A BALANCED APPROACH FOR ESTABLISHING FIRE PROTECTION REQUIREMENTS FOR CANDU PLANTS

S. P. Lee*, S.D. Nam**

* Fyrex Engineering Ltd. 6th Line RR #5, Orangeville, ON, Canada, L9W 2Z2

**Atomic Energy of Canada Ltd. 2251 Speakman Dr. Miss., ON, Canada, L5K 1B2

Abstract

Fire issues in a nuclear power plant are generally complex, often involving safety and/or regulatory implications that cannot be readily quantified. Selection of the most appropriate fire protection measures may require knowledge based rationale and alternatives, as well as consideration of a number of intangible factors.

Therefore significant assumptions and judgments are often required. When setting fire protection requirements, a balance needs to be struck between prescribing conservative requirements and allowing the designers to assess the individual hazards to determine specific requirements. Both approaches have their pros and cons and have room for improvements. This paper provides some discussion on how each approach can be improved to provide better fire protection design for a new CANDU plant like Advanced CANDU Reactor (ACR™*) and for the upgrade to existing plants.

Keywords: Prescriptive Based Approach, Performance Based Approach in Fire Protection, Fire Hazard Assessment (FHA), Fire Modeling, Defence-in-Depth philosophy, Advanced CANDU Reactor (ACR), Probabilistic Safety Assessment (PSA)

1. INTRODUCTION

There is a general consensus within the CANDU industry that additional fire protection requirements need to be established for new CANDU plants or for modifications to existing plants to increase the level of safety and to ensure uniformity in practice. The challenge to fire protection engineers is more than making the plants fire safe. This can be accomplished using current technology and applying conservatism at all levels of engineering. The true challenge is to achieve a level of fire safety, consistent with all established nuclear and life safety goals, without sacrificing safety or performance in other disciplines and to do so in a cost effective manner.

Generally, fire protection requirements may be established in two ways: by prescription or by assessment.

---

* ACR™ (Advanced CANDU Reactor™) is a trademark of Atomic Energy of Canada Limited (AECL).

Prescriptive requirements may be set by a regulating body, a technical standard, or an individual responsible for a design. The method is usually based on expert judgment on what is considered good practice and reflects the experience in the industry. Requirements are usually applied based on occupancy, type of usage of a floor area, type of equipment or some broad classification of hazard levels. Requirements generally contain sufficient conservatism to cover variations among the different buildings or variations in the hazards which they are intended to address. Until recently, building codes and many technical standards were prepared solely based on the prescription approach.

Setting requirements based on assessment of individual hazards is becoming more common in recent years. It is often called the performance-based approach or objective-based approach. The performance-based approach provides more flexibility as to the means of meeting those criteria. This process involves first setting the fire protection goals and objectives. The next step is to establish criteria that can be used to measure if the objectives are met. Then the fire hazards and consequences are assessed in each plant area to determine what specific measures are required to meet the criteria. For nuclear power plants, this involves a detailed assessment of the potential fires and their interaction with structures, systems, components and personnel and such work is documented in Fire Hazard Assessments (FHAs).

2. PRESCRIPTIVE APPROACH

The prescriptive approach establishes specific design requirements for the user. The bases for such requirements may come from derivation of fundamental safety regulations, conventional codes and standards, past CANDU plant practice, international nuclear plant practice, and lessons learned from fire events.

The advantages of this approach are:

- Requirements are usually clear and straightforward to apply.
- Requirements are known early in the design process.
- It covers many unknowns through the use of conservatism. Very often multiple levels of protection are used.
- There is less subjectivity, resulting in similar design or practice across plants.

The disadvantages of this approach are:

- The higher degree of conservatism may lead to a more costly design.
- The requirements may not account for unique hazards and therefore may not always be safe.
- Requirements are sometimes based on opinion and not always established in a rational manner.
- This approach does not encourage searching for other solutions and therefore provides less incentive for improvements.

3. PERFORMANCE-BASED APPROACH

The assessment approach allows the user to select a design that is based on the specifics in each area of application.

The advantages of this approach are:

- It addresses specific hazards and constraints of each plant area, resulting in a more efficient design.
- It involves a systematic identification of hazards from area to area; it may identify unique fire hazards or design constraints that have not been assumed in prescriptive based design.
- It provides more flexibility as to the means of meeting the fire protection objectives.

The disadvantages of this approach are:

- There are limitations in our ability to predict fires and consequences.
- Subjectivity in judgment can result in some variation of design even in similar situations.
- When a fire occurs that is different than what was assessed, there may be insufficient protection.
- In some situations, a significant effort is required to assess the potential fires and consequences.

4. BALANCE OF BOTH APPROACHES

Given the current state of art in fire protection technology, neither approach alone is sufficient for determining fire protection requirements in a nuclear power plant. Fire protection engineering therefore should employ both approaches in a balanced manner, with each approach complementing each other. The prescriptive approach should provide the broader framework while the performance approach should provide the focus on specifics. The prescriptive approach is more appropriate in setting the overall concept and basic design features in the plant while the performance-based approach is more appropriate for determining additional features or detailed requirements on an area or system basis. The performance-based approach can also be used where certain prescriptive requirements are impractical or too costly to apply. On the other hand, when a particular fire hazard proves too difficult to assess the designer could resort to a "fix it rather than to analyze it" approach. While there are pros and cons in each approach, there are ways of improving on each of these two approaches. These areas are discussed in more detail in the following sections.

5. IMPROVING ON THE PRESCRIPTIVE APPROACH

5.1 Diverse Opinions

Requirements that have significant impacts on plant design and operation should be set only after concerns from all viewpoints have been considered. This often requires participation of a sufficient number of experts to ensure diverse and qualified opinions have been considered. In a performance-based approach, each step of assessment and decision-making follows a rational method and is documented. By comparison, prescriptive requirements are often based on broad judgment, with no specific steps and criteria. Users of prescriptive requirements often do not know the justifications behind the requirements.

The Canadian Standards Association CSA N293 technical committee on fire protection for CANDU nuclear power plants, in their current work to revise the fire standard, put in significant efforts to ensure diverse opinions. A large number of fire protection professionals, from both within and outside the nuclear industry were involved in the committee work. Further, the draft standard was circulated to the public for comments. Efforts were also made to provide notes on major requirements to explain their basis or safety intent.

Diversity of opinions can also be improved through comparison with international practice. In this way, the opinions and experiences from other countries are considered. Consistency with international practice also improves the marketability of the CANDU reactors. Those in a position to establish prescriptive requirements should be familiar with practice in other countries.

5.2 Understand the Plant Design and Safety Principles

While diversity of opinion is an asset, those in a position to prescribe fire protection requirements should also have sufficient understanding of CANDU plant design features and the safety principles used. In particular, there is a need for fire protection features to be an integral part of the plant design rather than add-ons. A nuclear power plant is a complicated web of structures, systems and people. One cannot look only at the fire protection merits of a requirement without considering its impact on the rest of the plant. Fire protection practice should be consistent with the fundamental safety principles used in the plant design. Conflicts should be resolved so that the overall plant safety objectives are met. In general, there is sufficient flexibility in fire protection design to avoid conflicts with other plant requirements. However, the application will require a good understanding of the other design and safety disciplines. Fire professionals coming from outside the nuclear industry should acquire sufficient nuclear plant knowledge to better apply their expertise in providing fire protection solutions.

5.3 Learning from Fire Incident Data

A good understanding of fire incidents that have occurred in CANDU plants as well as nuclear power plants worldwide could have significant benefits to a requirement making process. As a minimum, requirements should be put in place to prevent recurrence of fire incidents that have led to major losses or safety impacts. In addition, insights from fire incident data and fire protection system operation experience could point to where emphasis should be put in future design. For example: there is currently some debate within the CANDU industry on the level of redundancy and reliability required for the power supply to fire alarm systems. The authors have reviewed a large pool of nuclear power plant fire incident and operating records [1, 2, 3, 4] and found no record of fires that were undetected due to total loss of power to the alarm panel. The data supports the argument that a power supply from the plant’s Class 2 or 3 power system plus dedicated system batteries is very reliable. The fire data also showed many incidents where fires were not detected quickly due to a lack of detectors or slow response of available detectors. There were also specific cases of failures of fire alarm systems due to hardware or software problems. The insights from such a review could be useful in the debate on where improvements in fire alarm system design should best be made. More discussions on the use of fire incident data are given later in this paper.

5.4 Flexibility in Application

Even after the most thorough considerations in the requirement making process, it is impossible to envisage every case of application. There is a common misconception that all CANDU plants are of the same or similar design. While they share a similar reactor design, the structures, layout, systems and components are different and they present different fire hazards and design challenges. The single unit CANDU 6 plants are very different than the multi-unit Ontario plants. Each of the Ontario plants is different as they represent a different generation of technology and design evolution. The Advanced CANDU Reactor (ACR) plants will also be different due to adoption of new technology. Prescriptive requirements should therefore be set with sufficient generality or flexibility so the same safety intent can be applied across different plants. Otherwise, requirements that are intended to help achieve good design become obstacles that must be overcome before one can achieve a good design.

There should also be flexibility to accommodate changes in fire protection technology and design creativity. For example, there is general consensus that sprinkler systems should be used more widely in new plants. However, over-emphasis of this requirement could discourage designers from putting efforts in fire prevention. In fact, under certain scenarios, a sprinkler poses a threat to nuclear safety. Particularly in advanced reactor designs, major fire hazards should be designed out if practicable, rather than just covered by a fire suppression system.

5.5 Improvement of Fire Protection Program

A good fire protection design should be able to compensate for some fluctuations in the standard of plant operation and common operator errors. However, design alone could never eliminate the need for a good fire protection program. Advanced reactor designs tend to employ more passive or inherent safety features but no feature is immune to defeat by human action. Over-emphasis of design capability can have a negative effect on the attitude of plant operating staff. For a high level of fire safety to be achieved, both design and operation must hold up their share of responsibilities.

6. IMPROVING ON THE PERFORMANCE APPROACH

6.1 Development of Fire Modeling Techniques

Fire modeling involves establishing a design basis fire for each compartment or zone, and estimating the fire initiation, growth and resulting conditions within the plant. The subject of fire modeling is too large to cover in this paper. There are numerous references that discuss the strengths and weaknesses of different modeling tools. This field is under fairly rapid development, especially after the introduction of performance-based building codes and standards around the world. When a fire protection design is based on fire models, the fire analysts should carefully consider the limitations and uncertainties involved in the models used, and employ suitable conservatism in the design to compensate.

It is worthwhile to point out two common misconceptions.

a) Performance-based methods do not always have to involve detailed, quantitative fire modeling. In some cases, fire modeling may not be possible or necessary. Qualitative assessment coupled with engineering judgment may be used, so long as the fire protection objectives and criteria can be shown to be met. It is worth pointing out that even the most detailed fire modeling is only a tool to provide insights for decision making. No modeling can produce a direct answer on adequacy.
b) Fire hazard assessments (FHA) need not always be performance-based. Some assessments or some part of an assessment may involve no more than a demonstration that the prescriptive requirements have been met. For example, FHAs for US nuclear power plants involve mostly a demonstration that requirements of the regulations (10 CFR 50 Appendix R) have been met.

6.2 Addressing Secondary Effects of Fires

Secondary effects of fires generally refer to the effects of smoke, toxic and corrosive gases, and fire suppression. In contrast, thermal effects are usually considered the primary effects. One of the characteristics of fires in nuclear power plants is that the thermal effects are usually low but secondary effects are usually high. Of course, there are exceptions, such as in the turbine building and a few other areas with significant inventories of hydrocarbons. Electrical fires are one of the most frequent types of fires in nuclear power plants. Indoor electrical fires seldom release significant heat but could produce very dense smoke and toxic gases, affecting fire fighting action, and causing immediate as well as longer term equipment damage. If water is used to extinguish these fires, there is potential for water damage to the equipment involved as well as equipment in the surrounding, or even on the floors below. Further, it is often necessary to shutdown power supplies to equipment as part of the fire fighting process. These actions could potentially cause failures of plant equipment such as switching off the wrong equipment. Past fire assessments and fire modeling often focused on heat release and temperature rise. For an electrical fire inside enclosed plant areas, such a focus could result in the secondary effects being ignored or not addressed adequately.

Currently our ability to deal with secondary effects lags behind our ability to deal with thermal effects. While there are computer codes that can be used to predict smoke travel, these codes require detailed inputs about openings in the fire compartment and about mechanical ventilation flow. Openings in a fire compartment may not be known in detail at the early stage of design. Ventilation flow, on the other hand, may not be fully determined even after the plant is fully constructed and in operation. Flow volumes and directions are usually only approximated in design. In an operating plant, they can change due to weather (heating or cooling modes) and plant operating status. Further, they can also change during a fire. For example, doors could be opened, fans could fail or be shutdown and fire dampers could close. There are some techniques to address these variations. One of these is to model different cases of ventilation patterns to determine which one or a combination would be the most severe. The most severe case would then become the basis for design.

In terms of assessing equipment damage due to the secondary effects of fires, while some relative ranking orders are available, there is not much data on the damaging effects of products of combustion on each piece of electrical and electronic equipment and components. For now, fire protection engineers should realize the limitations in this area and employ conservative design measures to overcome the uncertainties. One of these measures is the use of fire resistive and smoke tight barriers to separate redundant safety components. However, such measures may not be practicable in some locations (e.g., inside the reactor building).

6.3 Understanding the Limitations of the Assessment

Secondary effects of fires are only one of many areas where there are limitations to fire modeling and detailed consequence assessments. Human intervention during a fire (including errors) is another example. Within the CANDU industry, there is still a lot of debate on when and how one can credit fire fighting and operator actions.

It is the analyst's responsibility to identify limitations and uncertainties in the assessment. The fire protection design should demonstrate that sufficient measures are in place to cater to a range of outcomes. In some cases, it is easier to fix the problem than to assess the hazards. These fixes could involve elimination or reduction of the combustibles, preventing ignition, or putting in barriers to confine the effects of fires. For a new design, assessment and design should go hand in hand. However, for an assessment of an existing plant, options to change the design are more limited.

Employing a performance-based approach in fire protection is not contrary to the defense-in-depth principles. An assessment may indicate that one means is sufficient to meet an objective, but the analyst should decide if additional means are necessary given the insights from the assessment, including the uncertainties and the significance of the consequences. In this respect, one could regard the performance-based approach as a method to apply defense-in-depth principles.

6.4 Team Effort

On earlier CANDU plants, FHAs did not use rigorous performance-based methodology. They often used broad judgments of fire severity and extent of damage. Consequences of fires on plant systems were often determined based on general arguments or design concepts. As such, the work could be done by an individual with fire protection expertise and some plant design background. However, new requirements or expectations demand significantly more of a FHA, from justifications of the fire model, to the assessment of the consequences of fires on a component and circuit level. The assessment of circuit failures and their impact on fire safe shutdown demands an intimate knowledge of the electrical and control design of the plant, which is usually beyond the capability of fire protection engineers. Management and fire protection engineers should realize that future FHAs will have to be done as teamwork. The team should possess expertise in fire protection engineering, nuclear plant fire hazard assessment methods, plant design knowledge (particularly electrical power and control circuits) and nuclear safety principles. Assigning the FHA to one fire protection engineer, with a promise that others are available when needed, will not lead to an expeditious or thorough assessment. Design and safety engineers in the team can contribute to the establishment of the assessment methods to reflect the characteristics of the plant design, they can make data collection faster and more accurate and, and they can take on the responsibility for determining the consequences of plant impacts due to fires.

6.5 Reflecting As-built Details of a Plant

For a new plant design, the fire analysts often have no more than documents to work with. For a preliminary assessment to assist in defining the fire protection concepts and broad requirements, this level of input may be enough. However, the final assessment to demonstrate adequacy of fire protection in the plant will require a significant amount of details not contained or easily extracted from design documents. These details should be obtained or confirmed by field inspection when the plant is at a reasonably advanced stage. Further, changes could still occur from the time of these inspections to when the plant goes into full operation. A re-confirmation of the key data and assumptions should be made again. The latter could be done by the commissioning or operations group. The importance of design details to the outcome of a FHA is illustrated in the following example. A detailed assessment was made of a large oil fire at the heat transport pump motors. The analyst was aware of the limitations of fire modeling tools for the scenario and the uncertainties of some of the correlations used. It was believed that sufficient conservatism was used in assessing the degree of fire damage and impacts on the plant. However, a minor fire incident later revealed that the pump platform was not leaktight around the pump casing and oil could potentially flow down to the feeder cabinets and reactor vault below. This was not discernible through design documents. The consequences of this scenario out-weighed the impacts of most of the other fire modeling uncertainties and were not covered in the conservatism used.

6.6 Reflecting Plant Operating Conditions

Fire analysts without plant operating experience tend to see the plant exactly as it was designed. In an operating nuclear power plant, hundreds of people go about everyday to do various tasks. Large amounts of equipment, tools and supplies are brought in, and these could be significantly increased during an outage. Many components are tested, maintained and repaired. Design modifications also take place often during the lifetime of a plant. Assessments of earlier CANDU plants may not have given adequate consideration to fires caused by human errors and transient combustibles. A CANDU plant fire incident data summary was prepared many years ago from fire incident reports in Canadian CANDU plants [1]. A major finding of this summary was that a large percentage of fires were caused by people and involved ignition sources or combustible materials that were not part of the original design. This and other findings subsequently influenced the fire protection design and analysis in CANDU plants. Accounting for transient fire hazards is not easy to do. It requires a certain level of knowledge of plant operation, the control measures in place (such as hot work permits, housekeeping and transient combustible material procedures) and some way of gauging the effectiveness of the implementation of these control measures. An analyst cannot assume that simply because there is a procedure, it will be fully complied with at all times. On the other hand, excessive pessimism can create unrealistic scenarios that are impossible to design against. For example, it has been theorized by some that anywhere along the path used for shipping of lube oil for equipment maintenance, there was potential for an accidental oil spill and fire. This forces the design to cater to a large oil fire in most areas with mechanical components. The counter argument to this is that while a spill can indeed occur, attending operators are not likely to leave a large spill unattended for a long period, and the chance of ignition of a high flash point oil is low. In our opinion, scenarios of a large oil spill should only be considered in locations where the oil is regularly stored and handled. Along the paths of transportation and at the point of use, large spills may be assumed to be discovered and cleaned up in time to prevent ignition. However, unattended smaller spills and residues should be assumed credible.

Some design measures can be put in place to reduce the randomness of human errors so the FHA can be more accurate. One of these is to reduce the hazards of transient combustibles by designing adequate storage and staging spaces. Another one is to limit the spread of oil through curbing and containment. Even a small spill of oil could potentially spread over a large floor area, depending on the porosity, slope of the floor and drains. Since the burning rate of oil depends on the surface area, there could be large uncertainties associated with predicting the flow of oil. One measure that can be provided to reduce this uncertainty is to provide curbs and drip trays below all components prone to leakage. These are inexpensive, good fire prevention measures and at the same time they give the analyst a more assured boundary to calculate the oil fire area.

6.7 Fire Testing

Ideally, fire analysts should have at their disposal accurate heat release rates of fires on each type of component or array of combustibles in the plant, as well as the damage criteria of all targets they need to protect from fires. Obtaining this data requires a substantial testing program. Further, some of the tests cannot be carried out until the plant design and equipment specifications are complete. Most FHAs rely on generic data. Handbook information is limited and usually applicable only to residential or commercial fire hazards. Occasionally one can find in the literature results of fire tests on specific materials, cabling and equipment in other power plants. However, the results are seldom presented as handbook type of data. The analyst should exercise judgment in the application of such information. One of the factors to be considered is the differences in equipment between what is tested and what is used in the plant being assessed. Where the safety outcome of a fire depends heavily on an assumption of burning rates or damage criteria, specific fire testing may be required. These tests could be expensive and time consuming. By default, we can use a significant safety margin in the assessment or cover the uncertainty with fire protection features. However, there is a price to pay for these, too. For example, current FHAs often use US generic data for cable damage thresholds. For a new plant design, there should be a specific test on the specific type of cables used for their damage temperature and ignition temperature to provide more accurate data for the FHA and PSA. For the large quantities of cables that will be purchased, and the high potential impact of fires on cables, the efforts appear to be justified. Extensive fire tests on other components and materials may not be necessary. However, there should be some basis to justify the applicability of existing generic data, most of which are based on tests on older equipment, to the new equipment in a future plant. For example, new switchgear cabinets may contain less combustible materials than older equipment but the use of solid state technology may increase the vulnerability of the components to heat and smoke.

6.8 Learning from Fire Incidents

If we cannot always do fire tests on our equipment or materials we can at least test them by experience. Every fire incident is a test of the specific plant design. From each event, lessons can be learned on what failed and what succeeded. Collection of data on many events can produce trends and insights that add to our knowledge base and give perspective in decision-making. These insights will benefit both the prescriptive approach and performance approach.

The authors believe that fire incidents cannot be the only basis for important decision making. One cannot just say that something is incredible because it never happened in a nuclear plant before. On the other hand, by ignoring real life experience one can stray from reality and have the wrong focus.

It is common for fire engineers or fire fighters to picture every fire as a big inferno, based largely on fire experience in residential buildings, commercial/industrial buildings of combustible construction or buildings containing significant fire loads. The main structures of nuclear power plants are of noncombustible construction using mostly noncombustible interior finishes. By comparison to most other buildings, they have very low combustible loads in most areas. Further, these combustibles are segregated by space, walls or floors. It is necessary to be conservative, however, unrealistic assumptions not only push up the cost of fire protection, they could divert resources from other areas that could have a larger effect on safety. The following is an example:

Fire incident records indicate that, besides those fires involving combustible liquids (e.g., turbine, generator and oil filled components), most fires in nuclear power plants are of electrical origin, producing significant smoke and only moderate amounts of heat. If there is too much emphasis on the thermal aspects of fires, one may be pushing for higher sprinkler density, or bigger fire hose streams and not paying attention to smoke obscuration, human errors and electrical fault propagation. The authors have studied reports of a large number of electrical cabinet fires in nuclear power plants [1, 2, 3, 4]. The data reveal that the majority of fires on electrical systems had limited flame spread and low heat release rates. There were no reports of structural damage, no case of fire breaching fire barriers because the design had selected a fire rating too low, no direct damage to mechanical components and very few cases of thermal destruction of adjacent equipment or cables. However, the smoke conditions and inaccessibility often created delays or other problems in the plant response. Smoke damage and cleanup after some fires required significant effort and resulted in loss of production. The lesson learned from the data indicates that the common practice of simply specifying a fire suppression system is not sufficient. Sprinkler protection and even gas suppression systems usually cannot suppress fires within equipment cabinets. They could very well create more damage or keep fire fighters away. A combination of protection measures will have to be employed, involving separation of cabinets to reduce or limit the spread of fire, providing quick access to cabinet interiors for manual fire fighting, separating cable trays from fire hazards, providing means of smoke removal, and providing fire fighter training and pre-fire planning for this type of fires. Sprinklers or gas suppression systems, if deemed necessary, would be provided as backup protection, in case of failure to manually suppress the fire.

While there is a concern for overestimation of fire hazards, there is also a concern that fire hazards are ignored or under-estimated. In the past, some engineers have disposed of fire hazards too quickly where a large source of common combustibles was not present. Transient combustibles and oil leaks from components were not readily recognized. Some even ignored cables as combustibles, based on the cable fire test that shows a limited flame spread property. Fire incidents reveal many cable fires caused by external heat sources and some were caused by electrical faults.

It is our opinion that each fire protection engineer should study available fire reports related to nuclear power plants or industrial installations having similar fire hazards. The nuclear industry worldwide has gained significant experience from over 400 reactors, collectively accumulating thousands of reactor-years of operation. The IAEA has published an excellent report [2] containing fire incident data and related experience from most countries operating nuclear power plants. It is noted that no CANDU fire experience was included. US nuclear power plant data has been collected by EPRI and updated at least twice [3]. The recently published NUREG 1805 [4] contains detailed reports of a number of major fire incidents in US plants. These reports are detailed and offer valuable lessons for designers and analysts.

Fire incidents collected from Canadian CANDU plants have affected many design approaches and decisions since the 1980s. An operations exchange (OPEX) database is currently available from CANDU Owners Group (COG) for use by members. It contains over 1000 entries of fires and related events from CANDU and other plants. This database is regularly updated. Several years ago, CANDU fire data from this COG source, together with US fire data, was used to produce fire initiating event frequencies for fire probabilistic safety assessments [5]. Fire data is also useful in providing insights for deterministic fire protection design and assessments. The authors believe that an updated CANDU fire data summary should be prepared and published to benefit COG members as well as consultants involved in fire protection engineering in CANDU plants. The CANDU industry should also participate in international data banks such as the OECD Fire Incident Records Exchange [6] to be able to tap into a large pool of experience.

7. CONCLUSIONS

Better processes and requirements are now in place to address fire protection in CANDU plants. Still, it is a challenge to achieve all the goals of fire protection and satisfy all other design and plant operations considerations at the same time. Using both a prescriptive approach and a performance assessment approach in a balanced manner is consistent with Canadian and international standards of best practice. Both approaches have their strengths and weaknesses. The authors have expressed some opinions on where they can be improved upon. Improvement in the prescriptive approach can be achieved by considering diverse opinions, better understanding of the plant design and safety principles, learning from fire incident data and operating experience, allowing flexibility in the application of fire protection requirements, and putting efforts on both a strong design and a strong fire protection program. Improvement in performance-based approach can be achieved by continued development of fire modeling techniques and data, quantifying secondary effects of fires, understanding the limitations of the assessments, and reflecting plant design details and plant operating conditions. Fire hazard assessments should be done by a multi-disciplined team. It is hoped that these expressed emphases will lead to some new directions or at least some healthy debates within the industry.

8. REFERENCES

[1] Lee, S. P., "*Fire Protection in CANDU Nuclear Power Plants*", Proceedings of the CSNI Specialists Meeting on Interaction of Fire and Explosion with Ventilation Systems in Nuclear Facilities, Los Alamos, New Mexico, April 25-28, 1983.

[2] "*Experience Gained from Fires in Nuclear Power Plants: Lessons Learned*", IAEA TECDOC-1421, November 2004.

[3] "*Fire Events Database for US Nuclear Power Plants: Update through 1999*", EPRI 1000894, October 2000.

[4] "*Fire Dynamics Tools Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program*", NUREG 1805 Final Report, December 2004.

[5] Stretch, A., How Pak Hing, G., "*Development of Probabilistic Safety Assessment Methodology for Fire Events in CANDU Plants"*, International Workshop on Fire Risk Assessment, OECD Nuclear Energy Agency, Helsinki, Finland, June 29 to July 01, 1999.

[6] Roewekamp, M., Mathet, E., and Angner, A., "*Fighting Fire with Fire"*, an article in Nuclear Engineering International, May 2004.