
- Failure of deluge systems to control the fire.
- Fire growth at ultra-fast rates or beyond.

However, high challenge fires would not include ultra-fast growth rates (or faster), congested traffic and multiple failure of systems occurring simultaneously if the probability of this were to be determined to be beyond what would be considered “worst credible” as agreed in the FEB or standard methodology proposed to be developed.

## **CONCLUSIONS**

- There is concern that decision makers should be planning better for disasters and extreme events, as unexpected catastrophes are starting to occur far too often

- It has been suggested that experienced decision makers generally perform well in more familiar situations but even experts do not perform well when the tasks depart from the familiar<sup>[14]</sup>
- The development of fire scenarios and design fires is critical to proper fire engineering analysis and robust design.
- Research in the area of bushfire incident control and the field of industrial fire protection provide some insight into how fire safety engineering could improve in this area of decision making.
- A framework has been outlined for development of fire scenarios and design fires that could ensure more robust fire safety designs for buildings and infrastructure particularly for those facilities that are highly innovative and far from the “norm” of DTS provisions.

## REFERENCES

- [1] IFEG (2005), *International Fire Engineering Guidelines*, DBH, NZ; ABCB, Australia; NRC, Canada; ICC, USA; 2005.
- [2] SFPE Engineering Guide, *Performance Based Fire Protection – Analysis and Design of Buildings*, NFPA, 2006.
- [3] Bukowski, R.W., *Determining Design Fires for Design Level and Extreme Events*, 6th International Conference on Performance Based Codes and Fire Safety Design Methods, SFPE, June 14-16, Tokyo, 2006.
- [4] Koffel, W.E., *A Methodology to Analyse the Concept of Balanced Design*, Fire Protection Engineering, SFPE, Spring 2006.
- [5] Meacham, B., *Towards Development of Codified Design Fires for Use in Performance Based Building Regulation*, Discussion document – 4, August 2006.
- [6] Johnson, P.F., *Use of Worst Case Scenarios in Fire Safety Design*, NFPA Annual Meeting, Boston, June 2007.
- [7] NFPA 5000, *Building Construction and Safety Code*, National Fire Protection Association, Quincy, USA, 2003.
- [8] BCA96, *Building Code of Australia*, 1996 Edition, Australia Building Codes Board, Canberra
- [9] Johnson, C., *The Use of Worst Case Scenarios in Decision Making by Bushfire Fighters*, Proceedings of the 8th International Naturalistic Decision Making Conference, California, USA, June 2006.
- [10] Klein, G. A., *Sources of Power: How People Make Decisions*, Cambridge MA, MIT Press 1998.
- [11] Clarke, L., *Worst Cases; terror and Catastrophe in the Popular Imagination*, Chicago: The University of Chicago Press, 2006.
- [12] Mcleod, R., *Inquiry into the Operational Response to the January 2003 Bushfires in the ACT (No. 03/0537)*, Canberra: ACT Government, 2003.
- [13] Smith, B., *Report of Independent Review of Circumstances Surrounding Eyre Peninsula Bushfire of 10<sup>th</sup> and 11<sup>th</sup> January 2005 (Wangary Bushfire)*, Retrieved March 5, 2007 from [http://www.service.sa.gov.au/contentPages/sagovt/EPbushfire\\_2005.aspx](http://www.service.sa.gov.au/contentPages/sagovt/EPbushfire_2005.aspx), 2005.

- [14] Ross, K. G., Shafer, J. K., and Klein, G., *Professional Judgments and Naturalistic Decision Making*, The Cambridge Handbook of Expertise and Expert Performance, Ed: K. Andrews Ericsson etc all; Cambridge University Press, USA
- [15] Barry, T.F., *Risk Informed, Performance Based Industrial Fire Protection*, T.B.Barry Publications and TN Valley Publications, Knoxville, USA, 2002.
- [16] SFPE, *SFPE Handbook of Fire Protection Engineering, Third Edition*, Society of Fire Protection Engineers, USA 2002.
- [17] PD7974 – *The Application of Fire Safety Engineering Principles to Fire Safety Design of Buildings*; Part 6: 2004, Part 7: 2003.
- [18] *Factory\_\_\_ - Data Sheets (various)*, Factory Mutual International, USA
- [19] NFPA, *Fire Protection Handbook*, Vols 1 & 2, 19<sup>th</sup> Edition, National Fire Protection Association, 2003.
- [20] AFAC, *AFAC National Incident Database – Statistical Assessment; Preliminary Report*, Fire Australia, 2008.
- [21] Johnson, P., Gildersleeve, C., and Williams, P., *Road Tunnel Fire Safety – Approach to Fire Scenarios, International Performance Based Fire Safety Conference*, SFPE, New Zealand, 2008.