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Fire Safety Lessons Learned from the Design and Operation of Commercial Nuclear Reactor Facilities

Steven P. Nowlen

Prepared by
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Prepared for
U. S. Department of Energy
Office of New Production Reactors
Washington, DC 20555

ABSTRACT

This report summarizes the fire safety "lessons learned" that have resulted from the past 20 years of commercial nuclear power plant operations and 15 years of U. S. Nuclear Regulatory Commission sponsored fire safety research. These insights are intended to provide guidance to the Department of Energy (DOE) in the selection of appropriate design, contruction, and operational fire safety criteria for the planned New Production Reactor (NPR). The potential for fire-induced equipment damage has been consistently identified as an important core damage risk issue for commercial nuclear reactors. A significant knowlege base regarding many aspects of fire safety has been gained as a result of the commercial industry experience, research sponsored by the U. S. Nuclear Regulatory Commission (USNRC) and from the results of fire risk assessments. However, for the commercial nuclear industry, the implementation of fire safety provisions has been a long and difficult process. Much of this difficulty can be attributed to the fact that the USNRC's fire safety regulations were implemented as retrofit rules, which often required extensive and expensive plant modifications. Despite the improvements in the fire safety knowlege base, a number of fire safety issues remain unaddressed, are very poorly understood, and/or have not been addressed by past fire risk assessments. For NPR it will be important to implement fire safety as a part of the plant design and construction. It is also clear that the regulations that apply to the current generation of commercial reactors will not represent an adequate design basis for new reactors. Anticipated changes in the nuclear industry fire safety requirements should be incorporated into the NPR design in order to ensure that NPR acheives a level of fire safety which both exceeds that of current reactor sites and which will continue to comply with future fire safety requirements.

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EXECUTIVE SUMMARY

For the commercial nuclear power industry, fire has repeatedly been found to be a dominant contributor to estimates of the frequency of core damage accidents. The implementation of fire protection has been a difficult process which has often placed the United States Nuclear Regulatory Commission (USNRC) and the nuclear utilities in harsh adversarial roles. This results largely from the fact that the USNRC fire safety regulations were imposed on the commercial industry as retrofit rules requiring, in most cases, extensive and expensive plant backfits.

This report documents the insights into nuclear power plant fire safety that have been gained throughout 20 years of nuclear power plant operations and 15 years of USNRC-sponsored fire safety research. For the Department of Energy (DOE) New Production Reactor (NPR), it will be important to recognize these lessons learned early in the design process. The information presented here is not intended to represent specific formal guidelines for NPR fire safety. Rather, it is intended that the information in this report be used by DOE in support of its development of appropriate design, construction, and operating guidelines and criteria.

By recognizing the lessons gained from past experience, the NPR designers can avoid many of the limitations that result in fires continuing to represent a significant risk contributor for commercial U.S. reactors. In many cases, the dominant fire risk scenarios identified in risk assessments could have been eliminated, or, at least, had their importance significantly reduced, through design modifications. However, when addressed through backfits, it is almost inevitable that some level of residual risk remains. Often, this residual risk is significant in comparison to overall plant risk.

It must also be recognized by the designers of NPR that the current USNRC fire safety regulations (i.e. Appendix R to 10CFR50) will not represent an adequate design basis for NPR, nor for future commercial reactors. Because the USNRC fire safety regulations were specifically developed as retrofit rules, they do not represent the appropriate design considerations for a new reactor. The USNRC staff has made clear through a recently issued staff position document (reference SECY-90-016) that fire safety provisions for new reactor designs will be significantly strengthened over those which apply to current reactor sites.

This report provides a number of design recommendations for the implementation of fire safety for NPR. Most importantly, it is recommended that NPR consider fire safety provisions as a part of the plant design, and that NPR anticipate the direction of future USNRC and national fire safety standards. A number of the recommendations which are made can be expected to have a significant impact on the design of NPR. One such area is the question of redundant train separation. In anticipation of the development of new USNRC fire safety regulations and consistent with the aforementioned USNRC staff policy document, it is recommended that the following be utilized as the fundamental NPR fire safety design requirement in the determination of appropriate train segregation:

> The NPR project must ensure that safe shutdown can be achieved assuming that (1) all equipment in any one fire area (where a fire area is defined as an area bounded on all sides by three hour rated fire barriers) will be rendered inoperable by fire, (2) reentry into the fire area for repairs and operator actions is not possible, and (3) any possible single active component failure in other plant equipment outside of the fire area due to nonfire related causes occurs (e.g., random failure, maintenance outages, sabotage, personnel errors). Fire detection and fire fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems and components important to safety and plant operation consistent with existing DOE requirements. Because of its physical configuration, the control room is excluded from this approach, provided a diverse independent alternative shutdown capability, including a dedicated decay heat removal capability, that is physically and electrically independent of the control room is included in the design. The NPR project must provide fire protection for redundant shutdown systems in the reactor containment building that will ensure, to the extent practicable, that one shutdown division will be free of fire damage. Additionally, the NPR project must ensure that smoke, hot gases, or the fire suppressant will not migrate into other fire areas to the extent that they could adversely affect safe-shutdown capabilities, including operator actions. The NPR project must provide for the management of fire suppressants after release, including water from manual hose streams. The NPR project will consider the potential adverse impact of the spurious operation of fire protection systems, including common cause failures, and ensure that safe shutdown capability will not be compromised by such incidents.

The use of these criteria can be expected to significantly reduce fire risk and will ensure that NPR achieves a level of fire safety which both exceeds that of current reactor sites and which will satisfy the anticipated direction of future nuclear power plant fire safety regulations.

It should be noted that the third criteria (i.e., consideration of an additional single random active component failure beyond direct fire damage) represents an expansion of the USNRC policy as presented in SECY-90-016. It is recognized that this extension of the planned USNRC ALWR design criteria will represent a source of controversy. However, the additional constraint is considered to represent an important risk reduction consideration. Note, also, that it is not the intent of this extension to require three trains for all safety systems. The intent is to provide for the proctection of a given safety function, rather than a given safety system (e.g., proctection of AC power in general rather than protection of off-site power in particular).

As an alternative to adopting the above stated policy, it has been suggested[1] that the USNRC policy could be utilized directly as presented in SECY-90-016, and the impact of equipment failures in conjunction with a fire could be evaluated as a part of a parallel path fire risk assessment. While this may represent a viable approach, it should be recognized that this approach will place a higher level of importance on the fire risk

1. Reference: Meeting between representatives of DOE and its consultants, SNL, and the NPR design team held on March 6, 1991 in Washington DC.

assessment than that typically encountered in past assessments, and that which would result from endorsement of the enhanced fire safety design criteria outlined above. The enhanced criteria recommended by SNL is intended to ensure that risk reduction is achieved through the design, and thus, the fire risk assessment would be confirmatory in nature only. Using the alternative approach, the fire risk assessment will carry a more significant level of burden to identify and resolve significant risk scenarios. It should also be recognized that use of the alternative risk-based approach is likely to result in the need to implement significant design modifications relatively late in the design process.

It is Sandia's view that the use of the enhanced fire safety design requirement, as presented in this report, as the fundamental fire safety design criteria for NPR represents the optimal approach to insuring that NPR achieves a high level of fire safety. This enhanced criteria is designed to insure that a high level of fire safety would be achieved as a result of the initial design process. SNL does not consider the use of the alternative approach outlined above, which would place the burden for ensuring that the desired level of fire safety is achieved on a parallel path fire risk assessment, as optimal because (1) inherent uncertainties in the fire risk assessment approach make it difficult to assure that the desired level of risk reduction is achieved a-priori, and (2) the potential that design modifications will be identified late in the design process when implementation will be more difficult to achieve.

In addition to issues of safe shutdown system segregation, there are a variety of other fire safety issues which should be addressed by the NPR design. These issues include:

- Fire Risk Assessment Issues:
    - Inadequacies in Current Analytical Fire Models
    - Updating of Fire Experience Data Bases
    - Use of Expert Judgements in a Quantitative Analysis
    - Equipment Fire Damage Vulnerability Data Availability
    - Barrier Failure Probability Assessment
    - Analysis of Control Systems Interactions
    - Evaluation of Manual Fire Fighting Effectiveness
    - Assessment of Adverse Fire Suppression System Impact

- Fire Protection System Design Considerations:
    - Selection of Fire Detection and Suppression Systems
    - Evaluation of Fire Hazards
    - Corrosion in Water Based Fire Suppression Systems
    - Management of Fire Suppressants After Release
    - Consideration of Adverse Impact of Fire Suppressants on Plant Equipment
    - Consideration of Potential Spurious Actuation of Fire Protection Systems
    - Seismic Qualification of Fire Protection Systems
    - Design of Combustion Products Management Support Systems (Ventilation Systems)

- Issues of Plant Construction:
    - Timetable for Fire Protection System Implementation
    - Fire Protection Provisions for the Construction Site
    - Construction Material Fire Behavior Selection Criteria (Particularly Cable Insulation Materials)

- Operational Aspects of Fire Safety:
    - Staffing, Training and Equipping of Manual Fire Fighting Teams
    - Provisions for Fire Protection System Maintenance
    - Emergency Response Procedures

A number of specific recommendations are made in this report. These recommendations are summarized in Chapter 7.

1.0 INTRODUCTION

This report presents a discussion of the insights which have been gained through 20 years of nuclear power plant operations, and 15 years of USNRC-sponsored fire safety research and the impact these insights can be expected to have on the design of a new reactor facility. Also presented is a discussion of anticipated changes in both the USNRC fire safety regulations, and in the various national fire safety standards which will also apply to the design, construction and operation of a new reactor.

For the commercial nuclear power industry, fire has consistently been identified as one of the dominant contributors to core damage frequency estimates in many different risk studies. This can be attributed to two observations. First, significant fires continue to be experienced at nuclear reactor sites. Second, for most commercial reactor sites in the U. S., the operational aspect of fire safety was addressed as a backfit to an existing plant; and hence, the fire safety provisions are not as effective as might have been achieved if these aspects of fire safety had been considered as a part of the initial plant design.

The importance of fire safety is also highlighted by the fact that the list of unresolved USNRC Generic Issues includes eight issues directly related to fire safety, namely:

- GI-57 Adverse Impact of Fire Suppression Systems on Plant Equipment
- GI-81 Degraded Access Due to Locked Doorways
- GI-83 Control Room Habitability
- GI-106 Piping and Use of Combustible Gases in Vital Areas
- GI-107 Transformer Failures
- GI-147 Fire-Induced Alternate Shutdown Control Room Panel Interactions
- GI-148 Smoke Control and Manual Fire Fighting Effectiveness
- GI-149 Adequacy of Fire Barriers

For the New Production Reactor (NPR), it will be important to recognize both the operational importance of fire safety, and the fact that those USNRC fire safety rules which apply to current reactor sites will not represent an adequate basis for the design of NPR. Many of the unresolved fire safety issues can be readily addressed through design considerations which cannot be implemented in an already operating reactor. The NPR design should address these fire safety issues.

Documented in this report are a number of both general and specific recommendations intended to ensure that NPR achieves a higher level of fire safety than that of the current generation of commercial nuclear reactors, and to ensure that the NPR design will meet or exceed the fire safety regulations which will be applied by the USNRC and the national fire safety codes to a new generation of commercial reactors. Also included are recommendations for the development of general NPR fire safety design requirements, as well as very specific recommendations regarding various aspects of fire protection system selection and installation, selection of construction materials for fire behavior, and various operational aspects of the fire safety provisions.

It should be recognized that the recommendations made in this report are not intended to serve as specific NPR design requirements. Rather, it is intended that the information presented here be used by DOE in the formulation of appropriate NPR fire safety requirements and criteria.

2.0 HISTORICAL DEVELOPMENT OF NUCLEAR INDUSTRY FIRE SAFETY GUIDELINES

2.1 Overview

When the current generation of U. S. commercial reactor sites were initially designed and, in most cases, built, fire safety was governed by the same regulations which governed general industrial facilities. These included the National Electrical Safety Code and various local and national fire safety standards such as the National Fire Protection Association (NFPA) Life Safety Code (NFPA-101). These general industry standards are intended to address address, primarily, life safety and property loss prevention.

For the nuclear industry, there was initially little recognition on the part of plant designers that fires could represent a threat to safe plant operations. It is now recognized that in a nuclear reactor, fires can induce the failure of plant safety and support systems, and thereby, represent a potential threat to the integrity of the reactor core. These concerns are not of concern at most general industrial facilities. Similar concerns do arise in other critical operations such as in the military and in the civilian space program. However, it was the general industry fire safety standards which were applied in the initial design of commercial reactors.

It was only after the severe cable tray fire at the Brown's Ferry reactor site in 1975 that the operational importance of fire safety was fully recognized. As a result of this incident, the USNRC instituted a new set of fire safety requirements which specifically addressed these unique concerns. For the most commercial nuclear power plants, the these requirements has required the implementation of significant plant modifications. Because the rules were implemented, in most cases, as backfits, these modifications were often expensive undertakings as well.

It should also be recognized that those USNRC rules which apply to current reactor sites were specifically written as retrofit requirements. These regulations are presented in two parts. First, Appendix R to 10CFR50 provides the regulations which apply to all reactor sites licensed prior to January 1, 1979. Second, Section 9.5-1 of the Standard Review Plan (SRP) describes the criteria for evaluation of fire safety for reactors licensed after that date. Even the provisions set forth in the SRP recognize that all of the current generation of plants had already initiated construction by the time the guidelines were established, and hence, certain desirable factors might not be achieved. Neither of these sets of requirements will represent an adequate basis for the design of a new reactor facility. Furthermore, the various national fire safety standards are also presented in "living" documents, and changes in these standards are expected.

This chapter provides a discussion of the historical development of fire safety regulations for the nuclear industry, the experience of the nuclear industry in implementing these requirements, and the implications of this experience for the DOE NPR.

2.2 The 1975 Brown's Ferry Cable Fire

The unique concern for fire-induced safety system damage in nuclear plants was first brought to the forefront as a result of a severe cable tray fire at the Brown's Ferry reactor site in 1975. In this incident, a cable fire was initiated by a worker who was using a candle to inspect for cracks in fire barrier cable tray penetration seals which were being installed. A ventilation-induced differential pressure between the plant cable spreading room and a cable tunnel area was being used as the driving force for smoke from the candle. A crack in a penetration seal would be indicated by the movement of smoke toward and through the seal. During this inspection, a cracked penetration seal was set afire when the candle flame was sucked into the crack. The fire quickly spread to the cables on both sides of the penetration and burned uncontrolled for several hours. In large part, the continued burning of the fire resulted from a reluctance on the part of the plant operators to apply water to the fire for fear of shorting out needed electrical safety systems. Once water was applied to the fire, it was quickly brought under control.

The Brown's Ferry fire resulted in a significant number of plant safety systems being disabled. In particular, safety systems lost as a result of the fire included [1]:

- Automatic Depressurization System:
  Manual control of relief valves lost, only valve accumulators remained to provide a discrete number of automatic operations.
- High Pressure Coolant Injection System (HPCI):
  Lost due to loss of valve power.
- Residual Heat Removal Systems (RHR):
  All four redundant trains of RHR lost due to loss of valve power in all trains and pump power to one train.
- Core Spray Systems:
  All four redundant trains of core spray lost due to loss of valve power in all trains and pump power to one train.
- Standby Liquid Control System (SLC):
  Both trains of SLC lost due to loss of pump and valve power to both trains.
- Reactor Core Isolation Cooling System (RCIC):
  RCIC lost due to loss of power to steam isolation valve.
- Reactor Protection System (RPS):
  Two redundant train motor-generator sets lost due to loss of motor power, standby coolant valve lost due to power loss.

In this incident, the operators successfully brought the reactor to a safe shutdown condition from power operation. However, the loss of multiple safety systems resulted in significant difficulties in achieving a safe shutdown state. A number of operator-initiated repair actions were required to restore plant systems and to achieve a stable reactor condition.

2.3 Development of the Appendix R Requirements

As a direct result of the 1975 Brown's Ferry cable fire, the USNRC developed a new set of fire safety requirements specifically intended for application to all then existing commercial nuclear reactor sites. These requirements, formalized as Appendix R to 10CFR50, specifically addressed the issues of plant safety system operability in a fire situation, that is, those issues which had not been addressed by general industry standards. These fire safety requirements went into effect in November of 1980, and were to apply retroactively to all units licensed to operate prior to January 1, 1979.

However, the USNRC was faced with a situation which was far from ideal. That is, all of the current commercial reactor sites in the U. S. were already well beyond the design phase before the Appendix R guidelines were developed. In fact, most of the current sites had already initiated power operations, and for the remaining plants, construction had already been initiated. Thus, certain features that would be desirable in an ideal design could not be implemented at these sites. The Appendix R regulations were developed with this limitation in mind and were specifically written as a retrofit rule.

In general, the Appendix R requirements specify alternate methods for protecting, through separation, redundant trains of plant safety equipment. Because these requirements were to be applied as a retrofit, they specifically allow for the housing of redundant safety systems within a single fire area. (A fire area is a region that is bounded on all sides by three-hour rated fire barriers. Fire zones are a subset of fire areas and can be delineated by lesser barriers.) The most controversial, and least restrictive, of the alternative redundant train separation criteria identified in Appendix R was the so-called Twenty-Foot Separation Criteria by which:

1. redundant equipment must be separated by 20-feet of horizontal space with no intervening combustibles, <u>and</u>
2. the area must be protected by automatic fire detection and suppression systems.

However, Appendix R also allows for the consideration of case by case exemptions to these requirements, and allows for the use of alternative provisions shown to provide an "equal level of protection."

The Appendix R requirements also specified that actions be taken regarding other aspect of the plant design and operation as well. These additional requirements included installation of a remote shutdown station which is physically and electrically independent of the main control room, the institution and training of manual fire response teams, the use of low flame spread cables (as certified by the IEEE-383-74 Flame Spread Test) for all <u>new</u> installations (that is, no refitting of existing cables was required although all new installations and cables replaced as a part of maintenance activity were to meet the flammability qualification), and the formalizing of fire protection practices through the institution of a fire protection management structure.

Utility resistance to Appendix R was often quite strong. In fact, a law suit which attempted to strike down the Appendix R provisions was brought by a group of nuclear utilities against the USNRC. This was the first time that the USNRC had been sued by the nuclear industry over a rule-making decision. While the USNRC Appendix R guidelines were upheld by the courts, the courts issued a rather harsh statement which criticized the process by which Appendix R was developed and questioned the technical merits of the guidelines. The court's conclusion included the following statements [2]:

> "Our decision to uphold the NRC's adoption of the fire protection program is reluctant. At almost every step of the way, the NRC's procedures were less than exemplary. ... If the NRC treats the safeguards of the administrative process in too cavalier a fashion, however, it may be impossible for the reviewing court to discern that its action has indeed furthered the public safety. Nonetheless, this is a case in which the rule as tempered by the exemption procedure must be upheld. ..."

This experience illustrates the controversy associated with fire safety for the commercial nuclear industry and the Appendix R guidelines in particular.

2.4 Plant Appendix R Implementation Experience

Since the institution of Appendix R, the nuclear industry in the U. S. has struggled with the interpretation and implementation of these requirements. In practice, virtually every plant in the U. S. has requested at least one Appendix R exemption. Only during 1989 was the first round of Appendix R implementation audits completed by the USNRC.

The initial timetable for appendix R implementation called for all exemption requests and alternative safe shutdown implementation plans to be submitted to the USNRC by March 1981. By this date, approximately 60% of the reactor sites in the U. S. had requested that the submittal deadline be extended, and only two sites claimed to be in compliance with the new requirements. As a result, the deadline for Appendix R compliance submittals was extended to July 1982.

In July 1981, the USNRC issued Section 9.5.1 of the Standard Review Plan (SRP Revision 3). This document describes those fire safety provisions intended to apply to all reactors licensed after January 1, 1979. In general, the SRP reiterates the Appendix R reguirements. In certain areas, the requirements are expanded somewhat, but the differences are relatively minor. When the first draft of the retrofit requirements were issued in Branch Technical Position (BTP) CMEB 9.5-1, this document was accompanied by a companion Appendix A, which provided a draft version of fire safety regulations to be applied to a new reactor site. The differences between Appendix R and the SRP are far less significant than were the differences between the retrofit rules of the original BTP 9.5-1 and its associated Appendix A guidelines for new plants.

By December of 1982, approximately 500 exemption requests had been submitted to the USNRC, and 225 of these requests had been denied. In October of 1983, the USNRC issue Generic Letter 83-33, which clarified the USNRC staff position based on the results of exemption request reviews and Appendix R compliance inspection results. Shortly thereafter, the nuclear industry sponsored industry seminars and submitted an appeal of the Generic Letter 83-33 interpretation of Appendix R requirements. This appeal was rejected by the commission, and a new round of exemption requests was initiated. In this new round, 38 reactor units submitted new exemption requests, and 15 units submitted new alternative safe shutdown implementation plans. Only by the end of 1989 had the USNRC completed the initial review of all utility Appendix R implementation documentation.

2.5 Unresolved USNRC Generic Issues Associated With Fire Safety

The USNRC has identified eight Generic Issues which are either directly or indirectly associated with fire safety. These eight issues are:

- GI-57 Adverse Impact of Fire Suppression Systems on Plant Equipment
- GI-81 Degraded Access Due to Locked Doorways
- GI-83 Control Room Habitability
- GI-106 Piping and Use of Combustible Gases in Vital Areas
- GI-107 Transformer Failures
- GI-147 Fire-Induced Alternate Shutdown Control Room Panel Interactions
- GI-148 Smoke Control and Manual Fire Fighting Effectiveness
- GI-149 Adequacy of Fire Barriers

The following provides a discussion of each of these eight issues, their implications for fire safety, and their implications for the design, construction and operation of NPR.

Certain of these issues have been discussed in other sections of this report as well. In particular, Section 2.6 below discusses anticipated regulatory changes associated with GI-106. In Section 2.7 below, anticipated changes in the national fire safety standards applicable to GI-107 and GI-149 are discussed. Chapter 4 presents a detailed discussion of GI-57, including current USNRC-sponsored research efforts which are investigating the issue. Chapter 6 discusses the potential impact of issues related to GI-147, GI-148, and GI-149 on fire risk assessments. The discussions presented here are intended to provide only a broad overview of each of these issues.

2.5.1 GI-57 Adverse Impact of Fire Suppression Systems on Plant Equipment

As has been discussed immediately above, at most of the current generation of commercial nuclear power plants, fire safety requirements were imposed by the USNRC as a retrofit requirement. Even for newer reactor sites, that is those for which the SRP requirements apply, construction activities had, in all cases, been initiated and fire protection implementation was, in effect, a design retrofit. The USNRC Appendix R and SRP fire safety requirements included provisions which mandated that automatic fire detection and suppression systems be installed under certain conditions, in particular, when spatial separation was used as a means of fire protection for redundant trains of safe shutdown equipment. In addition, in order to meet other aspects of the requirements, most plants were required to install one or more fixed manually or automatically actuated fire suppression system.

Included in the USNRC fire safety requirements is a statement in General Design Criteria 3 (GDC3), which is presented in Appendix A to 10CFR50, that "fire fighting systems shall be designed to ensure that their rupture or inadvertent operation does not significantly impair the safety capability of (plant) structures, systems and components." However, in the years which have followed institution of Appendix R and the SRP, the nuclear industry has logged a significant base of experience in which the actuation of fire suppression systems has resulted in damage to safety related systems and components.

The USNRC has sponsored two efforts, one past and one currently ongoing, to examine the adverse suppression effects issue. The first, the Fire Risk Scoping Study [7], provided a preliminary examination of events in which fire suppression systems had been actuated inadvertently, that is, when no fire was present in the protected area. The second, the current review of GI-57 issues, has expanded the scope of the experience base review to include all actuations of fire suppression systems, both advertent and inadvertent. The results of the Fire Risk Scoping Study and the preliminary results of the current GI-57 investigations are discussed in detail in Chapter 4 below.

In summary, preliminary results of these investigations demonstrate both a continuing problem with adverse fire suppression effects, and a potential for significant risk impact associated with these incidents. Chapter 4 below identifies a number of factors which should be considered in the design of NPR. In particular, it is recommended that the anticipated NPR fire risk analysis include consideration of potential fire suppression induced equipment damage, and that the NPR design include provisions for the management of fire suppressants following either advertent or inadvertent release.

2.5.2 GI-81 Degraded Access Due to Locked Doorways

The issue of degraded access was initially raised, not due to fire safety concerns, but rather due to general plant operational concerns. The issue revolves around a conflict between the need for plant security and access control, and the need for operator access to plant areas for emergency response. In terms of fire safety, emergency responses that could be compromised by access control constraints are manual fire response actions and operator control and recovery operations.

Fires and fire suppression systems can also compound the problem of access control through induced failure of the access control system. One such case in point is an incident that occurred at the Surry site on December 9, 1986 [24]. In this incident while operating at 100% power, a break in a main feedwater return line occurred. The high steam temperatures and damage to several sprinkler heads in the immediate vicinity resulted in the actuation of a fire suppression sprinkler system. Water from the steam break and from the fire suppression system not only induced control panel failures resulting in the actuation of two additional fire suppression systems, but also penetrated and shorted out one local access control card reader in the area. The failure of this one card reader resulted in the failure of the plants entire automatic access control system. All controlled doors failed in the locked position. This required that plant personnel revert to the use of manual keys for all access controlled doors. In some cases, personnel were trapped in plant areas for which all exits were access controlled because override keys were not readily available. Plant personnel were successful in establishing access to vital plant areas, in part because two shifts of plant personnel happened to be on site and available to support plant recovery actions.

For NPR, the plant designers and the plant operations staff must recognize that the requirements of plant security and plant operations can be in conflict. (A proper balance must be achieved which both ensures plant security, and yet will not inhibit the ability of plant operators to respond to emergencies, including fires.) This balance may well be difficult to achieve, and will be heavily dependent on the particular plant design which will determine which areas of the plant may require unimpeded access in the event of a plant emergency. The problem is that it is likely to be these same areas which most need protection for security reasons as well.

2.5.3 GI-83 Control Room Habitability

The USNRC has developed a number of requirements for the design of control room ventilation systems to ensure the habitability of the control room in the event of a plant accident. These include the protection of ventilation system components and power sources, the ability to isolate the control room from all external inputs, and requirements to provide emergency air supplies within the control room for the use of plant operators. In terms of fires safety, two different concerns apply, namely, the protection of the control room environment from both internal and external fires.

A review of control room habitability requirements [20] revealed the the current requirements for the isolation of the control room in the event of a plant accident were considered adequate to deal with the potential for smoke to be introduced into the control room due to a fire in some other part of the plant. However, it was also found that the necessity and capability of a control room smoke purging systems were not adequately covered in the existing guidance.

Regulatory Guide 1.120 (RG 1.120) [21] and BTP CMEB 9.5-1 specify that the method for combustion products removal should be established during the initial stages of the plant design and that the use of the normal ventilation system is acceptable for smoke removal if it is "available and capable." However, RG 1.120 and the BTP do not provide a basis for evaluating the smoke removal capability. NFPA 204 [22] is referenced for additional guidance on smoke control. However, NFPA 204 is not directly applicable. It is concerned only with the venting of burning areas, generally through roof vents. Nuclear power plant control rooms do not use this concept because of other requirements, such as leak-tight construction, control room isolation capability, and radiological limitations. In these same documents, use of the normal ventilation system is allowed for removing smoke generated in the control room, provided that the recirculation portion of the normal ventilation system can be isolated and purge air can be used on a once-through basis.[2]

Since the performance of the control room habitability review [20], testing [17] has demonstrated that ventilation systems as typically designed for industrial applications, including nuclear power plant general areas and control rooms, will not effectively remove smoke from a fire enclosure, even when ventilation rates as high as ten room air changes per hour are available. The design of a smoke removal system requires specialized considerations. In particular, the system must be designed to make use of the buoyancy effect which will tend to drive combustion products (heat and smoke) to the upper reaches of an enclosure. As typically designed, in industrial ventilation systems both the ventilation inlets and ventilation outlets are located at or near the ceiling level. Testing [17] demonstrated that the location of ventilation inlets in the upper reaches of the room will result in the mixing of the room air and disruption of the hot layer formation process. This makes it virtually impossible to provide for effective combustion products removal.

For NPR is it recommended that the ventilation system for the main control room, and possibly for other vital plant areas, in particular the remote shutdown station, be designed so as to support combustion products removal. However, it should also be recognized that a fire of sufficient size will overwhelm even a well designed smoke removal system. Procedures should be established for the abandonment of the main control room in the event that an uncontrolled fire occurs. Further, emergency air supplies, which include eye irritation protection, should be available for all of the plant operating staff in the control room.

This final recommendation is based on two incidents. In one, smoke from a fire in the turbine hall of the Fort St. Vrain plant [25] was introduced into the control room through opened doorways. The second is the Surry feedwater line break [24] described above in Section 2.5.2 above. During this incident, two gaseous fire suppression systems were spuriously actuated, one in a room directly above the control room and one in a room directly below the control room. Because the access control card reader system had also failed, the doors to the control room were blocked open to facilitate control room access (guards were posted to control access). During the incident, both Halon and CO_2 were introduced into the control room through the ventilation system, by natural convection of the fire suppressants, and though unsealed conduits. As a result,

2. This paragraph is excerpted from Section 2.1, page 5, of Reference 20.

operators reported dizziness and eye irritation. In each incident, there were an insufficient number of emergency air supply lines to support all control room personnel and sharing of supply lines was required.

2.5.4 GI-106 Piping and Use of Combustible Gases in Vital Areas

As will be discussed in Chapter 3 below, the second most common source of fires in a nuclear power plant based on the Sandia Fire Incident Data Base [3] is leaks in hydrogen lines and systems. For light water reactors, hydrogen is used as both a component cooling medium and in the reactor chemistry maintenance system. For NPR it is unclear what role hydrogen or other flammable gases might play in the reactor design. Because of the large base of experience regarding fires involving flammable gases, certain factors should be considered in the NPR design if the use of flammable gases is a necessary part of the plant design.

First, all flammable gas lines should be equipped with flow limiting devices and flow isolation devices which would limit the release of flammable gas in the event of a line or component fault. Second, flammable gas lines should not be located in either the main control room, remote shutdown area, nor any area intended primarily for the routing of cables (e.g., cable spreading rooms and cable vault and tunnel areas). The placement of gas lines in other plant areas determined to be risk important should also be avoided wherever possible. This would minimize the likelihood that a flammable gas line rupture or leak would introduce a source of fire initiation in these critical plant areas and in areas of high combustible fuel loading.

2.5.5 GI-107 Transformer Failures

The issue of transformer failures is actually a broad issue of concern including issues not directly related to fire safety. However, the operating experience of commercial nuclear power plants includes numerous transformer failures which have resulted in severe fires [3]. Many of these fires have also resulted in significant challenges to operational safety.

An illustrative case is a recent transformer fire at the Palo Verde nuclear station [23]. In this incident, one of the main plant off-site power transformers faulted and burst into flames. This fault induced a plant transient and required that plant loads be shifted to the backup transformers, in this case, the startup transformers. A plant operator, uncertain as to which of several fire suppression deluge systems corresponded to the transformer actually on fire, actuated the deluge systems protecting all of the plant yard transformers, including the backup transformers. Water from the deluge systems shorted out the backup transformers inducing a loss of off-site power. An additional fault in switchgear inside the plant resulted in locking out of the station diesel generators, which resulted in a temporary station blackout condition. Operators were able to implement recovery actions and bring the diesel generators on-line, but this incident clearly challenged both the plant safety systems and operational staff. The transformer fire was eventually suppressed through a combination of the deluge system and manual fire fighting activities, but not before significant damage was done to one wall of the plant turbine building.

For NPR special considerations should be given to the selection and placement of plant transformers. Section 2.6 below describes the anticipated direction of future USNRC requirements with respect to transformer fire safety. In summary, oil-filled transformers should not be used inside of the primary plant structures, all external transformers should be spatially separated from primary plant structures, and redundant transformers should be segregated from each other by missile and fire barriers. All large transformers should be provided with fixed fire protection systems, and these systems should be clearly identified and located so as to minimize the potential for multiple spurious fire suppression system actuations to induce a common-cause loss of off-site power.

2.5.6 GI-147 Fire-Induced Alternate Shutdown Control Room Panel Interactions

The issue of control systems interactions is perhaps the most difficult of the fire-related Generic Issues to address. The issue raised is primarily associated with control room fire scenarios. In short, concern focuses on the potential for a control room fire to induce multiple spurious actuations and equipment failures prior to the transfer of control to the remote shutdown station. These occurrences (1) may not be indicated at the remote shutdown stations complicating operator recovery actions, (2) could, in some designs, render remote shutdown station controls ineffective or inoperable, (3) may not be possible to correct from the remote station, and/or (4) may not be considered in the station operating procedures.

The difficulty in addressing this issue is that deterministic reviews of control system independence which are required by the both the Appendix R fire safety regulations and the SRP may not identify all such vulnerabilities. These documents require that remote shutdown capabilities be analyzed using a single failure[3] criteria. Recent studies [9] indicate that the identification of potential multiple failure vulnerabilities requires that extensive evaluations of potential equipment fault states be performed using a probabilistic approach. For NPR it is recommended that the anticipated fire risk analysis (PRA) include consideration of potential multiple spurious actuation and component failures during a control room fire. Based on testing experience [15,16], identified vulnerabilities can likely be resolved through the inclusion of fire barriers and train segregation within the control panel complex.

3. This requirement is specified in the USNRC Standard Review Plan Section 9.5.1, Fire Protection Program, Branch Technical Position CMEB 9.5-1, Section C, Chapter 5, Paragraph C, Criterion 6.

2.5.7 GI-148 Smoke Control and Manual Fire Fighting Effectiveness

The specific concerns associated with the issue of smoke control and manual fire fighting effectiveness focus on the fact that most commercial nuclear plants place a high level of reliance on the ability of on-site personnel to provide for fire suppression. Both the Appendix R and the SRP requirements include provisions for the staffing and training of manual fire response teams at all operating reactor sites. However, these requirements ensure only minimal training for fire fighting personnel. For example, if only the minimum standards of training are implemented, plant personnel assigned to the fire response teams may never receive live-fire training.

A recent review of current plant fire protection practices [9] found that a wide plant-to-plant variability exists in this regards. Many plants reported compliance with only the minimum standards for manual fire fighting as specified in the regulations. Many others reported plant practices well in excess of the minimum requirements, some having gone so far as to implement dedicated fire brigades.

Testing has demonstrated that typical nuclear power plant fires can be expected to develop rapidly creating a thick toxic smoke layer within the fire enclosure [15,16,17]. In order to ensure that fire response teams are adequately prepared to deal with such fires, training in excess of the minimum requirements is recommended. Such training should include live-fire training and smoke room training.

However, one must also temper the needs for manual fire response with the operational aspects of fire safety. The USNRC manual fire brigade requirements include a requirement that at least one member of the fire response teams for each plant shift must have the equivalent of operator level knowledge of the plant systems and operational needs and procedures. In practice, plants have included at least one qualified plant operator on each manual fire response team. This is an important and prudent consideration as it is vital for the manual fire response teams to recognize the operational importance of a given fire area or a given component in that area. This will help to ensure that potentially significant collateral damage induced by suppression efforts is minimized in responding to a fire situation.

For NPR it is expected that manual fire response will be provided through a combination of reactor personnel and the overall DOE site fire department. As is discussed further below in Section 2.7.1, the NFPA has available and under development, standards for the staffing, equipping and training of fire fighting personnel. These standards are well in excess of the minimum standards established by the USNRC, and are likely to be applied in retrofit to all existing commercial reactor sites. As discussed below, the only real question is which of the two NFPA standards will be applied to the commercial nuclear industry. It is recommended, and in fact will likely be required by DOE, that NPR manual fire response teams and/or fire brigades be developed in accordance with these NFPA standards.

2.5.8 GI-149 Adequacy of Fire Barriers

The reliability, under actual fire conditions, of fire barriers which are qualified by standard tests endorsed in the U. S. has been questioned by various sectors of the fire protection community. Initial concerns were raised because current U. S. fire barrier qualification standards do not include a requirement to simulate fire pressure effects as a part of the standard test. The corresponding international standard fire tests require the imposition of a differential pressure across the barrier during testing.

Testing [17] has demonstrated that during an enclosure fire, it is to be expected that enclosure pressures will rise, in some cases significantly, due to the buildup of heat in the room and the resulting expansion of the gases in the room. The failure of U. S. standard qualification tests to simulate this behavior could mask mechanisms of barrier failure which might compromise barrier integrity during actual fires. To date, only limited data are available to support these concerns, and there is insufficient data available to support the assessment of the potential vulnerability of any given barrier element to premature failure. Of all the industrialized nations, only the U. S. and Canada continue to endorse neutral or negative pressure barrier testing.

For NPR, the principal item of concern in this regard will be cable tray fire barrier penetration seal systems. Primary fire barriers (i.e. walls, floors, and ceilings) are not likely to be impacted by the pressures typical of a fire situation. While the qualification of fire doors is likely to be impacted by regulatory changes, for NPR the current qualification tests are expected to remain conservative because it is unlikely that significant fuel loadings will be located in the immediate vicinity of fire doors such that flame passage would be likely. However, in the case of fire barrier cable penetration seal systems, combustible fuels are in intimate contact with both sides of the seal system, and hence, the passage of flame through the fire barrier due to pressure effects is more likely.

As discussed below in Section 2.7.4, it is expected that U. S. national fire testing standards will eventually be revised to conform with the international testing standards. The NPR designer, and DOE, should review and evaluate the relative strengths and weaknesses of the various fire barrier qualification standards available both in the U.S. and abroad. It is recommended that fire barrier cable tray penetration seals used in NPR be qualified using international testing standards. This would insure that the question of barrier reliability were resolved for NPR and would insure continued compliance with the anticipated direction of future fire protection standards in the U. S. However, this recommendation is based on an assumption (unsubstantiated at this point) that many of the cable penetration seal systems currently available in the U. S. would readily pass the international test standard, and that U. S. testing agencies can readily accommodate the conditions of the international standard tests. However, this recommendation should be reviewed if these assumptions prove false. That is, if the NPR design team can not identify a ready source of fire barriers qualified to international standards, and if U. S. manufacturers refuse to submit their barrier systems to international standards testing (a possibility given the reluctance of U. S. manufacturers to update the U. S. test standard) then this recommendation would be withdrawn. It is not intended that this recommendation stand in the way of the NPR construction process.

As an alternative to use of international testing standards, a comprehensive review of fire barrier performance in the U.S. could be performed in order to determine whether any fire barrier designs are particularly vulnerable to premature failure. It is anticipated that such a review would demonstrate that most U. S. barrier systems function well in actual fires, and hence, no significant risk impact would be expected. However, such a review might also reveal particular barrier systems which are vulnerable to premature failure, and hence, should not be used in NPR. This information, coupled with engineering judgement, could be used by the NPR design team to support the selection of a fire barrier penetration seal type (or types).

2.6 Anticipated Changes in the USNRC Fire Safety Regulations

For future nuclear reactor designs, the USNRC has made clear that a new and strengthened set of fire safety regulations will apply. As noted above, the current Appendix R regulations, as well as the provisions of the SRP, were written as a retrofit rule. That is, the rules were intended to apply retroactively to all then existing operating reactor sites and reactor construction projects, respectively. In practice, no new reactor construction projects have been initiated in the U.S. since Appendix R and the SRP were adopted. The USNRC has yet to formally establish the actual detailed fire safety requirements which will apply to a new reactor design. However, two documents are available which provide a relatively clear indication as to the direction future USNRC fire safety regulations will take.

During the same period in which the Appendix R fire safety retrofit requirements were first developed, the USNRC also formulated a draft set of regulations for new reactor sites. The initial version of the retrofit fire safety regulations, which was eventually revised and adopted as Appendix R, was presented in Branch Technical Position (BTP) APCSB 9.5-1. Attached to this document as Appendix A was the first draft of a set of fire safety regulations for application to a new reactor site.

This appendix was never formally adopted by the USNRC, and in practice, reactor sites which were licensed after January 1, 1979 are evaluated against the criteria presented in the Standard Review Plan (SRP) Section 9.5-1 which includes an updated version of BTP APCSB 9.5-1 reissued as BTP CMEB 9.5-1. These criteria are largely consistent with the Appendix R guidelines and include only a few limited additional constraints and considerations. However, the original version of Appendix A to BTP 9.5-1 identified a number of areas where new plant design requirements would have been significantly different than would the retrofit requirements. These included:

- Seismic Qualification of Fire Suppression Systems: For new plants, it was stated that the fire suppression systems should be capable of delivering water to manual hose stations in safety related equipment areas following a Safe Shutdown Earthquake (SSE). The fire protection systems were also to be designed to withstand other natural and man-made disasters. specifically identified disasters included tornadoes, hurricanes, floods, ice storms, oil barge collisions, and aircraft crashes. The retrofit rules included no such requirements.

- Timetable for Fire Protection Implementation: For new reactors, it was stated that the fire protection program for nuclear fuel storage buildings and adjacent fire areas must be fully operational prior to fuel being received at the site. The fire protection for the entire plant was to be fully operational prior to reactor fuel loading. For the retrofit rules, the implementation schedule was to be determined on a case-by-case basis.

- General Building Design Guidelines: For new reactors, the requirements stated that redundant safety related systems should be separated such that both systems would not be subject to damage from a single fire hazard. This implied separation into different fire areas. The retrofit rules allowed for the passive protection of one or more trains when redundant safety systems were subject to damage from a single fire hazard.

- Cable Spreading Area Fire Safety: For new reactor sites, the sharing of cable spreading rooms between multiple units was to be prohibited. It was also stated that cables for redundant safety trains must be separated by three hour rated fire walls. For the retrofit rules, alternative strategies were presented, including the twenty-foot separation criteria, as described above.

- Suspended Ceilings: For new reactors, concealed spaces were to be devoid of combustibles. For the retrofit rules, case-by-case exceptions were to be allowed when this could not be achieved.

- Transformers: No oil filled transformers were to be installed inside buildings containing safety related equipment at new reactor sites. For existing sites, enclosing such transformers within three hour rated fire barriers and installing water spray protection systems was acceptable. At new sites, all external oil filled transformers were to be located at least fifty feet from any building housing safety related equipment. Any wall within fifty feet of such transformers were to have no openings and were to be three hour rated fire barriers. For existing sites alternative strategies were outlined to reduce the hazard.

- <u>Water Drainage:</u> For new reactors, adequate drainage was to be provided to remove expected fire fighting water flow for all fixed systems. For existing sites, such drainage was required only if the failure to drain this water would "create unacceptable consequences" (this term was not defined). For new reactors, it was also stated that water curbs must be provided in many plant areas including the control room, diesel generator areas, pump rooms, and switchgear areas. Retrofitting of curbs in existing plants was not required.

- <u>Barrier Design:</u> For new reactors, no alternatives to the installation of three hour rated fire barriers surrounding all fire areas were allowed. For existing reactors, a variety of alternatives were identified.

After a period of public comment and revision, the retrofit rules for then operating plants were formalized as Appendix R. A short time later, Section 9.5-1 of the Standard Review Plan (SRP) was issued. This document provided the fire safety standards to be applied to all then existing reactor construction projects. Because these sites had already been designed and construction had already been initiated, these requirements are also effectively design retrofit requirements. In practice, no new reactor construction projects have since been initiated. In fact, the provisions of the SRP expand only slightly on the Appendix R requirements and most of the enhanced provisions outlined in the original Appendix A to the BTP and described above are not included in the SRP. To date, no formal adoption of new reactor site fire safety requirements has been pursued.

Recently, the USNRC staff has reiterated its previous position that new commercial reactor designs will be required to meet a more stringent standard of fire safety. In January 1990, the USNRC issued a staff position document which presented, among other issues, a new fire safety policy for advanced reactor designs.[4] This policy statement has been officially endorsed by the Commission. The staff position makes clear that new set of fire safety regulations for commercial reactors, and in particular Advance Light Water Reactors (ALWRs), will be developed. In particular, it is stated that:

> "fire protection issues that have been raised through operation experience and through the External Events Program must be resolved for evolutionary ALWRs. To minimize fire as a significant contributor to the likelihood of severe accidents for advanced plants, the staff concludes that current NRC guidance must be enhanced."

The USNRC staff policy statement goes on to say:

> "Therefore, the evolutionary ALWR designers must ensure that safe shutdown can be achieved assuming that all equipment in any one fire area will be rendered

4. Reference USNRC Policy Issue Memorandum SECY-90-016, dated January 12, 1990.

inoperable by fire and that reentry into the fire area for repairs and operator actions is not possible. Because of its physical configuration, the control room is excluded from this approach, provided an independent alternative shutdown capability that is physically and electrically independent of the control room is included in the design. Evolutionary ALWRs must provide fire protection for redundant shutdown systems in the reactor containment building that will ensure, to the extent practicable, that one shutdown division will be free of fire damage. Additionally, the evolutionary ALWR designers must ensure that smoke, hot gases, or the fire suppressant will not migrate into other fire areas to the extent that they could adversely affect safe-shutdown capabilities, including operator actions."

It is clear that the current Appendix R fire safety requirements will not represent an adequate basis for the design and implementation of fire safety for new reactors, including NPR. The USNRC staff policy statement implies that the new guidelines will specifically disallow the use of physical segregation or passive protection of redundant safety equipment within a single fire area as an acceptable means of fire hazards mitigation. Instead, redundant safety equipment will be required to be housed in separate fire areas which are bounded on all sides by three hour rated fire barriers.

There is one area in which it is expected that significant additional risk reduction could be realized through expansion of the USNRC policy statement. The stated USNRC staff position, as presented above, represents a purely deterministic criterion. As such, it will not address the residual risk associated with random equipment failures or outages in redundant safety trains. As currently stated, the staff position requires that a reactor must be designed so that safe-shutdown conditions can be reached assuming that all equipment in a single fire area might be rendered inoperable by a fire and that reentry into the fire area for recovery actions is not possible. The additional consideration of any possible single active component failure in other plant equipment outside of the fire area due to nonfire related causes (e.g., random failure, maintenance outages, sabotage, personnel errors, etc.) would significantly reduce the likelihood of any risk significant core damaging fire scenarios remaining.

Note, in particular, that this recommended extension is not intended to require that all safety systems be designed in a three-train configuration. The recommended extension is not directed at the protection of any one given plant safety system, but rather at protection of general safety functions and the overall ability of the plant to achieve a safe shutdown state. The primary impact of the additional constraint is likely to be on the plant support systems rather than on the front-line safety systems because even in a one- or two-train plant many alternate methods of achieving safe shutdown are typically available (for example high pressure injection versus depressurization and low pressure injection in a LWR plant). However, it is the plant support systems, such as the electrical power and service water systems, which may require three-train availability. Even in the case of electrical power, a true three-train system would not be required because offsite power and two 100% deisel generators could be configured to provide three way segragation provided appropriate issolation and switching capability is provided.

The intent of the enhanced criteria is to ensure that the designers consider that, in addition to fire induced damage, any one active component might either fail on demand or might be unavailable due to a service outage. It is not intended that the single failure necessarily be a full system failure unless a single component failure might render a redundant system inoperable. Should NPR be designed such that a fire in one fire area can render all but one of the available alternate shutdown methods inoperable such that a single additional component failure could lead directly to a core damage accident, then the fire risk will likely remain relatively high. (The actual level of risk will depend on factors such as spatial separation, the magnitude of the fire threat, passive protective features, etc.)

As an example of the type of risk scenario which this additional constraint is intended to address, consider the recently completed analysis of fire risk at the Peach Bottom reactor site [26]. In one scenario, a fire is postulated in the emergency switchgear room. Under the original plant design, because of the configuration of the cables in this area, a switchgear fire would induce the failure of off-site power and two out of three trains of emergency service water. (Emergency service water provides component cooling to the front-line safety systems in the event of a loss of off-site power.) The third train of emergency service water could fail due to any one of numerous single component failures (pump failures, valve failures, etc.). This scenario was estimated to have a fire-induced core damage frequency of approximately $1x10^{-4}$ core damage incidents per reactor year. This fire scenario would have dominated the entire full-scope risk assessment. This original design would have satisfied the first two conditions described above, but would not have satisfied the third condition.

The operators of the plant recognized the importance of this scenario and implemented a plant modification which removed a second train of the emergency service water system from the emergency switchgear fire area. This change resulted in a change in the fire scenario such that instead of only one random component failure, two random component failures, one in each of two trains of emergency service water, were required to lead to core damage. This reduced the estimated core damage frequency for this scenario by a factor of approximately 20 to a value of approximately $5x10^{-6}$ incidents per reactor year. The plant design for the emergency switchgear fire area as modified by the utility would satisfy the recommended NPR design requirement, including the third condition which requires consideration of any one single nonfire related component failure.

The use of a more rigorous fire safety design criteria such as that outlined in SECY-90-016, including the additional probabilistic constraint, can be expected to significantly reduce the likelihood that risk-important fire scenarios will remain unaddressed by future reactor designs. As described in the following sections, for the current generation of commercial nuclear reactors, many of the dominant fire risk scenarios involve cases in which the segregation of redundant safety system equipment within a single fire area has been used as a means of fire protection. The use of the above criteria would eliminate most of these plant vulnerabilities.

It would be appropriate for the DOE to include provisions for some form of a case by case exemption process. It is currently unclear what the details of the various potential NPR designs (e.g., HWR, LWR, and MHTGR) will encompass, and what the specific fire risk issues will be. The intent of the requirement is to eliminate high risk fire scenarios from the plant design, and if the above guidelines are met, it is considered unlikely that any fire risk scenario with an estimated core damage frequency greater that 1×10^{-5} incidents per reactor year will remain. If the plant designers can demonstrate that a given situation might represent an overwhelming design burden and that the risk impact is insignificant (this criteria would need to be clearly defined by DOE in terms of the overall probabilistic safety goals), then a case specific exemption might be warranted. It is considered unlikely, based on our current understanding of reactor designs, that more that a handful of such situations might arise. However, this cannot be guaranteed until the reactor designs are more firmly established.

It is recognized that the SNL recommended enhanced fire safety design criteria represents a departure from typical past design practices. However, SNL has been involved in the performance and review of numerous fire PRAs. This experience has shown that plants built in more recent years appear to have achieved a plant design generally consistent with the enhanced criteria as recommended by SNL. Further, for many of the older plants in which significant fire risk scenarios have been identified, retrofit modifications have often been implemented which would also be consistent with the SNL recommended enhanced fire safety design criteria.

It has been suggested[5] that as an alternative, the design criteria as presented in SECY-90-016 could be endorsed directly, and the impact of the additional SNL recommended constraint could be evaluated through risk assessment methods. This approach is not considered optimal for three reasons.

First, the use of a fire PRA as a design <u>definition</u> tool will represent a departure from the traditional application of risk assessment as a design <u>review</u> tool. This will imply that the fire PRA must take on a higher level of importance than that which is typical of past confirmatory review risk assessments. The degree to which potential design weaknesses are identified and evaluated in the fire PRA would become a critical consideration. This is not considered optimal because the overall level of uncertainty in a typical fire PRA is significant, and because differences in analysis methodology can significantly impact the level to which plant vulnerabilities are identified.

Second, the intent of the recommended enhanced fire safety design criteria is to provide a clear deterministic criteria by which significant reductions in fire risk would be assured. Thus, the role of the fire PRA would be confirmatory in nature, and a quality assurance level of "M", or mission-related, would likely be assigned to the fire PRA. If the alternative approach is taken, then a higher importance would be assigned to the fire PRA and it is likely that a higher quality assurance level of "S", or safety-related, would be assigned. Past fire PRAs have never been performed to "S"-level quality assurance standards. This will imply that a significant additional overhead burden will be placed

5. Reference: meeting between DOE and its consultants, SNL and the NPR design team held March 6, 1991 in Washington DC.

on the fire PRA in that the data bases, fire models, and expert judgement factors utilized in the analysis must be scrutinized to an extent never before implemented.

Third, a fire risk assessment can not provide meaningful results until the plant design has been firmly established. This must include very detailed information on the physical placement of all risk important electrical components (including cables) within the plant, and the availability of detailed and accurate plant systems models. This implies that the fire risk assessment must be performed at a relatively late stage in the design process. Any vulnerabilities identified in the risk assessment will need to be addressed through design modifications which will be more difficult to implement late in the design than had they been implemented early in the design.

For these reasons, it remains SNL's recommendation that the enhanced fire safety design criteria which include an expansion of the USNRC position be endorsed for NPR. However, it is clear that DOE must weigh the advantages and disadvantages of each approach and decide accordingly.

One area where special consideration will be required is the main control room. In this area, indication and control signals for many plant safety systems converge. This is necessary to meet the needs for controlling the plant. The USNRC staff position addresses this issue in that the control is specifically excluded from the separation requirements, provided that "an independent alternative shutdown capability that is physically and electrically independent of the control room is included in the design." This is a reasonable exclusion in that it is reasonable to allow credit for the fact that the control room is a continuously manned area, and the likelihood of a large uncontrolled fire is significantly reduced.

What remains to be defined by the USNRC is what specific capabilities the remote shutdown area will be required to provide. Current thinking at the USNRC[6] favors the use of "an independent, diverse remote shutdown panel .... (in) a bunkered remote shutdown facility with a dedicated decay heat removal capability to reduce not only the fire risk but also provide added protection against sabotage or natural disasters." It is expected that as the new USNRC policy evolves, more specific guidance in this and other areas will be developed.

For NPR it is also recommended that in order to further reduce the likelihood that a single fire might impact multiple redundant equipment trains, the control panel complex in the main control room should be subdivided using solid fire barriers with no interconnecting cable penetrations between electrical panels housing components associated with redundant equipment trains. This segregation should include the consideration of cable routing paths within the control room and the potential for even a relatively small fire to spread into these cables. The minimization of the use of power cables within the control room would also reduce the likelihood of fire initiation.

6. Based on a letter to SNL (Dated April 9, 1990) from the USNRC documenting USNRC review comments of a document entitled "A Quick Look at Fire Safety Lessons Learned as Applied to the New Production Reactor Design" which was prepared by SNL as a part of the NPR-HWR Fire Safety Confirmatory Investigations efforts and submitted to DOE-NP for consideration January 29, 1990.

2.7 Anticipated Changes in National Fire Safety Standards

Fire safety for general industrial applications is governed by a variety of both voluntary and mandatory fire safety standards. As DOE has committed to complying with all existing and anticipated environmental, health, and safety requirements, it is important to recognize that these national fire safety standards are "living" documents which are subject to change. There are, in fact, at least five major areas in which changes in the current standards can be expected in the near future. These five areas are (1) Manual Fire Brigade Standards, (2) Cable Flammability Testing, (3) Fire Induced Corrosion, (4) Fire Barrier Qualification, and (5) the use of Halon as a fire suppressant. Anticipated changes in each of these areas are discussed in the sections which follow.

2.7.1 Manual Fire Brigade Standards

The National Fire Protection Association (NFPA) is currently rewriting its standards on fire brigade staffing and training requirements. There are two primary standards, NFPA-600 and NFPA-1500, each of which covers different levels of fire fighting teams. NFPA-1500 is intended to set the standards for front line fire brigades including volunteer organizations and industrial fire brigades. NFPA-600 sets the standards for the training of general personnel in fire protection and fire fighting practices.

NFPA-1500 Is currently undergoing public review and comment prior to presentation to the full NFPA membership for adoption. The regulations are quite stringent and wide reaching. The standard covers issues such as physical fitness, training, equipment, leadership, organization, staffing levels, requirements to maintain a staff doctor and provide brigade specific drug and alcohol abuse counseling programs, and many other issues. The NFPA has received on the order of 35,000 public comments that must be addressed prior to presentation of the standard for approval. Many of these comments have come from volunteer fire fighters who, as the rules are currently written, would also need to meet the more stringent requirements of NFPA-1500.

The draft document is also a point of concern for the commercial nuclear industry.[7] As discussed above, the commercial nuclear industry is required by the USNRC to establish manual fire fighting teams within an overall fire protection management structure. The USNRC has set minimum criteria for the staffing and training of the manual fire fighting teams, although actual practices vary considerably. Many plants utilize personnel from other parts of the plant staff to make up these fire response teams (e.g., operators, maintenance, security, safety, etc.) while others have implemented some form of a dedicated fire brigade. As currently stated, the NFPA-1500 definition of a fire fighter would include all of these fire response teams. Representatives of the commercial

7. Based on discussions of the issue presented at the Spring meeting of the Edison Electric Institute Fire Protection Committee and Technical Advisory Task Force in Dallas, Texas, April 1-4, 1990.

nuclear industry have submitted, through the public comment process, a request that the definition of fire fighters covered by NFPA-1500 be revised such that the current commercial reactor sites which draw fire response teams from the general plant staff would not be required to meet the more stringent guidelines of NFPA-1500.

For NPR, it is expected that some form of a plant specific and/or site fire brigade will be required. Because of the nature of NPR requirements and the definitions of fire brigades used by each standard, the general DOE site fire brigade will almost certainly be required to meet the more stringent criteria for fire brigades as presented in NFPA-1500. For the training of plant specific fire response teams, the question of which standard will apply will depend on the outcome of the appeal made by the commercial nuclear industry, and if that appeal is successful, on the nature of the fire response teams which are assembled. It is expected that the implementation of NFPA-1500 would represent a lesser burden for the NPR site itself than it will for the commercial nuclear industry because the NPR site could easily be brought into compliance as a supplement to the overall DOE site fire brigade compliance measures.

2.7.2 Cable Flammability Testing

The USNRC Appendix R fire safety regulations currently require that cables for new installations must be certified as low flame spread as demonstrated by the IEEE-383-74 cable qualification flame spread test standard. This test utilizes an eight-foot vertical run of a single layer of cables exposed to a propane ribbon burner at their base. If flames do not propagate to the top of the array, then the cable passes the test. This test is a relatively simple test, and does not represent a very severe fire exposure. There are two factors that should be considered in the selection of a cable flammability standard for application to NPR.

First, there is currently under consideration a change to the IEEE-383 standard. It has been proposed that the flammability sections of the IEEE-383 test be revised to conform with the slightly more stringent Canadian standard test CS-4. This Canadian standard is quite similar to the IEEE standard. However, the angle of the gas burner is slightly changed, the loading density of cable is somewhat higher, and cables must be tested in their as manufactured condition. These relatively minor changes in the testing standard can result in a significant change in cable fire behavior. Certain cable products which will pass the current IEEE-383 standard flame test may not pass the CS-4 standard test.

The second factor that should be considered by NPR is that more stringent cable flammability testing standards are available. One of the most progressive of the current cable flammability test standards is a test standard developed by the Factory Mutual Research Corporation (FMRC) [27]. FMRC is a highly respected testing organization associated with the Factory Mutual Insurance Group. The new FMRC test standard significantly expands on the ability to differentiate between the fire performance of different cable products. While the IEEE-383 test is a simple pass/fail test, the FMRC test standard provides quantitative measures of the cable fire performance. In conjunction with the actual flammability tests, the FMRC standard also provides a framework within which a designer can select an appropriate level of fire protection (that is, fire detection and fire suppression) to apply to a particular application of a particular cable product [28]. This FMRC guideline provides a sensible engineering approach to the selection of cables and appropriate fire protection features.

However, it should also be recognized that the FMRC cable flammability standard is currently a point of considerable controversy. Cable manufacturers appear reluctant to endorse the new test standard, and hence, there are currently no cable products available which are certified in accordance with this new standard.

For NPR, it is recommended that cables should be selected based, in part, on a recognized flammability testing standard. The FMRC test standard is considered the most progressive and well founded of the currently available standards, and hence, is recommended as the flammability standard of first choise. However, this recommendation must be reviewed in the context of material availability. If the controversy surrounding the FMRC standard is not resolved prior to the initiation of procurement for the NPR design, then it is recommended that the IEEE-383 test standard be endorsed instead.

2.7.3 Fire-Induced Corrosion

There are currently a number of national organizations which are working to establish standard tests to assess the corrosive potential of material combustion products. This is an issue of concern to the fire protection community because fire loss experience includes extensive losses due to fire-induced corrosion. This issue has become of even greater importance because of the more extensive use of plastics (the largest source of corrosive products in a fire) and the increasing demands on the sensitivity of electronic equipment. These efforts have not yet yielded an accepted test standard. However, it is likely that within approximately 5-7 years such a standard will be established.

While no standard has yet been established, the understanding of fire-induced corrosion is expanding rapidly. Methodologies for assessing the relative corrosive potency of material combustion products have been established. In particular, the American Society for Testing and Materials (ASTM) fire corrosivity group (E5.21.70) is well advanced in the development of fire-induced corrosion assessment methods. For NPR, it is recommended that the selection of materials be based, in part, on the corrosion potential of the material combustion products. Cable insulation will be the most important candidate for such evaluation because it is cable insulation which will dominate the combustible fuel loading in most plant areas. By selecting cable materials for low corrosion potential, the recovery of NPR from those fires which will almost inevitably occur will be significantly simplified.

2.7.4 Fire Barrier Qualification Standards

The USNRC has identified the adequacy of current U. S. fire barrier qualification test standards as a Generic Issue (GI149, see Section 2.5.8 above). This issue is not associated with the design of the actual fire barriers themselves (i.e. the walls and ceiling/floor structures), but rather with the various elements which are used to seal openings in these primary structures. These elements include fire doors, ventilation dampers, conduits and cable tray fire barrier penetration seals.

The primary source of concern is that the current U. S. standards do not require the imposition of a differential pressure across the barrier element during testing. The failure of current U. S. standard tests to simulate anticipated enclosure fire pressure behavior could mask barrier failure vulnerabilities because cracks and air gaps in barrier elements can act as a conduit to fire spread to the unexposed side. In international test standards (e.g., International Standards Organization test ISO-3008 for fire doors) the imposition of a pressure differential is required as a part of barrier qualification testing. In fact, of the industrialized nations, only Canada and the U. S. continue to endorse neutral, or negative, pressure barrier tests.

The second difference between U. S. and international standards is that international standards include a limit to the severity of thermal radiation which is emitted from the unexposed side of the barrier element during fire testing while U. S. standards include no such provisions. This factor is of primary interest to the qualification of fire doors, and in particular, metal doors. (For cable penetration seals, ignition of the cables on the unexposed side would be considered a failure in qualification testing. Thus, while not explicitly stated, there is, in effect, a limitation that the unexposed side cannot exceed the cable material ignition temperature.) The result of this difference is that there is effectively no limit to the temperature which might be reached on the unexposed side of a fire door in the U. S. during the fire exposure. This raises the potential for fire to spread to the unexposed side of the fire barrier through thermal radiation induced ignition of flammable materials on the unexposed side.

The full impact of these and other minor differences in testing procedures has not been assessed. Testing of fire doors by the University of California at Berkeley[8] revealed significant differences in the performance of U. S. qualified fire doors when subjected to the ISO-3008 standard test. In these tests, a steel door rated in the U. S. as a 90-minute fire barrier failed the ISO test in just nine minutes. The evaluation of the performance of other types of barrier elements in ISO tests has not been undertaken.

As a result of this controversy, the ASTM-E-152 fire door test standard committee recently considered a proposal to revise the ASTM standard to be consistent with

8. Based on material presented to the ASTM committee responsible for the ASTM-E-152 fire door test standard by V. Radovic of the American VAMAG Company, Inc. Ridgefield NJ.

international standards. This proposal was supported by 28 committee members, but was blocked by 8 members, all representing steel door manufacturers.[9] While this most recent proposal to revise the U. S. fire barrier test standards was defeated, the controversy has not been resolved. It is expected that the U. S. testing standards will eventually be revised so as to be consistent with international standards.

The impact of potential barrier failures can be minimized by minimizing the installation of barrier penetration elements in those fire barriers which serve as primary segregation boundaries for redundant safe shutdown systems and components. For these primary segregation barriers, the plant layout should be carefully reviewed to identify penetration elements which can be eliminated or relocated. It is further recommended that those fire barrier penetration elements which are installed should be qualified using a rigorous procedure which includes consideration of fire pressure effects.

For NPR, as discussed in Section 2.5.8 above, the most important aspect of this question is that associated with cable tray barrier penetration seals. The NPR designer, and DOE, should clearly evaluate the relative strengths and weaknesses of the various fire barrier qualification standards currently available both within the U.S. and abroad. Based on our current state of knowledge, it is recommended that fire barrier penetration seals be qualified using international testing standards which include the imposition of a positive exposure side pressure during testing. In terms of availability, it is expected that most penetration seals manufactured in the U. S. will, in fact, meet the criteria of the international standards. Testing laboratories in the U. S. can accommodate the international test standard conditions with only slight modifications to existing facilities. This requirement would resolve the issue for NPR, would ensure continued compliance with the anticipated direction of fire regulations in the U. S., and would ensure a higher level of fire safety.

However, this recommendation must be considered in the context of material availability. That is, if no fire barrier penetration seal elements which are certified to international standards and available in the U. S. can be identified, and U. S. manufacturers refuse to cooperate in the certification of their barrier elements to international standards, then an alternative approach may be required. In fact, an alternative approach which would include a review and assessment of current fire barrier performance in the U. S. based on actual experience has been outlined in Section 2.5.8 above. However, it must be recognized that the use of fire barriers penetration seal elements certified using only the current U. S. testing standards will leave the issue of barrier performance (GI149) unresolved for NPR. Should research or experience demonstrate at some later date that premature fire barrier failure is possible under realistic fire conditions, then a backfit review of all of the critical NPR fire barriers may be required, and certain fire barrier penetration seal elements may require replacement or upgrading.

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9. Based on information presented in Open Safety Forum, an ASTM publication, by R. Patton, a fire protection engineer and member of the ASTM-E-152 committee.

Of lesser importance for NPR are fire doors. It is not expected that fire doors in NPR will be subjected to the harsh fire exposure levels typical of the qualification test because of the nature of the combustible fuels and limitations on fuel loading expected. Therefore, current U. S. test standards should provide an adequate qualification basis. However, currently available in the U. S. are retrofit doorway gasket kits which, under positive pressure conditions, can reduce the rate of airflow past a fire door during fire exposures. It is recommended that fire doors in critical safety areas (e.g., the main control room, cable spreading areas, remote shutdown area, and personnel escape routes) be equipped with this additional level of protection.

2.7.5 The Use of Halon as a Fire Suppressant

Halon[10] has been identified as one of the most aggressive attackers of atmospheric ozone currently being manufactured and released to the environment. On a pound-for-pound basis, Halons are three to ten times as potent in destroying ozone than are most other chlorofluorocarbons (CFCs). For this reason, the various Halons used in fire protection systems have been specifically identified in the Montreal Accords on the protection of the Ozone layer as chemicals to be completely phased out from all uses, including fire protection systems.

Halon has been a popular fire suppressant for application to electrical systems because of its low toxicity and corrosivity (until broken down) and its effectiveness as a fire suppressant. The manufacturer of Halon, DuPont, and others are working to develop an environmentally sound replacement for Halon fire suppressants. However, it cannot be expected that an alternative compound will developed within the timeframe for phasing out of Halon use. The current timetable calls for phasing out the manufacture of Halon by the year 2005. There is now considerable pressure, including support from the U.S. government, to accelerate this timetable and phase out all Halon manufacturing by the year 2000.

For these reasons, NPR should <u>under no conditions</u> employ Halon as a fire suppressant. Halon will not represent a long term option for fire suppression systems, and should not be employed in NPR.

2.8 Design Recommendations Based on Past Regulatory Experience and Anticipated Regulatory Changes

The most important lesson learned from past regulatory experience is that the potential operational impact of fires on the safety of a reactor should be addressed as a part of the fundamental requirements for the initial plant design. Fire protection must be implemented as a part of the design process to ensure that the highest level of fire safety which can be effected, is achieved. For the current commercial nuclear industry in the U. S., fire protection was implemented as a retrofit to existing plants. This process has made fire protection implementation quite difficult, quite expensive, and, in some cases, has left a number of fire safety questions unresolved. For NPR it will be important to

10. Halon is a registered trademark of the DuPont Corporation.

ensure that fire safety concerns are fully addressed as a part of the plant design. This will ensure that a higher level of safety is achieved for NPR than that of current reactor sites.

The NPR designers should also recognize that the USNRC fire safety regulations which will be applied to new reactor sites will be significantly strengthened over those which apply to current reactor sites. The current USNRC Appendix R fire safety requirements will not represent an adequate design basis for NPR. The most important aspect of the anticipated changes is that redundant safety train separation requirements will be significantly strengthened. The anticipated design requirements will have a significant impact on the NPR design. It is recommended that NPR use the following criteria as the fundamental basis for the evaluation of fire safety design provisions:

> The NPR project must ensure that safe shutdown can be achieved assuming that (1) all equipment in any one fire area (where a fire area is defined as an area bounded on all sides by three hour rated fire barriers) will be rendered inoperable by fire, (2) reentry into the fire area for repairs and operator actions is not possible, and (3) any possible single active component failure in other plant equipment outside of the fire area due to nonfire related causes occurs (e.g., random failure, maintenance outages, sabotage, personnel errors). Fire detection and fire fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems and components important to safety and plant operation consistent with existing DOE requirements. Because of its physical configuration, the control room is excluded from this approach, provided a diverse independent alternative shutdown capability, including a dedicated decay heat removal capability, that is physically and electrically independent of the control room is included in the design. The NPR project must provide fire protection for redundant shutdown systems in the reactor containment building that will ensure, to the extent practicable, that one shutdown division will be free of fire damage. Additionally, the NPR project must ensure that smoke, hot gases, or the fire suppressant will not migrate into other fire areas to the extent that they could adversely affect safe-shutdown capabilities, including operator actions. The NPR project must provide for the management of fire suppressants after release, including water from manual hose streams. The NPR project will consider the potential adverse impact of the spurious operation of fire protection systems, including common cause failures, and ensure that safe shutdown capability will not be compromised by such incidents.

These criteria are consistent with the anticipated direction of USNRC regulations, and would significantly reduce fire-induced core damage frequency estimates as compared to the current generation of commercial reactor sites. In one respect the above criteria exceed that presented in SECY-90-016. That is, the USNRC position does not include failure analysis criteria (3) as presented above which states that in addition to fire induced failures, any one additional single active component failure due to non-fire-related causes is to be considered. This supplemental criteria is designed to eliminate risk outliers, such as that described above in the case of the Peach Bottom fire risk assessment, which would not be addressed by the current USNRC position statement as presented in SECY-90-016. Also note, in particular, that extended criteria should not be interpreted as mandating the design of all safety systems in a three train configuration. The enhanced criteria does not address the design of a given safety system, but rather, protection of general safety functions and the overall ability to achieve safe shutdown in the event of a fire.

Should the enhanced fire safety design criteria presented above be endorsed by DOE, it would be appropriate to include an exemption procedure for the consideration of specific areas in which this criteria might represent an overwhelming burden for a situation of limited risk significance. Exemption requests should be considered on a case by case basis using a cost/risk benefit criteria. It is not expected that more than a handful of such situations would in fact arise in a new reactor design, although until the NPR designs are more firmly established, this cannot be established. The intent of the enhanced fire safety criteria is to eliminate fire risk "outliers" and compliance to the above criteria can be expected to accomplish this goal.

It is recognized that the recommendation to use a fire safety design criteria which exceeds the USNRC requirements will represent a point of significant controversy. It has been suggested[11] that as an alternative, the USNRC policy could be endorsed directly as presented in SECY-90-016 and the significance of additional random equipment failures could be considered as a part of the fire probabilistic risk assessment (PRA). The discussion presented above presents three reasons why this alternative approach is not considered optimal. These are:

- The use of a fire PRA as a design definition tool will represent a departure from the traditional application of risk assessment as a design review tool. While this is not altogether undesirable, it does imply that the methodology utilized must be scrutinized in detail because differences in analysis methodology can significantly impact the degree to which plant vulnerabilities are identified.

- The enhanced fire safety design criteria is intended to insure that any significant fire risk scenarios would eliminated from the initial design. Thus, the role of the fire PRA would be confirmatory in nature, and a quality assurance level of "M", or mission-related, would likely be assigned to the fire PRA. If the alternative approach is taken, then a higher importance would be assigned to the fire PRA and it is likely that a higher quality assurance level of "S", or safety-related, would be assigned. No fire PRA to date has been performed to such rigorous quality standards. This will imply that a significant additional overhead burden will be placed on the fire PRA to confirm the quality level of the required input information including data bases, fire models, and expert judgement factors.

11. Reference: meeting between DOE and its consultants, SNL and the NPR design team held March 6, 1991 in Washington DC.

- A fire risk assessment can not provide meaningful results until the plant design has been firmly established, including very detailed information on the physical placement of all risk important electrical components (including cables) within the plant, and the availability of detailed and accurate plant systems models. Thus, the fire risk assessment must be performed at a relatively late stage in the design process and any vulnerabilities identified in the risk assessment must be addressed through design modifications which will be more difficult to implement late in the design than had they been implemented early in the design.

It is SNL's recommendation that the enhanced fire safety design criteria as presented above be endorsed as the fundamental fire safety design criteria for NPR. However, it remains the province of DOE to evaluate the advantages and disadvantages of each of the proposed alternative approaches available. The final decision clearly rests with DOE.

A number of other, more specific changes in the USNRC fire safety requirements should also be anticipated. These involve (1) seismic fire protection system design provisions, (2) special considerations for cable installations, (3) maintaining concealed spaces free of combustibles, (4) transformer fire safety, (5) water drainage, and (6) barrier design. These factors should all be considered as a part of the NPR design as described above.

The timetable for implementation of NPR fire safety provisions also requires careful consideration. As a part of the USNRC's discussion of fire safety for new reactor sites in Appendix A of the original BTP 9.5.1, a specific timetable for fire protection system implementation was set forth. In particular, it was stated that fire protection for the fuel storage and handling facilities should be fully implemented prior to the shipment of fuel to the reactor site, and that the fire protection for the full reactor site should be implemented prior to fuel loading of the reactor core. The requirements also state that fire protection should be provided during construction activity at the site. As will be discussed in subsequent chapters, many nuclear plant sites have experienced severe large-loss fires during construction.

It should also be recognized that changes in the general industry national fire safety standards are also expected. Five specific areas in which changes are likely have been identified. As a result, it is recommended that for NPR the following actions be taken:

- NPR should anticipate the need to establish manual fire response teams consistent with the guidelines of NFPA-1500. (Manual fire response teams can likely be provided in coordination with the overall DOE site.) The NFPA-1500 standard is currently a point of considerable controversy, and numerous requests for review and modification have been formally submitted to NFPA. All of these requests must be addressed prior to adoption of the new standard. However, it is likely that the standard, probably in a somewhat modified form, will eventually be adopted.

- It is recommended that cable materials and appropriate levels of fire detection and suppression be selected based on the newly established FMRC Cable Fire Propagation Specification Test Standard Class Number 3972 and its associated Technical Advisory Bulletin 5-31 [27,28]. This standard provides the most sensible engineering approach to the selection and protection of cables for fire performance currently available.

- It is recommended that cable insulation materials also be selected for low corrosivity properties in order to reduce the post-fire recovery burden for NPR.

- A review of the relative strengths and weaknesses of the various fire barrier qualification standards currently available both within the U.S. and abroad should be performed by DOE and the NPR design team. It is recommended that fire barrier cable tray penetration sealing elements be qualified using accepted international fire test standards rather than current U.S. fire test standards because of the controversy associated with the adequacy of current U.S. test standards. (Testing organizations in the U. S. can accommodate the international test standard conditions with relative ease, and most current U. S. cable penetration seals can be expected to pass the more stringent test standards.)

- Halon should not be used as a fire suppressant in NPR because of its ozone depleting properties and the the fact that the manufacture of Halon will be halted in the near future.

3.0 NUCLEAR POWER PLANT FIRE INCIDENT EXPERIENCE BASE

3.1 Overview of the Data Base

One of the most valuable sources of information on the frequency of fires, the sources of fire initiation, the eventual extent of fire involvement, and the extent of impact of fires on plant operations is the nuclear power plant operating experience itself. Commercial nuclear reactors in the U. S. have logged several hundred years of combined operating experience. In an effort to characterize the actual history of fires in nuclear power plants, a review of past fire incidents in U. S. commercial nuclear reactors was performed. This review was performed by Sandia National Laboratories (SNL) as a part of the USNRC-sponsored Risk Methodologies Integration and Evaluation Program (RMIEP). The results of this review were utilized as the basis for the development of a data base of U.S. nuclear power plant fire occurrences [3].

This review of fire incidents included fires from as early as 1965 through June of 1985. Incidents were identified through both the USNRC incident reporting system (Licensee Event Reports or LERs), certain insurance industry data bases, and the public literature. A total of 364 events are identified in the data base. To the extent possible, incident reports include identification of the source of the fire, the extent of fire growth, the extent of fire damage, the impact on plant systems, fire detection and suppression methods and times, as well as several other factors. It is this same data base which was used as a part of the Hanford N-Reactor [4] and Savannah River K-Reactor [5] fire risk assessments.

One of the difficulties encountered in the formulation of a fire incident data base is that fire reports are quite inconsistent in the level of detail provided. Incident reports can vary in detail from a few words stating simply that a fire occurred, to quite complete descriptions of a fire event. This inconsistency is reflected in differences in the level of detail provided for each fire event. The data base has drawn as much information as possible from each incident report, and presents that information in a structured format.

The data base itself is accessed using a standard International Business Machines (IBM) Personal Computer (PC) or compatible system with commercially available software. The data base files are contained on three 360 kbyte 5¼ inch floppy diskettes available in the public domain. This ready availability and ease of application have made the data base a quite useful tool in the assessment of plant fire risk. It is routinely utilized to estimate fire ignition frequencies for specific plant areas, to classify anticipated fire initiation sources, and to provide preliminary assessments of the anticipated effectiveness of detection and suppression efforts. The data base also provides some limited insights into the types of equipment most vulnerable to fire initiation and to fire damage.

3.2 Fire Incident Occurrence Rates

Based on the current fire data base, a given commercial nuclear power plant can expect to encounter a significant fire, on average, once every 6-10 years of operation. In this context, a significant fire is one which could have or actually did result in the degradation of one or more safety systems. Furthermore, the U. S. commercial nuclear industry as a whole experiences on the order of 10-15 reportable fires each calender year. The yearly history of fire occurrences documented in the data base is illustrated in Figure 3.1. (As noted above, an effort is planned to formally update the data base as a part of NPR/HWR fire safety efforts.)

3.3 Causes of Fire Initiation

The most common sources of nuclear power plant fires (other than during plant construction) in the approximate order of fire frequency are as follows:

- oil line leaks and oil spills (including diesel generator fires, pump fires, and fires caused by oil contacting hot pipes),
- hydrogen leaks and explosions (hydrogen is present as a component cooling agent and as a part of the reactor chemistry maintenance system),
- welding and cutting operations,
- electrical faults in switchgear, breakers, and motor control centers,
- transformer faults,
- electrical faults in control and instrumentation circuits,
- personnel error, and
- cable and cable splice faults.

3.4 Fire Induced Equipment Damage

In general, the fire incident data base provides insufficient detail to assess the vulnerability of plant equipment to fire-induced damage. However, the data base does indicate certain insights regarding the types of equipment which are typically reported as damaged in a fire incident, and conversely, those types of equipment which are rarely reported as fire damaged.

For example, cables are quite often identified as the equipment damaged by fires. Another commonly identified class of equipment damaged by fires is control circuitry. This includes relays, solid state circuitry, and switches. A number of damaging fire incidents to both types of equipment have been reported.

In contrast, large plant equipment such as pumps and motors are rarely reported as damaged by secondary fire effects. Unless these components are directly involved in the fire itself (i.e. the source of the fire or the source of a fuel or oil leak) these components will typically survive the fire intact. Similarly, large transformers, diesel generators, switchgear, and large circuit breakers are often identified as the source of

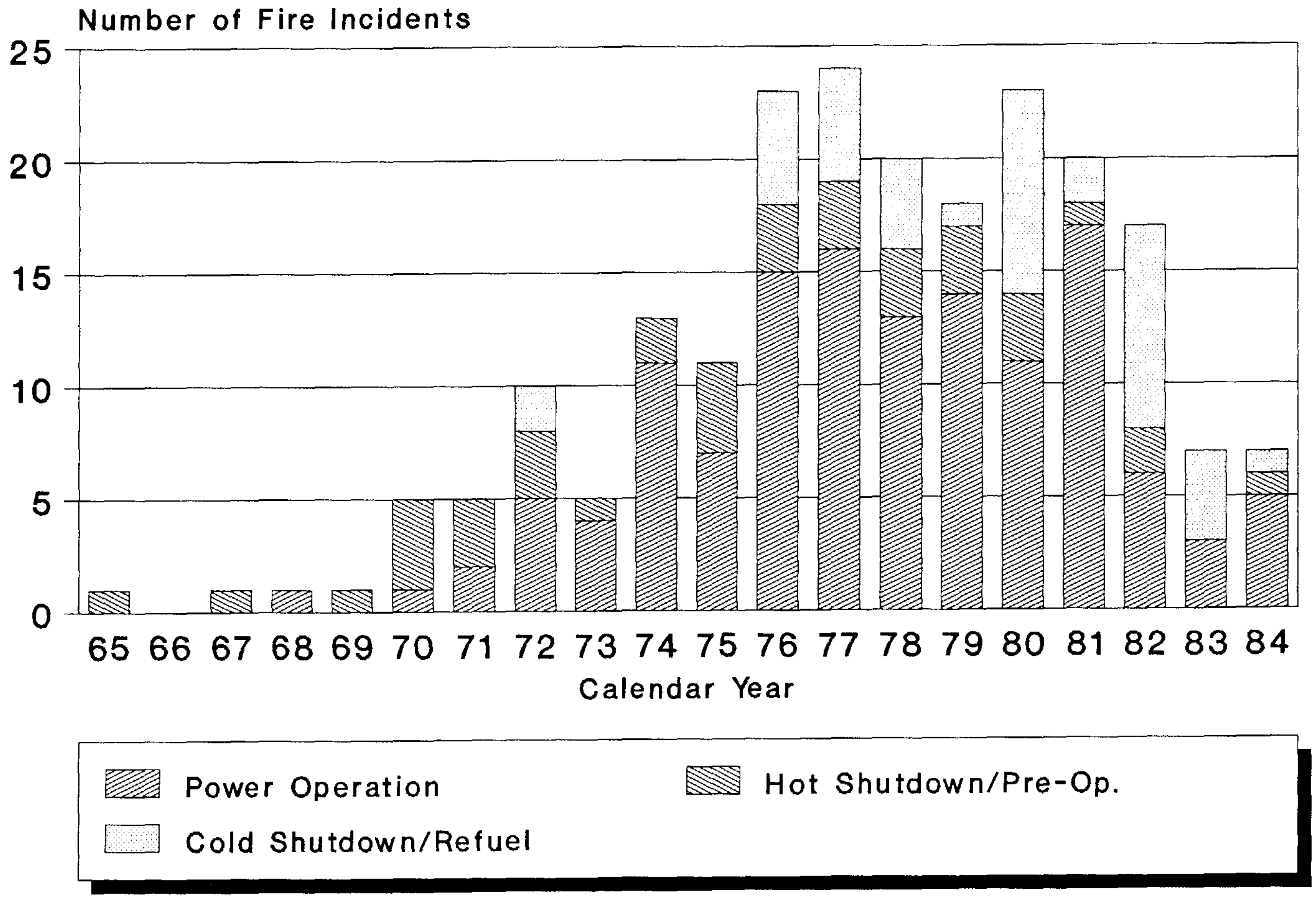

Figure 3.1 Yearly History of Fire Events as Documented in the SNL Data Base

fire initiation, but are rarely damaged by exposure fires. In most fires involving these types of large electrical equipment, it is equipment failure which induces a fire, rather than a fire which induces direct equipment failure. In fact, most of the incidents involving the failure of larger plant equipment as a result of a fire can be attributed to fire induced control or power circuit failures, rather that to direct fire damage.

Beyond this limited information, there is virtually no information available associated with actual equipment damage fire experience. This conclusion is supported by another study in which a review of both the nuclear and general industry experience on equipment fire damageability was performed, that is, the Equipment Sensitivity Ranking Study [6]. This study included the examination of fire reports available from the U.S. Air Force, the Society of Fire Protection Engineers, General Telephone Company, the Institute for Nuclear Power Operations, American Nuclear Insurers, Florida State Fire Marshal, University of Maryland Fire Prevention Engineering school, Factory Mutual Insurance, Factory Mutual Research Corporation, and the National Fire Prevention Agency. It was concluded that the fire reports available from these sources did not provide a sufficient level of detail to be useful in assessing equipment fire vulnerability. Most of the fire reports concentrated on the identification of the source of the fire, code violations, and monetary loss. Only a very few described either damaged or undamaged equipment. For those reports which specifically identified equipment damaged by the fire, very few described the mechanisms of the observed damage, and none provided environment severity estimates.

This observation is, in retrospect, not surprising. In the nuclear industry there is a unique concern with equipment operability issues. In other industries, fire safety concerns are dominated by life safety and property loss prevention issues. This is a significant difference between general and nuclear industry fire safety goals. This also explains why general industry fire reports provide little or no insights regarding equipment operability in fire environments.

3.5 Fire Suppression Insights

The fire incident data base also provides insights into the detection and suppression of nuclear plant fires. These insights are associated with both the methods of fire suppression most commonly employed, and the time typically required to suppress fires.

For example, in the nuclear power industry, by far the majority of fires are manually detected and manually suppressed. Manually detected fires outnumber automatically detected fires by approximately 5 to 1. Nearly all of the fires reported in the SNL data base have been suppressed by manual actions and in only a relatively few fires have automatic suppression systems played a role. These observations can be attributed to a number of factors.

First, the current USNRC regulations require the installation of automatic fire detection and fire suppression systems only in plant areas containing redundant trains of safety equipment. In practice, relatively few plant areas will meet this criteria, and thus, relatively few areas in most plants will be protected by such systems. (The implementation of fire protection varies widely between utilities. In practice one will find plants with extensive automatic detection systems and several fixed fire protection systems, while in other plants, one will find very few such systems installed.)

Another related factor is that all nuclear power plant sites in the US are required to have, on site, manual fire response teams. These teams may be comprised of personnel drawn from plant security, maintenance, and operation staffs, or may be personnel dedicated to fire protection activities. This requirement tends to increase the reliance of utilities on their personnel to represent the first line of fire defense for most plant areas.

A third factor which tends to increase the ratio of manually to automatically detected and suppressed fires is that many fires are either caused by personnel actions or occur as a result of test and maintenance operations during which personnel are present in the immediate area. These fires are typically handled quickly by the personnel on the scene before any automatic measures might have become involved.

A final factor, which will be discussed in more detail below, is that plants, on occasion, have been reluctant to implement automatic fire suppression system due in large part to a significant history of adverse spurious fire suppression system actuation incidents. Nuclear power plants must be concerned with the continued safe operation of the reactor safety systems, and in some cases, it has been judged that an automatic fire protection system might represent a greater hazard that did the perceived fire hazard.

Included in the fire event data base are 69 events for which an actual fire suppression time is reported. The reported fire suppression times ranged from two minutes to over seven hours. The 69 data points which are available are well represented by a log-normal probability distribution curve. The parameters of this curve, based on a least-squares fit to the linearized log-normal data, are a mean suppression time of 42 minutes, a median suppression time of 20 minutes, a 5th percentile value of 3 minutes, and a 95th percentile value of 150 minutes. The data and the fitted log-normal curve are presented in Figure 3.2 as the cumulative suppression probability versus time.

The suppression probability curve in Figure 3.2 lumps all of the reported incidents into a single curve, and as noted above, the majority of these incidents are manually detected and suppressed fires. This curve does not include consideration of a number of factors which will influence actual fire detection and suppression times.

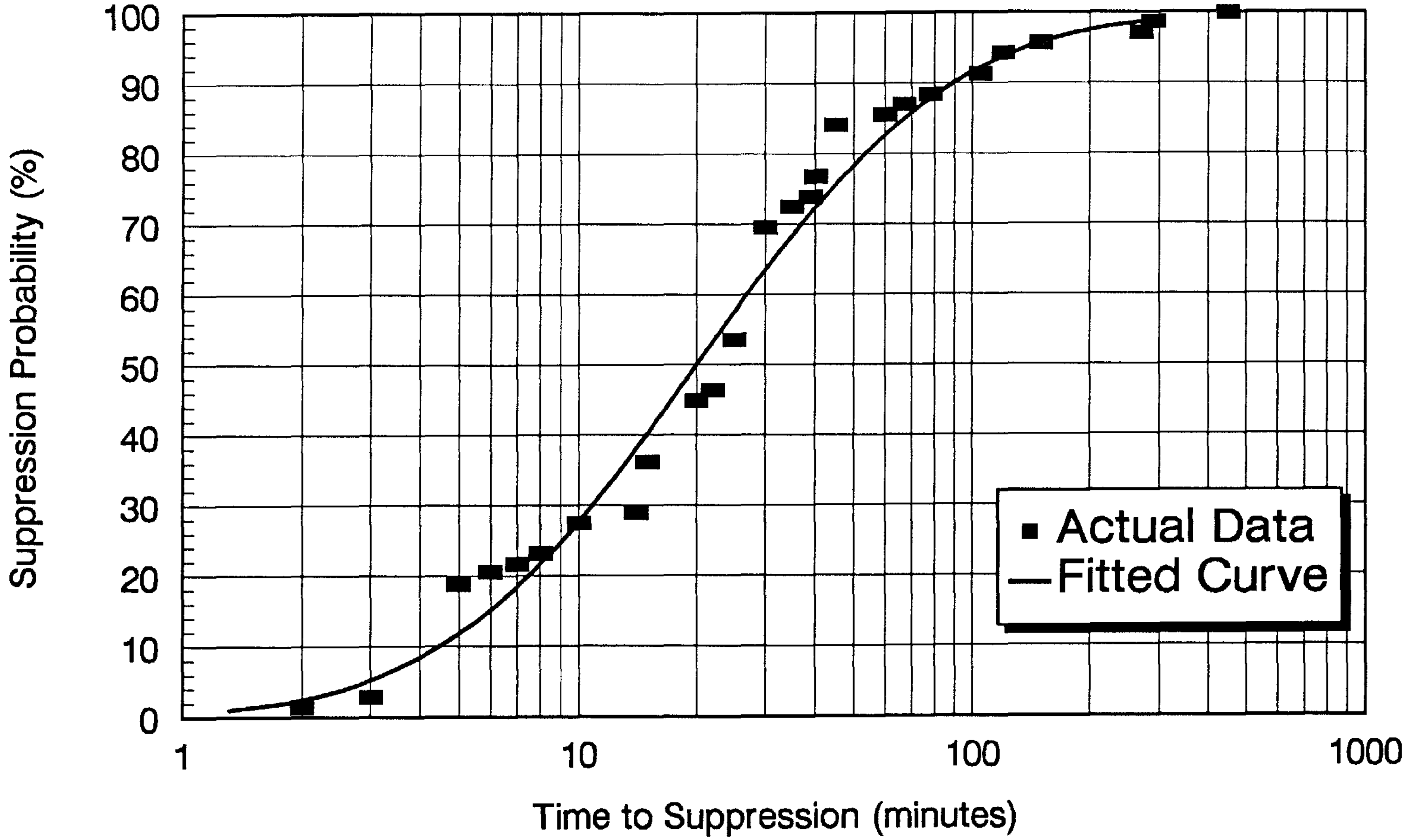

Figure 3.2 Fire Suppression Probability Curve Based On Incidents In the SNL Fire Occurrence Data Base for Which a Time to Fire Suppression is Reported.

Among others, these factors include the presence of automatic fire detection and suppression systems in the fire area, the level of training received by the manual fire team, the type of fire source, the location of the fire, and the level of activity associated with the fire area. These factors can be expected to play a significant role in the actual fire response times to be expected in a given situation. However, there is insufficient data available upon which to base an assessment of the actual impact of these, or other, factors on the probability of fire suppression within any given time frame.

The assessment of fire suppression times is particularly important in the context of fire risk assessment. The suppression of a fire is typically assumed to interrupt the process of fire damage and is typically incorporated into the risk quantification in the same way as are operator recovery actions. In the performance of a fire risk assessment, one is largely dependent on the use of judgment in the evaluation of such factors. Typical practice involves the use of a combination of experience based time estimates and engineering judgements based on the review of plant specific fire protection practices and procedures. The methodology used in the assessment of fire suppression times for risk assessments is described further in Section 6.2.2.

3.6 Design Recommendations Based on Past Fire Incidents

The experiences of the commercial nuclear power industry demonstrate that fire events can be expected in every area of the plant, and during all modes of construction, operation, and shutdown. Experience also indicates that a nuclear plant will experience, on average, on the order of one significant fire during each six to ten years of plant operation, in addition to numerous smaller fires.

The primary fire hazards identified in the fire data base include self-induced electrical equipment fires (and in particular involving switchgear, motor control center, transformers, cable faults, inverters and chargers, and control panel circuitry), personnel error, maintenance activity, sabotage, liquid fuel and lubricant leaks and spills, and hydrogen leaks. The NPR design should locate equipment so as to minimize the fire hazard in areas of high combustible loading or of particular importance to plant operations. For example, the following are recommended design considerations for NPR:

- The use of power cables in the main control room and remote shutdown area should be minimized to minimize the potential for self-induced cable fires in these areas.

- Plant areas intended primarily for the routing of cables (such as the cable spreading rooms and cable vault and tunnel areas) should not be used to house any other types of electrical equipment. This will minimize the hazard of exposure fires for these areas of high combustible loading.

- Piping for flammable gases should not be routed in trays used for the routing of cables, and should not be routed through areas intended primarily for the routing of cables (such as the cable spreading rooms and cable vault and tunnel areas). Flammable gas lines should also be equipped with flow limiting devices to prevent uncontrollable leaks.

- Oil-filled transformers should be located outside of the plants primary structures and at least 50 feet from any primary plant structure. The potential for transformer explosions should be anticipated, and redundant transformers segregated appropriately by debris shields and fire barriers.

- The potential for initiation of fires in electrical control panels should be recognized in the design of control panels for the main control room, remote shutdown area, and other remote operation stations. Appropriate segregation of plant safety systems should be maintained and fire barriers should be provided to subdivide panels. Fast response fire detectors (e.g., smoke detectors) should be provided in all enclosed electrical panel areas which are not vented directly into an occupied area. (In many plant designs, control panels areas are used as return air plenums which vent directly to ventilation exhaust ducts. It is this type of panel design which will require automatic fire detection because of the reduced likelihood of manual detection.)

Based on past experience, plant personnel are often the first line of fire defense. Personnel intervention in the early stages of a fire can be very effective. Adequate provisions should be made for manual fire suppression to be available in all plant areas, including both hose stations for the use of the fire brigade and hand-held fire extinguishers for use by general plant personnel against small fires. All plant personnel should be trained in the use of hand-held fire extinguishers, and should be trained in the proper procedures to follow in the event of a fire. Fire suppression equipment should be made readily available whenever maintenance activities which could result in a fire (e.g., welding and cutting operations) are under way.

Experience also demonstrates that construction activities introduce unique fire hazards to the plant site. Many large-loss fires have been experienced at plant construction sites. It is recommended that a fire protection plan for the NPR construction site be developed. This plan should be coordinated with the overall DOE site, the operating contractor, and the cognizant DOE office. This plan should include provisions for a manual fire fighting capability to be provided during the plant construction phase. This would imply that the installation of the plant fire water supply system and the main fire water yard headers should be a high priority for early completion. Adequate hydrants should be installed to provide hose stream protection to all construction areas, including storage sheds and temporary structures.

4.0 ADVERSE IMPACT OF FIRE SUPPRESSION SYSTEMS ON PLANT EQUIPMENT

4.1 Overview of the Adverse Fire Suppression System Impact Issue

For most reactor sites in the U. S., fire protection systems were installed as a retrofit to an existing plant during the period following institution of the Appendix R fire safety requirements in 1980. During the years since Appendix R was established, a significant base of adverse experience has been logged in which the actuation of fire suppression systems has induced plant safety systems equipment damage. The initial documentation of this problem was presented in USNRC Information Notice 83-41. This notice discussed several incidents in which plant equipment had been damaged by the inadvertent actuation of a fire suppression system.

The USNRC Appendix R fire safety regulations specifically state that fire suppression systems must be installed such that the actuation of the system will not adversely impact plant safety systems. Because of the continuing adverse operating experience, the status of the adverse suppression effects issue has been raised to the level of an unresolved Generic Safety Issue (GI57). The USNRC has sponsored one previous study of the issue, and is currently sponsoring a follow-up effort to further refine the understanding of adverse suppression effects.

4.2 Overview of the Suppression Effects Incident Experience Base

Since the problem was initially identified, the U. S. commercial nuclear industry has continued to experience actuations of fire suppression systems which have adversely affected plant safety systems. A preliminary review of such incidents has been completed [7]. A second, more comprehensive review is currently under way [8]. In the initial review, only inadvertent fire suppression actuation incidents were considered (that is, incidents in which no fire was present in the areas for which a fire protection system was actuated). The review which is currently under way is expanding the scope of the incident review to include both inadvertent actuations and advertent incidents (that is incidents in which fixed fire suppression systems were actuated to aid in the suppression of an actual fire).

Based on the preliminary results[12] of the current review, a total of 131 separate fire suppression system actuation incidents have been identified in the USNRC Licensee Event Report (LER) data base. This review includes all incidents reported between January 1, 1980 and December 31, 1989. Of these 131 events, 104 were inadvertent actuations occurring after initial plant criticality, 15 were advertent actuations, and 12 were inadvertent actuations occurring prior to initial criticality.

12. The current review, Reference 8, has largely been completed; however, the results are not yet published and have not undergone full peer review.

4.3 Frequency of Suppression System Actuation Incidents

Figure 4.1 illustrates the number of fire suppression system actuation incidents occurring at commercial U. S. reactor sites by calendar year. This figure is based on the preliminary results of the current review and distinguishes between inadvertent and advertent incidents. These data indicate that the U. S. commercial nuclear power industry is experiencing anywhere from 3 to 23 fixed fire suppression system actuation incidents per year, with an average of approximately 13 incidents per year. Of these incidents approximately 1 in 10 are advertent incidents, with the remainder being inadvertent actuations.

The frequency of inadvertent fire suppression system actuations per reactor year of operation is quite similar to that observed for actual fire incidents as well (see Figure 3.1 and Section 3.2 above). For the time in which the suppression effects and fire event data bases overlap, from 5 to 15 fire incidents per year were being reported in the commercial nuclear industry. During the same period, from 5 to 21 spurious suppression system actuation incidents were reported per year. In fact, when one refines the incident frequencies to account for the probabilistic frequency of fires or inadvertent suppression system actuations only in risk important plant locations, an interesting result appears.

In the development of risk assessment event frequencies, a process called "partitioning" is invoked by which the generic incident data base is refined for application to specific plant locations. For fires, this process typically considers the relative ratio of the area considered important to the risk assessment to the generic area considered by the data base. As an example, fire frequencies for a switchgear room are typically based on generic data for auxiliary building fires. Thus, for example, the ratio of the floor area of a switchgear room to the total floor area of the auxiliary building is used as a multiplier on the generic auxiliary building fire frequency to estimate the room specific fire frequency. This typically results in a significant reduction in fire frequency estimates.

In the case of spurious suppression incidents, only those areas with fixed fire suppression systems will factor into the partitioning process. As stated above, relatively few plant areas will be equipped with such systems because of the nature of the USNRC fire safety regulations. Hence, the overall area covered by the generic data base is much reduced, and the resulting partitioning factors will not reduce the generic frequencies to as great an extent as is observed for fire incidents. The fact that the generic plant wide frequencies for fires and spurious suppression incidents are quite similar, leads to a prediction that, generally, an inadvertent suppression incident is more likely to affect an important plant area than is an actual fire.

4.4 Suppression System Actuation Causes

The fire suppression system actuation incidents identified include actuations of all three of the most common fire suppression system types, that is, water based, carbon

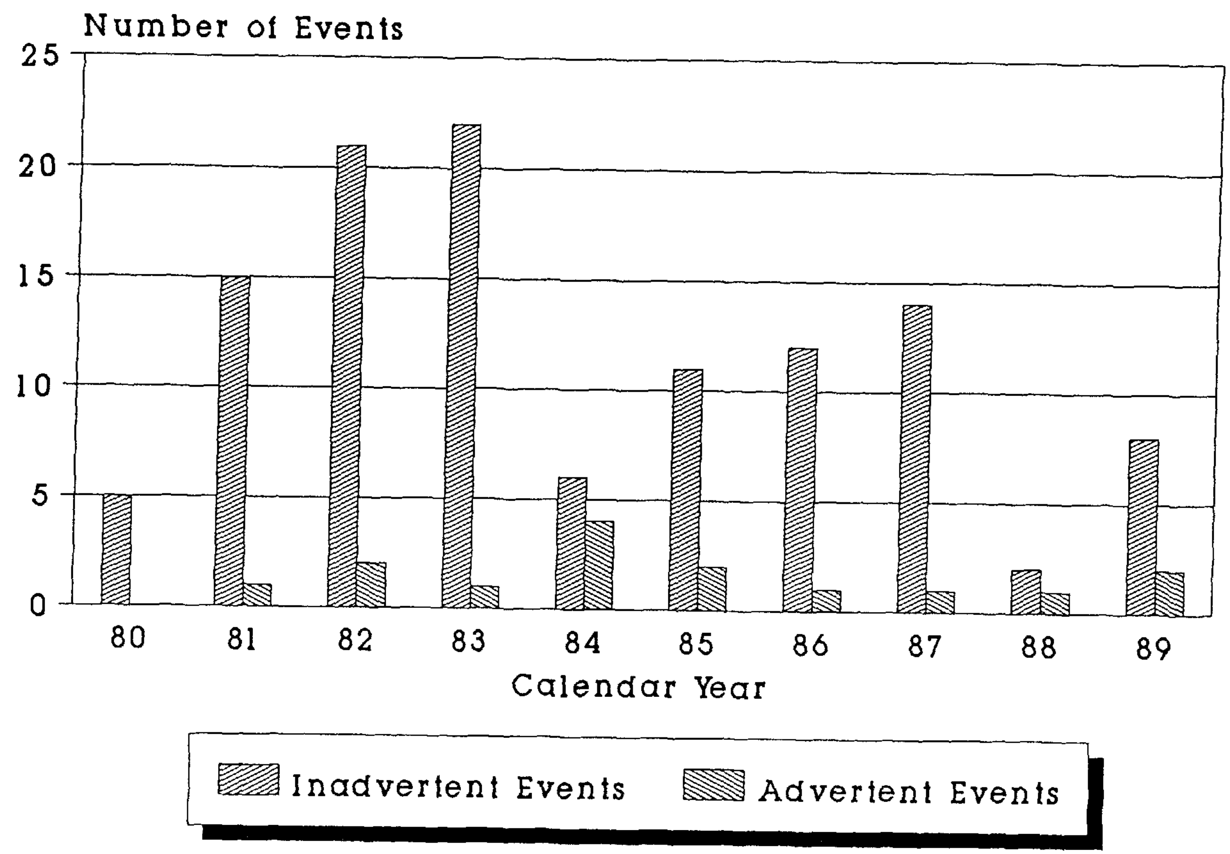

Figure 4.1: Yearly History of Fixed Fire Suppression System Actuation Incidents as Documented in USNRC LERs.

dioxide (CO_2), and Halon. The post-criticality inadvertent suppression incidents identified included 90 water based system actuations, ten CO_2 system actuations, and nine Halon systems actuations (note that in two cases, more than one suppression system was actuated inadvertently). This illustrates that virtually all fire suppression systems are subject to spurious actuation. In the case of the advertent operations, The identified incidents include 11 water system actuations, six CO_2 system actuations, and two Halon systems actuations.

The most commonly identified cause was personnel error (22.8% of the incidents). This includes failure to follow proper test and maintenance procedures, bumping activators, mis-communications, and other personnel errors. The second most commonly identified cause was leakage of water based systems (22.1% of the incidents). These incidents would include leaking valves and sprinkler heads, and pipe ruptures. The third most common cause of inadvertent actuation identified was test and maintenance procedure inadequacies (8.8% of the incidents). These were incidents in which personnel were following the approved procedure for system maintenance or testing, and yet an unplanned actuation occurred. Other common causes of system actuation were steam/dust/humidity actuation of smoke detectors (8.1%), pressure spikes in water systems (5.1%), smoke from welding and maintenance activities actuating smoke detectors (2.9%), wetted detectors (2.2%), electrical failure of fire suppression system components (2.2%), and lighting induced actuation of flame detectors (1.5%). Eleven percent of the incidents were caused by advertent factors, and 13.2% of the incident reports gave no specific cause.

4.5 Fire Suppressant Induced Equipment Damage

Of the 131 fire suppression actuation incidents identified, 55 (or 42%) adversely impacted other systems in the plant. Of these, 31 (or 23.7%) were found to have caused damage to front-line safety systems or to other support systems which are risk significant. This proportion of incidents which actually resulted in safety system damage is much higher than that observed for actual fire incidents. This is not entirely surprising because fixed fire suppression systems are typically employed only in areas which house safety equipment, and in some cases, redundant trains of safety equipment. Thus, it can be expected that most suppression system actuations, advertent or inadvertent, would potentially expose safety-related components to damage. In contrast, fires are observed in all plant areas, many of which will not represent a potential for safety system damage. Another factor which contributes to the high rate of equipment failure in suppression incidents is that most fixed fire suppression systems have a relatively large area of influence, that is, the entire area protected by the system. In contrast, most fires are controlled quickly while still very small and have only a very limited range of influence.

The fixed suppression actuation incidents also demonstrate that a wide variety of plant equipment and systems are vulnerable to fire suppression induced damage, and in particular, to damage by water intrusion. For the advertent actuation incidents it is unclear whether the reported damage is attributable to the fire itself or to the suppression system actuation. However, in the case of the inadvertent actuations, it is clear that the damage was suppression induced. For the inadvertent actuations, damaged components which are considered risk important included, in order of frequency:

- Transformers (10 Shorting and 4 Spurious Trip Signal Incidents),
- Load Centers, Switchgear, Motor Control Centers and Electrical Busses (10 Incidents),
- Control Panel Circuitry (9 Incidents),
- High Pressure Coolant Injection Equipment Oil Supply (3 Incidents)
- Diesel Generator Actuator and Dampers (3 Incidents),
- Shorting of Electrical Junction Boxes (2 Incidents),
- Engineered Safety Features Pumps and/or Valves (2 Incidents),
- Pump/Motor Set (1 Incident), and
- Motor/Generator Set (1 Incident).

Components reported damaged in inadvertent suppression events which are not considered risk important included:

- Charcoal Filters (15 Incidents),
- Depletion of Fire Water Storage Tanks (9 Incidents)
- Fire Detectors (3 Incidents),
- Misc. Instrumentation, Indicators or Monitors (2 Incidents), and
- Instrument Air Lines (2 Incidents).

In addition, one incident per component was identified involving the failure of non-risk important equipment including the plant computer, a doorway access card reader, an internal plant radio repeater, a cable tray fire retardant barrier system, and a fire door. Other incidents reported system damage without identifying the specific component damaged.

Nearly all of the component damaging incidents are attributed to water intrusion into electrical equipment. In only two cases involving a carbon dioxide system discharge has any damage to plant equipment been observed. In one case, a nonsafety related radio repeater was frozen due to its proximity to the CO_2 discharge nozzle. In a second case, not included in the inadvertent suppression incident data base because this incident involved a pre-operational test of a CO_2 system, icing of relays was observed inducing a number of spurious control room indication signals. In no case has Halon been observed to induce plant equipment damage. (Halon is not expected to be used in NPR as discussed in Section 2.4.5.)

Fire suppressant induced component failures have resulted in the failure of a variety of plant safety systems. Those risk important systems which have been reported damaged by inadvertent suppression system actuation include:

- Power Transmission/Distribution (13 incidents),
- HPCI, RCIC (8 incidents)
- Core Spray, RHR, ESFs (3 incidents),
- RCS, RCPs, Pressurizer (3 incidents),
- Turbine/Generator (3 incidents),
- Diesel Generators (2 incidents),
- Reactor Protection System (2 incidents),
- Control Rod Drive System (1 incident), and
- Instrumentation (1 incident).

Because of the "defense in depth" strategy to power plant design, a failure in any one plant safety system may have little or no effect on plant operations. However, in 6 of the 104 post-criticality inadvertent actuation incidents, other plant equipment failures which induced a plant trip directly induced the fire suppression system actuation. Because the fire suppression system actuations have often caused safety system damage, the combination of a spurious actuation concurrent with a plant transient already in progress could complicate plant shutdown procedures. In an additional 23 of the 104 post-criticality incidents, the spurious actuation of one or more fire suppression systems directly induced a forced shutdown of a plant from power operation. In these incidents, it is the loss of plant equipment due to suppressant release which induces a plant trip. Here again, the fraction of spurious suppression events which are associated with a plant transient (i.e., either the direct result or the direct cause of a plant transient) exceeds the fraction of actual fires which are associated with plant transients.

4.6 Fire Suppression System Interactions in Diesel Generator Areas

There is one particular vulnerability which has recently been identified which is not illustrated in the suppression effects data base. This vulnerability involves an interaction between seismic events and the potential spurious actuation of fire suppression systems in diesel generator areas.

In the event of a significant earthquake, it is generally expected that off-site power will be lost due to the failure of ceramic insulators commonly used in the power switching yard. This damage is generally considered to be irrecoverable (that is, repair is not possible in the short term). The loss of off-site power will place a demand on the diesel generators to provide emergency station power throughout the shutdown process. Should the diesel generators fail, then station blackout conditions would result, and only station batteries would remain.

Because of the operational importance of the diesel generators, and because of the perceived fire hazard associated with diesel generators (a number of fires involving diesel generators have been reported), most plants provide some form of fixed fire protection in the diesel generator areas. Two types of fire suppression systems have been commonly employed in the protection of diesel generator areas, namely, water based deluge or sprinkler systems and carbon dioxide room flooding systems.

Because fire protection systems are not required to be seismically qualified by the USNRC, it is considered likely that spurious actuation of the fire suppression systems will be observed during a significant earthquake event. This introduces the potential for a common mode failure of both off-site and on-site power.

For water based suppression systems, the data base indicates that approximately 30% of the actuation incidents have resulted in the failure of safety related equipment. In the case of the diesel generator areas, it is expected that failure of the generator system would be induced through the failure of either the motor control centers or the diesel control circuitry, both of which are typically located in the immediate vicinity of the motors themselves.

For CO_2 systems, suppressant concentrations must be maintained for as much as 15 minutes. This typically requires that room ventilation be isolated. In many plants, the diesel generators are cooled by air/water heat exchangers which dump the excess heat into the general room air. The room air is in turn cooled by the normal room ventilation system. In the case of a seismically induced loss of off-site power, the diesel generators will automatically start. If, at the same time, the gaseous room flooding system is actuated and room cooling is isolated, then the failure of the diesel generators due to over-heating of either the control panels or the generators themselves would result. It has been estimated that this would take only on the order of 20 minutes [9]. This would place the plant in a non-recoverable station blackout condition.

This situation was first brought to light by one particular plant, Brunswick, which identified a similar vulnerability at their own facility [9]. To date, no operating reactor in the U.S. has experienced a significant earthquake incident, and hence, no incidents such as that postulated here have been recorded. However, in the perspective of plant risk, a common-cause station blackout event will likely be judged significant. The actual seismic hazard curves which apply to the site in question will determine the risk significance of the scenario.

4.7 Design Recommendations Resulting from Suppression Damage Experience

One must recognize that fixed fire suppression systems, both manually and automatically actuated, have played an important role in reducing fire risk for commercial reactor sites. For NPR, it is to be expected that fixed fire suppression systems will also play an important role in the overall fire protection strategy. The installation of fixed fire suppression systems represents the most reliable means of providing for fire protection. However, one must also recognize that fire suppression systems can represent a hazard in and of themselves.

In general, the vulnerabilities identified in these reviews have been attributed to design and installation inadequacies. In the past implementation of fire protection, equipment vulnerabilities to fire suppressant discharge do not appear to have been fully considered in all cases. Consideration of these factors in the design and installation of fixed fire suppression systems could largely eliminate the vulnerabilities which have been documented in past inadvertent suppression incidents. In particular, it is recommended that the NPR design consider the following factors:

- Provisions should be made for the management of water in all areas where water is expected to be used as a fire suppressant. This should include water from either fixed suppression systems or manual hose stations.

- Provisions should be made to manage gaseous suppression agents following discharge. This should include consideration of appropriate ventilation discharge paths and administrative procedures for the venting of suppression agents and fire products from the fire area.

- Floor penetration seals should be water tight for areas in which water is likely to be employed as a fire suppressant, including manually applied water.

- Cable and conduit penetrations into electrical cabinets should be sealed to prevent water intrusion in any area in which water is likely to be used as a fire suppressant, including manually applied water.

- Electrical conduits should be examined for the potential to channel water to sensitive components and sealed if necessary. In particular, conduits which pass form one fire area to another should be examined.

- CO_2 discharge nozzles should not be located near components sensitive to freezing such as integrated circuits, circuit breakers, motor control centers, and relays. (Based on a the accumulated experience of the fire protection community, a distance of at least 10 feet is generally considered adequate to mitigate the immediate cooling effects of gaseous discharge.)

- Multiple gaseous storage tanks should be used for multiple suppressant systems rather than a single large storage tank to service many systems. (One incident has occurred in which a plant's entire suppressant inventory was discharged into a single fire area.)

- Placement of fire protection system control panels should ensure that a multiple safety system vulnerability is not created through the potential for common mode failures to occur in multiple actuation control panels (for example, from fire induced damage or from a steam line break).

- Suppression system design should consider the significance of potential inadvertent actuation induced equipment damage. Designs must consider a balance between fast response and inadvertent actuation likelihood. (For example, automatic deluge sprinklers are the most likely type of suppression system to be spuriously actuated. The use of a wet pipe or pre-action system would reduce the likelihood of spurious actuation though might increase system response times.)

- Suppressant system actuation switches should be clearly marked, including a clear description of the protected area or equipment, and should be protected from inadvertent actuation due to casual contact. (Incidents have occurred in which personnel have accidentally set off systems not realizing they were manipulating an actuator handle, and in which personnel have set off several systems because they were uncertain as to which system provided coverage to a specific fire area.)

- Single smoke detectors should not be used as the sole criteria for the initiation of fire suppressant discharge (at the least, multiple detection logic or cross zoning should be employed, or an alternate detector type should be employed, particularly in areas of high humidity, high dust levels, or potential steam leak areas).

- Administrative procedures are needed to ensure that routine plant maintenance activities do not inadvertently set off fixed fire suppression systems. (For example, welding or cutting operations might require that smoke detectors be deactivated, and a fire watch be posted. Procedures should also ensure that fire protection systems are properly restored upon completion of work.)

- Fire hazards analyses and fire risk analyses should consider fire suppressant discharge, either inadvertent or advertent, as a source of equipment failure.

- All plant personnel should be trained in the use of hand-held fire extinguishers, and should be made aware of fire emergency procedures.

- Fire protection systems in diesel generator areas will require special consideration. These systems should be seismically qualified to ensure that spurious actuation during a seismic event will not occur. Diesel generator cooling systems and combustion gas intakes should not be compromised by the actuation of gaseous suppression systems. Generator support equipment (control panels, wiring, junction boxes, fuel supplies, motor control centers, etc.) should be protected from water intrusion induced damage. The design should ensure that common mode failure of multiple generators can not occur due to fire suppression efforts (either manual or fixed systems).

- The plant design should consider the potential for a seismic event to induce the actuation of fire protection systems. This introduces the potential for common cause failures of multiple safety systems and may require that the fire protection systems in certain critical plant areas be seismically qualified to prevent spurious actuation. In one case in particular, scenarios involving the failure of both off-site and on-site power source have been postulated at operating reactors. However, the concerns also extend to other plant areas and systems.

These design considerations would generally address the vulnerabilities identified. However, even with such consideration, vulnerabilities are expected to remain because not all equipment can be adequately protected from suppressant induced damage without compromising fire fighting effectiveness, and because not all failure modes and circumstances can be foreseen. Analyses should be performed to ensure that redundant safe shutdown capability will remain given conceivable inadvertent suppression actuations and damage. These analyses should include consideration of the potential for multiple areas to be impacted by a common mode source such as a seismic event or large pipe rupture.

5.0 FIRE PROTECTION RESEARCH EFFORTS

5.1 Introduction

Under the sponsorship of the USNRC, Sandia National Laboratories (SNL) has investigated a number of fire safety issues through the performance of specialized tests and analyses. Efforts in this area were initiated in fiscal year[13] 1975 (FY-75) under the Fire Protection Research Program. This particular program continued through the end of FY-87. In more recent years, three additional USNRC-sponsored research efforts have been initiated. These are the Fire Vulnerability of Aged Electrical Components Program, a USNRC/West German cooperative fire safety research effort, and the investigation of Generic Issue 57 (GI-57) Adverse Fire Suppression Effects. This final program, the GI-57 investigations, has been discussed in detail in Chapter 4 above and will not be discussed further here. It is the remaining past and present USNRC-sponsored fire safety research efforts which are the focus of this chapter. In the following sections, those insights into nuclear power plant fire safety which have been developed, and the impact of these insights on the design of NPR will be discussed.

5.2 The USNRC-Sponsored Fire Protection Research Program

5.2.1 Overview of Program Efforts

Under the USNRC Fire Protection Research Program (FPRP), a number of individual efforts involving both analytical and experimental efforts associated with a broad range of nuclear power plant fire safety issues have been performed. It is not possible, as a part of this document, to fully discuss all of the results and conclusions generated as a result of these effort. This section provides a brief overview of the efforts undertaken as a part of the FPRP and the major conclusions generated as a result. For more detailed information, the reader is referred to a recently published program summary report [10] which describes the results and conclusions of each of the individual FPRP efforts.

5.2.2 Areas of Investigation

As initially conceived, the early FPRP investigated specific regulatory concerns. These concerns were raised in large part by the cable tray fire at the Brown's Ferry Plant in 1975, although the program actually predates that fire by approximately 3 months. As a result of the Brown's Ferry fire, awareness of the potential impact of fire on the operability of a nuclear power plant increased significantly. The early FPRP investigations focused on the identification of areas of weakness in the general industry fire regulations as applied to the nuclear industry, and on the support of effort at the USNRC to establish of a new set of fire protection guidelines to address these weaknesses.

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13. For U. S. Government sponsored efforts fiscal year extend from October 1 through September 30.

In later years, the focus of the FPRP shifted towards an integrated investigation of more general fire safety concerns and fire phenomena. The individual efforts performed as a part of this integrated approach to fire safety can be grouped into five areas of investigation. These areas are:

1. Source Fire Characterization,
2. Detection and Suppression System Effectiveness,
3. Room Effects,
4. Equipment Response, and
5. Room-to-room Fire Effects.

Source fire characterization is associated with the identification of potential fire initiation sources and the characterization of the burning behavior of these sources. Detection and suppression system effectiveness includes consideration of the degree of additional safety afforded by such systems, and the adequacy of the general industry guidelines for system implementation in nuclear power plant applications. Room effects issues are associated with the mechanisms for the transport of fire products (heat, smoke, etc.) within the room of fire origin. Equipment response issues are associated with the effects of a fire environment on the operability of plant components. The final area, room-to-room fire effects, is associated with the potential adverse effects of a fire beyond the room of origin. These effects include fire spread through barriers, the management of fire products and fire suppression agents, manual fire brigade accessibility issues, and spurious suppression system operation in uninvolved areas.

Listed below are the specific areas of research conducted under the FPRP. The studies have been grouped to indicate their applicability to either specific regulatory issue investigations, and/or the specific areas of investigation identified as a part of the integrated approach to fire safety. It will be noted that several of these efforts provide insights into more than one area of investigation.

Investigations of Specific Regulatory Concerns:

- 1975 Cable Use Screening Survey
- 1976 Fire Protection Systems Study
- 1979 Fire Protection Subsystems Study
- 1976-81 Cable Tray Fire Testing:
  - 1976 Electrically Initiated Cable Fire Tests
  - 1977 Exposure Fire Cable Fire Tests
  - 1978 Fire Retardant Cable Coating Tests
  - 1978 Cable Tray Fire Barrier Tests
  - 1979 Cable Tray Fire Corner Effects Tests
  - 1981 Cable Radiant and Convective Heating Damage Tests
  - 1981 Burn Mode Analysis of Cable Fires
- 1980 Investigation of Fire Stop Test Parameters
- 1980-83 Fire Suppression System Effectiveness Investigations:
  - 1980 Halon Suppression Effectiveness Tests
  - 1981 Water Sprinkler Suppression Effectiveness Tests
  - 1982 Directed Water Spray Suppression Effectiveness Tests
  - 1983 Carbon Dioxide Suppression Effectiveness Tests

1981 Cost Analysis of Fire Protection Systems
1982 Detector Siting Criteria Requirements Study
1982 Twenty-Foot Separation Adequacy Investigations

Source Fire Characterization Studies:
- 1975 Cable Use Screening Survey
- 1976-81 Cable Tray Fire Testing:
  - 1976 Electrically Initiated Cable Fire Tests
  - 1977 Exposure Fire Cable Fire Tests
  - 1978 Fire Retardant Cable Coating Tests
  - 1978 Cable Tray Fire Barrier Tests
  - 1979 Cable Tray Fire Corner Effects Tests
  - 1981 Burn Mode Analysis of Cable Fires
- 1981 Trash/Pool Fire Correlation Tests
- 1984 Identification and Classification of Transient Fuel Ignition Sources
- 1985 Review of Fire Characterization Data
- 1985 Development of Electrical Ignition Apparatus
- 1985 Transient Fuel Source Fire Tests
- 1985 Electrical Cabinet and Control Room Fire Tests
- 1986 Development of Nuclear Power Plant Fire Occurrence Data Base

Detection and Suppression Effectiveness Studies:
- 1980-83 Fire Suppression System Effectiveness Investigations:
  - 1980 Halon Suppression Effectiveness Tests
  - 1981 Water Sprinkler Suppression Effectiveness Tests
  - 1982 Directed Water Spray Suppression Effectiveness Tests
  - 1983 Carbon Dioxide Suppression Effectiveness Tests
- 1982 Detector Siting Criteria Requirements Study

Room Effects Studies:
- 1982 Twenty-Foot Separation Tests
- 1985 Base Line Validation Enclosure Fire Tests
- 1985 Electrical Cabinet and Control Room Fire Tests

Equipment Response Studies:
- 1976-81 Cable Tray Fire Testing:
  - 1978 Fire Retardant Cable Coating Tests
  - 1978 Cable Tray Fire Barrier Tests
  - 1981 Cable Radiant and Convective Heating Damage Tests
- 1984 Cable Steady State Thermal Damage Tests
- 1985 Cable Transient Thermal Damage Tests
- 1985 Equipment Damage Sensitivity Ranking Study
- 1985 Relay Thermal Damage Tests
- 1985 Component Testing in Secondary Fire Environments

Room-to-Room Fire Issue Studies:
- 1979 Fire Protection Subsystems Study
  - Fire Barriers
  - Ventilation Systems
- 1980 Investigation of Fire Stop Test Parameters

5.2.3 Results and Conclusions of the FPRP

As a result of the investigations undertaken through the FPRP, a number of insights have been gained. The following lists some of the major results and conclusions which have resulted from these efforts:

- Fire retardant cable insulation, cable coatings, cable tray covers, and other passive cable tray protective measures reduce fire severity. However, such measures do not ensure that fire-induced damage will not occur and wide variability in relative effectiveness of different systems and products was demonstrated.

- While cables which pass the IEEE-383-74 flame spread test are more difficult to ignite and spread fire more slowly than nonrated cables, most of the rated low flame spread cables can be ignited, burned, and/or damaged. It has also been observed that once a self-sustaining fire is established in low flame spread cables, these fires tend to be more intense and more difficult to extinguish.

- Water is the most effective fire suppressant for suppressing even deep seated cable fires. The use of water does, however, produce severe moisture environments which may lead to equipment damage, even beyond the region of immediate fire involvement. The proper management of fire suppression water should also be considered as a part of system design.

- If properly designed and installed, carbon dioxide and Halon suppression systems will eventually extinguish even deep seated fires such as those encountered with cable installations. However, the maintenance of proper concentrations of suppression agents for sufficient periods of time is critical to prevent reignition.

- Gaseous suppression agents applied during a fire permit enclosure temperatures to remain higher than do water based suppression systems. Sensitive control circuitry may experience loss of function and/or calibrations shifts during extended exposures at even relatively mild temperature elevations.

- Cable and ventilation duct wall penetration seals can allow hot gases and flame to pass through prematurely under conditions of positive pressure differential if the seal system is such that air passages are incorporated, even though such penetration seal systems may pass standard U. S. fire barrier qualification tests.

- Hot gas layers from fires have, during testing, been observed to cause damage to cables spatially separated in accordance with the provisions of the Appendix R fire regulations even though these cables are not directly involved in the fire. (In these tests no active suppression of the room fires was attempted. Appendix R does specify the use of automatic fire detection and suppression where spatial separation is used as a fire protection measure.)

- Failure mechanisms identified for electrical components include high temperature effects (e.g., melting), calibration shifts due to relatively low elevations in temperature, smoke deposition, moisture, and/or corrosion. Thermal cut-out protective features activation has also been observed. Such cut-out may require operator action to restore equipment operability.

- Testing has shown that cables can fail at temperatures well below the material ignition temperatures.

- Electrical cabinet fires which consumed all of the available combustible materials within approximately 15 minutes of ignition were observed for both IEEE-383-74 rated low flame spread cables and for nonrated cables.

- For the nonrated cables, full involvement cabinet fires can be electrically initiated as a result of a low intensity (less than 15 Ampere) simulated electrical fault.

- The deterministic criteria of the Appendix R guidelines do not address the residual risk associated with probabilistic events such as multiple faults, multiple spurious operations, and multiple random equipment failures.

- Manual fire fighting and operator control and recovery actions may be severely hampered by the rapid development of a thick toxic smoke layer during cable fires, even in very large rooms having high forced ventilation rates. Standard approaches to the design of industrial ventilation systems, including those installed in current nuclear power plants, do not include the consideration of smoke removal as a design constraint. Therefore, these ventilation systems can not be expected to provide effective combustion products removal, and may, in fact, aggravate the spread of combustion products to nonfire areas.

- Chlorides released during PVC cable insulation fires were observed to become bound to smoke particulate which was subsequently deposited on surfaces throughout a fire enclosure. These chlorides, when combined with water, can form a highly corrosive and electrically conductive deposit.

- Fire models currently used in the U. S. to support the analysis of nuclear power plant fire risk have not been adequately validated. Numerous questions have been raised regarding the computational accuracy and overall adequacy of the available fire models as applied to the analysis of nuclear power plant fire scenarios. For NPR an improved fire model will be needed to support the assessment of fire risk. (This issue is discussed further in Chapter 6 below.)

5.3 Current USNRC Sponsored Fire Safety Research Efforts

The USNRC is currently sponsoring three studies directly related to the understanding of fire safety for nuclear power plant applications. These are the Fire Vulnerability of

Aged Electrical Equipment Program, the USNRC/West German Cooperative Effort, and the Investigation of Generic Issue 57 (GI-57) Adverse Effects of Fire Suppressants on Plant Equipment. Issues associated with the final effort, the GI-57 investigations, have been described above in Chapter 4 and will not be discussed further here. This section will provide a brief overview of the two remaining current USNRC-sponsored fire safety research efforts.

5.3.1 The Fire Vulnerability of Aged Electrical Components Program

For the USNRC, the investigation of plant aging issues is currently a high priority area of research. As a part of the Nuclear Plant Aging Research (NPAR) program, an effort called the Fire Vulnerability of Aged Electrical Components Program has been initiated. The objectives of this program are to identify and investigate potential issues of plant aging which might lead to an increase in fire risk.

To date, several such issues have been identified. These include the impact of aging on:

- Cable Flammability,
- Cable Damageability,
- The Vulnerability of Other Types of Class 1E Equipment to Fire-Induced Damage,
- The Vulnerability of Electrical Equipment to Self-Induced Fire Initiation,
- The Integrity of Passive Cable Tray Fire Retardant Coatings and Insulation Systems,
- The Integrity of Fire Barrier Penetration Seals, and
- The Reliability of Fire Detection and Suppression Systems.

The first issue investigated as a part of this program was the impact of aging on the thermal damageabilty of electrical cables. A series of thermal exposure tests has been completed which examined two popular types of electrical cables. Preliminary results[14] did indicate that aging can affect both the threshold of thermal damage and the time to thermal damage at a given temperature above the damage threshold. However, the differences noted due to aging are not considered risk significant, and in the case of one cable, thermal aging actually improved the damageability performance. That is, for one cable, thermal aging increased both the limit of thermal damage and the time to failure for exposures above the damage limit. For NPR, the impact of aging on the thermal damageability of electrical cables should not be a significant risk issue.

In a second effort, a series of four large scale cable flammability tests have been performed to assess the impact of thermal aging on cable flammability. Two popular types of cables were tested, each in both an unaged and thermally aged condition.

14. Based on the preliminary analysis of a series of 50 tests performed by the author of this report. The data and results of these tests have not yet been published.

Preliminary results[15] of these tests indicate that the aged cables were actually less flammable than were the unaged cables. This result was expected because the aging process has a tendency to drive off certain of the volitale constituents of the cable insulation materials. It is these same volitales which contribute to cable fires. For NPR, the potential loss of fire retardancy due to cable aging should not represent a fire safety issue.

Currently, investigations are focussing on the evaluation of the impact of aging on the vulnerability of plant equipment other than cables to fire induced damage. It is also expected that future efforts will include the investigation of aging effects on fire barrier penetration seals. To date, no specific results are available in these areas. These investigations may, in the future, provide important insights relevant to the NPR design.

There is one particular issue which is not included within the scope of the current fire aging program investigations which should be considered by NPR. This is an issue which has been raised by the commercial nuclear industry itself, and for which industry sponsored research efforts are being initiated. The commercial nuclear industry has experienced cases of significant corrosion in water based fire protection system piping. In some cases, utilities have reported that pipes have been corroded so severely that flow was reduced to essentially zero. The nuclear industry investigation of this problem is expected to focus on the source of fire water used in these systems. In many plants, raw, untreated water is used in fire suppression systems. It is these plants which appear to be experiencing the worst corrosion problems. It is also suspected that the presence of oxygen in the water will increase the rate of microbial induced corrosion. For NPR it is recommended that a source of treated water and/or deoxygenated water be made available for use in fire protection systems. As an alternative approach to providing a large capacity supply of treated water, the NPR designers could provide a limited source of treated water to be used in periodic flow tests and in the purging of untreated water from system piping. The bulk of the fire suppression water could still be provided from untreated sources, provided that this untreated water is not left in the fire protection system piping for extended periods of time. The findings of the industry sponsored efforts in this area should be closely monitored by NPR.

5.3.2 The USNRC/West German Cooperative Fire Research Effort

In West Germany, researchers are conducting a series of fire tests in an actual reactor containment building at a decommissioned reactor site. These tests represent a unique series of full-scale fire tests involving a complex multi-room interconnected structure. The USNRC is currently sponsoring an effort at SNL to cooperate with the West Germans in the performance of these tests, and to participate in an international fire model benchmarking effort. The primary objective of this effort is to gather the results

15. Based on the preliminary analysis of a series of 4 large scale fire tests performed by the author of this report. The data and results of these tests have not yet been published.

of the West German tests for consideration by the USNRC.

To date, no specific recommendations can be made based on the limited information available. However, these tests will represent a valuable source of data which can be used to help validate fire analysis tools to be used in the evaluation of NPR fire safety provisions. The structure used in the performance of these tests is highly compartmentalized as is expected for the NPR plant design. These tests will be unique, and are not likely to be repeated in the near future. The results of these tests should also provide interesting insights into the design of smoke control systems and systems to maintain clear personnel access and escape routes.

5.4 Recommendations Based on USNRC-Sponsored Fire Research

As a result of the USNRC-sponsored fire safety research efforts a number of insights into fire behavior, fire mitigation strategies, fire induced equipment damage, and fire analyses have been realized. Based on these insights, it is recommended that the following factors be considered in the design of NPR:

- Despite the use of low flame spread cables, fires in cable installations should be anticipated and appropriate mitigation measures put in place. The FMRC cable selection protocol described in Section 2.6.2 of this report provides a sound engineering approach to cable selection and fire protection.

- Water is considered the most effective suppressant for application to cable installations.

- Gaseous suppression agents, CO_2 and Halon, can be effectively employed against cable fires. However, designs must allow for the maintenance of suppressant concentrations for up to 15 minutes to ensure effective suppression of deep seated fires. (As has been discussed in Section 2.6.5 above, Halon is not expected to be used as a fire suppressant in NPR due to its ozone depleting properties.)

- Severe fires have been observed during the testing of electrical control panel fire behavior, even when low flame spread cables were installed. Control panel designs should recognize this potential by maintaining safety train segregation and by providing appropriate fire barriers to subdivide panel installations (such as in the main control room and the remote shutdown area). These segregation provisions should include the consideration of cable routing paths, particularly cables routed above the electrical panels themselves.

- For cable tray installations, local flame barriers and fire retardant coatings can reduce, but not eliminate, cable fire hazards. For NPR, such measures should not be relied upon as the sole means of providing protection to redundant trains of safety equipment from the damaging effects of a single fire. Segregation into separate fire areas should be the preferred method for achieving protection for redundant safe shutdown capability.

- During testing, component (cable) damage has been observed due to hot layer effects alone, even when these components (cables) were separated in accordance with the Appendix R spatial separation requirements. The preferred method for the protection of redundant safe shutdown equipment from the damaging effects of a single fire should be segregation into separate fire areas as defined by three-hour-rated fire barriers on all sides.

While many insights have been gained through the FPRP efforts, a number of areas remain in which the knowledge base remains poor. In certain of these areas, it is expected that NPR will require that the knowledge base be expanded in order to ensure that fire safety issues have been resolved.

For example, the currently available enclosure fire growth and equipment damage models employed in the analysis of nuclear plant fire scenarios are not considered adequate and do not reflect recent developments in the understanding of fire growth and damage. Nuclear power plant fire situations involve relatively unique fuel types and geometries, in particular, cable tray arrays and electrical equipment. Current analytical models used to predict fire growth behavior for these types of fire sources have not been validated. Furthermore, while data on the impact of a fire on the environment of a large enclosure was gathered under the USNRC-sponsored FPRP, this data has not been fully processed and has not been generally applied in the validation of enclosure fire simulation models. For NPR it is expected that improved fire analysis tools will be needed to demonstrate the adequacy of specific fire safety provisions.

Significant shortcomings also remain in the available base of knowledge regarding the operability of plant equipment in a fire environment. Very little is known about the mechanisms and thresholds of fire damage for most types of plant equipment. Cables have been studied more extensively than have other types of equipment, but even the data base on cable fire damage is quite limited. Concerns for the potential impact of smoke on high voltage equipment, the impact of low level thermal exposure and gaseous suppression systems on sensitive control circuitry, and the potential adverse effects of manual fire fighting efforts have not yet been addressed by research. For NPR it is expected that plant specific component fire vulnerability data will be needed to support fire risk assessment efforts. This is discussed further in Chapter 6 below.

There are also a number of issues associated with the potential adverse effects of a fire and fire products beyond the room of fire origin which remain unaddressed. These issues include the assessment of the reliability of fire barrier systems under actual fire conditions, the characterization of potential mechanisms for the spread of smoke, the evaluation of fire suppressant management measures, the potential for spurious operation of suppression systems in nonfire areas, and manual fire fighting accessibility issues. For NPR, these questions are expected to impact both the design and selection of fire barriers, and the design and installation of the normal ventilation system. Issues of barrier design have been discussed in Section 2.6.4 above. In the area of ventilation system design it is recommended that NPR consider the following factors:

- The NPR designers should recognize that a thick toxic smoke layer is likely to develop rapidly during a fire, even in very large enclosures with high ventilation rates. As typically designed and installed in industrial plants, the normal ventilation system would not be capable of maintaining a habitable environment in the event of a large fire.

- The normal plant ventilation systems should be designed to allow for the management of fire products both during a fire event and as a part of post-fire recovery actions. The objectives of this design would be to (1) ensure that personnel escape paths and manual fire fighting access routes remain habitable, (2) that fire products do not migrate to other areas causing either equipment damage or spurious actuation of fire detection and/or suppression systems, and (3) that post-fire recovery times are minimized both by allowing quicker post-fire access to the affected area and by minimizing the extent of secondary fire damage (e.g. soot deposition and corrosion). This would imply that ventilation systems be designed such that air flow can be realligned to allow full exhaust air flow from the fire area and full supply air flow to adjacent areas and escape/access routes.

- It should be recognized that ventilation systems can act as a conduit for the passage of fire products to uninvolved areas. Ventilation systems should be equipped to minimize this potential. For example, ventilation exhaust structures should be designed so as to prevent fire products recirculation into intake structures and ventilation intake structures should be equipped with products of combustion detectors.

- Ventilation system design should consider the possibility that high efficiency filters (e.g., HEPA filters) will become clogged with soot very quickly in a fire situation. Alternate high capacity course particle filtering schemes may be required to maintain ventilation flow capability.

Under the Fire Aging of Electrical Components Program (reference USNRC FIN A-1833), an investigation of plant aging and fire safety has been initiated. These investigations are still in their very early stages, and only preliminary results are currently available. These preliminary results do indicate that for cables, thermal aging is not expected to significantly impact fire damage vulnerability nor increase material flammability. Hence, the evaluation of cable fire performance using unaged test specimins should be an acceptable approach for NPR material selection. No further design recommendations can yet be made based on the preliminary results of this program. However, it should be recognized that these investigations may eventually develop insights which could impact the design, construction and operation of NPR. In particular, issues of material selection for fire aging properties should be expected.

The final USNRC-sponsored fire research effort which may impact the design, construction and/or operation of NPR is the U. S./West German cooperative fire research effort. As with the Fire Aging Program, this effort is still in its very early stages and no design recommendations can yet be made based on this effort. However, it is expected that this effort will make available, to NPR, the results of a series of large-scale multi-compartment fire tests. These data sets will represent a valuable and unique source of information on various aspects of multi-room fire scenarios, and can be used in the benchmarking of the NPR fire analysis tools.

6.0 FIRE RISK ASSESSMENT METHODOLOGY AND RESULTS

6.1 Introduction

Based on plant operating experience over the last 20 years, it has been observed that typical nuclear power plants will have three to four significant fires over their operating lifetime. Previous probabilistic risk assessments (PRAs) have concluded that fires are a significant contributor to the overall core damage frequency, contributing anywhere from 7 percent to 50 percent of the total mean plant risk estimates. This includes consideration of the contributions from internal, seismic, flood, fire, and other events. These risk assessments have been performed by a number of different analysts using a variety of quantification methodologies.

Because of the relatively high core damage contribution predicted, fires are now considered as an accident initiator in most full-scope PRAs. Many of the earlier PRAs did not consider fire initiated events. In the more recent PRAs, fires have been examined in a level of detail which is consistent with all other categories of initiating events, and in particular, using event trees and fault trees which were developed during the analyses of the internal events risk. This chapter will discuss currently employed fire risk analysis methodologies, the results of past and current fire PRAs, and certain perceived limitations and needs with respect to these analyses. Also to be discussed are the benefits derived as a result of the performance of a fire PRA.

6.2 The NUREG-1150 Fire Risk Analysis Methodology

6.2.1 Overview of NUREG-1150

The original study which quantitatively examined the risk of core damage at U. S. nuclear reactor sites was a study sponsored by the USNRC known as WASH-1400 [18]. This study was limited to an examination of events initiated by faults in plant systems and components. These events were later identified by the label "internal events." As part of a major update of the understanding of risk as provided by the original WASH-1400 risk assessments, the USNRC has sponsored probabilistic risk assessments of six operating commercial nuclear power plants. These more recent analyses are known collectively as the NUREG-1150 analyses [12]. In contrast to the WASH-1400 studies, two of the NUREG-1150 risk assessments included an analysis of risks due to earthquakes, fires, floods etc., which are collectively known as "external events." This section summarizes the methods which were used in the fire analyses for NUREG-1150.

6.2.2 Fire Risk Assessment Procedures for NUREG-1150

The internal events analyses for NUREG-1150 were intended to be "smart" PRAs making full use of all insights gained during the past ten years of development in risk assessment methodologies. In keeping with this philosophy, the corresponding fire analyses were also performed by newly developed simplified methods. These methods were developed at SNL under the sponsorship of the USNRC's Division of Risk

Assessment as part of the Dependent Failure Methodology Development Program [11]. These methods have been extended to fire risk assessment during the past three years and have been applied to the two NUREG-1150 fire analyses (Peach Bottom Unit 2 and Surry Unit 1), the DOE Savannah River K-reactor, the DOE Hanford N-reactor, and the LaSalle Unit #2 fire risk analyses.

In most past external event analyses, rudimentary systems models were developed reflecting each external event under consideration. In contrast, the simplified NUREG-1150 analyses were based on the availability of the full internal event PRA systems models (event trees and fault trees) and make use of extensive computer-aided screening to reduce these internal events models to sequence cut sets important to each external event. This approach provides two major advantages. First, consistency and scrutability with respect to the internal events analysis is achieved. Second, the full gamut of random and test or maintenance unavailabilities were automatically included to the same level as in the internal events analyses, while only those occurrences which are probabilistically important survive the screening process. Using this approach, the full benefit of the internal events analysis is obtained by performing the internal and external event analyses sequentially.

An overview of the NUREG-1150 simplified fire PRA methodology is as follows:

Step 1: Documentation Review

The fire analysis begins with a review of the Final Safety Analysis Report (FSAR), related design documents and the systems descriptions in the internal events PRA. Important components are located on the general arrangement drawings using the plant Appendix R submittals as the basis for the initial identification of fire area boundaries and fire barriers.

Step 2: Plant Visit

Shortly after the documentation review, a plant visit of two to three days duration is made, involving an integrated team of six to eight specialists representing the various external events and at least one systems analyst from the internal events PRA analysis team. This initial plant visit provides the fire analyst with a means for seeing the physical arrangements in each of the identified areas. The analyst prepares a fire zone checklist which will aid in the screening analysis.[16]

The second purpose of the initial plant visit is to confirm with plant personnel that the documentation being used is, in fact, the best available information and to get clarification of any questions that might have arisen in a review of that

16. Note that fire areas are generally defined as areas bounded on all sides by three-hour rated fire barriers while fire zones are a subset of the fire areas and may be delineated by lesser barriers.

documentation. Also, a thorough review of fire-fighting procedures, both manual actions and fixed detection and suppression systems, will be conducted.

Step 3: Screening

The next step is to select important locations within the power plant under investigation having the greatest potential for producing fire initiated risk-dominant accident sequences. The objectives of location screening are somewhat competing and must be balanced in a meaningful risk assessment study. The first objective is to maximize the likelihood that all risk important locations are analyzed, which can lead to the consideration of a potentially large number of candidate locations. The second objective is to minimize the effort spent in the quantification of event trees and fault trees for fire locations that will turn out to be unimportant. A proper balance of these objectives is one that results in the identification of all of the important fire risk scenarios, while at the same time screening out scenarios which will prove to be unimportant.

The screening analysis is comprised of:

1. Identification of relevant fire zones: Fire zones which have either safety-related equipment or power and control cables for that equipment will be identified as requiring further analysis.

2. Screen fire zones on probable fire-induced initiating events: This step determines the fire frequency for all of the plant locations identified in the first step, and determines the resulting fire-induced initiating events and "off-normal" plant states.

3. Screen fire zones on both order and frequency of cut sets: This step further screens the areas for consideration based on their relative importance as risk contributors.

4. Initial quantification of remaining cut-sets: Each fire zone remaining is numerically evaluated and culled on frequency.

Step 4: Quantification of Risk Contribution

After the screening analysis has eliminated all but the potentially risk-significant fire zones, quantification of dominant cut sets is completed as follows:

1. Determine temperature response in each fire zone: Specific fire hazards are postulated and the response of the fire zone to those fire hazards is predicted based on an enclosure fire model of some type. In the NUREG-1150 analyses, a modified version of the COMPBRN III enclosure fire model [14] was used. (The modifications made to the model

are documented in Reference 7.)

2. Compute component fire fragilities: The predicted enclosure temperature response is compared to estimates of the important component thermal damage thresholds. Based on this comparison, an estimate of the time to fire damage for each postulated fire hazard is generated. For the NUREG-1150 analyses, the modified COMPBRN III model was used.

3. Assess the probability of barrier failure for all remaining combinations of fire zones: A barrier failure analysis is conducted for those combinations of two adjacent fire zones which, with or without additional random failures, remain after the screening analysis.

4. Perform a recovery analysis: In a similar fashion to that utilized in the internal event analysis, the likelihood of recovery for non-fire-related random failures in a cut-set is accounted for. Also, credit for the likelihood of either automatic or manual extinguishment of a fire before the predicted time to damage is given.

5. Analysis of quantification uncertainty: An uncertainty analysis is performed to estimate error bounds on the computed fire-induced core damage frequencies. The TEMAC code [12] was utilized in the NUREG-1150 uncertainty analysis.

6.3 Sources of Fire Risk Assessment Uncertainty

6.3.1 Overview

In general, there are two types of uncertainty which arise in a fire risk assessment. These are data and modeling uncertainties and uncertainties which arise from questions of analysis completeness. This section provides a brief discussion of these sources of uncertainty and provides a discussion of the implications of these uncertainties for NPR.

6.3.2 Data and Modeling Uncertainties

In the performance of a fire PRA, the analyst must utilize a number of data bases and analysis tools as a part of the quantification process. In addition, because the state of knowledge in many areas of fire behavior and analysis remains relatively poor, the analyst must also use expert judgment when the available data will not support the direct formulation of PRA inputs. The use of these fire analysis tools and data bases, and the use of expert judgement introduces uncertainty in the quantification process. The uses to which these tools and data bases are put include:

- <u>Estimation of Fire Frequencies:</u> The experience of the nuclear industry with fires is typically utilized in a PRA to generate estimates of the frequency of fire initiation for specific fire locations. Because of the nature of the experience data base, only relatively course estimates of fire frequency for generic plant areas can be directly generated. This requires that the analyst use a process called "event screening and partitioning" to refine the generic event frequencies to the specific fire scenario under consideration. The methodologies utilized in this process will vary from analysis to analysis.

- Determination of Equipment Damage Thresholds: In the quantification process the analyst must make an assessment as to the anticipated mode of equipment damage (e.g. thermal damage or smoke damage), the post damage state of the equipment (e.g. open circuit or hot shorting), and the thresholds of the postulated damage mode. In general, the available information on equipment fire damageability is quite sparse. For most equipment and most damage modes, virtually no quantitative information has been developed. Electrical cable fire damage has been investigated more extensively than any other type of equipment, and even for electrical cables the available data is relatively sparse, and in some cases, the validity of available cable damage threshold values have been questioned [13]. This often requires that the analyst utilize expert judgement in the determination of the equipment damage factors.

- Estimation of Fire Growth Rates and Equipment Damage Times: One of the critical questions in the quantification of a particular fire scenario is the estimated time to critical equipment damage for a particular fire threat in a particular plant location. In practice, sequence timing is determined through the application of a fire growth and damage computer model. (COMPBRN [14] is the most commonly employed model in the U. S.) Uncertainty arises in the application of these models due to (1) the adequacy of the models themselves, (2) the uncertainty in the model inputs, and (3) the random nature of actual fires which is not simulated in deterministic models.

- Assessing the Probability of Fire Suppression: In application, the probability of fire induced equipment damage within a given time frame competes with the probability of fire suppression within that same time frame to determine the risk significance of a particular scenario. In developing fire suppression probability estimates, PRA analysts have relied on (1) the available experience based information on the time to fire suppression for actual fire incidents, and/or (2) expert evaluations of the on-site fire protection provisions. In the quantification process, suppression probabilities are incorporated in the form similar to that used for the consideration of recovery actions. These suppression probability estimates are typically assigned relatively high orders of uncertainty.

6.3.3 Issues of Risk Assessment Completeness

In a fire risk assessment, uncertainty can be introduced through questions of the completeness of the analysis. That is, an analysis may not have considered all of the potential fire risk issues. In a recent study [7] six unaddressed fire risk issues were identified, of which five were associated with questions of the completeness of past fire risk assessments. (A sixth issue was identified associated with the adequacy of fire analysis tools. This issue has been discussed immediately above.) These five completeness related unaddressed risk issues are:

- Control System Interactions,
- Seismic Fire Interactions,
- Total Environment Equipment Survival Including Fire Suppression Induced Equipment Damage,
- Manual Fire Fighting Effectiveness Including Smoke Control, and
- The Adequacy of Fire Barriers

These issues were identified as potentially important aspect of the fire safety problem which had not been addressed in previous risk assessments. Since the performance of this study, three of these issues have been designated by the USNRC as unresolved Generic Issues. Each of the identified issues was examined in terms of both the potential impact of the issue on fire induced core damage frequency estimates and the potential for the issue to be either a plant specific issue or a generic issue. Table 6.1 summarizes the findings for each of the five issues. The following provides a brief discussion of each of these completeness issues. For those three issues which have been identified as unresolved Generic Issues, a more detailed discussion is presented in Chapter 8 below.

Control Systems Interactions: The issue of control systems interactions is perhaps the most difficult of the identified unaddressed fire risk issues to resolve. The issue raised is primarily associated with control room fire scenarios. The USNRC has identified fire-induced control room and remote shutdown panel control systems interactions as an unresolved Generic Issue (GI-147) and the specific concerns associated with this issue are discussed in more detail in Chapter 8 below. In short, concern focuses on the potential for a control room fire to induce multiple spurious actuations and equipment failures prior to the transfer of control to the remote shutdown station which (1) may not be indicated at the remote shutdown stations complicating operator recovery actions, (2) could, in some designs, render remote shutdown station controls ineffective or inoperable, (3) may not be possible to correct from the remote station, and/or (4) may not be provided for in station operating procedures. Identification of potential multiple failure vulnerabilities requires that extensive evaluations of potential equipment fault states be performed, typically using a probabilistic approach. To date, fire PRAs have not provided complete consideration of this type of control room fire scenario. For NPR it is recommended that a fire risk analysis be performed, including consideration of potential multiple spurious actuation and component failures during a control room fire. Based on testing experience [15,16], the scope of these considerations can be limited to subsections of the control panel complex based on the presence of fire barriers between control panels. This issue is considered to have a potential order of magnitude impact on the estimation of control room fire risk.

Table 6.1 Summary of Unaddressed Fire Risk Assessment Issues Investigation Findings

Issue:	Potential CDF Impact*:	Applicability	Comments:
Control Systems Interactions	O(10)	Generic	Difficult to Quantify, Probabilistic Issue Not Deterministic
Manual Fire Fighting Effectiveness	O(10)	Generic	
Total Environment Equipment Survival			
Fire Induced Effects	Unknown	Generic	Not Quantified, Insufficient Data
Spurious Suppression Effects	Small-O(10)	Plant Specific	Not Quantified, Insufficient Data
Barrier Reliability	Small-O(10)	Generic	Vulnerability Not Assessed, No Data
Seismic/Fire Interactions	Small	Generic	Easily Resolved on Plant Specific Basis

* - O(10) Is a mathematical representation for order of magnitude.
Note: The core damage frequency (CDF) impacts are not expected to display multiplicative character when more than one issue is considered, rather, the effects will be additive.

Manual Fire Fighting Effectiveness: Smoke control and manual fire fighting effectiveness has been identified by the USNRC as an unresolved Generic Issue (GI-148). The specific concerns associated with this issue are discussed in detail in Chapter 2 above. In short, most commercial nuclear plants place a high level of reliance on the ability of on-site personnel to provide for fire suppression. A review of current plant fire fighting practices found that wide plant-to-plant variability exists in staffing and training of fire fighting personnel. In most past fire PRAs, the reliability of manual fire fighting activities has been treated in a relatively simplistic manner; and yet, relatively small variations in assumed fire suppression times can result in order of magnitude changes in fire risk estimates [7]. Manual fire fighting provisions should be evaluated on a plant specific basis. For NPR it is expected that manual fire response will be provided through a combination of reactor personnel and the overall DOE site fire department. In the performance of the NPR fire risk assessment, it will be necessary to perform an independent evaluation of these manual fire response provisions. This issue is considered to have the potential for an order of magnitude impact on fire risk estimates for areas not equipped with automatic fire detection and suppression systems.

Total Environment Equipment Survival: In most fire PRAs, only damage induced by direct thermal heating is considered, and in fact, most past fire PRAs have considered only damage to electrical cables. Other fire damage mechanisms, such as corrosion, suppression damage, and soot deposition have not been considered, and in many PRAs, damage to plant equipment other than cables has not been considered. This is due in large part to the fact that the available data on the vulnerability of plant equipment to fire or fire suppression induced damage is quite sparse. Most of the data which is available deals with thermally induced cable damage. Even for cables, relatively little is known about the mechanisms and thresholds of fire induced damage. Certain of the publicly available cable damageability threshold data has been criticized for having been extrapolated in a nonconservative manner and is considered inappropriate for use in fire risk assessments [13]. For other types of plant equipment, and for damage mechanisms other than direct thermal heating, virtually no information is available. One aspect of this issue, the adverse impact of fire suppression systems on plant equipment, has been identified by the USNRC as an unresolved Generic Issue (GI-57). These concerns have been described in detail in Chapter 4 above, and are also discussed briefly in Chapter 2 above. For NPR it is expected that plant specific component vulnerability data will be needed to support the assessment of fire risk. The fire risk analysis should also consider the potential impact of fire suppression activities, either advertent or inadvertent, on plant safety. Because of the poor state of the current knowledge base, it is not possible to assess the impact of this issue on fire risk estimates.

Seismic/Fire Interactions: There are potential interactions between fire safety and seismic events. Issues of concern include (1) seismically induced fires, (2) seismically-induced actuation or failure of fire detection and suppression systems, and (3) degradation of personnel access to plant areas for fire fighting activities. It has been concluded [7] that the seismic/fire interactions vulnerabilities which have been identified could be corrected more easily than they can be quantified in a risk assessment. For NPR, it is recommended that specific guidelines be developed against which the plant design could be evaluated to ensure that seismic/fire vulnerabilities are identified and resolved in the design. This may require the implementation of such factors as the seismic qualification of fire detection and suppression systems in critical plant areas, anchoring electrical panels to prevent cable pulling faults, anchoring fuel tanks and compressed gas cylinders, and other similar measures. These types of design measures will not significantly impact the fundamental aspects of the NPR design. However, factors such as seismic qualification of fire protection systems must be performed as a part of the system procurement process.

Reliability of Fire Barriers: The reliability of U. S. qualified fire barriers under actual fire conditions has been questioned by various sectors of the fire protection community. This issue has been identified by the USNRC as an unresolved Generic Issue (GI-149). Regulatory aspects of this question have been discussed in Section 2.6.4 above and presented in Chapter 2 above is a more detailed discussion of the technical aspect of the issue. In short, standard fire barrier qualification tests endorsed in the U. S. have been criticized for failing to require the simulation of anticipated enclosure fire pressure effects. It has been demonstrated that this can in fact mask mechanisms which can lead to the premature failure of a fire barrier element under realistic fire conditions. In terms of fire risk assessments, only very limited examinations of the risk importance of potential fire barrier failures have been performed. In general, only potential random barrier failures (e.g. fire doors blocked open or degraded fire stops) have been considered. A recent study [7] found that if barrier reliability is reduced to on the order of 90%, then an order of magnitude increase in fire risk could result. For NPR, it is recommended that the use of penetrations (doors, and cable and ventilation duct passages) be minimized for those barriers which represent primary segregation boundaries for redundant trains of safety-related systems. Furthermore, those fire barrier penetration elements, and in particular cable tray barrier penetration seals, which are used in NPR could be qualified using international testing standards. This would reduce the likelihood of barrier failure and thereby reduce fire risk. As an alternative, a comprehensive review of fire barrier performance in the U.S. could be performed in order to determine whether any fire barrier designs are particularly vulnerable to premature failure. It is anticipated that such a review would demonstrate that most barrier systems function well in actual fires, and hence, no significant risk impact would be expected. However, such a review might also reveal particular barrier systems which are vulnerable to premature failure, and hence, should not be used in NPR. This issue is considered to hold the potential for an order of magnitude impact on the estimation of fire risk for adjacent plant areas housing redundant trains of safe shutdown systems.

6.4 Results of Past and Current Risk Assessments

A fire risk assessment can provide information in two basic forms. First, a fire risk assessment provides a numerical indication of both the relative importance of fire hazards to operational safety as compared to other accident initiators, and the relative importance of specific fire scenarios in comparison to the overall fire risk. This importance ranking can allow for the consideration of various fire safety measures in terms of the risk impact. Second, a fire risk assessment can provide for the identification of the risk important fire areas and equipment. These insights can help in the planning of fire protection and fire response measures, aid in the implementation of remote shutdown station design, and can aid in the development of operating procedures.

Table 6.2 provides a comparison of the estimated frequency of fire-induced core damage accidents to that of other significant accident initiators for a number of past and current fire PRAs. Fire risk in each case represents a dominant contributor to the overall plant risk. In some cases, the estimated fire risk approaches or even exceeds the USNRCs stated probabilistic safety goal of no more than 1E-4 (this notation is used to represent $1x10^{-4}$) core damage incidents per reactor year.

From the perspective of the plant operators, perhaps the most valuable insight gained through a fire PRA is that of the identification of significant plant vulnerabilities which had not previously been identified. It has been found that the implementation of fire protection measures for areas identified as important in past fire risk assessments has reduced the total estimated fire-induced core damage frequency by as much as an order of magnitude. One such case is Indian Point Unit 2. A fire risk assessment for this plant identified one fire scenario with an original estimated core damage frequency of 6.5E-5 incidents per reactor year [19]. A more recent requantification of this scenario based on updated modeling capabilities and updated fire incident and damage data bases generated an estimate for this same scenario of 2.0E-4 incidents per reactor year [7]. In either case, this scenario represented a dominant risk scenario for that plant. As a result of the identification of this scenario in the risk assessment, plant personnel installed an alternate set of power cables for a particular system which bypassed the effected fire area. This provision for an independent power feed reduced the estimated core damage frequency to 8.8E-6 incidents per reactor year [7].

A fire risk assessment can also identify specific plant features which result in either a significant increase or decrease in plant risk. For example, it has been found that the level of indication and control provided on the alternate shutdown panels can significantly impact risk estimates [7]. This results from the assumed reliability of operator

Table 6.2 Summary Past Fire Risk Assessment Results (all Results Presented In Terms of the Core Melt Frequency per Reactor Year).

Risk Source:	Fire	Aircraft Crash	External Flooding	Hurricane	Internal Flooding	Lightning	Seismic	Internal Events
Plant:								
Quac Cities	1.3E-5	N/A	9.8E-8	1.3E-7	I	1.7E-6	8.3E-5	1.8E-4
Point Beach	3.2E-5	N/A	1.9E-8	4.0E-6	7.7E-5	5.8E-8	6.1E-5	1.8E-4
Zion	4.4E-6	I	N/A	I	I	N/A	5.0E-6	5.4E-5
Indian Pt.2	2.0E-4	I	N/A	4.3E-5	I	N/A	1.4E-4	7.7E-5
Limerick	2.3E-5	I	I	I	5.7E-7	N/A	5.8E-6	1.5E-5
Seabrook	2.5E-5	I	I	N/A	3.9E-6	N/A	2.8E-5	1.7E-4
Oconee 3	1.0E-5	N/A	2.5E-5	1.3E-5	8.8E-5	N/A	6.3E-5	5.4E-5

N/A - Not Analyzed
I - Considered an Insignificant Contributor

actions at the remote shutdown panel during recovery operations. A second example is found in the analyses of the DOE Hanford N-Reactor and Savannah River K-Reactor facilities [4,5]. It was found that the Savannah river facility had a significantly lower estimated fire-induced core damage frequency than did the Hanford facility. This was attributed to the more extensive physical separation of safety systems into independent fire areas in the Savannah River design. This insight illustrates both the insights which can be gained as a result of the performance of a PRA and the importance of physical boundaries in the protection of safety systems from fire damage.

6.5 Recommendations Based on the Results of Past Fire PRAs

Past fire PRAs have demonstrated that the most effective means of assuring the integrity of safe shutdown capability in the event of a fire is the segregation of redundant equipment trains into separate fire areas bounded by three-hour rated fire barriers. This should be the preferred method of protecting plant safety related equipment for NPR, consistent with the recommendations presented in Chapter 2 above. It is also recommended that penetrations (doors, cable penetrations, and ventilation passages) in the primary fire barriers separating redundant trains of safety related equipment be minimized. Significant questions remain regarding the adequacy of U. S. qualified fire barrier elements under actual fire exposure conditions. By minimizing the penetration of primary segregation boundaries, NPR can minimize the impact of potential barrier failures on plant risk. The need for each fire barrier penetration in a primary segregation boundary should be carefully examined in view of the operational importance of the equipment on both sides of the boundary.

For NPR, it is recommended that a full-scope PRA be performed, including the consideration of fire as an event initiator. It is further recommended that a methodology, such as that employed in the NUREG-1150 analyses, which utilizes the full internal events fault trees as the basis for analysis be utilized.

In order to support the PRA analysis, it is also recommended that the fire event data base, fire suppression effects data base, and the equipment damage data base be updated and formalized. These data bases represent fundamental inputs to the risk assessment. Updating will ensure that the risk estimates are based on the most complete information available. These updates should include the insights developed as a part of the DOE N-Reactor and K-Reactor fire risk assessments. In the case of the equipment damage data base, it is known that relatively little information on the vulnerability of plant equipment to fire-induced damage is currently available. Therefore, NPR specific component fragility data will be needed to support the fire risk assessment. This will require the performance of equipment damageability tests for NPR specific components.

One important fire risk assessment issue which remains unresolved is the adequacy of the currently available computer fire simulation models. Currently available models will not address the needs of the NPR fire risk assessment due to inadequate validation and/or significant unresolved questions of model accuracy and completeness. It is recommended that for NPR an improved fire simulation model be assembled. This model should be based on currently available fire analysis correlations and techniques, and should be benchmarked using the available large-scale enclosure fire test data which was gathered as a part of the USNRC-sponsored Fire Protection Research Program [17]. Certain portions of the fire model will require the support of benchmark experiments. Based on our current understanding of such models, this would include correlations for cable and component damage predictions, fire plume correlations, and cable fire growth correlations.

7.0 SUMMARY OF DESIGN RECOMMENDATIONS FOR NPR

For the commercial nuclear power industry, the implementation of fire protection has been a difficult process, largely because the USNRC fire safety regulations were imposed on the commercial industry as retrofit rules requiring, in most cases, extensive and expensive plant backfits. For the Department of Energy (DOE) New Production Reactor (NPR), it will be important to address fire safety early in the design process. By doing this, the NPR designers can avoid many of the limitations which result in fires continuing to represent a significant risk contributor for commercial U.S. reactors.

The following provides specific recommendations for the implementation of fire safety in the NPR design. These recommendations are intended to ensure that NPR will achieve a level of fire safety which exceeds that of the current generation of commercial nuclear power plants, will achieve the stated DOE probabilistic safety goal, and will conform to the anticipated direction of fire safety regulations to be applied to a future generation of commercial reactor sites.

7.1 Protection of Redundant Safe Shutdown Capability

It should be recognized by the designers of NPR that the current USNRC fire safety regulations will not represent an adequate design basis for NPR, nor for future commercial reactors. Because the USNRC fire safety regulations were specifically developed as retrofit rules, they do not represent the appropriate design considerations for a new reactor.

In particular, it is anticipated that requirements for the protection of redundant safe shutdown capability from the damaging effects of a fire will be significantly strengthened. Segregation into independent fire areas should be the preferred method for protecting safe shutdown capability from the impact of a single fire event. In anticipation of the development of new USNRC fire safety regulations, it is recommended that the following be utilized as the fundamental NPR fire safety design requirement in the determination of appropriate train segregation:

> The NPR project must ensure that safe shutdown can be achieved assuming that (1) all equipment in any one fire area (where a fire area is defined as an area bounded on all sides by three hour rated fire barriers) will be rendered inoperable by fire, (2) that reentry into the fire area for repairs and operator actions is not possible, and (3) that any possible single active component failure in other plant equipment outside of the fire area due to nonfire related causes occurs (e.g., random failure, maintenance outages, sabotage, personnel errors). Fire detection and fire fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems and components important to safety and plant operation consistent with existing DOE requirements. Because of its physical configuration, the control room is excluded from this approach, provided a diverse independent alternative shutdown capability, including a dedicated decay heat removal capability, that is physically and electrically independent of the control room is included in the design. The

> NPR project must provide fire protection for redundant shutdown systems in the reactor containment building that will ensure, to the extent practicable, that one shutdown division will be free of fire damage. Additionally, the NPR project must ensure that smoke, hot gases, or the fire suppressant will not migrate into other fire areas to the extent that they could adversely affect safe-shutdown capabilities, including operator actions. The NPR project must provide for the management of fire suppressants after release, including water from manual hose streams. The NPR project will consider the potential adverse impact of the spurious operation of fire protection systems, including common cause failures, and assure that safe shutdown capability will not be compromised by such incidents.

In one respect this requirement exceeds that presented by the USNRC in a recently issued staff policy statement. That is, the USNRC policy does not include failure analysis criteria (3) as presented above, that is, consideration of any one additional active component failure in addition to fire induced failures. Note, in particular, that this criteria should not be interpreted as requiring that all safety systems be designed in a three train configuration because the emphasis is place on protection of safe shutdown capability in general rather than the protection of a given safety system. This additional constraint is designed to eliminate residual risk outliers such as those which have been observed in past fire PRAs, and can be expected to ensure a significant reduction in fire risk. While the enhanced design criteria represents a departure from past design practices, it is considered by SNL to represent the optimal approach to insuring that NPR achieves a high level of fire safety. The text (see Chapter 2) discusses an alternative approach which would involve endorsing the USNRC policy directly as presented in SECY-90-016 and coupling the design process to a parallel path fire risk assessment. This alternative approach is not considered optimal by SNL for reasons stated in the text, primarily because of the uncertainties which are inherent in fire risk assessment.

7.2 Fire Risk Assessment Issues

7.2.1 Inadequacies in Current Analytical Fire Models

Significant questions of computational accuracy and overall code adequacy remain unresolved for the computer fire simulation models which are currently used to support the assessment of fire risk for U. S. commercial nuclear power plants. For NPR it is recommended that an improved fire analysis model be assembled using currently available fire modeling capabilities. This model must address the unique needs of a nuclear plant risk assessment and should be benchmarked by comparison to enclosure fire test data which was gathered as a part of the USNRC Fire Protection Research Program.

7.2.2 Updating of Fire Experience Data Bases

One of the fundamental inputs used in the analysis of fire risk is experience based information on the frequency and impact of actual fire related incidents. In particular, the commercial nuclear industry has logged a significant base of experience with both actual fire incidents and incidents involving the advertent or inadvertent actuation of fire suppression systems. It is recommended that these data bases be updated and/or formalized for use by NPR in the analysis of fire risk.

7.2.3 Use of Expert Judgments in a Quantitative Analysis

In the analysis of fire risk, one of the most significant sources of uncertainty is that associated with the use of expert judgments. For NPR it is recommended that procedures be formalized for the incorporation of such judgments in the NPR fire risk assessment. It is expected that formalizing of existing methodologies will be required to comply with the stringent NPR quality assurance requirements.

7.2.4 Equipment Fire Damage Vulnerability Data Availability

The available data on the vulnerability of plant equipment to fire induced damage is very sparse. For NPR it is recommended that NPR specific component vulnerability data be gathered. This data will be needed to support equipment damage assessments as a part of the fire risk assessment.

7.2.5 Barrier Failure Probability Assessment

In the performance of the NPR fire risk assessment, it will be necessary to assess the likelihood that fire barriers might fail during a fire exposure. Two potential approaches are possible. The first, and recommended approach, is to ensure that cable tray fire barrier penetration seals are qualified using accepted international test standards. This would largely resolve the issue of premature barrier failure, and would significantly reduce the assumed barrier failure rates. This recommendation must be considered in the context of the availability of suitable fire barrier penetration seal systems. Second, a comprehensive review of fire barrier performance in actual fire incidents could be performed. Certain quite limited tests of barrier performance under positive pressure conditions have been performed and the results of these test can be use to supplement the experience based information. In addition, it may be possible to draw upon the experience of the standards testing organizations which utilize positive pressure tests as the basis for identifying potentially vulnerable barrier systems and types. This would provide an experience based assessment of barrier failure probabilities which could then be used in the NPR fire analysis.

7.2.6 Analysis of Control Systems Interactions

The issue of control systems interactions has been identified by the USNRC as a Generic Issue, and recent studies have demonstrated that control systems interaction scenarios can represent significant risk contributors, even for plants in full compliance with the current Appendix R fire safety requirements. Control system interactions which might, in the event of a control room fire, compromise the ability of plant operators to perform recovery actions at the remote shutdown station should be evaluated as a part of the NPR fire risk assessment. Such an analysis will require the use of probabilistic methodologies because deterministic reviews such as those currently performed in the assessment of plant Appendix R compliance will not identify all of the significant multiple failure scenarios.

7.2.7 Evaluation of Manual Fire Fighting Effectiveness

In the performance of the NPR fire risk assessment it is recommended that an independent evaluation of the provisions for manual fire fighting be performed. This evaluation should consider the availability of manual fire fighting equipment, the anticipated manual response times for each plant area, and the level of training provided to manual fire fighters. Such assessments can also provide the plant designers with input into the identification of plant areas for which manual fire fighting provisions might not be sufficient to ensure plant safety, and hence, might require the installation of fixed fire protection systems.

7.2.8 Assessment of Adverse Fire Suppression System Impact

The commercial nuclear power industry has logged a significant base of experience in which the actuation of a fixed fire suppression system has resulted in the failure of safety related plant equipment and systems. These incidents have included both advertent and inadvertent fire suppression system actuations. For NPR, the fire risk assessment should include consideration of the potential adverse impact of fire suppression systems on plant equipment.

7.3 Fire Protection System Design Considerations

7.3.1 Selection of Fire Detection and Suppression Systems

For NPR it is recommended that fire detection systems be installed in all major plant areas. These systems should alarm to a central location such as the main control room. In current reactor designs, electrical control panels have often been used as return air plenums thereby providing electrical panel cooling as a part of the normal ventilation system design. For NPR, electrical control panels which are not ventilated into an area equipped with fire detectors should be equipped with a dedicated fire detection capability.

It is anticipated that certain plant areas will require the additional protection of fixed fire suppression systems. For cable tray installations, the FMRC cable flammability test standard and cable protection selection procedure [27,28] provides a sound engineering approach to fire protection implementation. For other plant areas, the need for fixed fire suppression systems should be based on (1) an evaluation of the fire hazard, (2) the nature and density of fuel sources in the area, (3) the operational importance of a given area (as identified by the plant risk assessment), and (4) the adequacy of manual fire fighting provisions to deal with a given fire hazard.

7.3.2 Evaluation of Fire Hazards

In the design and selection of fire protection systems, a fire hazards analysis should be performed by an independent fire protection evaluation organization. This review should focus on the identification of specific fire hazards, and the protection of plant systems, components, structures and personnel from those hazards.

7.3.3 Corrosion in Water Based Fire Suppression Systems

The commercial nuclear industry has recently identified a problem with corrosion in water based fire suppression system piping. These problems appear to be tied to the use of raw untreated water in fire suppression systems, and the presence of oxygen in fire protection water. For NPR it is recommended that a source of treated, deoxygenated water be made available for use in fire protection systems. It is the intent to have available a source of treated water for use in routine suppression system flow tests, and for purging a fire suppression system following actuation. The primary source of fire protection water could remain raw untreated water, provided that this water is not left in the suppression system piping for extended periods.

7.3.4 Management of Fire Suppressants After Release

The NPR design should allow for the management of fire suppressants following release. In particular, adequate drainage should be provided in all plant areas where water is likely to be used as a fire suppressant, either manually applied or from fixed fire suppression systems. Floor penetration seals in such areas should be either waterproof, or should be provided with adequate curbs to prevent the inadvertent introduction of water into other fire areas. Conduit penetrations through fire boundaries should be examined for the potential to channel fire suppression water to important plant components or through fire barriers and sealed as appropriate. Critical electrical panels should be provided with dikes or placed on pedestals to minimize flooding potential.

For gaseous suppression systems, suppressant management provisions should include consideration of the need to maintain suppressant concentrations for an adequate period of time following initial discharge to ensure effective fire suppression. Provisions should be made for the removal of the gaseous suppression agent as a part of post-fire recovery actions. Potential paths for the spread of the gaseous agent from the protected areas, such as open conduits, should be identified and sealed.

7.3.5 Consideration of Adverse Impact of Fire Suppressants on Plant Equipment

The designers of NPR must recognize that the release of fire suppressants, either advertently or inadvertently, introduces a potential for important plant components to be rendered inoperable by the suppression agent. This is particularly true of water based fire suppressants, but can also result from the discharge of gaseous suppressants. An analysis should be performed to assure that the actuation of any fixed fire suppression system will not compromise operational safety consistent with the segregation requirements described in Section 7.1 above. Plant designers should also minimize the potential for manual fire fighting activities to compromise safe shutdown capability.

7.3.6 Consideration of Potential Spurious Actuation of Fire Protection Systems

Fire suppression systems should be designed to minimize the potential for inadvertent actuation. Fire suppression system actuation controls should be clearly identified, including the identification of the actual area or component protected by the system. All plant personnel should be provided with instructions on what to do, or not do, in the event of a fire. Fire protection system control panels should be located such that common cause failure mechanisms are not introduced (e.g. multiple actuations due to a steam line break such as in the case of the Surry feedwater line break, or a fire which might induce the actuation through control panel failures of fire protection systems covering other plant areas).

In the case of automatically actuated fire suppression systems, the actuation logic should be such that inadvertent actuations are minimized. This must be balanced against the need for rapid fire response, but the designers must recognize the significance of potential spurious fire suppression system actuation induced equipment damage. For example, a single smoke detector should not be utilized as the sole criteria for initiation of suppressant release. Smoke detectors are known to be vulnerable to actuation by dust and steam. Thus, the use of smoke detectors as an actuation device should involve multiple actuation logic (for example, smoke detectors used to pressurize a dry pipe fusible link sprinkler system). Procedures should also be established for dealing with plant construction and maintenance activities which are likely to activate fire detection and/or suppression systems (such as welding and cutting operations and fire protection system maintenance activities).

7.3.7 Seismic Qualification of Fire Protection Systems

Certain portions of the fire protection system should be designed to survive a design basis seismic event both intact, and without spuriously actuating. In particular, the main fire water distribution system should be capable of delivering water to all plant manual hose stations following a safe shutdown earthquake. This is consistent with the anticipated direction of the USNRC fire safety regulations for new reactor sites.

In addition, plant designers should consider that fire detection and suppression systems might be inadvertently actuated during a seismic event. Mechanisms for such actuations include dust setting off smoke detectors, seismic failure of a fire detector, and fire protection system control panel failures (such as relay chatter or equipment faults). For certain critical plant areas, it may be appropriate to seismically qualify fire protection systems to ensure that inadvertent actuation does not occur. The results of a fire risk assessment could be used as a partial basis for these evaluations, and should include consideration of potential multiple actuations due to common cause failure modes.

One such area would be diesel generators. Because it is considered likely that off-site power would be lost during an earthquake, the emergency diesel generators will play an important role in post earthquake recovery. Instances have been identified in which the actuation of a fire protection system might compromise the operability of the diesel generators either through loss of engine cooling, loss of control circuitry, or loss of combustion air. For NPR, two approaches might be taken. First, diesel generator fire protection systems could be seismically qualified to ensure that inadvertent actuation would not occur. Second, the designers could ensure the availability of the diesel generator systems given that fire suppression system actuation occurs. This would require the protection of control circuitry, protection of power feed circuitry from the generator (e.g. switchgear), providing combustion air for the engine from an uncompromisable location, and providing engine cooling from an uncompromisable source.

However, these concerns will also be applicable to other areas of the plant and to other plant systems. For example, any fire protection systems installed in either the main control room or the remote shutdown station should also be seismically qualified. Other plant areas must be examined to determine the need to assure equipment operability following a seismic event. It must be recognized that the actuation of multiple fire suppression systems during a single seismic event would represent a potential common mode failure mechanism for diverse and segregated plant equipment and systems. This potential should be considered in the design of NPR, and in the selection of fire protection systems for specific applications.

7.3.8 Design of Combustion Products Management Support Systems (Ventilation Systems)

Current industrial ventilation system design practices do not specifically provide for the design of ventilation systems to support the management and removal of combustion products (heat, smoke, and toxic or corrosive products). For NPR it is recommended that the normal plant ventilation system be designed to support the management and removal of combustion products. This would require that ventilation systems be provided with a realignment capability by which a fire area could be placed under full exhaust conditions, and adjacent fire areas and personnel access and escape paths could be placed under conditions of full fresh air supply. This would help to contain the smoke within the affected fire area and prevent the spread of smoke to other fire areas.

For the main control room, it is recommended that the normal ventilation system be designed to optimize smoke removal. This would require that ventilation inlets be located at or near the floor level and that ventilation outlets be located at or near the ceiling level. This will allow the ventilation system to take advantage of the buoyancy effect common to enclosure fires which will tend to drive combustion products to the upper reaches of the room. If ventilation inlet ports are located at higher elevations, then the formation of an upper level smoke layer will be disrupted through ventilation induced mixing, and removal of the smoke will not be possible.

Unfortunately, the data base on the effectiveness of such ventilation design measures is quite poor. To date, no large scale experimental evaluation of such measures has been undertaken. The measures described above are considered, within the fire protection community, to represent a prudent approach to the design of ventilation systems as a part of the overall fire protection system.

Plant ventilation systems should also be designed to prevent the introduction of smoke from external fires, or the recirculation of smoke from internal fires vented to the plant exterior into the plant through ventilation intake structures. This would imply that ventilation intake structures should be physically isolated from ventilation outlet structures, and that intake structures should be provided with products of combustion (smoke) detectors.

7.4 Issues of Plant Construction

7.4.1 Timetable for Fire Protection System Implementation

Consistent with the anticipated direction of USNRC fire safety requirements for new reactor sites, a specific timetable for implementation of the fire protection measures should be established. In particular, all fire protection systems associated with the fuel handling and storage facilities, including manual fire fighting provisions, should be installed and operational prior to the transfer of nuclear fuel material to the NPR site. All fire protection systems for the overall reactor site should be installed and operational prior to fuel loading of the reactor core.

7.4.2 Fire Protection Provisions for the Construction Site

Plant construction activities will introduce unique and heightened fire hazards to the reactor site. It is recommended that, prior to the start of construction, a plan for providing fire protection during construction should be developed. This plan should be coordinated with the cognizant DOE field office and the operating contractor. The plan should include provisions for manual fire fighting capability to be available to all parts of the construction site, including temporary structures.

7.4.3 Construction Material Fire Behavior Selection Criteria

It is recommended that the selection of materials to be used in the construction of NPR be based, in part, on fire performance. Of particular importance in this context is the selection of cable insulation materials. Cables will represent the dominant source of combustible materials in most areas of the plant. For this reason, it is important to select cable materials based on a rigorous flammability test standard.

The current Factory Mutual test standard [27,28] is recommended for application to NPR provided that cable products which endorse this standard are made available by the cable manufacturing industry. (This test standard is available to DOE. However, the

FMRC standard is currently a topic of controversy within the cable manufacturing industry, and suitable cable products may not be available within the time frame of NPR construction. In this event, the IEEE-383 standard should be used as an alternative.) In any case, construction materials should be chosen so as to minimize the fire hazard.

In other plant areas, the use of combustible materials in construction should be minimized. For example, flammable wall and floor coverings should not be used.

7.5 Operational Aspects of Fire Safety

7.5.1 Staffing, Training and Equipping of Manual Fire Fighting Teams

Experience has demonstrated that provisions for manual fire fighting will often play a critical role in fire response activities. For NPR, it is recommended that three levels of manual fire response be provided. First, all plant personnel should be provided with minimal training in (1) how to handle a hand-held fire extinguisher, and (2) what to do, and not do, in the case of a fire. Second, reactor personnel should include manual fire response teams, similar to those required by the current USNRC Appendix R fire safety requirements. These personnel should receive a higher level of fire training, including live fire and smoke room training. Adequate equipment (e.g., protective clothing, SCUBA gear, hoses, etc.) should be made available at the reactor site to support these personnel in providing the initial response to a fire situation. Consistent with the USNRC guidelines, at least one member of each fire response team should have the equivalent of operator level knowledge of the reactor systems and operational needs. (In practice, commercial plants have included at least one qualified plant operator on each fire response team.)

Finally, the overall DOE site fire brigade should be provided with training on fire response requirements specific to the NPR reactor site. This training should be coordinated with the training of reactor site fire response teams, and should include familiarization of fire fighters with the unique operational concerns which are associated with a nuclear reactor site. The overal site fire brigade should also be prepared to fight fires on building rooftops. The reactor operations management should identify members of the operational staff who will act as an interface between the reactor site and the DOE site fire brigade. These would, presumably, be the same individuals which provide the operational insights for each of the reactor specific fire response teams.

7.5.2 Provisions for Fire Protection System Maintenance

Fire detection and suppression systems require periodic maintenance and operational testing. At commercial reactor sites fire protection system maintenance procedures vary considerably. The most successful approach to date is to have fire fighting personnel perform the system maintenance and testing. This approach helps to ensure that personnel will have a clear understanding of the operational importance of the systems.

For NPR it is assumed that these activities will become the responsibility of the overall DOE site fire brigade.

7.5.3 Emergency Response Procedures

For NPR it will be necessary to develop a set of procedures to be implemented in the event of a fire in a particular fire area. These procedures should discuss manual fire response, ventilation system interactions, personnel evacuation, fixed fire protection systems, an identification of critical plant equipment in each area, operational requirements, and post-fire recovery.

Of particular importance in this regards is the main control room. For this area procedure need to allow for the abandonment of the main control room and the transfer of operations to the remote shutdown station and/or local control locations.

Procedures should also be established to deal with multiple spurious and/or legitimate fire detection signals expected to occur during a seismic event.

Fire response plans should also include procedures for fire fighting in contaminated areas. This would require special considerations for protective clothing, exposure monitoring, and suppressant management following discharge.

7.5.4 Administrative Procedures

Administrative procedures should be established to minimize the potential for fires to occur. These procedures should include provisions for the control, monitoring, reporting and prompt removal of transient combustible fuel sources. Procedures should also be established to control and monitor maintenance activities likely to result in an increased fire hazard (such as welding and cutting operations).

It is expected that certain maintenance activities will require that fire protection systems be taken out of service temporarily (for example, welding activities which will create smoke will likely require that smoke detector systems be deactivated). Procedures should be established for such cases to ensure that (1) fire protection systems are properly removed from service (spurious actuations have occurred during such efforts), (2) that fire response teams are notified of the out-of-service condition of these systems, (3) that adequate alternate fire protection measures are provided during the outage period (for example fire watches and extra portable extinguishers), and (4) that the fire protection systems are promptly and properly restored to operation following completion of work activity.

NPR should also establish, consistent with the USNRC Appendix R requirements, a clear chain of command for fire safety responsibility.

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