Crystal River 3
Individual Plant Examination of External Events

Revision 1

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1. Executive Summary

1.1 Background and Objectives

Florida Power Corporation (FPC), Nuclear Operations has been active in the area of probabilistic risk (or safety) assessment since 1984 when work was begun on a Level 1 probabilistic safety assessment (PSA) for the Crystal River 3 (CR-3) nuclear unit. The CR-3 PSA (Reference 1-1) was completed in July 1987 and submitted to the NRC in September 1987. The NRC reviewed the CR-3 PSA and published the review in NUREG/CR-5245 (Reference 1-2).

In November 1988, the NRC issued Generic Letter 88-20 (Reference 1-3), requesting that all nuclear utilities perform a Level 2 PSA for each of their nuclear units. The requested analysis was called an Individual Plant Examination (IPE). The IPE was to address internal events and the one "external" event of internal flooding. Analyses of other external events, such as seismic, fire, high winds, and external floods were not requested. Following the guidance set forth in the generic letter and NUREG-1335 (Reference 1-4), the CR-3 PSA staff added a Level 2 (containment) analysis and an internal flooding analysis to the CR-3 Level 1 PSA to fulfill the generic letter request and bring the CR-3 PSA up to the IPE specifications. The CR-3 IPE was submitted to the NRC in March 1993.

In June 1991, the NRC issued Supplement 4 to Generic Letter 88-20 (Reference 1-5), a request that each nuclear utility add an external events analysis to their existing IPE. This analysis would be known as an Individual Plant Examination of External Events (IPEEE). At that time, FPC reviewed its susceptibility to the external events specified in Supplement 4 and decided that fire was the only external event which merited the quantitative analysis requested. FPC committed to submitting a fire risk analysis as the CR-3 IPEEE by June 30, 1996. A fire PSA was performed for Crystal River 3, is documented herein, and was submitted in June 1996 as the CR-3 IPEEE. During the latter stages of the fire risk analysis, however, FPC decided it would be prudent to also perform a quantitative analysis of high winds, external floods, and transportation and nearby facility accidents, as described in Supplement 4 and NUREG-1407 (Reference 1-6). These analyses were performed following the June 1996 submittal of the IPEEE with the intention of publishing them as a revision to the IPEEE for submittal in March 1997 (Reference 1-7). This document is that revision.

In June 1992, NRC issued Information Notice 92-01: Failure of Thermo-Lag 330 Fire Barrier to Maintain Cabling in Wide Cable Trays and Small Conduits Free from Fire Damage (Reference 1-8). The net result of this information notice and the ensuing communications between NRC and the industry was that the Thermo-Lag material provided only a fraction of its claimed fire protection. Tests were run on the material to determine just how much protection Thermo-Lag provided. The tests showed that the one-hour Thermo-Lag provided about 20 minutes of protection, and the three-hour Thermo-Lag provided about one hour of protection. These test durations were used in the fire modeling for the fire PSA in this submittal.

1.2 Plant Familiarization

The Crystal River Station is located on the Gulf of Mexico, in the township of Crystal River, Florida. It is approximately 7.5 miles northwest of Crystal River, and 70 miles north of Tampa.

The nuclear steam supply system (NSSS) consists of a pressurized-water reactor and a two-loop reactor coolant system (RCS). This system was supplied by the Babcock and Wilcox Company. The generating unit has a licensed core design output of 2544 megawatts thermal with a corresponding net dependable capability electrical rating of 821 megawatts electric with the reactor at rated power.

The reactor coolant system is comprised of the reactor vessel, two vertical once-through steam generators, four shaft-sealed reactor coolant pumps, an electrically-heated pressurizer, and interconnected piping. The system is housed within the reactor building (or containment), a seismic Category I reinforced concrete structure with a 3/8-inch carbon steel liner.

Heat produced in the reactor is converted to electrical energy by the steam and power conversion system. A turbine-generator system converts the thermal energy of steam produced in the steam generators into mechanical shaft power and then into electrical energy. The unit's turbine-generator consists of one high-pressure double-flow cylinder and two low-pressure double-flow cylinders driving a direct-coupled generator at 1800 rpm. The turbine is operated in a closed feedwater cycle which condenses the steam and returns the heated feedwater to the steam generators. Heat rejected in the main condenser is removed by the circulating water system. The Gulf of Mexico serves as the normal ultimate heat sink for Crystal River 3.

1.3 Overall Methodology

The IPEEE fire analysis was performed using the fire PRA methodology developed by EPRI for the Fire Probabilistic Risk Assessment (Fire PRA) project. The methodology is described in detail in Section 4.0. For the analysis of the potential hazards associated with high winds, external flooding, and transportation and nearby facility accidents, a comparison of the plant design and site characteristics to the criteria and guidance summarized in NUREG-1407 (Reference 1-6) and NUREG/CR-5042 (Reference 1-9) was made. In many cases, it was possible to screen out the hazards without more detailed analysis. Where events could not be screened readily, a more detailed assessment was performed.

1.4 Summary of Major Findings

The major finding of the IPEEE fire risk analysis is that, despite the reduced effectiveness of the installed Thermo-Lag protection, the core damage frequency due to internal fires is comparable to that of many other nuclear units, and the total core damage frequency for CR-3, from both internal and external events, still falls below the NRC safety goal of 1×10^{-4} per year. The core damage frequency due to fires for the current plant configuration, assuming 20 minutes of protection for the one-hour Thermo-Lag and one hour of protection for the three-hour Thermo-Lag, is $4.2x10^{-5}$ per year. The core damage frequency from all events is $5.2x10^{-5}$ per year. A pie chart showing the relative contribution of the different initiating events is shown in Figure 1.4-1.

There were two transient fire ignition sources which were significant contributors to the total core damage risk due to fire. These sources were in a specific location in their respective fire zones. Measures will be taken to forbid the placement of transient fire sources in these two locations, and these ignition sources will be removed from the fire PSA model.

The majority of the core damage risk due to fire for CR-3 is associated with fires occurring in fire zones within the control complex. Table 1.4-1 lists the fire zones which have a core damage frequency due to fire of greater than $1x10^{-6}$ per year, along with the control room and cable spreading room.

The remainder of the external events (high winds, floods, and transportation and nearby facility accidents) were found to have minimal impact on the overall risk of core damage at CR-3. Using a bounding analysis to assess the impact of tornadoes at CR-3, the core damage frequency contribution was calculated to be $9.2x10^{-8}$ per year. The core damage frequency associated with high winds other than tornadoes was calculated at $1.6x10^{-8}$ per year. Application of the appropriate standard for evaluation of the hazards associated with external flooding resulted in an estimate of the annual occurrence frequency of the probable maximum hurricane (PMH) coincident with the 10% exceedance high tide orders of magnitude below the acceptance criterion of 10-6 per year. Thus, there are no vulnerabilities at Crystal River 3 due to external flooding. Outside of the potential for inducing a loss of offsite power, which is addressed in the internal events analysis, no other specific vulnerabilities to lightning strikes at CR-3 were found. The frequency of an aircraft striking a category I building at the CR-3 site was calculated to be $1.8x10^{-7}$ per year using the applicable standard, effectively screening this threat. A review of nearby marine, highway, and rail traffic found their potential contribution to a core damage accident to be negligible. Facilities close to the plant were also examined for their potential to impact the risk of core damage and were found not to pose a hazard. The core damage frequencies calculated for the external events other than fire were not added to the overall core damage frequency due to the bounding nature of the calculations and their relatively low frequencies.

Table 1.4-1
Fire Zone Core Damage Frequencies

Zone	Description	CDF
CC-108-106	BATTERY CHARGER ROOM 3A	1.49E-05
CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	7.31E-06
CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	6.79E-06
CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	3.79E-06
CC-108-105	BATTERY CHARGER ROOM 3B	2.72E-06
CC-108-102	HALLWAY AND REMOTE SHUTDOWN ROOM	2.66E-06
CC-124-111	CRD & COMMUNICATION EQUIP ROOM	[illegible]8E-06
CC-108-109	INVERTER ROOM 3B	1.45E-06
CC-145-118B	CONTROL ROOM	5.7E-07
CC-134-118A	CABLE SPREADING ROOM	9.9E-08

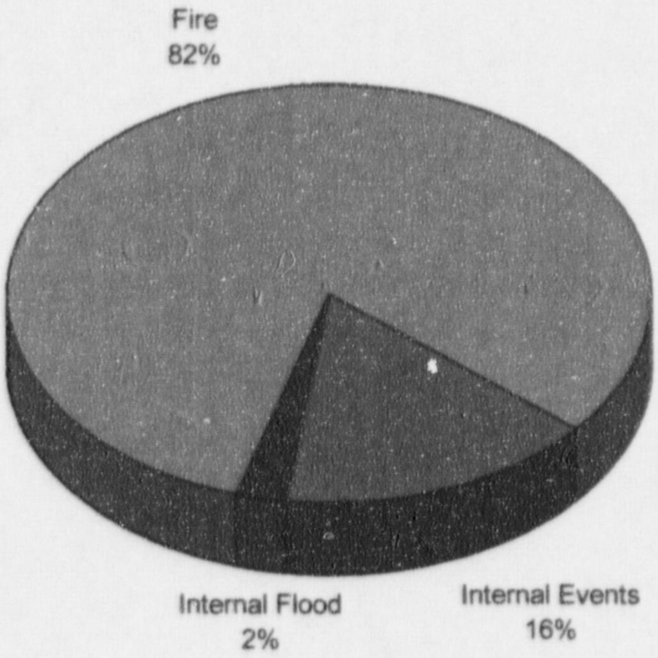


Figure 1.4-1 Initiating Event Contribution to CR-3 Core Damage Risk

1.5 References

1-1 Letter from FPC to NRC, "Probabilistic Risk Assessment (PRA) Submittal," 3F1187-01, November 2, 1987.

1-2 NUREG/CR-5245, "A Review of the Crystal River Unit 3 Probabilistic Risk Assessment," N.A. Hanan, Argonne National Laboratory, January 1989.

1-3 Individual Plant Examination for Severe Accident Vulnerabilities - 10 CFR 50.54(f), Generic Letter 88-20, November 23, 1988.

1-4 NUREG-1335, "Individual Plant Examination: Submittal Guidance," USNRC, August 1989.

1-5 Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities - 10 CFR 50.54(f), Generic Letter 88-20, Supplement 4, June 28, 1991.

1-6 NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities," USNRC, June 1991.

1-7 Letter from FPC to NRC, "Individual Plant Examination for External Events," 3F0696-12, June 28, 1996.

1-8 NRC Information Notice 92-01: "Failure of Thermo-Lag 330 Fire Barrier to Maintain Cabling in Wide Cable Trays and Small Conduits Free from Fire Damage," June 1992.

1-9 Kimura, C. Y. and R. J. Budnitz. *Evaluation of External Hazards to Nuclear Power Plants in the United States*. U.S. Nuclear Regulatory Commission Report NUREG/CR-5042, December 1987.

2. Examination Description

2.1 Introduction

The CR-3 IPEEE submittal consists of an internal fire risk analysis using fire PRA methodology. An analysis of high winds, external floods, and transportation and nearby facility accidents is also included. The seismic analysis is considered to be addressed by USI A-46 (see Section 3).

2.2 Conformance with Generic Letter

The CR-3 IPEEE was performed in a manner conforming with Generic Letter 88-20, Supplement 4.

3. Seismic Analysis

An IPEEE seismic analysis was not performed A quantitative probabilistic analysis of seismic events at CR-3 was not performed due to its anticipated minor contribution to the overall core damage frequency, and the fact that FPC's resolution of USI A-46, Seismic Qualification of Equipment in Operating Plants, is considered to be sufficient to address the seismic aspects of the IPEEE. See Reference 3-1.

3.1 References

3-1 Letter from FPC to NRC, "Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, Unresolved Safety Issue (USI) A-46, Generic Letter 87-02," 3F1295-18, 12/31/95.

4. Internal Fires Analysis

4.0 Methodology Section

The IPEEE internal fire analysis was performed using fire PSA methodology, specifically that developed by EPRI for the Fire Probabilistic Risk Assessment (PRA) project. A fire PSA develops and quantifies fire damage sequences. The fire PSA methodology used for the CR-3 IPEEE employs NUREG/CR-2300 (Reference 4-1) for the basic framework; however, fire modeling techniques, data, and technical bases are drawn from more recent sources. For example, the method uses the fire models described in the Fire-Induced Vulnerability Evaluation (FIVE) (References 4-2,3) to calculate temperature profiles in the fire zones. For data, this method draws upon not only FIVE, but data sources in NUREG/CR-4840 (Reference 4-4) and NUREG/CR-2815 (Reference 4-5), and insights from both Sandia's and EPRI's fire research programs. The methodology, as applied at CR-3, proceeded as follows.

Information was gathered which would be required or helpful for the evaluation. This information consisted of existing fire studies and related databases. Additional information was gathered by performing several plant walkdowns. All of the fire zones in the plant, except those in the reactor building, were walked down to identify or verify potential ignition sources (including transient sources), the targets for the ignition sources (cable trays, conduits, and intervening combustibles), the types of suppression available, and the general fire-related characteristics of the fire zone. Based on this information, an early screening evaluation was completed using the conservative assumption that any fire would develop a hot gas layer (HGL), and all targets in the zone would be damaged. If a zone screened, no additional evaluation was needed for that zone. Additional walkdowns were made for the unscreened fire zones in order to define the ignition source/target models and evaluate the possibility for a fire in the zone. Detailed fire modeling was then performed for each ignition source to determine the propagation of damage, the heat release rates, the potential for formation of a hot gas layer, and the time to damage of cables and fire barriers. All of this information was necessary in order to supply the CR-3 core damage risk model with the likelihood of a fire initiating event and the impact of each potential fire on the systems and components designed to mitigate an accident.

The walkdowns and fire modeling described above provided the fire ignition frequency information and the targets damaged for each ignition source. Additional information was needed to relate this damage to the plant components which are disabled by the fire, and ultimately to the CR-3 core damage risk model. Because the targets identified were conduits and trays carrying cables, not systems and components, a link between the target trays and conduits, and the components modeled in the CR-3 fault tree was established. A relational database was created linking trays and conduits in each fire zone to circuits, circuits to the components which they support, and the components to the basic events in the fault tree model. In addition, the database defined the fire protection ratings of the cable trays and conduits within each zone. With this database, the information obtained by the fire modeling was translated to a set of initiating events (fires), each with its own set of PSA basic events to be set to TRUE, i.e., failed, in the CR-3 core damage risk fault tree model.

The CR-3 fire risk fault tree model was constructed from the internal events CR-3 core damage fault tree model used for the CR-3 PSA. For the fire analysis, all LOCA sequences (other than transient-induced LOCAs) were removed from the standard CR-3 PSA fault tree model. All initiating events were also removed, as the fire was now the initiating event. In addition, human error events were modified to reflect the conflict, time constraints, and spatial barriers associated with a fire.

The first quantification was a zone screening calculation. The conservative assumption was made that all components in a particular zone were destroyed given a fire in that zone. Credit for Thermo-Lag was given only if automatic suppression was available in the zone. No credit for manual suppression was given. No consideration was given to the possibility that a hot gas layer might not be formed. Given these assumptions, the relational database was used in conjunction with the fire risk fault tree model to obtain core damage frequencies for each fire zone. Those zones with a core damage frequency less than 1×10^{-6} per year were screened. Only the unscreened zones were evaluated in more detail.

This next level of detail in the quantification entailed identification of the individual ignition sources and their targets for each of the unscreened zones. Prior to the final source quantification, all of the possible scenarios for each ignition source were identified. The factors of interest in the scenario development were automatic and manual suppression success or failure and the associated timing, the time required for hot gas layer formation, and the protection time provided by any Thermo-Lag present. From the scenario definitions, a set of scenario frequencies and their appropriate conditional core damage probability (CCDP) types was developed. Using the CR-3 fire core damage risk fault tree model and the relational database, the CCDPs were calculated for each ignition source, combined with the scenario frequencies to give the individual ignition source core damage frequencies.

Control room and cable spreading room fires were evaluated separately due to the possibility of evacuation to the remote shutdown panel in the event of a fire.

Multi-compartment scenarios were evaluated. Multi-compartment scenarios address the effects on plant safety should a fire propagate beyond a single location. If the fire is severe enough and if fire protection systems or personnel fail, the fire or its products of combustion may reach another compartment. While this is unlikely, the potentially high consequences of damaging additional shutdown equipment may yield notable risk.

The sum of the individual ignition source core damage frequencies, the control room and cable spreading room core damage frequencies, and the multi-compartment fire core damage frequency constituted the total core damage frequency due to fire at CR-3.

Besides the traditional fire analysis, a special set of issues that have been raised by NRC's Research Branch were evaluated. These issues, called the Fire Risk Scoping Study (FRSS) issues, were analyzed using an approach developed for FIVE.

Each of the tasks described above is discussed in detail in the report.

4.1 Fire Modeling

4.1.1 Description

The objective of fire modeling is to determine if equipment damage can occur, and if so, when. Equipment damage is caused by excessive thermal exposure. Modeling will help determine the temperatures to which safe shutdown equipment in the fire zone will be exposed as the result of a fire in the fire zone. The ability to detect and suppress the fire before the safe shutdown equipment is damaged is determined in Section 4.2.

Convective and/or radiative heating from a fire causes thermal loads. The amount of heat transferred depends on the type of fire and its proximity to equipment as well as the overall geometry of the fire zone. The type of fire depends on the energy of the ignition source and whether other combustibles ignite and add more energy. Determining whether other combustibles ignite is similar to determining whether equipment is damaged, only the damage criteria is now based on the thermal loads necessary to cause ignition.

If equipment or combustibles are close to the fire, they may be damaged or ignited. If equipment is not close, it may still be damaged if the entire fire zone heats up. A layer of hot gas will build up above the fire. The equipment immersed in that layer can be damaged. The temperature of the layer will depend on the amount of energy released by the fire. Generally, the total energy released by the ignition source is insufficient to cause damage. Therefore another combustible such as cable must be ignited to generate a hot gas layer with sufficient energy to damage targets at a location which is at some distance from the ignition source fire.

To identify and model specific scenarios in each fire zone, the following three steps were used:

- **Scoping Evaluation**
- **Screening Walkdowns**
- **Detailed Fire Modeling**

In the scoping evaluation phase of fire modeling, the following was determined:

- the types of ignition sources and their potential energy release,
- the types of equipment present as targets and their corresponding damage criteria, and
- the potential for other combustibles to ignite, especially those with high heat content (e.g., cable, stored anti-contamination clothing, and flammable liquids).

The screening walkdowns were used to:

- identify fixed ignition sources that cannot propagate because of their design or because there are no nearby targets or intervening combustibles, and screen them from further analysis,
- collect data for scenarios from unscreened fixed ignition sources to use in detailed fire modeling, and
- determine damaging locations for transient ignition sources.

The detailed fire modeling step involved realistic (rather than screening) calculations of individual scenarios. Fire growth to beyond the closest target was modeled and evaluated, including the potential for generating a hot gas layer sufficient to damage all or most of the targets in the fire zone. The impact of protective features was evaluated. More precise evaluations of heat release rates and damage criteria were used when appropriate. Finally, a time-to-damage evaluation was performed. The time to damage is used in suppression modeling. The analysis of transient ignition sources was also done in the detailed modeling step.

4.1.2 Scoping Evaluation.

The principal objective of the scoping evaluation was to collect and evaluate the information on which to base the screening of fixed ignition sources during the walkdown. Ignition sources were screened if they were incapable either of damaging any target or igniting an intervening combustible.

Some fire zones did not contain fixed ignition sources or sources which could propagate. These zones were temporarily screened until it was time to evaluate transient ignition sources.

The first step in this evaluation was to summarize information from all fire zones. The information was used to pre-calculate "no-damage" heights and radii. That is, a slightly conservative fire modeling calculation was performed to predict the maximum distances at which damage can occur. An ignition source can be screened if all targets are beyond this height or have at least the calculated horizontal separation. This information was recorded on walkdown sheets for each zone.

To determine these no-damage distances, two important plant-specific inputs were required:

- the potential energy released from the various ignition sources, and
- the damage criteria of the various safe shutdown equipment i.e. "targets."

Evaluate Ignition Sources. In this step, information on the fire zones, and the results of tests sponsored by the industry or the NRC, was summarized and used to obtain a heat release rate and total heat content for each ignition source type.

Fixed Ignition Sources. The first activity in this evaluation was to summarize the types of fixed ignition sources in the fire zones. This process was performed by reviewing the generic types of sources selected in the FIVE methodology and adopting the appropriate items. Ignition frequency worksheets for each fire zone were then generated listing the different source types. Representative ignition sources were included in the evaluation forms. These included: electrical cabinets, small pumps with berms or other means of confining an oil spill, transformers, and anti-contamination clothing (PCs). No attempt was made to screen oil bearing equipment during the walkdown if there was no means of confining the spill.

Transient Ignition Sources. Transient ignition sources are welding activities, tobacco smoking, extension cord use, space heater use, and the heating of lubrication fluid or grease. Smoking is prohibited within the confines of the walls of the power plant and is therefore not further considered as a transient ignition source. Welding activities are rigidly controlled by administrative procedure and always requires a fire watch and special preparation of the area in which the work will be performed. Welding is the leading cause of fires cataloged in the Fire Events Database (FEDB, Reference 4-6). Heating of lubricating compounds has caused a problem at CR-3, although a minor one. This is now procedurally controlled. Space heater use is not significant at CR-3 due to the generally mild climate of the region and natural heatup of enclosed spaces within the power plant. The use of extension cords is less rigorously controlled and was accounted for in the consideration of transient ignition sources as was welding and heating of oils or greases.

It must be noted that a transient source by itself cannot generate a propagating fire. A transient fuel package must be associated with the transient ignition source. It was necessary for the analyst to determine just what a fuel package was most likely to contain. After review of plant procedures, and interviews with craft and supervisory personnel, a package was selected from the FIVE Implementation Guide, Appendix E, Table E-4, included herein, to represent the typical CR-3 maintenance refuse package.

Heat Release Rates (HRRs). Once the types of ignition sources were known, heat release rates were determined. Electrical cabinets were evaluated as described in Appendix H. Other influential characteristics were whether or not they were vented and the amount of combustibles contained. Amounts of contained oil and the contents of the transient fuel package were factors considered for other types of ignition sources. The HRR for each type of ignition source is listed in Appendix E, Table E-1, Part 1. The specific HRRs selected for use in this IPEEE are presented in Table 4.1-1.

There are numerous transformers in the plant which generate large amounts of heat and hold a significant place in the list of fire starters in power plants. All transformers inside CR-3 plant structures, e.g., switchgear rooms, are dry-type transformers. That is, they do not contain oil. Dry transformer fires generate lower heat release rates than fires in oil-filled transformers. Therefore, all transformer fires were assigned a heat release rate commensurate with testing performed by Sandia National Labs and listed in Appendix E, Table E-1, Part 1.

Table 4.1-1
Selected Heat Release Rates

Ignition Source from FEDB	Fire Source Type	Characteristic Combustibles	Selected Values
Electrical Cabinets	Qualified Cable in vertical cabinets	Qualified Cable	65 BTU/s
Pumps (large)	Motor	Motor Windings	65 BTU/s
Pumps (large)	Lube Oil	Oil	135 BTU/s-ft^2
Pumps (small)	Motor and Oil	Motor Windings and Lube Oil	270 BTU/s
Transformers	Oil	Transformer Oil	135 BTU/s-ft^2
Main Turbine Oil System	Oil	Lube Oil	135 BTU/s-ft^2
Electrical Motors	Motor	Motor Windings	65 BTU/s
Transient	Transient Fuel Package - Maintenance Refuse	2.5 gal Polyethylene bucket, 1 liter polyethylene bottle, 16 oz kimwipes, 1 qt acetone	32 BTU/s

Selecting Final Heat Release Rates for Pumps and Motors. Two types of fires can ignite from a pump or motor fire. They are motor winding fires and oil/grease fires.

For motors, a conservative bound, namely the electrical cabinet heat release rate for qualified cable, was used. Oil fire heat release rates vary depending on the size of the spill. An unconfined oil spill gives incredible HRRs (based on FIVE Table 2E). The probability of these larger (unconfined) spills was established using insights from the FEDB. Oil pool size was based on confining design features (e.g., berms or drip pans), or other factors (e.g., observable oil loss from the component or on the floor).

The amount of oil in small pumps was also considered. Of the pump ignition sources, the majority were small pumps. A pump was identified as a "small pump" if its motor was smaller than 25 horsepower. The resultant fire from one of these ignition sources was considered to be a composite of the motor windings and oil which leaked from the bearings, reservoir, etc. It was possible to show that fires in many of these pumps would not damage targets even if all the oil in them was ignited. In actuality, the majority of small pumps contained less than two gallons of oil in any one reservoir.

Using cable qualification, oil content, and construction characteristics and materials allowed general heat release rates to be developed and used in the walkdown.

Selected Parameters

Heat Content. Representative total Btu was estimated based on fire duration (15-minute fire for cabinets) or amount of combustibles (e.g., cable in the cabinet or lube oil in the pump).

Damage Criteria. Information on damage criteria for nuclear plant components has been difficult to obtain. In its letter approving FIVE, NRC acknowledged this fact. NRC allows documented engineering judgment when data is unavailable. It also requested evaluations of the appropriateness of results from new testing and analysis. Recent testing and analysis generally confirms FIVE's temperature criteria for qualified cable are conservative. For other components, limited test data and references from past fire PRAs are available to guide engineering judgment. Appendix F describes available data on damage criteria.

Generally, a simple approach was appropriate for representing the diverse types of equipment present in unscreened fire zones. The analyst performed two basic tasks. The first task was to determine whether qualified or unqualified cable had been used in the plant. It was determined that the amount of cable which was not qualified in accordance with IEEE 383 standards was insignificant. Therefore all cable was evaluated as "qualified" and assigned a heat release rate (HRR) commensurate with that classification and the cable type.

FIVE's recommended damage criteria generally seem consistent with recent test and analytical evaluations:

- 700°F and 1 Btu/s/ft^2 for qualified cable
- 450°F and 0.5 Btu/s/ft^2 for unqualified cable.

The second task was to determine if solid-state equipment was present in any of the fire zones. This equipment could fail if fire zone temperatures reached 150°F or if they were exposed to incident heat fluxes of 0.19 $Btu/s/ft^2$. Because of the lower damage criteria, it was important to be aware of the potential for damage to solid-state devices in a fire zone before the walkdown was performed.

This simple approach is based on typical characteristics of nuclear power plants. First, the targets are usually cable. Second, other equipment in the fire zone (such as pumps) are usually not in the hot gas layer. That layer does not descend below the fire source which produces the heat to create the HGL, typically elevated cable trays. If a unique condition does exist (e.g., an elevated component in the HGL), the analyst must perform a detailed analysis for that fire zone.

One such unique condition is the presence of liquid combustibles. The volatility of the fuel may result in extremely intense fires of very short duration. Another consideration is the mobility of the fuel/fire. Each of these conditions requires special consideration in the detailed analysis of a fire zone.

Combustible/Flammable Liquids

Oil Fires - Presence of a high energy ignition source is needed to ignite damaging quantities of oil. The FEDB shows that ignition of oil occurs almost entirely during welding and grinding, when a fire watch is in effect. Of the 46 non-welding transient fires in the FEDB, only three involved oil and one involved grease. None of these fires resulted from a spill (i.e., a pool fire). The oil fires involved a blanket soaked in oil, wood scaffolding catching on fire because it was soaked in oil, and smoking (no flames) as the result of heating a 55-gallon oil drum. When modeling activities that require a continuous fire watch or equivalent presence by trained plant personnel (e.g., welding and grinding), presence of the fire watch was credited.

Other Flammable Liquids - Other liquids such as acetone, etc. do not pose a spill-type hazard if handled in safety containers. If spilled in limited quantities, these liquids tend to burn off too quickly to cause any damage. The operating experience also shows that only two of the 46 non-welding fires involved flammable liquids. Both occurred while cleaning electrical motors and not as the result of a spill. Flammable liquids of less than one quart were not modeled because the standard maintenance refuse package (Appendix E, Table E-4, SNL test # 3) is modeled, and acetone is already present in the package.

Preparation for the Walkdown. Preparation for the walkdown is the last step in the scoping evaluation. Scoping calculations using fire modeling tools are performed to calculate "no-damage" heights and radii for ignition sources based on the generic source types and target damage criteria.

4.1.3 Screening Walkdown

The walkdown had several objectives. Primarily, the walkdown was performed to count and locate ignition sources and to identify the targets associated with each source. In addition, the walkdown performance provided firsthand knowledge of the physical characteristics of the source and targets such as position in the room, height, length, width, relationship to other equipment, and construction characteristics . One of the construction details which was important was whether or not the cabinet was vented. If it had vents, were they open holes in the face, side, or top of the cabinet, or were they attached conduit? If they were conduits, were they short lengths of conduit or long lengths? Were they plugged with fire penetration packing material or open, located high on the cabinet, low on the cabinet, or both? Other conditions were noted such as the presence of fire barrier wrap material or armored flexible conduit which may prevent ignition of cables.

During the walkdown, specific conditions were identified which prevented ignition sources from being capable of propagating a fire. Some electrical cabinets were fully enclosed or had all openings packed with fire seal material thus making them incapable of igniting other combustibles. These were eliminated from further consideration. The details of the enclosures were most easily identified in the field and were recorded on the Walkdown Ignition Source Screening Form B (Appendix G).

Ignition sources with no targets overhead, with targets above the damage height and more than the damage radius to the side, or ignition sources separated from targets by a non-combustible shield were also screened. If the ceiling was lower than the pre-calculated damage height, consideration was given to targets in the ceiling jet such that distance from source to the ceiling plus target offset was less than the damage height. Damage to such a target could not be precluded without further fire modeling and it was not screened out at this point. Also, cable inside conduit cannot be ignited unless the conduit is breached.

The non-propagating fixed ignition sources, identified at the end of this step, did not require detailed fire modeling and were closed out at that point. However, before these components were eliminated as fire risk sources, it was important to verify that fire damage to the ignition source itself was not risk-significant. In particular, this concern needed to be carefully evaluated for components such as switchgear and MCCs.

The following is the guidance used to ensure that loss of the ignition source alone did not result in a risk-significant fire-induced sequence.

- Check if loss of the ignition source is modeled (as an accident initiator or equipment failure) in the internal events PSA (IPE). If the data used for equipment unavailability is based on historical events such that it includes fire, then the internal events PSA (IPE) already includes the fire-induced loss of the ignition source and no further evaluation will be needed. If not, perform the following checks.

- If loss of the ignition source does not result in a reactor trip (automatic or manual) and there is not a loss of equipment which was used in the CCDP model, screen the ignition source.

4.1.4 Documentation

Various forms were developed to assist in data collection, presentation and calculation. These forms are described below and are presented in **Appendix G** of this document.

- **Walkdown Ignition Source Screening Form A** was used as the input information link for zone-specific information and generic ignition source information. It is the source of information required to perform the calculations for damage heights and damage radii for the typical sources and plume conditions.

- **Walkdown Ignition Source Screening Form B** displays the calculated data on damage heights and damage radius for typical sources using the FIVE fire models (Reference 4-2). Form B was also used to simplify and document all sources in the zone and to facilitate screening of the non-damaging sources. The form does not include a radiation-induced ignition radius. This distance is similar to the damage radius.

- **Walkdown Ignition Source Screening Forms C-1 through C-27** calculated the damage heights and radii for each generic source type based on the particular dimensional characteristics of the fire zone.

- **Form S, Scenario Information Sheet,** was used to document unscreened scenarios for detailed fire modeling. The documentation identifies the ignition source, the height to the target or intervening combustible, and the raceway identification number. Passive fire protection features that would prevent ignition of the target combustible or limit flame propagation were also documented. Examples are fire breaks, solid-bottom trays, tray covers, mastic coatings, and fire wraps. Other passive plant features that would prevent ignition could include HVAC ducts, partitions, and unvented cabinets. Flammable liquids stored in listed flammable liquid storage lockers were not considered combustibles. Active fire protection features that could prevent or limit ignition of combustibles were identified on the forms. These included detectors and/or sprinklers in proximity to the combustible. The Scenario Information Sheet was used for each scenario.

- **Forms H and H-1, Calculation of Time to Damage / Ignition by HGL,** were used for 700°F and 1000°F calculations, respectively. Each sheet is identical to the other with the exception that the reference temperatures differ as does the resultant Qnet/V from Table 7E of the FIVE methodology manual. The calculation performed by this sheet is for determining the amount of time required to generate a hot gas layer given the particular input values associated with a particular ignition source and its associated intervening combustibles.

- **Drawings** To effectively present the specific geometric arrangements of ignition sources to targets required the generation of drawings. Drawings were made for each propagating source and its respective targets. Drawings were often done from various perspectives depending on the needs of the situation. For instance, "frontal" drawings were prepared to exhibit the source construction characteristics and dimensions, target heights, and vertical relationships (Appendix B drawings D-1, D-2, and D-3). In some cases, there existed the need to present an overhead view to adequately portray the positioning of overhead targets in relationship to the sources in a room (Example D-4). Drawings were also used to provide mobile visual references for the analyst of complex or abnormal configurations of Thermo-Lag or cable trays (Example D-5, and D-6). During the analysis of transient ignition sources/combustibles, drawings were used to show the probable locations for fuel packages to be left in a zone. From that information, each location's associated targets could be determined and an evaluation of the potential impact of a transient combustible fire could be performed (Example D-7). In special cases such as the Main Control Room (MCR) evaluation, it was beneficial to make floor plan drawings showing the placement of all sources in the MCR (D-8 and D-9).

4.1.5 Detailed Fire Modeling

Detailed fire modeling involved an evaluation of fixed and transient ignition sources, heat release rates, damage criteria, and spatial relationship of sources and targets. Finally, the analyst performed specific fire modeling calculations of individual scenarios, and determined times to damage and/or ignition.

Fixed Ignition Sources. After identifying the types of fixed sources present in a room, the appropriate HRR was selected. Drawings were prepared of the source giving dimensions of the source, vent locations, and target locations in relative position and distances. Electrical cabinets were evaluated for potential spread of fire to adjacent cabinets based on the guidance provided in Appendix H. The source HRR and total heat released were used to determine if the source alone released enough energy to damage nearby targets or if there were nearby combustibles which would be ignited and further impact circuits in the area. Any target not in either the plume of the ignition source fire, the ceiling jet of the ignition source fire, within restricted distance of plume centerline, or in the hot gas layer (HGL) if one was generated, was not considered to be damaged by that source. Examples of the drawings created are presented in Appendix B.

Transient Ignition Sources. The fire PRA method for transient ignition sources is based on insights from the FEDB, fire modeling, and typical plant administrative controls. The FEDB indicates that transient ignition sources ignite transient combustibles.

The FEDB further indicates that fixed ignition sources are unlikely to ignite transient combustibles. Class A materials would have to be stored within one to three feet of a fixed ignition source. (This calculation uses a range of heat release rates for typical fixed ignition sources and an ignition heat flux of 1.8 Btu/sec/ft^2 for trash and other types of Class A combustibles.) Hence, the evaluation of transient combustibles becomes part of the evaluation of transient ignition sources. The transient ignition sources evaluated included principally welding, but also other sources such as extension cords, heaters, etc.

Plant administrative controls apply to both transient ignition sources and transient combustibles. The evaluation to determine ignition frequency considered the impact of plant administrative controls on transient ignition sources in a particular fire zone. In this step, the analyst evaluates the impact of administrative controls on transient combustibles.

Administrative controls at CR-3 significantly reduce the risk that large amounts of transient combustibles can become involved in a fire area containing safe shutdown equipment. However, it is not practical to control transient combustibles so that all damage can be prevented. Procedures typically allow transient combustibles in specified quantities and those quantities, if ignited, are large enough to damage overhead targets. Based on interview results, procedural allowances, and plant practices the analyst determined what the constituents of a transient fuel bundle was likely to be at CR-3. This provided the basis for selection of spatial criteria, HRR, and total heat content for a transient fuel package fire. The more damaging criteria and specifics of the packages presented in Appendix E Table E-4 as the SNL Nowlen TEST #3 and #4 were selected as representative of the most probable transient fuel package at CR-3.

In this analysis, consideration was given not only to plant procedures but also to plant practices, such as where trash bags are typically stored, which fire zones, and where in the fire zones. The evaluation identified not only where combustibles are stored, but in what quantities and with what compensatory actions, if any.

The following describes the initial evaluation portion of the transient ignition source analysis. The evaluation involved a review of procedures, combustible loading calculations, and interviews with plant personnel..

Procedure Review. Applicable plant procedures, including housekeeping procedures, were reviewed, to identify limits that apply to various storage conditions:

- designated storage devices, e.g., liquids stored in approved containers and storage of ordinary combustibles in enclosed metal containers,
- limits on types of combustibles,
- limits on quantities, e.g., no liquid combustibles in excess of five gallons,
- the compensatory measures (e.g., fire watch or not left unattended), if any, that apply to various storage conditions, and
- the inspections that would or might uncover violations and the frequency of such inspections.

The probability of a violation of storage restrictions is generally a few percent or less. FIVE provides a screening value of ten percent for exposed combustibles if the plant fire protection program (applicable to the fire zone) includes features similar to the following:

- flammable and combustible liquids are stored in approved containers,
- storage of ordinary combustibles or WRP clothing in enclosed metal cabinets or metal containers with fusible link actuated covers or with FM-approved self-extinguishing lids, and
- all exposed transient combustibles used by plant personnel while working in the fire zone are removed upon completion of the work unless otherwise approved.

Heat release rates for transients. The FEDB indicates that transient ignition sources (i.e., welding and other sources such as cigarettes, extension cord, heaters, open flames, over-heating or hot pipes) ignite transient combustibles while fixed ignition sources do not. This finding is also supported by fire modeling results. Consequently, presence of both a transient ignition source and transient combustibles is needed for a transient fire. Based on these findings, the following guidance for modeling transient fires was used.

It is important to note that liquid combustible fires occur mostly when people are present. Plant housekeeping requires that personnel attempt to clean up a spill before it spreads. These plant practices reduce the chance for creation of critical spills leading to pool fires. It is unrealistic to assume that the only factor affecting the size of an spill is the thickness (i.e., viscosity) of the fuel. Liquid combustible/flammable spills are deemed credible and ignitable without the presence of trained personnel, only in the case of a pump losing some or all of its contained oil. In such a case, the amount of oil credited was the amount contained in the largest single reservoir of the pump. The heat release rate for oil and acetone are 135 and 100 Btu/s/ft^2, respectively (FIVE).

Operating experience indicates that solid fuels can be ignited by high energy transient sources other than welding. Heat release rate for trash, maintenance refuse, paper, wood, and protective clothing is provided in Appendix E. This data was used, together with plant-specific quantities, to estimate heat release rates.

Transient ignition source walkdown. The use of extension cables is permitted throughout the plant including safety-related equipment areas. Therefore, the first core damage frequency calculation was done with a generic transient source frequency as a factor. Subsequently, all fire zones with a core damage frequency of $1x10^{-6}$ per year or greater were walked down to locate likely storage areas for transient fuel packages because it takes both an ignition source and a transient fuel package to yield a fire. Each location was recorded and special note made of limitations, specific to that location. Typically, special notes consisted of area available for transients, height to targets, and/or the presence of walkways and doorways. It was assumed that exposed combustibles within five feet of each other were part of the same storage area since it is possible that exposed transient combustibles within that distance will propagate and involve both packages.

For other than designated storage areas, targets such as cable trays which were lower than the damage height were identified. The damage height was calculated for the fire zone during the scoping evaluation. It was documented on the Ignition Source Screening Form.

Table 4.1-2
Summary of CR-3 Transient Combustible Controls

Definitions

Compensatory Measures - Actions taken to minimize the possibility or consequences of a fire. Such actions may include but are not limited to:

- Posting of fire watches
- Increasing fire suppression capabilities
- Removal of combustible material from the area
- Removal of ignition sources

Safety-Related Areas - Those areas containing equipment essential to the safe shutdown of the plant or have importance to safety (i.e., Auxiliary Building, Emergency Diesel Generator Building, Intermediate Building, Reactor Building and all areas of the Control Complex above the 95' elevation).

Transient Combustibles

a. Materials, liquids, or gases located at the job site or bulk storage area in the plant but not installed as part of the plant nor any of its systems.
b. Combustibles are not considered transient while being transported or when stored in UL-listed or FM-approved storage cabinets.

HLF - Heat Loss Factor. - The EPRI Fire PRA methodology recommends using, and CR-3 adopted the use of, 0.94 as a heat loss factor if times ≥ 5 minutes where the whole fire zone is filled with HGL. However, smaller values (0.85) were considered appropriate for exposure fire scenarios away from a wall and quickly developing hot gas layers (e.g., large flammable liquid pool fires).

Table 4.1-2 (cont.)
Summary of CR-3 Transient Combustible Controls

Policies Based on Procedures

General Control of Combustibles

- Waste, debris, rags, oil spills, and other excess material must be collected, removed from the job site, and disposed of properly. As a minimum, this must be done upon the completion of each job.
- Combustible liquids that must be kept in the area must be in UL-listed or FM-approved Flammable Liquids Storage Cabinet or otherwise approved by the fire protection supervisor.
- Flammable Liquid Storage Cabinets are not to be used for long-term storage of combustibles (i.e. > 30 days)
- Non-fire-retardant wood is not to be used.
- The quantity of transient combustibles allowed in a specific fire zone without imposing compensatory measures is specified by the Fire Hazard Analysis.
- Rags must be removed from the work area at the completion of the job or at the end of each shift, whichever is sooner.

The following materials may not be stored in areas containing safety-related equipment:

Charcoal
HEPA Filters
Resin
Wood
Cardboard
Explosives
Compressed Gases

- Debris and waste resulting from work activities shall be removed from plant areas at the end of each work activity or at the end of each shift, whichever is sooner.
- Caps or plugs shall normally be secured in-place on empty or full containers of liquid combustibles/flammables when not in use.
- The use of wood in the plant must be minimized. Only flame-retardant wood should be used.
- Combustible/flammable liquids shall not be used nor placed near heat, open flame, or other sources of ignition.
- Transient combustibles must be removed from within 35 feet of welding operations.
- Smoking shall not be permitted within plant areas.

Compensatory Measures for Ignition Sources or Combustibles

- Welding shall be performed only in the presence of a fire watch.

Inspections

- Plant housekeeping inspections are performed weekly.
- Transient combustible inspections are performed monthly.

Cable Ignition in Horizontal Trays. The EPRI Fire PRA methodology recommends a piloted cable ignition temperature of 932°F based on a wide variety of sources including a FMRC test summary (NUREG/CR-4840, Reference 4-4) and the Fire Protection Handbook. The same value is recommended for both qualified and non-qualified cable. Sources indicate a wider range of findings for the time to ignition.

NUREG/CR-4527 (Reference 4-7), in its discussion of cabinet fire tests (as well as other tests described in NUREG/CR-3656), states:

> "Direct flame impingement for ten minutes is necessary to ignite and propagate a fire in qualified cable."

In a description of earlier tests, NUREG/CR-5384 (Reference 4-8) reports that the time to ignition was five minutes in tests of both qualified, uncoated cable and cable trays. It also reports that the time to open flaming was one minute for unqualified cable.

Finally, FMRC has found ignition times varying from one to seven minutes for qualified cable at heat fluxes between two and four times the heat flux FIVE indicates is necessary to cause damage (22 and 43 kW/m^2).

In conclusion, the ignition time for qualified cable varies from five to ten minutes for situations typical of nuclear plant fires. A time of five minutes was adopted for initial calculations.

Propagation of Fires in Horizontal Cable Tray Stacks. Final fire modeling requires the analyst to determine time to damage and ignition for each tray, and heat release rate for cable tray stacks. However, fire modeling tools are limited in this regard. First, FIVE does not offer any related fire modeling capability. Next, COMPBRN is extremely conservative (see FRSS criticisms and NSAC-181 insights) and difficult to use (e.g., the non-communication matrix). Fortunately, experimental evidence from Sandia's fire test program can be used to guide the analysis.

The experimental evidence is documented in NUREG/CR-5384. The trays at CR-3 and the trays in the experiments met RG 1.75 minimum separation:

- 8" horizontal, 10.5" vertical for same train, and
- 5' vertical for redundant train.

The cables were IEEE 383-74 qualified. During the experiment, the lower tray was ignited after five minutes of exposure to a 40 Btu/sec HRR from two propane burners. The following times were reported:

First tray at sustained burning	0 minutes
Second and third trays involved	5 minutes
Fourth tray involved	10 minutes
Sixth tray involved	18 minutes
Eighth tray	22 minutes

These times were adopted for CR-3 modeling purposes due to extreme similarity of CR-3 cable to the tested cable. The EPRI fire modeling solution bases ignition timing and heat release on experiments, assumes damage based on worst case plume, and bases initial ignition on ignition source HRR. The process of fire propagation within a stack of cable trays is depicted and explained in Appendix I.

Time-to-Damage Calculations. Time to damage is a necessary term for calculating suppression reliability. Suppression systems may take time to actuate, but more importantly manual response takes time to be effective. The time to damage is an uncertain term subject to many of the limitations of fire modeling, e.g., the ability to model fire barriers. Two times were considered. The first consideration was given to those targets in the plume and within a distance from the source which resulted in the plume having sufficient energy to expose the target to damaging temperatures. A ultra-conservative position was taken on such a scenario in that we elected to consider all such targets immediately damaged. That is, at the time the fire begins, the target loses its functionality.

The second time considered was the time required to develop a hot gas layer (HGL) of sufficient temperature to expose the cables, fire barrier material, or other equipment to damaging temperatures. Determination of the HGL generation time was performed as described in Appendix I.

For cables, the time to damage is a strong function of the peak temperature. Appendix F provides data for determining the time to damage based on peak temperature. While this time factor was not initially accounted for in the analysis, it could be used in a more detailed analysis if necessary.

Cable ignition also takes time after ignition temperature is reached. Propagation of a fire from cable tray to stacked cable tray as described in Appendix I after ignition also can take a significant amount of time. Both types of times were described in the previous section. For coated cables and cable trays with barriers, time to damage information is presented in Appendix J.

Significant time is required to generate hot gas layers with temperatures high enough to cause damage. Forms H and H-1 were used to facilitate the calculation of the time to generate hot gas layers of 700 and 1000°F respectively. A conservative assumption is made initially that as soon as the HGL is generated, damage occurs to circuits with that specific damage criteria. This identified time is conservative in that although it is called the TTD, TTD actually exceeds this value by the amount of time it takes after reaching 700 or 1000°F for the circuit to fail.

In addition to damage being prevented after fire fighters reach the scene and begin their attack, damage is also prevented if the fire duration is less than the time to damage. That is, the ignition source fire may not last long enough to cause damage. The following fire durations were used for calculations in the modeling process:

Fire Source	**Duration**
Vertical electrical cabinets	
Unqualified cable - doors closed	30-40 mins
Unqualified cable - doors open	15-20 mins
Qualified cable	15-30 mins
Transients (paper, plastic)	
FIVE trash bag	2-3 mins @ > 300 Btu/sec
SNL trash and maintenance refuse	up to 60 mins
Transients (flammable liquid)	
Oil/acetone	seconds to minutes

Example problem. The example area is an electrical room in an auxiliary building. The total floor area of the area is 900 ft^2 and the ceiling height is 20 ft. The physical boundaries of the fire compartment are three-hour rated concrete walls, floor, and ceiling, with fire-rated fire doors, dampers, and penetration seals.

In this scenario, a cabinet fire is postulated to propagate to the open trays above. The target for the scenario is a conduit near the ceiling as shown in Figure 4.1-1. The conduit is approximately 18.5 feet above the floor. The fixed ignition sources for this scenario is an electrical cabinet SK01A/B. Per walkdowns, the cabinet is four feet wide and 7.5 feet tall and is within two feet of the wall. There are three cable trays directly above the cabinet. Cable fill in the bottom two is approximately 50%. The calculations performed to support the walkdowns determined that the cable trays could be ignited and burn. The top tray has a solid bottom and top and will not burn.

Based on the geometry described in the figure the target is actually in the hot gas layer (2 feet from the plume region and at the bottom edge of the ceiling jet) yet is conservatively evaluated as though it was located in the ceiling jet region of the fire model. The model predicts the fire exposure at the conduit. Scenario-specific combustible burning characteristics (heat release rates) are from the table in Appendix E.

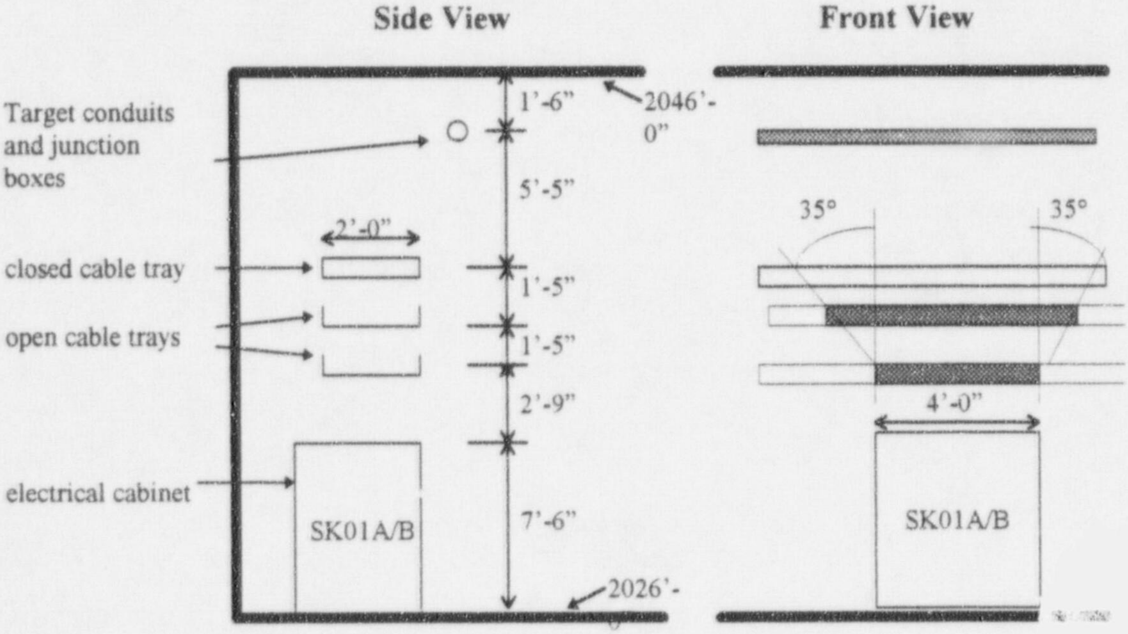


Figure 4.1-1. Fixed Scenario

The following is a summary of the specific input values used to determine the time-temperature exposure to the target conduit:

Cabinet:

Heat Release Rate (HRR) = 65 Btu/s
Heat Content (Qtot) = 65 Btu/s * (60s/min) * 15 min = 58,500 Btu
Fire Duration = Qtot/HRR = 15 min

Cable trays:

HRR = Unit HRR * Surface Area of Tray Involved
Unit HRR = 0.45 + $\mathrm{HRR}_{\mathrm{bench\ scale}}$ = 0.45 * 41.85 = 19 Btu/s/ ft^2
Area of involved tray = (2*4 ft + 2*(1.5 ft tan 35 deg.))*(2 ft) = 20.2 ft^2
HRR = 20.2 ft^2 * 19 Btu/s/ft^2 = 384 Btu/s

Q_{tot} = Length of tray involved * weight cable insulation per unit length * percent cable fill * heat content * percent burned
Unit weight of cable insulation = 1.0 lb/in width * ft length of tray
70% of total cable mass burns
Qtot = 10.1 ft * 1.0 lb/(in width * ft length of tray) * 24 in tray width * 50% * 12,000 Btu/lb * 70% = 1,020,000 Btu

Fire Duration = Q_{tot}/HRR = 1.02M Btu / [(384 Btu/s)/(60 s/min)] = 45 min

Combustible	HRR (Btu/s)	Q_{tot} (Btu)	Fire Duration (min)
Panel	65	58,500	15
Cable trays	384	1,020,000	45

The specific input values are show below. The data on the left represents the heat release rate from the burning materials at specific time steps in the scenario. In this scenario, the cabinet and cable trays are assumed to be burning. The virtual surface of the fire is taken to be at the bottom cable tray of the stack.

The cabinet and the cable are assumed to start burning at time = 0. This is a simplifying (and conservative) assumption. The heat release rate (HRR) of 449 Btu/s represents the sum of 65 Btu/s for the cabinet and 384 Btu/s for the cable. The cabinet burns for 15 minutes, when it has burned all the Btus available, leaving the cable to burn until it is entirely consumed at time = 45 minutes.

The right side of the data sheet is primarily geometric data required for the FIVE fire modeling equations.

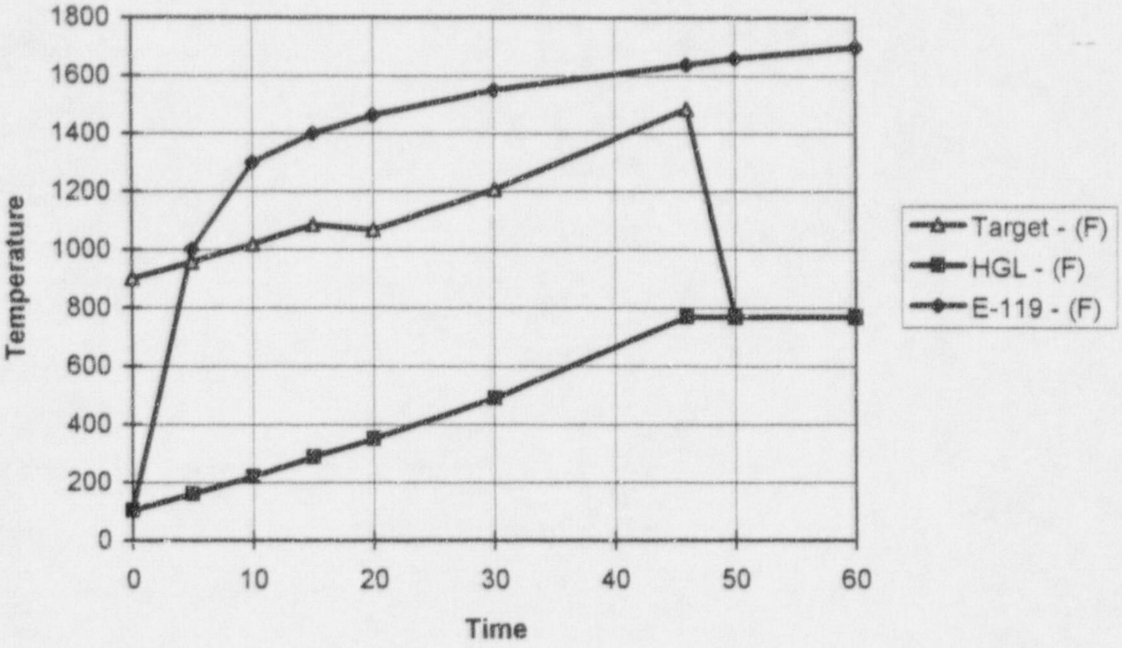
Time Step	HRR to Target (Btu/s)	HRR to HGL
0	449	449
5	449	449
10	449	449
15	449	449
20	384	384
30	384	384
45	384	384
50	0	0
60	0	0
120	0	0
180	0	0

Room Area	900
Ceiling Height	20
Target Height	18.5
Fire Height	10.25
Target in Plume? (Y or N)	N
Target Distance from Plume	2
Enclosure Width	14
Max. Ambient Temperature	104
Fire Location Factor	2
Estimated Heat Loss Fraction	0.94

The location-specific temperature-time history for components in the plume and in the hot gas layer are both shown in Figure 4.1-2. Using a 700°F damage criteria, exposed targets in the plume will be damaged almost immediately while exposed targets in the hot gas layer will be damaged at about 40 minutes.

The figure also includes the ASTM E-119 temperature exposure for reference purposes. The figure indicates the significant difference in margin between realistic exposures and those assumed in the Appendix R compliance process.

Figure 4.1-2
Time-Temperature Profile



4.1.5 Summary

The results of months of planning, performing scoping studies, performing walkdowns, making source and target identifications, identifying the spatial relationships between sources and targets, measurement data collection, fire brigade drill time data collection, drawing preparation, calculation performance, verification of data, calculation verification, source screening, detailed analysis of special configurations, determination of a "time to damage", and documentation of all the above, culminates in the production of data which is representative of the probability and severity of fire damage for each source and fire zone. This data is then used in the quantification of core damage probability as detailed in Section 4.5 of this document.

4.2 Fire Detection and Suppression

The detection and suppression analysis addresses the probability that the fire is detected and suppressed before it reaches its maximum damage potential. Automatic and manual suppression are both considered. The probability of successful suppression is a strong function of the time available for suppression. The key times for the fire risk analysis are the time to formation of a hot gas layer, the time for the fire to reach the temperature at which the Thermo-Lag begins to burn, and the time the Thermo-Lag lasts once this temperature is reached.

4.2.1 Automatic Suppression

Each of the CR-3 fire zones was examined to determine if automatic suppression was available, the type of automatic suppression, and if the automatic suppression was designed for full-zone coverage. The probabilities for failure of automatic suppression were taken from NSAC-179L (Reference 4-6), an evaluation of automatic suppression system data for application to nuclear plants. The data indicates the following reliability values:

System Type	Unavailability of System
Wet-Pipe Sprinkler	0.02
Pre-action Sprinkler	0.05
Deluge Sprinkler	0.05
CO_2	0.04
Halon	0.05

These values, also used in FIVE, provide realistic estimates of system unreliability. However, the estimates do not include:

- maintenance contributions to unavailability,
- credit for manual actuation of the system,
- dependent failures, or
- plant-specific data.

Maintenance contributions were not considered because of the compensatory measures taken if the automatic suppression system or a portion thereof is taken out of service. If the system cannot be reconfigured operable while the maintenance is ongoing, then a fire watch is posted. This was assumed to be equivalent to full availability of automatic suppression.

Credit for manual actuation is important because many failures of automatic suppression systems are recoverable. Specifically, the most likely causes are detection failure and valves left closed in the suppressant delivery system, e.g., the fire main. Roughly two-thirds of automatic suppression system failures are recoverable. Recovery can be credited if it can be shown that manual action can occur before damage. This recovery action is one of the reasons why the first responder in the brigade is important. No credit was taken for manual actuation of automatic suppression.

Dependencies in automatic suppression systems can be very important. Loss of offsite power and other plant conditions may make the fire water system less reliable, thereby increasing the system unreliability. The only potential dependency of importance is a loss of offsite power, and, considering the existence of two redundant diesel-driven fire service water pumps, this dependency was judged to be negligible.

The fact that the reliability figures used for automatic suppression did not include plant-specific data is considered to be of little significance. The data evaluation in NSAC-179L included a number of sources, some of which contained thousands of events. Hence, it is unlikely that plant-specific data would vary dramatically from the generic values used.

The non-suppression probabilities used for automatic suppression in the CR-3 fire zones are shown in Table 4.2-1.

Table 4.2-1
CR-3 Fire Zone Automatic Suppression

Zone	Description	Automatic Suppression	NSP	TL-1hr	TL-3hr
AB-119-12	HOT MACHINE SHOP	None	1	No	No
AB-119-6A	NORTH HALLWAY	Wet-Pipe Sprinkler-dual level	0.02	Yes	No
AB-119-6B	STAIRWELL AREA	Wet-Pipe Sprinkler	0.02	No	No
AB-119-6C	SPENT FUEL COOLANT PUMP ROOM	None	1	No	No
AB-119-6E	EAST HALLWAY	Wet-Pipe Sprinkler-dual level	0.02	Yes	No
AB-119-6F	MAKE-UP & PURIF. DEMIN. & FILTERS	None	1	No	No
AB-119-6G	HALLWAY	None	1	No	No
AB-119-6H	SEAL RETURN COOLERS & MAKE-UP TANK	None	1	No	No
AB-119-6J	CENTRAL HALLWAY	Wet-Pipe Sprinkler	0.02	Yes	Yes
AB-119-6K	DECONTAMINATION ROOM	Wet-Pipe Sprinkler	0.02	No	No
AB-119-6L	RADIOACTIVE WASTE PRESS ROOM	Wet-Pipe Sprinkler	0.02	No	No
AB-119-6M	WASTE DRUMMING AREA	None	1	No	No
AB-119-6N	DEBORATING DEMINERALIZER ROOM	None	1	No	No
AB-119-6P	DEMINERALIZER ROOM	None	1	No	No
AB-119-6Q	HALLWAY	None	1	No	No
AB-119-6R	MAKE-UP & PURIF. PRE-FILTER ROOM	None	1	No	No
AB-119-6S	HALLWAY	None	1	No	No
AB-119-6T	PURIFICATION FILTERS & RESIN TRAPS	None	1	No	No
AB-119-6V	STAIRWELL AREA	None	1	No	No
AB-119-7A	EMERGENCY DIESEL GENERATOR CONTROL ROOM 3B	Pre-Action Sprinkler	0.05	Yes	No
AB-119-7B	EMERGENCY DIESEL GENERATOR ROOM 3B	Pre-Action Sprinkler	0.05	No	No
AB-119-8A	EMERGENCY DIESEL GENERATOR CONTROL ROOM 3A	Pre-Action Sprinkler	0.05	No	No
AB-119-8B	EMERGENCY DIESEL GENERATOR ROOM 3A	Pre-Action Sprinkler	0.05	No	No
AB-138-6W	CONDUIT/PIPE CHASE	None	1	No	No
AB-143-6AA	CHEMICAL MIXING AND CENTRAL AREA	None	1	No	No
AB-143-6AB	PENETRATION AREA	None	1	No	No
AB-143-6AC	MAIN EXHAUST FILTER ROOM	Fixed Water Spray- in filter housing only	1	No	No
AB-143-6X	STAIRWELL AND SPENT FUEL COOLER ROOM	None	1	No	No
AB-143-6Y	SPENT FUEL COOLER ROOM	None	1	No	No
AB-143-6Z	EAST HALLWAY	None	1	No	No
AB-162-6AD	FUEL HANDLING FLOOR	None	1	No	No
AB-75-10	TENDON GALLERY	None	1	No	No
AB-75-4	DECAY HEAT PIT 3B	None	1	No	No
AB-75-5	DECAY HEAT PIT 3A	None	1	No	No
AB-95-2	ELEVATOR	None	1	No	No
AB-95-3AA	MAKE-UP PUMP ROOM 3B	Wet-Pipe Sprinkler	0.02	No	No
AB-95-3B	NORTH HALLWAY & NUCLEAR SAMPLE ROOM	Wet-Pipe Sprinkler- dual level	0.02	Yes	No
AB-95-3C	WEST HALLWAY	Wet-Pipe Sprinkler	0.02	Yes	Yes
AB-95-3D	HALLWAY	None	1	Yes	Yes
AB-95-3E	MAKE-UP PUMP ROOM 3A	Wet-Pipe Sprinkler	0.02	No	No
AB-95-3F	MAKE-UP PUMP ROOM 3C	None	1	No	No
AB-95-3G	CENTRAL HALLWAY	Wet-Pipe Sprinkler	0.02	Yes	Yes
AB-95-3H	NEUTRALIZER ROOM	None	1	No	No
AB-95-3J	EAST HALLWAY	Wet-Pipe Sprinkler	0.02	No	No
AB-95-3K	MISC. RAD WASTE ROOMS & HALLWAY	None	1	Yes	Yes
AB-95-3L	WASTE EVAPORATOR	None	1	No	No

Table 4.2-1 (cont.)
CR-3 Fire Zone Automatic Suppression

Zone	Description	Automatic Suppression	NSP	TL-1hr	TL-3hr
AB-95-3M	WASTE EVAPORATOR ROOM	None	1	No	No
AB-95-3N	REACTOR COOLANT EVAPORATOR ROOM	None	1	No	No
AB-95-3P	WASTE & RECYCLE PUMP ROOMS	None	1	No	No
AB-95-3Q	CONCENTRATE TANK ROOM	None	1	No	No
AB-95-3R	WASTE GAS ROOMS	None	1	No	No
AB-95-3S	WASTE GAS DECAY TANK ROOM	None	1	No	No
AB-95-3T	REACTOR COOLANT BLEED TANK ROOM	None	1	No	No
AB-95-3U	DECANT AND SLURRY PUMP ROOM	None	1	No	No
AB-95-3V	SPENT RESIN STORAGE TANK ROOM	None	1	No	No
AB-95-3W	WASTE TRANSFER PUMP ROOMS	None	1	Yes	Yes
AB-95-3X	NUCLEAR SERVICE BOOSTER PUMP ROOM	Wet-Pipe Sprinkler	0.02	Yes	Yes
AB-95-3Y	RCP SEAL INJECTION FILTER ROOM (TRIANGLE ROOM)	None	1	Yes	No
AB-95-3Z	RWSW PUMP ROOM	Wet-Pipe Sprinkler	0.02	Yes	No
CC-108-102	HALLWAY AND REMOTE SHUTDOWN ROOM	None	1	No	Yes
CC-108-103	PLANT BATTERY ROOM 3B	None	1	No	Yes
CC-108-104	PLANT BATTERY ROOM 3A	None	1	No	Yes
CC-108-105	BATTERY CHARGER ROOM 3B	None	1	No	Yes
CC-108-106	BATTERY CHARGER ROOM 3A	None	1	No	Yes
CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	None	1	No	Yes
CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	None	1	No	Yes
CC-108-109	INVERTER ROOM 3B	None	1	No	Yes
CC-108-110	INVERTER ROOM 3A	None	1	No	Yes
CC-124-111	CRD & COMMUNICATION EQUIP ROOM	Wet-Pipe Sprinkler	0.02	Yes	Yes
CC-124-112	EFIC ROOM "A"	None	1	No	Yes
CC-124-113	EFIC ROOM "C"	None	1	No	No
CC-124-114	EFIC ROOM "D"	None	1	No	Yes
CC-124-115	EFIC ROOM "B"	None	1	No	Yes
CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	None	1	No	Yes
CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	None	1	No	No
CC-134-118A	CABLE SPREADING ROOM	Total Flooding Halon Room	0.05	No	No
CC-145-118B	CONTROL ROOM	None	1	No	No
CC-145-119	OPERATORS AREA	None	1	No	No
CC-164-121A	HVAC EQUIPMENT ROOM	None	1	No	No
CC-164-121B	HVAC EMERGENCY EQUIP 3B	Fixed Water Spray-in filter housing only	1	No	No
CC-164-121C	HVAC EMERGENCY EQUIP 3A	Fixed Water Spray-in filter housing only	1	No	No
CC-164-121D	HVAC MAINTENANCE SHOP	None	1	No	No
CC-95-100	ELEVATOR	None	1	No	No
CC-95-101A	HEALTH PHYSICS/CHEM AREA	Pre-Action Sprinkler	0.05	Yes	No
CC-95-101B	CHEMISTRY LAB	Pre-Action Sprinkler	0.05	No	No
CC-95-101C	COUNT ROOM	Pre-Action Sprinkler	0.05	No	No
CC-95-122	STAIRWELL	None	1	No	No
FH-119-1	FIRE SERVICE PUMP HOUSE	Wet-Pipe Sprinkler	0.02	No	No
IB-119-201A	INDUSTRIAL COOLER ROOM	Wet-Pipe Sprinkler	0.02	Yes	No
IB-119-201B	PERSONNEL ACCESS AREA	Wet-Pipe Sprinkler	0.02	Yes	No
IB-95-200B	MOTOR DRIVEN EFW PUMP ROOM	Wet Pipe Sprinkler	0.02	Yes	No
IB-95-200C	TURB. EFW PUMP, PENET.	Wet Pipe Sprinkler	0.02	Yes	Yes

Table 4.2-1 (cont.)
CR-3 Fire Zone Automatic Suppression

Zone	Description	Automatic Suppression	NSP	TL-1hr	TL-3hr
	AREA, FAN ROOM				
RB-119-302	REACTOR BUILDING MEZZANINE FLOOR	None	1	Yes	No
RB-160-303	REFUELING FLOOR	None	1	No	No
RB-95-300	REACTOR & PRIMARY SYSTEM COMPARTMENT	None	1	No	No
RB-95-301	AREA OUTSIDE REACTOR COMPARTMENT	None	1	Yes	No
TB-119-400E	TURBINE BLDG MEZZANINE FLOOR	Wet-pipe Sprinkler	0.02	No	No
TB-119-401C	UNIT AUXILIARY TRANSFORMER AREA	Deluge System	0.05	No	No
TB-119-401D	BACKUP ES TRANSFORMER AREA	Delige System	0.05	No	No
TB-119-403	4160V SWITCHGEAR ROOM	None	1	No	No
TB-119-405A	COLD MACHINE SHOP	None	1	No	No
TB-119-405B	INSTRUMENT CALIBRATION LABORATORY	None	1	No	No
TB-119-410A	START UP TRANSFORMER AREA	Deluge System	0.05	No	No
TB-119-410B	MAIN TRANSFORMER AREA	Deluge System	0.05	No	No
TB-145-400F	TURBINE BUILDING OPERATING FLOOR	Local Fixed CO2 Auto & Manual Pull Stations	0.04	No	No
TB-95-400A	TURBINE BUILDING BASEMENT FLOOR	Wet-Pipe Sprinkler	0.02	No	No
TB-95-400B	RAD CHEM STORAGE AREA	Wet-pipe Sprinkler	0.02	No	No
TB-95-400C	SECONDARY SAMPLE ROOM	None	1	No	No
TB-95-400D	INSTRUMENT ROOM	None	1	No	No
TB-95-401	480V SWITCHGEAR ROOM	None	1	No	No
TB-95-402	NON 1E BATTERY CHARGER ROOM	Wet-pipe Sprinkler	0.02	No	No
TB-95-402A	NON 1E BATTERY ROOM	Wet-pipe Sprinkler	0.02	No	No

4.2.2 Manual Suppression

If automatic suppression is unsuccessful, then, depending on the individual fire characteristics, there may be time for manual suppression to limit the fire damage by either preventing hot gas layer formation, terminating the fire before protected circuits are lost, or preventing the fire from spreading to another compartment. For use in the CR-3 fire risk quantification, manual suppression time-reliability curves were used to determine the probability of failure of manual suppression.

Manual Suppression Time-Reliability Curves

In the EPRI Fire PRA methodology, the probability of manual suppression is based on fire events data from the EPRI FEDB as interpreted in NSAC-179L (Reference 4-9). The FEDB-based probabilities are applied based upon what is burning. Suppression curves for the ignition source are used unless another combustible (e.g., cable) becomes involved. Then, cable fire suppression is assumed to be the limiting factor once cable is ignited.

Manual suppression curves are available for the following ignition sources:

- Electrical cabinets (Figure 4.2-1)
- Pumps (Figure 4.2-2)
- Transients caused by welding (Figure 4.2-3)
- Transients caused by other ignition sources (Figure 4.2-4)
- Cable fires (Table 4.2-2)

The fire durations in Table 4.2-2 plot as a straight line on a semi-log plot of probability versus time. The resulting equation for probability of suppression versus time is:

$$P_{SC}(t_D) = 0.44 \log(t_D) + 0.12 \qquad \text{where } t_D \leq 100 \text{ minutes}$$

The equation calculates $P_{SD}(t_D)$ for $t_D \leq 100$ minutes. A plot of the equation is given in Figure 4.2-5. For $t_D > 100$ minutes, a $P_{SD}(t_D)$ of 0.01 is used. The equation is particularly interesting in that it implies that quick response to a cable tray fire may allow the fire to be suppressed quickly by portable extinguishers. More severe fires require more than portable extinguishers and will take longer to suppress.

Since credit was taken for manual suppression in the prevention of hot gas layer formation and not for prevention of an ignition source becoming a propagating fire, only the suppression table and equation for manual suppression of cable fires was used.

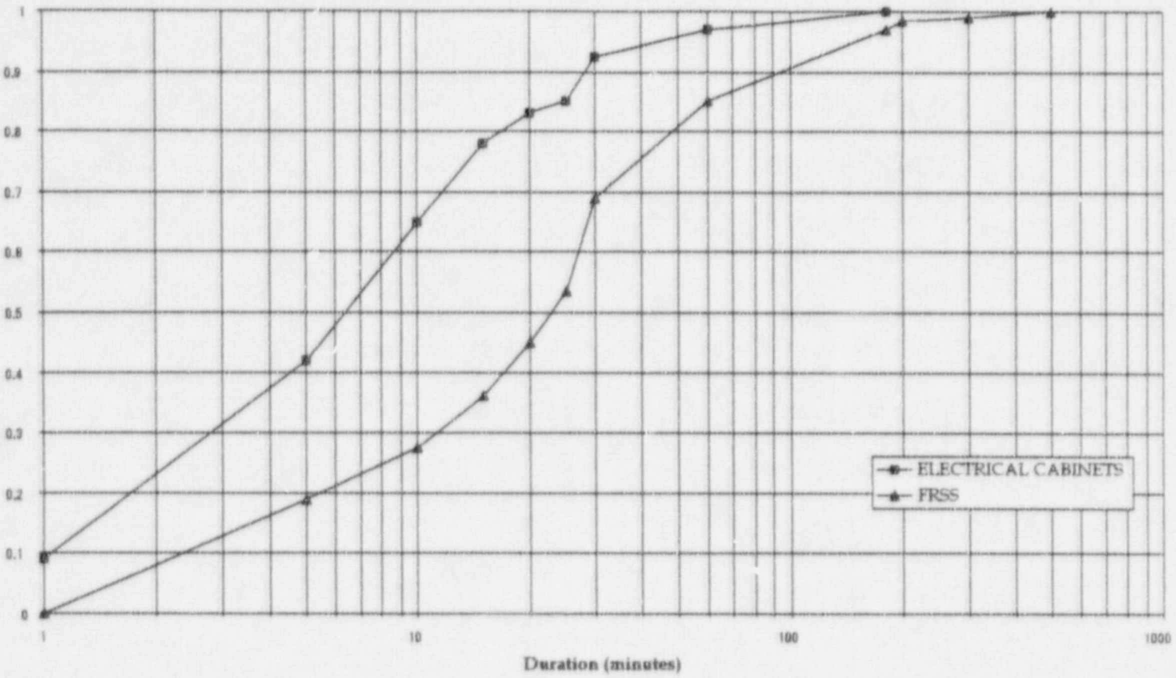


Figure 4.2-1. Cumulative Distribution for Fire Durations (Electrical Cabinets)

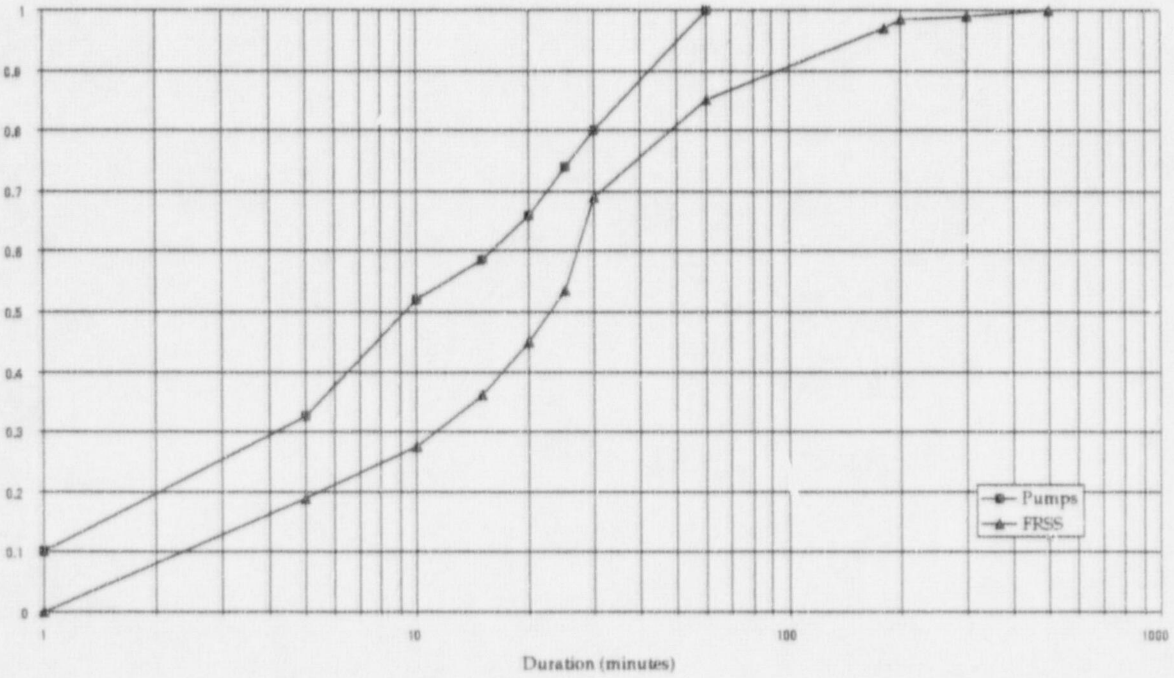


Figure 4.2-2. Cumulative Distribution for Fire Durations (Pumps)

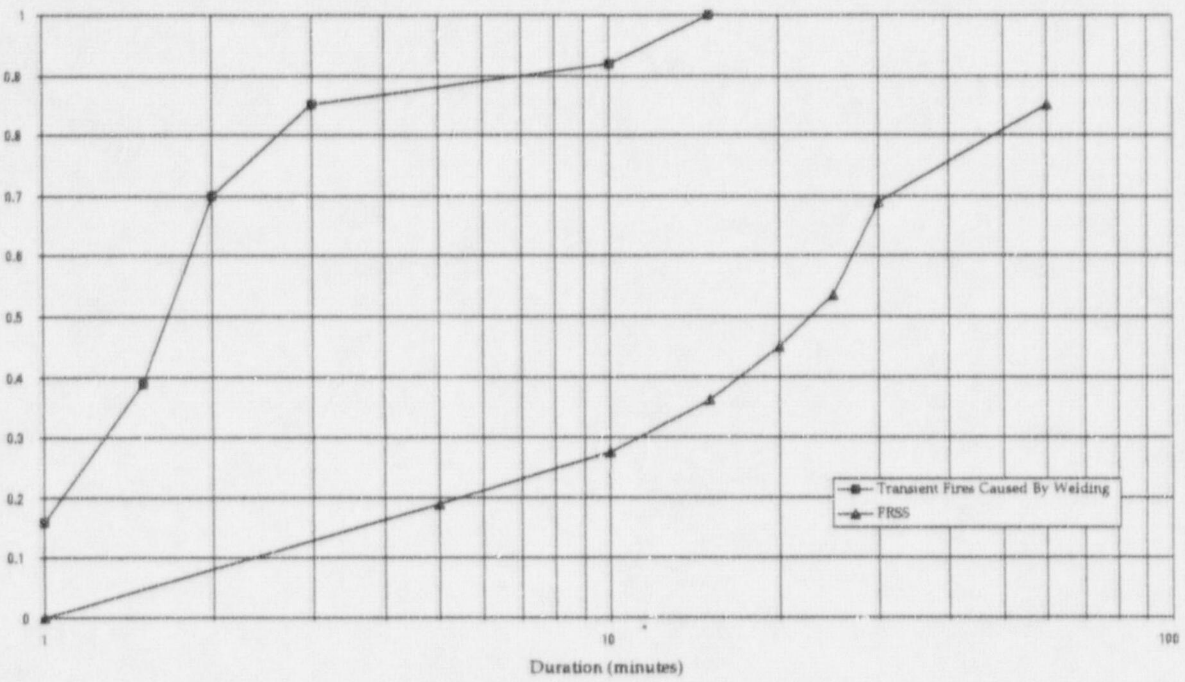


Figure 4.2-3. Cumulative Distribution for Fire Durations (Transient Fires Caused by Welding)

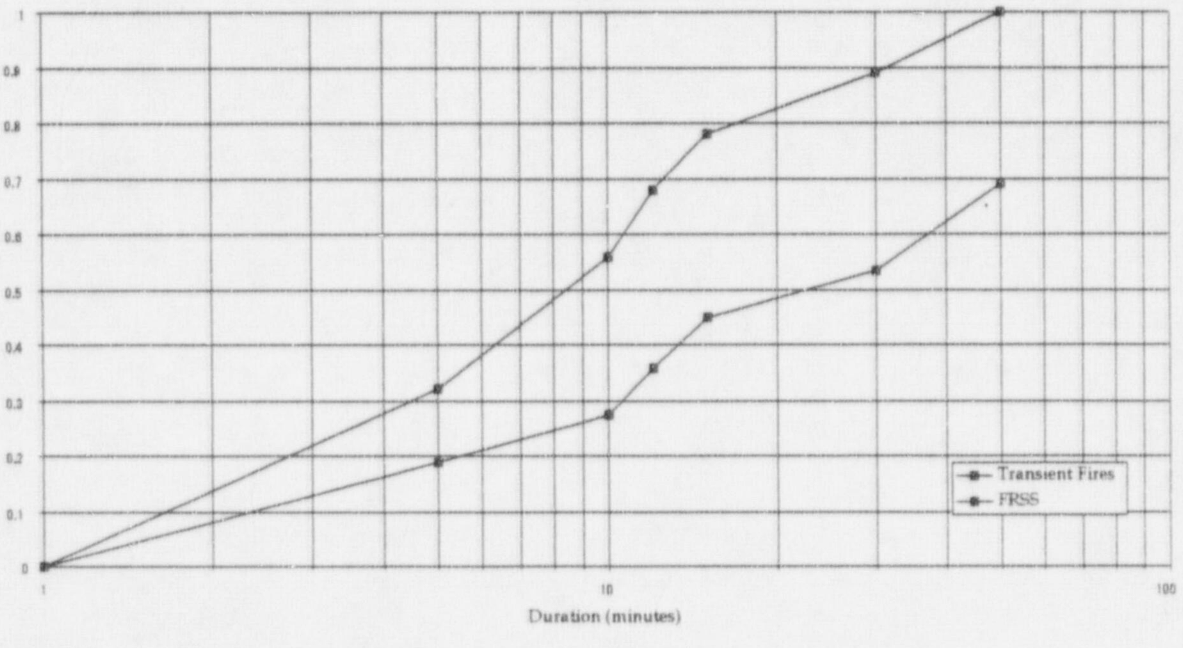


Figure 4.2-4. Cumulative Distribution for Fire Durations (Transient Fires Other than Welding Induced)

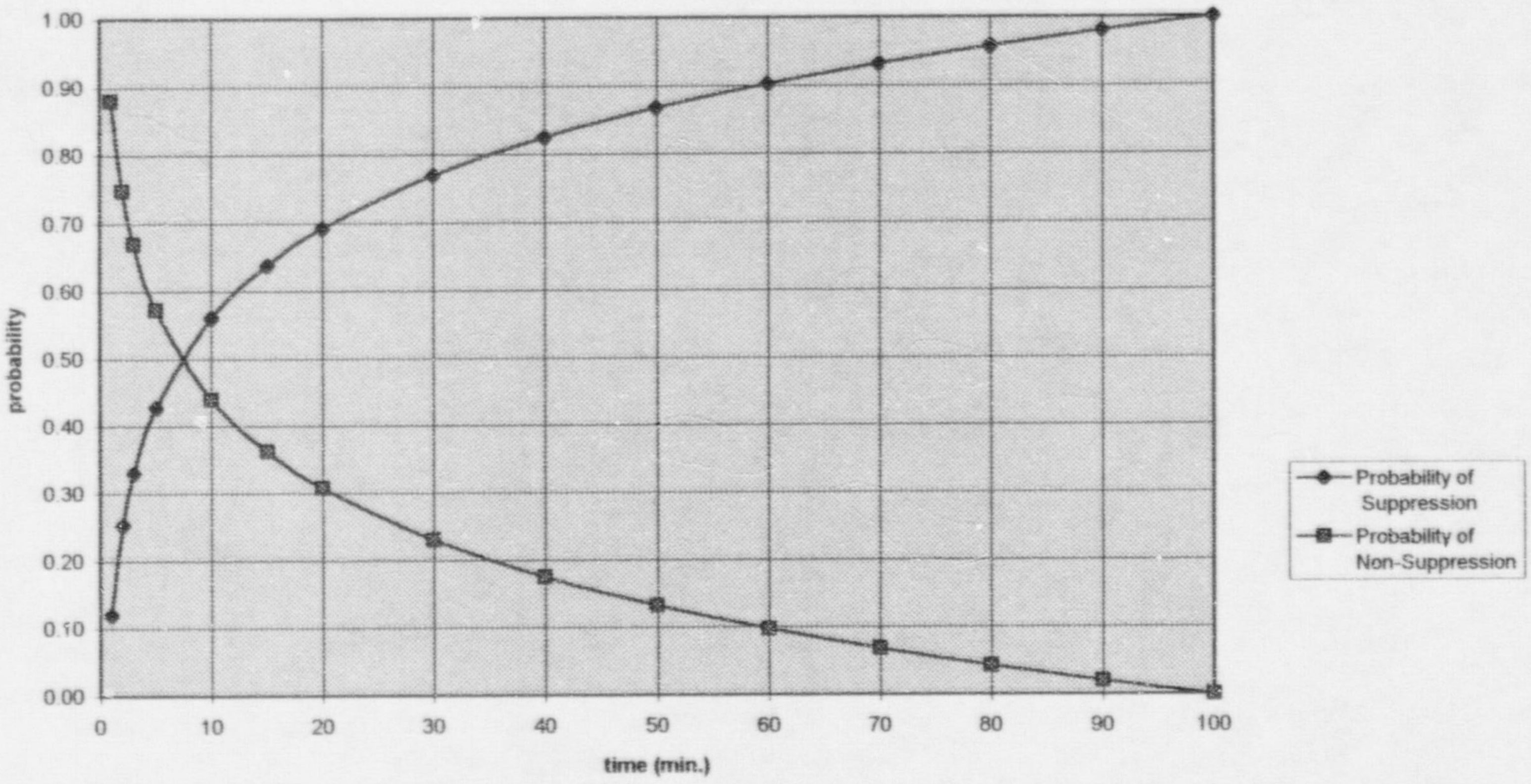


Figure 4.3-5 Manual Suppression Probability

Table 4.2-2
Cable Fire Suppression Data

Date	Fire Duration	Suppression Time	Means of Extinguishment
3/9/68	1:45	NA*	Portable extinguishers ineffective, fire department used outside hose streams
11/2/87	0:50	0:30	Portable extinguishers ineffective, hose streams used
7/16/72	0:30	NA	Self-extinguished after two trays burned five feet
11/27/84	0:15	NA	Portable extinguishers
2/1/81	0:10	0:10	Portable extinguishers
6/9/77	0:10	NA	No damage, no cable replacement required
9/7/83	0:02	0:02	Portable extinguishers
9/18/82	0:02	0:02	Portable extinguishers

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* NA = Not Available

4.3 Fault Tree Model

The CR-3 fire core damage risk fault tree model was created from the CR-3 PSA internal events fault tree model. All of the transient and transient-induced LOCA sequences were linked together to form a fire risk fault tree model with one core damage top event. All initiating events were removed from the fault tree since fire was now the only initiating event being considered. New offsite power basic events were added to the model to maintain the offsite power dependency lost due to the removal of the loss of offsite power initiating event.

Because post-accident human actions may be precluded by a fire or made less reliable due to the stress induced by it, all post-accident human error events are set to appropriate screening values (Table 4.3-1). In some cases, such as the first ten basic events in Table 4.3-1, the probability was set to 1.0. For those basic events which involved actions outside the control room which had to be performed within the first three hours of the fire initiating event, a screening probability of failure was used which was assumed to be the ten-minute point on the basic event's time-reliability curve (TRC). The path, expressed as a list of fire zones, that the operator would have to take in order to accomplish the human action was also determined. If the fire sequence involved a fire in any of the listed zones, the human action was disallowed, i.e., no credit for the action was given. If the human action involved operator actions in the control room only, then no such path was necessary. If the human action was not required until three or more hours had passed since the initiating fire, it was assumed that the fire was either extinguished or had burnt itself out; therefore, no screening value was used, no path set, and the failure probability was left unchanged.

Table 4.3-1
CR-3 Fire PSA Human Error Screening Values

Basic Event	Description	Probability	CR	Fire Screening Value	Comments
ASTE3ABY	Fail to transfer power to ES MCC 3AB.	0.1	Out	1	Set path.
ASTVB1AY	Fail to transfer power to VBDP-3 using VBXS-1A.	0.1	Out	1	Set path.
ASTVB1BY	Fail to transfer power to VBDP-4 using VBXS-1B.	0.1	Out	1	Set path.
ASTVB1CY	Fail to transfer power to VBDP-5 using VBXS-1C.	0.1	Out	1	Set path.
ASTVB1DY	Fail to transfer power to VBDP-6 using VBXS-1D.	0.1	Out	1	Set path.
ASTVB1EY	Fail to transfer power to VBDP-7 using VBXS-1E.	0.1	Out	1	Set path.
ASTVB3AY	Fail to transfer power to VBDP-8 using VBXS-3A.	0.1	Out	1	Set path.
ASTVB3BY	Fail to transfer power to VBDP-10 using VBXS-3B.	0.1	Out	1	Set path.
ASTVB3CY	Fail to transfer power to VBDP-9 using VBXS-3C.	0.1	Out	1	Set path.
ASTVB3DY	Fail to transfer power to VBDP-11 using VBXS-3D.	0.1	Out	1	Set path.
BFDWBH	Failure to provide flow to OTSG-B. PSA assumes main steam/feed line break is in OTSG-A.	0.0001	CR	0.163	
DBCSPREY	Failure to switch in spare battery charger in 8 hours.	0.001	Out	0.001	>3 hrs.
HO0130M	Failure to go to recirculation early or isolate open line to sump (30 min.).	0.0582	CR	0.238	
HO024H	Failure to switch power source to MUP-1B (>4 hrs.).	0.001	Out	0.001	>3 hrs.
HO043H	Failure to start RWP-2A (3 hrs.).	0.001	Out	0.001	>3 hrs.
HO0630M	Failure to close relevant MU pump recirculation valve (30 min.).	0.0155	Out	0.163	Set path.
HO093H	Failure to align MUP-1A cooling to DHCCC-A (3 hrs.).	0.001	Out	0.001	>3 hrs.
HO1050M	Failure to switch MUP-1B power source (50 min.).	0.0155	Out	0.163	Set path.
HO113H	Failure to align MUP-1C cooling to NSCCC (3 hrs.).	0.001	Out	0.001	>3 hrs
HO1530M	Failure to align MUP-1A/1B via MUV-62 to BWST and start (30 min.).	0.0155	CR	0.163	
HOPINJAY	Failure to switch power source to MUV-23/24 (30 min.)	0.001	Out	0.163	Set path.
HOPINJBY	Failure to switch power source to MUV-25/26 (30 min.)	0.001	Out	0.163	Set path.
HPMRCPTY	Failure to trip RCPs (no seal injection or cooling) in 30 min.).	0.01	CR	0.163	
JSECAIRY	Failure to switch to backup air for Aux Bldg dampers (30 min.).	0.00187	Out	0.163	Set path.
JXVCHPBY	Failure to open CHP-1B isolation valves (30 min.).	0.00187	Out	0.163	Set path.
LIDLPMIY	Failure to isolate failed DH train (30 min.).	0.0001	CR	0.0001	>3 hrs (HPR).
LO0130M	Failure to accomplish DHR crosstie (30 min.).	0.0155	CR	0.0155	>3 hrs (HPR).
LO023H	Failure to accomplish DHR crosstie (3 hrs.).	0.001	CR	0.001	>3 hrs (HPR).
PAFWH	Failure to start AFW (15 min.).	0.0158	Both	0.0425	Set path.
PRECMFWY	Failure to recover MFW (>3 hrs.)	0.001	CR	0.001	>3 hrs.
PTK0AFWY	Failure to switch AFW suction source (>10 hrs.)	0.001	Out	0.001	>3 hrs.
QHUCONTY	Failure to manually maintain OTSG level control.	0.002	CR	0.163	
QPMEFW1Z	Failure to restart EFP-1 after control reestablished.	0.001	CR	0.163	
QTKEFT2Y	Failure to switch EFW suction source (>10 hrs.).	0.001	Out	0.001	>3 hrs.
QTKEFT2Z	Failure to respond to EFT-2 low level alarms.	0.001	CR	0.001	>3 hrs.
QTPEFW2Z	Failure to restart EFP-2 after control reestablished.	0.001	CR	0.163	
RSVRC10Y	Failure to reclose PORV after HPI cooling.	0.001	CR	0.001	>3 hrs.
RSVRC10Z	Failure to open PORV for HPI cooling	0.001	CR	0.0425	
SPMSWPAY	Failure to start SWP-1A manually (>3 hrs.)	0.001	CR	0.001	>3 hrs.
SPMSWPBY	Failure to start SWP-1B manually (>3 hrs.)	0.001	CR	0.001	>3 hrs.
XHPR12H	Failure to go to high pressure recirculation (>12 hrs.).	0.001	CR	0.001	>3 hrs.

4.4 Data

The goal of the data effort was to provide sufficient data to support the preparation of inputs for the fire quantification. This included data to determine the appropriate ignition frequencies, and to allow the determination of plant damage, or unavailable equipment, due to fires for individual ignition sources. The data had to be applicable to a variety of scenarios involving the formation of hot gas layers, automatic and manual suppression availability, and the existence of Thermo-Lag fire protection. This effort was approached from two directions. First, each of the applicable basic events used in the CR-3 fault tree was related to a specific CR-3 component as defined in the CR-3 Configuration Management Information System (CMIS) database, and the circuits necessary for component operability were identified. Next, fire sources, targets, and the affected circuits were identified for each fire zone. Finally, the applicable fire damage was related to the CR-3 core damage fault tree.

Much of the plant information needed to perform the fire analysis was contained in existing documents and databases at CR-3. This information was in various formats and at various levels of detail. Information which was not previously documented was obtained by performing plant drawing reviews and walkdowns.

In order to manage the extensive amount of information, the data was compiled into a relational database using Microsoft Access. This database was an integral part of the fire core damage risk quantification described in Section 4.5 of this document. Table 4.4-1 is a summary description of this data. Details of all of the data tables used in the fire analysis are contained in Appendix A.

Table 4.4-1
CR-3 Fire PSA Base Data Summary

Table Name	Description	Field Descriptions
IGNF_GENERIC	Generic source ignition frequency data.	Generic ignition sources Generic plant locations Generic ignition frequencies Severity factors Total sources at CR-3
CIRCUIT	Circuit description and routing.	Circuits Routing through trays and conduits
CIRTAG	Circuit to tag relationships.	Circuits Dependent components
CONDCIR	Conduit-to-circuit relationships.	Circuits Conduits
CONDZONE	Conduit routing and Thermo-Lag protection.	Conduit Fire zones T-L Protection
TRAYCIR	Tray to circuit relationships.	Cable tray Coordinates Circuits at coordinates
TRAYZONE	Tray routing and Thermo-Lag protection.	Cable tray Coordinates Fire zone at coordinates T-L protection at coordinates Coordinate location data
ZONE	Fire Zone data	Fire zone Generic plant location Detection available Automatic suppression Auto non-suppression probability Manual suppression available T-L requirements
BETAG	Basic event to component relationships.	Basic event name Module name Component ID
TAG	Component data	Component ID Component type Fire zone
SOURCE	Ignition source data.	Component ID Source type Fire zone HGL times
SOURCE_TARGET	Ignition source-Fire Target relationships.	Component ID Tray and conduit targets

4.4.1 Fire Zones

The CR-3 Appendix R Fire Study (Reference 4-10) was used as a basis for defining fire zones. A fire zone is a well-defined, enclosed room, not necessarily having fire barriers. Fire zones are bounded by non-combustible barriers where heat and products of combustion from a fire within the enclosure will be substantially confined. Fire barriers may have open equipment hatches, ladder ways, doorways, or unsealed penetrations.

Containment fires were excluded for evaluation because of the infrequent number of fires in containment at power, the finding by previous fire PSAs that such fires were not risk-significant, and the low likelihood that a fire in containment could affect redundant trains.

Each zone was assigned a "zone type" which could be related to a FEDB (Reference 4-6) location classification to allow ignition frequency determination as described in Section 4.4.3. The fire zone information is contained in the ZONE database table. Table 4.4-2 lists each of the CR-3 fire zones and the corresponding "zone type" classification.

4.4.2 Fire Ignition Sources

In general, the ignition sources at CR-3 were identified using the methods described in Appendix C. This approach is identical to the EPRI FIVE methodology.

Two separate walkdowns were conducted to identify the ignition sources. The first walkdown was primarily concerned with counting the ignition sources in each fire zone. In order to use these counts to calculate ignition frequencies, the sources were sub-totaled by the generic source types and locations as described in the FEDB (Reference 4-6). The walkdown team consisted of two fire protection engineers. The results of this walkdown are documented in the IGNF_GENERIC database table and are shown in Table 4.4-2. A second, more detailed, walkdown was conducted by a PSA Engineer, proficient in fire modeling, to identify those sources which have the potential to propagate and cause damage external to the source itself. As before, each source was related to a generic source type. In addition to documenting information on the source itself, a list of potential damage targets were identified for each source. These targets consisted of cable trays, conduits, and/or intervening combustibles located near the ignition source. The information gathered in this walkdown formed the basis for the fire modeling analysis described earlier in Section 4.1.

In order to account for transient ignition sources, each zone was assigned one or more transient sources identified as "TRANS-###-x," where "###" represents the appropriate zone and "x" is used to distinguish between multiple transient sources in a given zone.

The results of this effort are documented in the SOURCE and SOURCE_TARGET database tables.

Table 4.4-2
CR-3 Ignition Source Types and Locations

IGNITION SOURCE TYPE	ZONE CLASSIFICATION	FEDB LOCATION	CR-3 SOURCE COUNT BY FEDB LOCATION
AIR COMPRESSOR	AUX. BLDG	PLANT	14
AIR COMPRESSOR	DIESEL GENERATOR ROOM	PLANT	14
AIR COMPRESSOR	TURBINE BLDG	PLANT	14
BATTERY	BATTERY ROOM	BATTERY ROOM	3
BATTERY CHARGER	CONTROL COMPLEX	PLANT	9
BATTERY CHARGER	TURBINE BLDG	PLANT	9
DIESEL GENERATOR	DIESEL GENERATOR ROOM	DIESEL GENERATOR ROOM	2
DRYER	AUX. BLDG	PLANT	2
ELECTRICAL CABINET	AUX. BLDG	AUX. BLDG	848
ELECTRICAL CABINET	CONTROL COMPLEX	AUX. BLDG	848
ELECTRICAL CABINET	CONTROL ROOM	AUX. BLDG	848
ELECTRICAL CABINET	DIESEL GENERATOR ROOM	DIESEL GENERATOR ROOM	4
ELECTRICAL CABINET	INTERMEDIATE BLDG	AUX. BLDG	848
ELECTRICAL CABINET	SWITCHGEAR ROOM	SWITCHGEAR ROOM	250
ELECTRICAL CABINET	TURBINE BLDG	TURBINE BLDG	275
FIRE SERVICE PUMP	AUX. BLDG	PLANT	26
FIRE SERVICE PUMP	CONTROL COMPLEX	PLANT	26
FIRE SERVICE PUMP	INTERMEDIATE BLDG	PLANT	26
FIRE SERVICE PUMP	TURBINE BLDG	PLANT	26
MAIN FEEDWATER PUMP	TURBINE BLDG	TURBINE BLDG	2
OTHER PUMP	AUX. BLDG	AUX. BLDG	73
OTHER PUMP	INTERMEDIATE BLDG	AUX. BLDG	73
OTHER PUMP	TURBINE BLDG	TURBINE BLDG	26
TRANSIENT	AUX. BLDG	PLANT	112
TRANSIENT	BATTERY ROOM	PLANT	112
TRANSIENT	CONTROL COMPLEX	PLANT	112
TRANSIENT	CONTROL ROOM	PLANT	112
TRANSIENT	DIESEL GENERATOR ROOM	PLANT	112
TRANSIENT	FIRE SERVICE BLDG	PLANT	112
TRANSIENT	INTERMEDIATE BLDG	PLANT	112
TRANSIENT	SWITCHGEAR ROOM	PLANT	112
TRANSIENT	TURBINE BLDG	PLANT	112
VENTILATION SUBSYSTEM	AUX. BLDG	PLANT	41
VENTILATION SUBSYSTEM	CONTROL COMPLEX	PLANT	41
VENTILATION SUBSYSTEM	INTERMEDIATE BLDG	PLANT	41
VENTILATION SUBSYSTEM	SWITCHGEAR ROOM	PLANT	41
VENTILATION SUBSYSTEM	TURBINE BLDG	PLANT	41
TRANSFORMER	AUX. BLDG	PLANT	66
TRANSFORMER	CONTROL COMPLEX	PLANT	66
TRANSFORMER	INTERMEDIATE BLDG	PLANT	66
TRANSFORMER	SWITCHGEAR ROOM	PLANT	66
TRANSFORMER	TURBINE BLDG	PLANT	66

4.4.3 Fire Ignition Source Frequencies

The plant fire frequencies were generated by using the generic fire frequencies developed in the FEDB (Reference 4-6) and listed in Table 4.4-3. Database table IGNF_GENERIC relates the FEDB information to the CR-3 zone classifications and ignition source types described above.

The generic fire frequencies were modified for use in the fire PSA by applying severity factors to certain types of ignition sources. The severity factors were used to account for the number of non-propagating fires counted in the Fire Events Database (FEDB). Most severity factors are in the range of 0.1. The ignition frequencies given in the EPRI Fire Events Database are derived from fires recorded at U.S. nuclear power plants between 1965 and 1988. These fires range from very minor (smell, no fire observed with no effect) to those which cause considerable damage. Fire modeling, both in the FIVE and Fire PRA methodologies, presumes a fully developed fire with peak heat release rate at the inception of the fire. Obviously not all incipient fires become fully-developed as is demonstrated by the fire events database. A detailed evaluation of the operating experience used to generate the fire ignition frequencies was done to develop fire severity factors for key ignition sources. A fire severity factor is defined as the fraction of the incipient fires that result in a fully-developed fire. The approach used to derive these fire severity factors is documented in Appendix D.

Table 4.4-3
FEDB Generic Ignition Sources and Frequencies by Applicable Plant Location

Plant Location	Fire Ignition Source Type	Fire Frequency
Auxiliary Building (PWR)	Electrical cabinets	$1.9\text{x}10^{-2}$
	Pumps	$1.9\text{x}10^{-2}$
Diesel Generator Room	Diesel generators	$2.6\text{x}10^{-2}$
	Electrical cabinets	$2.4\text{x}10^{-3}$
Switchgear Room	Electrical cabinets	$1.5\text{x}10^{-2}$
Battery Room	Batteries	$3.2\text{x}10^{-3}$
Control Room	Electrical cabinets	$9.5\text{x}10^{-3}$
Cable Spreading Room	Electrical cabinets	$3.2\text{x}10^{-3}$
Intake Structure	Electrical cabinets	$2.4\text{x}10^{-3}$
	Fire Pumps	$4.0\text{x}10^{-3}$
	Others	$3.2\text{x}10^{-3}$
Turbine Building	T/G Excitor	$4.0\text{x}10^{-3}$
	T/G Oil	$1.3\text{x}10^{-2}$
	T/G Hydrogen	$5.5\text{x}10^{-3}$
	Electrical cabinets	$1.3\text{x}10^{-2}$
	Other pumps	$6.3\text{x}10^{-3}$
	Main feedwater pumps	$4.0\text{x}10^{-3}$
	Boiler	$1.6\text{x}10^{-3}$
Radwaste Area	Miscellaneous components	$8.7\text{x}10^{-3}$
Transformer Yard	Yard transformers (propagating to Turbine Building)	$4.0\text{x}10^{-3}$
	Yard transformers (LOSP)	$1.6\text{x}10^{-3}$
	Yard transformers (Others)	$1.5\text{x}10^{-2}$
Plant-Wide Components	Fire protection panels	$2.4\text{x}10^{-3}$
	RPS MG sets	$5.5\text{x}10^{-3}$
	Non-qualified cable run	$6.3\text{x}10^{-3}$
	Junction box/splice in non-qualified cable	$1.6\text{x}10^{-3}$
	Junction box in qualified cable	$1.6\text{x}10^{-3}$
	Transformers	$7.9\text{x}10^{-3}$
	Battery Chargers	$4.0\text{x}10^{-3}$
	Off-gas/H_2 Recombiner (BWR)	$8.6\text{x}10^{-2}$
	Hydrogen Tanks	$3.2\text{x}10^{-3}$
	Misc. Hydrogen Fires	$3.2\text{x}10^{-3}$
	Gas Turbines	$3.1\text{x}10^{-2}$
	Air Compressors	$4.7\text{x}10^{-3}$
	Ventilation Subsystems	$9.5\text{x}10^{-3}$
	Elevator motors	$6.3\text{x}10^{-3}$
	Dryers	$8.7\text{x}10^{-3}$
	Transients	$1.3\text{x}10^{-3}$
	Cable fires caused by welding	$5.1\text{x}10^{-3}$
	Transient fires caused by welding and cutting	$3.1\text{x}10^{-2}$

With the exception of transients, the individual source ignition frequencies were calculated by dividing the generic fire frequency by the corresponding number of ignition sources at CR-3 and applying the severity factor.

$$IGF_{source} = (IGF_{generic} / SOURCES_{fedb\ location}) * (SEVERITY\ FACTOR)$$

The transient source ignition frequencies calculations were more complicated. First, administrative controls (AI-2210 and CP-118) do not permit welding and cutting activities during power operation without extensive review and preparation. This includes surveys to assure combustible materials are removed or protected, and fire watches implemented during the work. Therefore, a severity factor of 0.1 was applied to the welding contribution to the total transient ignition frequency. An additional weighting factor of six was applied to all other transient sources to account for the use of extension cords and potential overheating of transient combustibles. For several zones, more than one location for transient combustibles was postulated. For these zones, the ignition frequency was divided equally among the locations.

Therefore:

$$IGF_{zone\ welding} = (IGF_{generic\ welding}) * (SEVERITY\ FACTOR) = 3.1\times10^{-2} * 0.1 = 3.1\times10^{-3}$$

$$IGF_{zone\ others} = (IGF_{generic\ trans} * WEIGHTING\ FACTOR) = 1.3\times10^{-3} * 6 = 7.8\times10^{-3}$$

If welding is allowed in the zone, then:

$$IGF_{trans\ source} = ((IGF_{zone\ welding} + IGF_{zone\ others}) / \#ZONES) / \#LOCATIONS_{zone}$$

$$= ((3.1\times10^{-3} + 7.8\times10^{-3}) / 112) / \#LOCATIONS_{zone} = 9.73\times10^{-5} / \#LOCATIONS_{zone}$$

Without welding:

$$IGF_{trans\ source} = (IGF_{zone\ others} / \#ZONES) / \#LOCATIONS_{zone}$$

$$= (7.8\times10^{-3} / 112) / \#LOCATIONS_{zone} = (6.96\times10^{-5}) / \#LOCATIONS_{zone}$$

The results of this calculation for each source is contained in the database query IGNF_SOURCE.

The zone ignition frequencies were calculated by summing the ignition frequencies for each individual ignition source within the zone. These results are contained in the database query IGNF_ZONE and listed in Table 4.4-4.

Table 4.4-4
Fire Zone Ignition Frequencies

Zone	Description	Ignition Frequency
AB-119-12	HOT MACHINE SHOP	9.73E-05
AB-119-6A	NORTH HALLWAY	9.73E-05
AB-119-6B	STAIRWELL AREA	1.16E-04
AB-119-6C	SPENT FUEL COOLANT PUMP ROOM	9.73E-05
AB-119-6E	EAST HALLWAY	1.73E-04
AB-119-6F	MAKE-UP & PURIF. DEMIN. & FILTERS	9.73E-05
AB-119-6G	HALLWAY	9.73E-05
AB-119-6H	SEAL RETURN COOLERS & MAKE-UP TANK	9.73E-05
AB-119-6J	CENTRAL HALLWAY	2.36E-04
AB-119-6K	DECONTAMINATION ROOM	1.02E-04
AB-119-6L	RADIOACTIVE WASTE PRESS ROOM	9.73E-05
AB-119-6M	WASTE DRUMMING AREA	9.73E-05
AB-119-6N	DEBORATING DEMINERALIZER ROOM	9.73E-05
AB-119-6P	DEMINERALIZER ROOM	9.73E-05
AB-119-6Q	HALLWAY	1.23E-04
AB-119-6R	MAKE-UP & PURIF. PRE-FILTER ROOM	9.73E-05
AB-119-6S	HALLWAY	9.73E-05
AB-119-6T	PURIFICATION FILTERS & RESIN TRAPS	9.73E-05
AB-119-6V	STAIRWELL AREA	9.73E-05
AB-119-7A	EMERGENCY DIESEL GENERATOR CONTROL ROOM 3B	1.73E-04
AB-119-7B	EMERGENCY DIESEL GENERATOR ROOM 3B	5.30E-03
AB-119-8A	EMERGENCY DIESEL GENERATOR CONTROL ROOM 3A	1.02E-04
AB-119-8B	EMERGENCY DIESEL GENERATOR ROOM 3A	5.30E-03
AB-138-6W	CONDUIT/PIPE CHASE	9.73E-05
AB-143-6AA	CHEMICAL MIXING AND CENTRAL AREA	1.85E-04
AB-143-6AB	PENETRATION AREA	1.15E-04
AB-143-6AC	MAIN EXHAUST FILTER ROOM	1.15E-04
AB-143-6X	STAIRWELL AND SPENT FUEL COOLER ROOM	9.73E-05
AB-143-6Y	SPENT FUEL COOLER ROOM	9.73E-05
AB-143-6Z	EAST HALLWAY	9.73E-05
AB-162-6AD	FUEL HANDLING FLOOR	1.44E-04
AB-75-10	TENDON GALLERY	2.01E-04
AB-75-4	DECAY HEAT PIT 3B	2.01E-04
AB-75-5	DECAY HEAT PIT 3A	2.01E-04
AB-95-2	ELEVATOR	9.73E-05
AB-95-3AA	MAKE-UP PUMP ROOM 3B	1.49E-04
AB-95-3B	NORTH HALLWAY & NUCLEAR SAMPLE ROOM	1.99E-04
AB-95-3C	WEST HALLWAY	1.06E-04
AB-95-3D	HALLWAY	9.73E-05
AB-95-3E	MAKE-UP PUMP ROOM 3A	1.49E-04
AB-95-3F	MAKE-UP PUMP ROOM 3C	1.49E-04
AB-95-3G	CENTRAL HALLWAY	3.27E-04
AB-95-3H	NEUTRALIZER ROOM	1.49E-04
AB-95-3J	EAST HALLWAY	9.73E-05
AB-95-3K	MISC. RAD WASTE ROOMS & HALLWAY	9.73E-05
AB-95-3L	WASTE EVAPORATOR	2.01E-04
AB-95-3M	WASTE EVAPORATOR ROOM	9.73E-05
AB-95-3N	REACTOR COOLANT EVAPORATOR ROOM	9.73E-05
AB-95-3P	WASTE & RECYCLE PUMP ROOMS	3.06E-04
AB-95-3Q	CONCENTRATE TANK ROOM	9.73E-05
AB-95-3R	WASTE GAS ROOMS	2.18E-04
AB-95-3S	WASTE GAS DECAY TANK ROOM	9.73E-05
AB-95-3T	REACTOR COOLANT BLEED TANK ROOM	9.73E-05
AB-95-3U	DECANT AND SLURRY PUMP ROOM	9.73E-05
AB-95-3V	SPENT RESIN STORAGE TANK ROOM	9.73E-05

Table 4.4-4 (cont.)
Fire Zone Ignition Frequencies

Zone	Description	Ignition Frequency
AB-95-3W	WASTE TRANSFER PUMP ROOMS	2.53E-04
AB-95-3X	NUCLEAR SERVICE BOOSTER PUMP ROOM	2.53E-04
AB-95-3Y	RCP SEAL INJECTION FILTER ROOM (TRIANGLE ROOM)	1.02E-04
AB-95-3Z	RWSW PUMP ROOM	3.24E-04
CC-108-102	HALLWAY AND REMOTE SHUTDOWN ROOM	1.20E-04
CC-108-103	PLANT BATTERY ROOM 3B	9.73E-05
CC-108-104	PLANT BATTERY ROOM 3A	9.73E-05
CC-108-105	BATTERY CHARGER ROOM 3B	4.03E-04
CC-108-106	BATTERY CHARGER ROOM 3A	3.68E-04
CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	2.27E-04
CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.60E-04
CC-108-109	INVERTER ROOM 3B	2.14E-04
CC-108-110	INVERTER ROOM 3A	1.90E-04
CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.06E-04
CC-124-112	EFIC ROOM "A"	1.23E-04
CC-124-113	EFIC ROOM "C"	1.15E-04
CC-124-114	EFIC ROOM "D"	1.23E-04
CC-124-115	EFIC ROOM "B"	1.47E-04
CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	1.90E-04
CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	2.04E-04
CC-134-118A	CABLE SPREADING ROOM	9.73E-05
CC-145-118B	CONTROL ROOM	1.24E-04
CC-145-119	OPERATORS AREA	9.73E-05
CC-164-121A	HVAC EQUIPMENT ROOM	9.73E-05
CC-164-121B	HVAC EMERGENCY EQUIP 3B	9.73E-05
CC-164-121C	HVAC EMERGENCY EQUIP 3A	9.73E-05
CC-164-121D	HVAC MAINTENANCE SHOP	9.73E-05
CC-95-100	ELEVATOR	9.73E-05
CC-95-101A	HEALTH PHYSICS/CHEM AREA	9.73E-05
CC-95-101B	CHEMISTRY LAB	9.73E-05
CC-95-101C	COUNT ROOM	9.73E-05
CC-95-122	STAIRWELL	9.73E-05
FH-119-1	FIRE SERVICE PUMP HOUSE	9.73E-05
IB-119-201A	INDUSTRIAL COOLER ROOM	2.62E-04
IB-119-201B	PERSONNEL ACCESS AREA	1.20E-04
IB-95-200B	MOTOR DRIVEN EFW PUMP ROOM	9.73E-05
IB-95-200C	TURB. EFW PUMP, PENET. AREA, FAN ROOM	1.34E-04
TB-119-400E	TURBINE BLDG MEZZANINE FLOOR	6.15E-04
TB-119-401C	UNIT AUXILIARY TRANSFORMER AREA	9.73E-05
TB-119-401D	BACKUP ES TRANSFORMER AREA	9.73E-05
TB-119-403	4160V SWITCHGEAR ROOM	4.07E-04
TB-119-405A	COLD MACHINE SHOP	1.47E-04
TB-119-405B	INSTRUMENT CALIBRATION LABORATORY	9.73E-05
TB-119-410A	START UP TRANSFORMER AREA	9.73E-05
TB-119-410B	MAIN TRANSFORMER AREA	9.73E-05
TB-145-400F	TURBINE BUILDING OPERATING FLOOR	9.73E-05
TB-95-400A	TURBINE BUILDING BASEMENT FLOOR	6.73E-04
TB-95-400B	RAD CHEM STORAGE AREA	9.73E-05
TB-95-400C	SECONDARY SAMPLE ROOM	1.16E-04
TB-95-400D	INSTRUMENT ROOM	9.73E-05
TB-95-401	480V SWITCHGEAR ROOM	4.50E-04
TB-95-402	NON 1E BATTERY CHARGER ROOM	4.11E-04
TB-95-402A	NON 1E BATTERY ROOM	5.24E-04

4.4.4 Plant Equipment and Components

Identification of plant equipment and components relevant to the CR-3 fire PSA was determined from two sources. Components which were identified as ignition sources were documented in the SOURCE table, which includes the necessary location information for relating fire damage as developed in the walkdown. Components which are modeled as basic events in the CR-3 fault tree are documented in the BETAG and TAG database tables. Location information in the TAG table for these components was developed by reviewing the Configuration Management Information System (CMIS) and plant drawings. BETAG links the fault tree basic events to component tag numbers. For some basic event types in the fault tree model, equipment tag numbers are not applicable. Typically, these basic events include test and maintenance unavailabilities, pre- and post-accident human errors, and common-cause failures. Maintenance unavailability events and pre-accident human errors occur before the fire, and therefore no tag number is needed for these basic events.

4.4.5 Electrical Circuits

Each of the components modeled in the CR-3 fault tree has the potential to affect core damage risk if it is rendered inoperable due to a fire. This can be due to actual equipment damage, or the damage of the electrical circuits which provide power or control to the equipment.

Relevant electrical circuits for many of the components were available in the Appendix R Fire Study (Reference 4-10). Circuits for the remainder of the components were identified by FPC electrical engineering staff, via review of plant drawings. The engineers were instructed not to distinguish between "hot shorts" and "burn-throughs." Either failure mode was to be included in the database as a failure of the relevant component. All circuits included in the database are assumed to cause equipment unavailability if they are damaged. This is a conservative assumption since many circuits will not cause the component to fail to perform its intended function, e.g., loss of power to a normally-open motor-operated valve whose failure mode was "transfer closed." All of these circuit-to-tag relationships are documented in the CIRTAG Access table.

4.4.6 Circuit Routing

The electrical engineering department at CR-3 uses a computerized application to perform cable tray loading analysis. The application is called CKS and includes detailed cable tray and circuit routing information. The electrical engineering group correlated the physical location coordinates of the cable trays to plant fire zones. This data is documented in the TRAYZONE table of the fire database. The CKS data also identifies all of the circuits at all coordinates of the trays. This is documented in database table TRAYCIR. Using these tables, it is possible to identify all circuits which are routed through a cable tray in any fire zone.

For circuits which are contained in conduits, a different approach was used. The CKS data provides individual circuit routing information in terms of the trays and conduits through which the circuits are routed. This data was included in the database in the CIRCUIT table. Using this data, the conduits were identified which contained circuits which could affect components modeled in the CR-3 fault tree (CONDCIR database table). Zone routing for these conduits was performed manually by members of the CR-3 electrical engineering department. The results of this effort are documented in the CONDZONE database table. By using both of these tables, it is possible to identify all relevant circuits which are routed through a conduit in any fire zone.

Section 4.5 discusses the procedures used to identify all of the circuits applicable to whole zone or individual ignition source fires.

4.4.7 Thermo-Lag

During the initial Appendix R project at CR-3, many circuits were protected by using a fire wrap know as Thermo-Lag. Subsequent testing has shown Thermo-Lag to be less effective than originally reported by the manufacturer, and FPC is currently re-evaluating its extensive use of this material. For the purposes of the IPEEE, the Appendix-R-installed Thermo-Lag configurations are being analyzed using conservative values for their effectiveness. For the Thermo-Lag configurations designed to protect the circuits for one hour, a protection time of 20 minutes was assumed. For the Thermo-Lag configurations designed to protect the circuits for three hours, a protection time of one hour was assumed. These conservative protection times were based on generic worst-case tests of the Thermo-Lag material. At CR-3, for most of the Thermo-Lag installations, the thickness of the application was greater than standard, the joints were pre- and post-buttered, and extra trowel-grade material was applied. Therefore, the abbreviated protection times assumed for the Thermo-Lag installed at CR-3 are even more conservative than they would be for a standard application.

The circuits which are protected with Thermo-Lag are identified in the CR-3 Appendix R Fire Study (ZONECIRfha database table). This information has been added to the conduit and tray routing information and is documented in the TRAYZONE and CONDZONE database tables.

4.5 Quantification of Fire Risk

4.5.1 Description

The quantification process for the CR-3 fire risk analysis was progressive. First, before the actual quantification began, the quantification tools and data were used to conduct a data verification. Much effort was involved in assembling all of the data contained in the Access relational database. The records numbered in the hundreds of thousands. As discussed in Section 4.4, some of the data was directly transferable from other pre-existing databases which required little or no modification. The majority, however, required considerable effort to either modify or update to reflect plant changes since their last use, and some had to be generated from scratch. This being the case, verification of the databases before their use in quantifying core damage risk due to fire was necessary. Verification was done at the "zone" level of quantification.

Verification of the databases consisted of an iterative technique using the FRANC quantification code. FRANC (Fire Risk ANalysis Code, Reference 4-11) was developed by SAIC as a part of EPRI's Risk and Reliability Workstation project. FRANC's primary function is to quantify the various plant fire scenarios. FRANC was used to determine the availability of Appendix R safe shutdown trains using files generated from queries of the relational database tables described in Section 4.4. Using FRANC with full credit given for Thermo-Lag protection, reflecting the assumptions of the Appendix R Fire Study, the status of the shutdown trains, as calculated by FRANC, should reproduce the safe shutdown status described in the Appendix R Fire Study. Differences in the results were traced back to determine if their source was due to an error in the database, credit for manual actions not modeled in the PSA model, or conservatisms in the PSA model. After many iterations and database modifications, the FRANC results for the fire zones reflected the Appendix R analysis, with the exception of some differences due to lack of credit for manual actions or model conservatism. This verification was an extensive process, with the net result being a relational database capable of generating reliable and meaningful fire risk results.

The first quantification was, like the data verification, at the "zone" level. Core damage frequencies due to fire were calculated for each fire zone. Those zones with a core damage frequency less than 1×10^{-6} per year were screened. Details of these calculations are discussed in Section 4.5.4.

The next, and final, set of calculations was performed at the "source" level. Ignition sources residing in the unscreened zones were quantified to determine their conditional core damage probabilities (CCDPs). Multiple scenarios were developed for each ignition source calculation to take into account all possible suppression sequences. Severity factors and ignition frequencies were factored in to calculate the core damage frequency associated with each ignition source. Details of these calculations are discussed in Section 4.5.5.

Control room and cable spreading room fires were treated separately in order to properly take into account the effect of control room evacuation and manning of the remote shutdown panel. Details of these calculations are discussed in Section 4.5.6.

Finally, fire risk associated with multi-compartment fires was evaluated. Details of these calculations are discussed in Section 4.5.7.

4.5.2 FRANC Input Preparation

In order for FRANC to perform the CCDP calculations, the relevant data must be provided in the proper format. FRANC inputs consist of a combination of Access and dBASE database tables. Table 4.5-1 lists the data tables which were developed to provide the fire damage-to-component relationships to FRANC.

Table 4.5-1
Data Tables Created for FRANC

Database Table	Description	Origin
ZONEA.DBF	Zone - Unavailable Components, relationships (HGL, no Thermo-Lag credit).	ACCESS queries (francZONEA_#)
ZONEB.DBF	Zone - Unavailable Components, relationships (HGL, with TL credited).	ACCESS queries (francZONEB_#)
SOURCEA.DBF	Ignition Source - Unavailable Components, relationships (no HGL, no Thermo-Lag credit).	ACCESS queries (francSOURCEA_#)
SOURCEB.DBF	Ignition Source - Unavailable Components, relationships (no HGL, with Thermo-Lag credited).	ACCESS queries (francSOURCEB_#)
SOURCEC.DBF	Ignition Source - Unavailable Component, relationships (HGL, with Thermo-Lag credited except at source).	ACCESS queries (francSOURCEC_#)
TAGBE.DBF	Component - Basic Event relationship.	ACCESS queries (francBETAG_0)
ZONESCENARIOS	ACCESS table listing each specific Zone scenario to be evaluated by FRANC.	ACCESS queries (francZONESCANARIOS_#)
SOURCESCENARIOS	ACCESS table listing each specific Ignition Source scenario to be evaluated by FRANC.	ACCESS queries (francSOURCESCANARIOS_#)

The ZONESCENARIOS and SOURCESCENARIOS tables are used by FRANC to define the specific inputs and record the results of the zone and source quantifications, respectively. Detailed information about the Access queries which created these tables can be found in Appendix A. The use of these databases in the quantifications is discussed below.

Zone Scenarios

Two scenarios were evaluated for each zone. Scenario A assumes a hot gas layer (HGL) forms within the zone which damages all equipment and circuits in that zone. In order to define the appropriate list of unavailable equipment, a series of Access queries was developed. These queries identify the cable trays and conduits which are routed through the zone, the circuits contained in the trays and conduits, and the components which could be disabled due to the circuits failing. The resulting table, ZONEA.DBF, relates all of the relevant components which could fail to the zone in question.

Scenario B assumes a hot gas layer (HGL) forms within the zone damaging all equipment and circuits in that zone, except those protected by Thermo-Lag. Queries similar to those described above for Scenario 'A' were used, except that cable trays and conduits protected by Thermo-Lag were not included. The resulting table, ZONEB.DBF, relates all of the relevant components which could fail to the zone in question.

TAGBE.DBF was used to relate the component tag numbers to their respective basic events in the fire core damage risk fault tree model.

Source Scenarios

Three scenarios were evaluated for each ignition source identified for the zones which passed the initial screening. Scenario A assumes that all of the targets (cable trays and conduits) identified by the fire modeling for that source are damaged. In order to define the appropriate list of unavailable equipment, a series of Access queries were developed. The queries identify the circuits contained in the identified trays and conduits, and the components which could be disabled due to the circuits failing. The resulting table, SOURCEA.DBF, relates all of the relevant components which could fail to the ignition source in question.

Scenario B assumes that all of the targets (cable trays and conduits) identified by the fire modeling for that source are damaged except those protected by Thermo-Lag. Queries similar to those described above for Scenario A were used, except that cable trays and conduits protected by Thermo-Lag were not included. The resulting table, SOURCEB.DBF, relates all of the relevant, unprotected components which could fail to the ignition source in question.

Scenario C is more complicated. This scenario assumes that all of the targets identified for the ignition source are damaged, and a hot gas layer forms within the zone, which damages the remaining <u>unprotected</u> circuits. This scenario is applied for special cases where manual suppression successfully stops the fire before the protected circuits in the zone, which are not directly in the plume, are destroyed. In order to define the appropriate list of unavailable equipment, queries were developed to combine the SOURCEA and ZONEB tables. The resulting table, SOURCEC.DBF, relates all of the relevant components which could fail to the ignition source in question.

TAGBE.DBF was used to relate the component tag numbers to their respective basic events in the fire core damage risk fault tree model.

4.5.3 CCDP Calculations

Using FRANC, the input tables described above were processed to calculate a conditional core damage probability (CCDP) for each zone and source scenario described above. The calculational process begins by setting the relevant basic events in the fault tree to TRUE (i.e., failed) and solving the fault tree using CAFTA to generate a list of cutsets (sequences) which could cause a core damage accident. The cutsets are then recovered automatically using a set of rules developed earlier based on CR-3 procedures and experience. The process also evaluates each zone in case the recovery action would be hindered by the fire, and blocks the recovery if necessary. The blocked recoveries are listed in Table 4.5-2. The recovered cutsets are then summed to provide the scenario CCDP. It should be noted that additional recoveries may be possible, if a manual cutset review is performed. This step was not performed at this time due to the plant modifications pending resolution of the Thermo-Lag concerns at FPC.

The CCDPs calculated by FRANC for use in the CDF calculations of fire risk were classified as one of following types, based on the extent of the damage:

Name	Description
ZoneA	CCDP for all targets in the zone, no credit for Thermo-Lag.
ZoneB	CCDP for all targets in the zone, credit for Thermo-Lag.
SourceA	CCDP for all targets of the ignition source, no credit for Thermo-Lag.
SourceB	CCDP for all targets of the ignition source, credit for Thermo-Lag.
SourceC	CCDP for all targets of the ignition source, no credit for Thermo-Lag; plus all targets in the zone, credit for Thermo-Lag.

Table 4.5-2
Blocked Recoveries

Zone	Basic Event	Description
AB-119-7B	ADGBR12Y	FAILURE TO RECOVER EGDG-1B WITHIN 12 HOURS 50 MINUTES
AB-119-7B	ADGBRC1Y	OPERATORS FAIL TO RESTORE EGDG-1B WITHIN 50 MINUTES
AB-119-7B	ADGBRC4Y	OPERATORS FAIL TO RESTORE EGDG-1B WITHIN 4 HOURS 50 MINUTES
AB-119-8B	ADGAR12Y	FAILURE TO RECOVER EGDG-1A WITHIN 12 HOURS 50 MINUTES
AB-119-8B	ADGARC1Y	OPERATORS FAIL TO RESTORE EGDG-1A WITHIN 50 MINUTES
AB-119-8B	ADGARC4Y	OPERATORS FAIL TO RESTORE EGDG-1A WITHIN 4 HOURS 50 MINUTES
AB-95-3C	HOPINJAY	OPERATOR FAILS TO SWITCH MUV-23/24 TO BACKUP POWER
AB-95-3C	HOPINJBY	OPERATOR FAILS TO SWITCH MUV-25/26 TO BACKUP POWER
AB-95-3G	HO0630M	CLOSE RELEVANT MUP RECRC VLV IN 30 MIN.
AB-95-AA	HO1050M	OPERATOR FAILS TO SWITCH MUP-1B POWER SOURCE IN < 50m
CC-108-102	ASTVB1AY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1A
CC-108-102	ASTVB1BY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1B
CC-108-102	ASTVB1CY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1C
CC-108-102	ASTVB1DY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1D
CC-108-102	ASTVB1EY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1E
CC-108-102	ASTVB3AY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3A
CC-108-102	ASTVB3BY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3B
CC-108-102	ASTVB3CY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3C
CC-108-102	ASTVB3DY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3D
CC-108-109	ASTVB1BY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1B
CC-108-109	ASTVB1DY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1D
CC-108-109	ASTVB1EY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1E
CC-108-109	ASTVB3BY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3B
CC-108-109	ASTVB3DY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3D
CC-108-110	ASTVB1AY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1A
CC-108-110	ASTVB1CY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1C
CC-108-110	ASTVB3AY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3A
CC-108-110	ASTVB3CY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3C
CC-124-111	ASTE3ABY	OPERATOR FAILS TO TRANSFER POWER TO ES MCC 3AB
CC-124-117	ASTE3ABY	OPERATOR FAILS TO TRANSFER POWER TO ES MCC 3AB
CC-95-122	ASTE3ABY	OPERATOR FAILS TO TRANSFER POWER TO ES MCC 3AB
CC-95-122	ASTVB1AY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1A
CC-95-122	ASTVB1BY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1B
CC-95-122	ASTVB1CY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1C
CC-95-122	ASTVB1DY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1D
CC-95-122	ASTVB1EY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-1E
CC-95-122	ASTVB3AY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3A
CC-95-122	ASTVB3BY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3B
CC-95-122	ASTVB3CY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3C
CC-95-122	ASTVB3DY	OPERATOR FAILS TO TRANSFER POWER USING VBXS-3D
TB-95-400A	PAFWH	CREW FAILS TO START AFW IN 15 MIN.

4.5.4 Initial Screening

Combining the zone CCDPs with the ignition frequencies and automatic fire suppression probabilities as documented in Sections 4.4 and 4.2, core damage frequencies for each fire zone scenario were calculated as follows, where automatic suppression was assumed failed for scenario 'A' and successful for scenario 'B':

$$CDF_{\text{zone scenario A}} = IGF_{\text{zone}} * NSP_{\text{auto zone}} * CCDP_{\text{zone scenario A}}$$

$$CDF_{\text{zone scenario B}} = IGF_{\text{zone}} * (1 - NSP_{\text{auto zone}}) * CCDP_{\text{zone scenario B}}$$

The representative CDFs from both scenarios were then totaled for each zone to give zone CDF. If a fire zone had a CDF of less than $1x10^{-6}$ per year, it was screened from further consideration. This is consistent with FIVE (Reference 4-2) and the NEI Severe Accident Issue Closure Guidelines (Reference 4-12). Table 4.5-3 lists the unscreened zones.

Table 4.5-3
Zone Results (Initial Screening)

Zone	Description	CDF
CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.06E-04
CC-108-105	BATTERY CHARGER ROOM 3B	4.62E-04
CC-108-106	BATTERY CHARGER ROOM 3A	3.69E-04
CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.91E-04
CC-108-109	INVERTER ROOM 3B	2.14E-04
CC-108-102	HALLWAY AND REMOTE SHUTDOWN ROOM	1.45E-04
CC-108-103	PLANT BATTERY ROOM 3B	9.98E-05
AB-95-3G	CENTRAL HALLWAY	6.93E-05
CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	6.40E-05
AB-95-3Z	RWSW PUMP ROOM	5.32E-05
CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	4.86E-05
AB-95-3K	MISC. RAD WASTE ROOMS & HALLWAY	1.60E-05
AB-95-3B	NORTH HALLWAY & NUCLEAR SAMPLE ROOM	1.25E-05
IB-95-200C	TURB. EFW PUMP, PENET. AREA, FAN ROOM	1.10E-05
TB-119-400E	TURBINE BLDG MEZZANINE FLOOR	4.98E-06
CC-108-104	PLANT BATTERY ROOM 3A	3.64E-06
IB-119-201B	PERSONNEL ACCESS AREA	2.55E-06
CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	2.25E-06
TB-95-400A	TURBINE BUILDING BASEMENT FLOOR	1.50E-06

4.5.5 Final Quantification

For the final quantification, source CDFs were calculated taking into account the severity of the fire, the effectiveness of Thermo-Lag, and the use of both automatic and manual suppression.

Because of the added complexities due to timing issues involving HGL formation, manual suppression, and Thermo-Lag effectiveness, a separate application was developed to query the relevant data for each source, assess the applicable scenarios, calculate the manual suppression probabilities, and apply the appropriate CCDPs.

Using this application, five possible cases were evaluated for each ignition source as follows:

Case ID	Description	CDF Formulation
AUTO	Automatic suppression successful.	$IGF * (1 - AUTO_{nsp}) * CCDP_x$
HGL	Automatic suppression fails and manual suppression succeeds before HGL formation.	$IGF * AUTO_{nsp} * MANUAL_{hgl} * CCDP_x$
TL	Automatic suppression fails and manual suppression succeeds before TL damage.	$IGF * AUTO_{nsp} * MANUAL_{tl} * CCDP_x$
TLZ	Automatic suppression fails and manual suppression succeeds after HGL formation but prior to TL damage due to the HGL.	$IGF * AUTO_{nsp} * MANUAL_{tlz} * CCDP_x$
NONE	Automatic and manual suppression fails.	$IGF * AUTO_{nsp} * MANUAL_{nsp} * CCDP_x$

For automatic suppression, the success and failure probabilities were taken from Table 4.2-1. For manual suppression, the equation given in Section 4.2.2 was used. The total manual suppression success probability was divided into three segments called $MANUAL_{tl}$, $MANUAL_{hgl}$, and $MANUAL_{tlz}$, which represent the appropriate probability for the conditions described for each case. The probability of non-suppression is $MANUAL_{nsp}$, where:

$$MANUAL_{nsp} = 1 - (MANUAL_{hgl} + MANUAL_{tl} + MANUAL_{tlz})$$

If a case was not applicable, such as no HGL or TL for a particular source, then a manual suppression probability of zero was used for the applicable cases.

In order to evaluate each case, the applicable times for HGL formation, TL damage, and TLZ damage (HGL+TL) were identified. Next, a timeline was developed to sequence these events in order to determine the appropriate CCDPs and manual suppression probabilities. Four generic timelines are shown in Table 4.5-4 which demonstrate the manual suppression and CCDP determination methodology. Table 4.5-5 lists all of the possible scenarios for each case in table format. Table 4.5-5 uses a slightly different terminology for the relevant times than Table 4.5-4. As an aid to understanding the relationship between the times used in the two tables, the following equations are given:

$t_{HGL} = t_{HGL700}$
$t_{TLZ} = t_{HGL1000} + t_{TL}$

The results of the CDF calculations for each case are documented in the database table CDF_20/60 in the Access database. The final CDF for each source is calculated by summing the five cases (database query CDF_BySource). The corresponding zone CDFs are calculated by summing the source CDFs by zone (database query CDF_ByZone).

Table 4.5-6 is a tabulation of the results by ignition source. Table 4.5-7 is a tabulation of the results by zone.

The total core damage frequency due to internal fires at CR-3 in these zones is 4.18×10^{-5} per year.

Table 4.5-4
Generic Manual Suppression Timelines

1. No HGL:

Event	t_{ign}	t_{TL}
CCDP	SourceB	SourceA

MANUALtl = Probability @ tTL
MANUALhgl = 0
MANUALtlz = 0

2. No T-L:

Event	t_{ign}	t_{HGL}
CCDP	SourceA	ZoneA

$MANUAL_{hgl}$ = Probability @ t_{HGL}
$MANUAL_{tl}$ = 0
$MANUAL_{tlz}$ = 0

3. T-L Damaged Prior to HGL Development:

Event	t_{ign}	t_{TL}	t_{HGL}	t_{TLZ}
CCDP	SourceB	SourceA	SourceC	ZoneA

$MANUAL_{tl}$ = (Probability @ t_{TL}
$MANUAL_{hgl}$ = (Probability @ t_{HGL}) - (Probability @ t_{TL})
$MANUAL_{tlz}$ = (Probability @ t_{TLZ}) - (Probability @ t_{HGL}) - (Probability @ t_{TL})

4. HGL Develops Prior to T-L Damage:

Event	t_{ign}	t_{HGL}	t_{TL}	t_{TLZ}
CCDP	SourceB	ZoneB	SourceC	ZoneA

$MANUAL_{hgl}$ = (Probability @ t_{HGL})
$MANUAL_{tl}$ = (Probability @ t_{TL}) - (Probability @ t_{HGL})
$MANUAL_{tlz}$ = (Probability @ t_{TLZ}) - (Probability @ t_{TL}) - (Probability @ t_{HGL})

Table 4.5-5
Ignition Source Quantification Scenarios

Applicable Case ID	Automatic Suppression	HGL Potential	TL in the Zone?	t_{TL} / t_{HGL700} Relationship	Manual Suppression Time (t)	CCDP
AUTO	Yes	NA	No	NA	NA	SourceA
AUTO	Yes	NA	Yes	NA	NA	SourceB
HGL	No	Yes	No	$t_{TL} = 0$	$t < t_{HGL700}$	SourceA
HGL	No	Yes	Yes	$t_{TL} < t_{HGL700}$	$t_{TL} \leq t < t_{HGL700}$	SourceA
HGL	No	Yes	Yes	$t_{TL} \geq t_{HGL700}$	$t < t_{HGL700}$	SourceB
TL	No	No	Yes	$t_{HGL700} = 0$	$t < t_{TL}$	SourceB
TL	No	Yes	Yes	$t_{TL} < t_{HGL700}$	$t < t_{TL}$	SourceB
TL	No	Yes	Yes	$t_{TL} \geq t_{HGL700}$	$t_{HGL700} \leq t < t_{TL}$	ZoneB
TLZ	No	Yes	Yes	$t_{TL} < t_{HGL700}$	$t_{HGL700} \leq t < t_{HGL1000} + t_{TL}$	SourceC
TLZ	No	Yes	Yes	$t_{TL} \geq t_{HGL700}$	$t_{TL} \leq t < t_{HGL1000} + t_{TL}$	SourceC
NONE	No	No	No	$t_{HGL700} = t_{TL} = 0$	All	SourceA
NONE	No	Yes	No	$t_{TL} = 0$	$t \geq t_{HGL700}$	ZoneB
NONE	No	No	Yes	$t_{HGL700} = 0$	$t \geq t_{TL}$	SourceA
NONE	No	Yes	Yes	$t_{TL} < t_{HGL700}$	$t \geq t_{HGL1000} + t_{TL}$	ZoneA
NONE	No	Yes	Yes	$t_{TL} \geq t_{HGL700}$	$t \geq t_{HGL1000} + t_{TL}$	ZoneA

$t =$ time at which manual suppression is successful.
$t_{TL} =$ survival time of Thermo-Lag protection. If there is no Thermo-Lag in the zone, $t_{TL} = 0$.
$t_{HGL700} =$ time of hot gas layer formation. If no hot gas is formed by the ignition source, $t_{HGL700} = 0$.
$t_{HGL1000} =$ time at which hot gas layer reaches 1000°F formation.

Table 4.5-6
CR-3 Fire PSA Results by Ignition Source

Source	Zone	Description	CDF
DPBC-1E	CC-108-106	BATTERY CHARGER ROOM 3A	8.68E-06
DPBC-1A	CC-108-106	BATTERY CHARGER ROOM 3A	5.31E-06
TRANS-108-A	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.29E-06
AHF-69	CC-108-102	HALLWAY AND REMOTE SHUTDOWN ROOM	1.90E-06
AHF-71	CC-108-105	BATTERY CHARGER ROOM 3B	1.40E-06
MTSW-3F	CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	9.67E-07
TRANS-117-C	CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	9.49E-07
DPBC-1C	CC-108-106	BATTERY CHARGER ROOM 3A	8.94E-07
MTSW-2E R2	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	8.48E-07
MTSW-2E R5	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	8.31E-07
MTSW-2E R6	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	8.31E-07
MTSW-2E R4	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	8.30E-07
MTSW-2E R3	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	8.27E-07
MTSW-2E R7	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	8.18E-07
REMOTE SHUTDOWN PNL	CC-108-102	HALLWAY AND REMOTE SHUTDOWN ROOM	7.64E-07
DPDP-1B	CC-108-105	BATTERY CHARGER ROOM 3B	6.40E-07
MTSW-2D R4	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	5.70E-07
MTSW-2C R7	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	4.87E-07
MTSW-2C R3	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	4.87E-07
MTSW-2C R6	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	4.69E-07
VBIT-1D	CC-108-109	INVERTER ROOM 3B	4.40E-07
MTSW-3F R3	CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	4.25E-07
MTSW-3F R1	CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	4.25E-07
MTSW-3F R2	CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	4.25E-07
AHDP-12	CC-108-105	BATTERY CHARGER ROOM 3B	4.09E-07
DPDP-5A	CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	3.54E-07
MTSW-2D R3	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	3.31E-07
MTSW-2F R5	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	3.28E-07
MTSW-2F R1	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	3.28E-07
VBTR-3E	CC-108-109	INVERTER ROOM 3B	3.24E-07
MTSW-2C R4	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	3.00E-07
VBIT-1B	CC-108-109	INVERTER ROOM 3B	2.99E-07
RSD RLY A	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.73E-07
MTSW-2E R1	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	2.73E-07
MTSW-2D R1	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.65E-07
MTSW-2D R2	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.65E-07
RSD RLY A1	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.64E-07
MTSW-2C R1	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.56E-07
DPDP-8A	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.48E-07
DPDP-8C	CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	2.42E-07
MTSW-2F R4	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	2.33E-07
MTSW-2F R2	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	2.04E-07
MTSW-2D R7	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.02E-07
MTSW-2D R6	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.02E-07
MTSW-2D R5	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	2.02E-07
MTSW-2C R2	CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	1.86E-07
MTSW-2F R3	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	1.57E-07
DPBC-1B	CC-108-105	BATTERY CHARGER ROOM 3B	1.35E-07
DPBC-1D	CC-108-105	BATTERY CHARGER ROOM 3B	1.35E-07
VBTR-2E	CC-108-109	INVERTER ROOM 3B	1.23E-07
VBTR-3B	CC-108-109	INVERTER ROOM 3B	1.20E-07
RSD RLY B	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	1.17E-07
DRRD3-1	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.75E-08
DRRD3-5	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.75E-08
DRRD3-4	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.75E-08
DRRD3-6	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.75E-08
DRRD3-2	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.75E-08

Table 4.5-6 (cont.)
CR-3 Fire PSA Results by Ignition Source

Source	Zone	Description	CDF
DRRD3-3	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.75E-08
MTSW-2F R6	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	5.73E-08
MTSW-2F R7	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	5.73E-08
DRRD3-8	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD5L	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD4-8	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD4-7	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD4-6	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD4-5	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD4-1	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD4-3	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD4-2	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD5R	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD3-7	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
DRRD4-4	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	5.72E-08
MTSW-3G	CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	4.90E-08
VBXS-1B	CC-108-109	INVERTER ROOM 3B	4.81E-08
VBXS-3B	CC-108-109	INVERTER ROOM 3B	4.60E-08
VBXS-3D	CC-108-109	INVERTER ROOM 3B	4.58E-08
DPDP-1A	CC-108-106	BATTERY CHARGER ROOM 3A	4.50E-08
TRANS-116-C	CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	4.14E-08
DRRD7-8B	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
CRDM GROUP POWER SUPPLY CAB	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD8A	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD7-6A	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD7-8A	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD7-7B	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD7-7A	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD7-6B	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD6A	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD6B	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD7-5A	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD7-5B	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
DRRD8B	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	3.92E-08
MTMC-3 R6	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R5	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R9	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R4	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R7	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R1	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R3	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R2	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R14	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R13	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R12	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R11	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R10	AB-95-3G	CENTRAL HALLWAY	2.57E-08
MTMC-3 R8	AB-95-3G	CENTRAL HALLWAY	2.57E-08
RSD RLY B1	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	2.34E-08
MTSW-3G R1	CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	2.19E-08
MTSW-3G R2	CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	2.19E-08
MTSW-3G R3	CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	2.19E-08
RSD AUX B RLY	CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	2.14E-08
DPDP-8D	CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	1.95E-08
RR3	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	1.53E-08
DRRD2-3	CC-124-111	CRD & COMMUNICATION EQUIP ROOM	1.31E-08

Table 4.5-7
CR-3 Fire PSA Results by Zone (Final)

Zone	Description	CDF
CC-108-106	BATTERY CHARGER ROOM 3A	1.49E-05
CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	7.31E-06
CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	6.79E-06
CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	3.79E-06
CC-108-105	BATTERY CHARGER ROOM 3B	2.72E-06
CC-108-102	HALLWAY AND REMOTE SHUTDOWN ROOM	2.66E-06
CC-124-111	CRD & COMMUNICATION EQUIP ROOM	1.58E-06
CC-108-109	INVERTER ROOM 3B	1.45E-06
AB-95-3G	CENTRAL HALLWAY	3.86E-07
CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	1.76E-07
AB-95-3B	NORTH HALLWAY & NUCLEAR SAMPLE ROOM	7.98E-09
TB-119-400E	TURBINE BLDG MEZZANINE FLOOR	4.96E-11
TB-95-400A	TURBINE BUILDING BASEMENT FLOOR	4.84E-11
AB-95-3Z	RWSW PUMP ROOM	4.21E-11
IB-95-200C	TURB. EFW PUMP, PENET. AREA, FAN ROOM	1.07E-11
AB-119-6A	NORTH HALLWAY	1.05E-11

4.5.6 Control Room and Cable Spreading Room Fires

Introduction

The CR-3 control room is at elevation 145 of the control complex. The control room has a floor area of 3,308 ft^2 and a total ceiling height of 15 ft. An intervening false ceiling at 9.75 ft has a 5.25 ft high air space above it before reaching the true ceiling at elevation 160. The false ceiling has sufficient openings to allow smoke to pass into the upper air space. The control room is part of fire zone CC-145-118B. It is protected from the effects of fires in other locations by three-hour fire barriers.

The analysis of the control room differs from other portions of fire propagation analysis. Fire propagation analysis typically addresses damage to overhead cables from a plume, ceiling jet, or room heatup by a hot gas layer. Control rooms typically however have cable enclosed in cabinets. Additionally, the people manning the controls are important "targets."

In control room fire analysis, fires begin in electrical cabinets and their effects on controls within the cabinet and in adjacent cabinets need to be evaluated. People manning controls must see them, so smoke rather than temperature in the hot gas layer is evaluated to determine if and when evacuation could occur.

Just as the nature of the evaluations are different, the tools to perform them are also different. Practical fire models that exist do not have the capability to predict fire growth within a cabinet or descending smoke layers in a room. However, a reasonable body of evidence is available in the Sandia cabinet fire tests (NUREG/CR-4527, Reference 4-11) and in EPRI's Fire Events Database (NSAC-178L, Reference 4-6) to characterize the likelihoods that cabinet controls are damaged and smoke obscures control panels.

While fire modeling is different, the analysis of the CR-3 control room nevertheless followed a process similar to the rest of the fire PSA. Boundaries for fire spread in cabinets and the equipment within those boundaries were identified. Core damage probabilities and ignition frequencies were estimated. Cabinet core damage frequencies were calculated for the most significant cabinets. Finally, smoke effects were analyzed for their potential to cause evacuation of the control room.

Both the deterministic and probabilistic insights from the analysis indicate that the CR-3 control room fire risk is low. The probabilistic results, conservatively calculated at 9.3×10^{-7} per year, reflect the effectiveness of the CR-3 control room fire response and the redundant means for safely shutting down the plant in the event of a panel fire. The results reflect the quality of the plant's control room fire procedures, which allow full use of plant equipment and do not require isolation of offsite power. They also reflect the plant's remote shutdown capability, i.e., two redundant trains. The most important cabinets are those which cause a sustained loss of offsite power.

Assumptions

The major assumptions in the control room analysis are:

- Main control board fires disable the entire panel section if they became fully developed.

- Suppression prior to loss of a cabinet function was considered only as part of the electrical panel fire severity evaluation, i.e., probability of fire becoming fully developed.

- Evacuation of the control room was assumed to occur at the time smoke visibly obscures the panels.

- The time for evacuation assumed a response similar to representative Sandia National Laboratories (SNL) cabinet fire tests.

- Each MCB panel section and control/instrumentation cabinet was assumed to contain sufficient cable or combustible loading so that enough smoke would be generated to cause control room evacuation.

- Human detection was credited to be as effective as an in-cabinet smoke detector.

- Operators would switch HVAC from recirculation to smoke evacuation mode in the event of a control room fire.

Analysis Overview

The analysis of the control room is based upon two levels of fire severity. In the most severe case, a fire can develop and fail to be suppressed for a long time. In this case, smoke can accumulate in the control room until a layer begins to descend and become dense enough to obscure the main control board. These scenarios will be referred to as "evacuation scenarios." As described below, fires in the CR-3 control room causing evacuation are an insignificant source of risk.

Fires less severe than this extreme case can also be significant. While the fire is suppressed before evacuation becomes necessary, it has nevertheless damaged the controls of one (or sometimes more) cabinets, and safe shutdown capability has been compromised. Operators are assumed to attempt to shutdown the plant using the remaining capability available from the control room. If that capability fails, e.g., equipment fails to operate, operators are assumed to use the remote shutdown capability. These scenarios will be referred to as "critical cabinet scenarios."

The first part of the analysis of these scenarios, identifying the boundaries for fire spread in cabinets and the equipment within those boundaries, involved four steps:

Step 1 - Evaluate the plant capability available for responding to control room fires.

Step 2 - Select the critical cabinets, i.e., those most likely to dominate control room fire risk.

Step 3 - Identify the safe shutdown capability remaining after the loss of a single section of the Main Control Board (MCB).

Step 4 - Determine the logical boundaries for the spread of fires initiated in a panel in the MCB (or panel section).

The evaluation involved visual examination of the entire MCB. Internal cabinet boundaries were evaluated to determine the probability of fire spread among cabinet sections. Also, radiative damage was considered for nearby panel sections and, if appropriate, associated solid-state components. Completing these steps determined the equipment affected and the design and procedural capability for remote shutdown alternatives.

The second effort included three steps to evaluate core damage probabilities for the entire panel section, ignition frequencies for critical panel sections, and the probability of severe fire development.

Step 5 - Calculate the conditional core damage probability (CCDP) for the necessary MCB panel sections.

Step 6 - Determine the ignition frequency for each critical panel section.

Step 7 - Evaluate probability of severe fire development.

The evaluation involved visual examination of ignition source loadings to develop panel specific ignition frequencies, and use of the IPE fire accident sequence model to calculate probability of core damage from, for example, a sustained loss of offsite power.

Fire effects also were analyzed for their potential to cause more widespread damage, e.g., smoke causing evacuation of the control room and damage to components in adjacent cabinets. This analysis included three steps:

Step 8 - Determine the probability of suppression failure prior to control room evacuation.

Step 9 - Calculate the conditional probability of core damage (CCDP) for the control room evacuation cases.

Step 10 - Evaluate fire effects on adjacent cabinets

Lastly, the analysis calculated, compiled, and evaluated the final results.

Control Room

The following describes how each of these steps was performed to determine the contribution of control room fire risk from evacuation and critical cabinet scenarios.

Step 1 - Evaluate the plant capability available for responding to control room fires.

CR-3 has considerable capability for responding to control room fires. Two trains of equipment are available and isolable from the effects of a control room fire. The AFW pump can also be operated from outside the control room. Additionally, CR-3 control room fire procedures are well designed for the dominant accident types found in this study. The key attributes of these procedures are that they: 1) do not require operators to isolate offsite power unless the fire affects it, 2) explicitly state that remote capability can be used in conjunction with the control room, and 3) provide a clear and easy interface with the EOPs

Consequently, the procedures allow safe shutdown to be performed based on the equipment that is available. For example, not isolating offsite power allows shutdown without relying on the emergency diesel generators which are typically the weak point as far as safe shutdown reliability is concerned. These attributes were also a significant factor in determining that the operators would reliably use both in-control room and remote shutdown capability.

Step 2 - Select the critical cabinets, i.e., those most likely to dominate control room fire risk due to critical cabinet scenarios.

Based on the design and operation of the CR-3 control room for fires and the results of other control room analyses performed in the EPRI fire PRA and FIVE test applications, cabinets without the following attributes were assumed to be the critical cabinets.

- Given the failure of all equipment in the cabinet, there are two safe shutdown trains available, and
- failure of the cabinet does not result in a special initiator, e.g., loss of offsite power.

A safe shutdown train is reliable provided no other conditions exist which degrade the reliability of the path, e.g., loss of offsite power. A reliable path (e.g., one to three percent unavailability) implies that the CCDP for two paths available is between $1x10^{-3}$ and $1x10^{-4}$. Typical panel fire frequencies of $1x10^{-4}$ imply an insignificant contribution to total control room CDF.

An evaluation performed by FPC engineers indicated that:

- only the main control board (MCB) contains controls for redundant trains of safe shutdown equipment, and
- offsite power controls are contained in only two portions of the MCB, namely the Electrical Distribution Panel and the Electrical Plant Relay Panel.

CR-3's remote shutdown capability and control room fire procedures ensure that for any cabinet fire affecting only a single safe shutdown train, another train will be available from the control room. Should that train fail to operate, the fire-damaged train can be controlled locally while operators monitor plant response in the control room. If only one train is available in the control room, redundant means of safe shutdown are still typically available, e.g., EFW, AFW, feed and bleed, with associated redundant support system trains. Consequently, the MCB was the focus of further analysis.

Step 3 - Identify the safe shutdown capability remaining after the loss of a single section of the Main Control Board.

The following evaluates the safe shutdown capability remaining assuming complete loss of a front panel section of the MCB and the Electrical Plant Relay Panel portion of the back panel. The remainder of the back panel (five sections), the adjacent Radiation Monitoring Panel, and the ten internal panels did not contain controls for either redundant trains or offsite power.

The front panel sections with potential consequences were:

Engineered Safeguards Panel A
Engineered Safeguards Panel B
RCS Volume Control Panel
Reactor Control Panel
Secondary Plant Control Panel
Electrical Distribution Panel
Electrical Plant Relay Panel

The following identifies the decay heat removal capability and associated support systems available assuming a fire damages all equipment on the MCB panel section. It describes the potential impact on RCS integrity (i.e., fire-induced LOCAs). Finally, the discussion concludes whether two safe shutdown paths are available and whether offsite power is affected. Conclusions for additional analyses are then stated.

Engineered Safeguards Panel A

Decay Heat Removal Available	**Support Systems Available for DHR Path**
MUP-1C with DHP-1B	SWP-1B, 1C, and all RWPs except RWP-1 and 2A
EFP-1	SWP-1B, 1C
EFP-2	none needed - self-cooled
MFW	
AFW	

RCS integrity/makeup safety function is not needed. LOCAs are not possible because the pressurizer vent valves on the panel are de-energized. All power supports are available.

No further analysis is needed for ES Panel A because controls for at least two shutdown paths and offsite power are available from other sections of the MCB.

Engineered Safeguards Panel B

Decay Heat Removal Available	Support Systems Available for DHR Path
MUP-1A with DHP-1A	DCP-1A with RWP-3A
MUP-1B with DHP-1A	RWP-2A with SWP-1A
EFP-1	SWP-1B, 1C
EFP-2	none needed - self-cooled
MFW	
AFW	

RCS integrity/makeup safety function is not needed. LOCAs are not possible because their are no energized boundary valves on the panel. All power supports are available.

No further analysis is needed for ES Panel B because controls for at least two shutdown paths and offsite power are available from other sections of the MCB.

RCS Volume Control Panel

Decay Heat Removal Available	Support Systems Available for DHR Path
MUP-1A with DHP-1A	DCP-1A with RWP-3A
MUP-1B with DHP-1A	RWP-2A with SWP-1A
MUP-1C with DHP-1B	SWP-1B, 1C and all RWPs except RWP-1 and 2A

MFW and AFW were assumed failed because of the possibility of spurious actuations causing EFIC to isolate the steam generators. Two trains of RCS integrity/makeup safety function are available. All power supports are available.

No further analysis is needed for the RCS volume control panel because controls for at least two shutdown paths and offsite power are available from other sections of the MCB.

Reactor Control Panel

Decay Heat Removal Available	Support Systems Available for DHR Path
MUP-1A with DHP-1A	DCP-1A with RWP-3A
MUP-1B with DHP-1A	RWP-2A with SWP 1A
MUP-1C with DHP-1B	SWP-1B & 1C and all RWPs except RWP-2A and RWP-1
EFP-1	SWP 1B & 1C
EFP-2	none needed - self-cooled

MUPs would need to pump against the pressurizer SRVs since the PORVs are not available. RCS integrity/makeup might be required since spurious PORV opening plus fire induced block valve failure could occur. However, two makeup and two decay heat removal paths are still available. All power supports are available.

No further analysis is needed for the reactor control panel because controls for at least two shutdown paths and offsite power are available from other sections of the MCB.

Secondary Plant Control Panel

Decay Heat Removal Available	Support Systems Available for DHR Path
MUP-1A with DHP-1A	DCP-1A with RWP-3A
MUP-1B with DHP-1A	RWP-2A with SWP-1A
MUP-1C with DHP-1B	SWP-1B, 1C, and all RWPs except RWP-1 and 2A

MFW and AFW was assumed failed because of the possibility of EFIC isolating the steam generators if spurious steam dump actuations occurred. Two trains of RCS integrity/makeup are available. LOCAs are not possible because there are no energized boundary valves on the panel. All power supports are available.

No further analysis is needed for the secondary control panel because controls for at least two shutdown paths and offsite power are available from other sections of the MCB.

Electrical Distribution Panel

There is no direct effect on decay heat removal or RCS integrity after a fire in this panel. The fire does cause a loss of offsite power in which the operators must locally actuate both diesel generators. Application of power from the diesel generators is a dead bus transfer. Offsite power may be recoverable.

The conditional core damage frequency (CCDP) for this case was calculated to be 3.24×10^{-3}. The CCDP calculation took no credit for recovery of offsite power. CR-3 is designed to cope with the effects of a station blackout for four hours, made possible through the use of battery power and steam generator cooling using the turbine-driven emergency feedwater pump, EFP-2. Therefore, there is ample time for the operators to manually actuate the diesel generators. This action is proceduralized (AP-990). Applying the time-reliability curves used in the CR-3 IPE to the action of manually actuating the diesel generators, even when considering the action to involve conflict due to the fire, the probability falls below the administrative floor for recovery actions of 1×10^{-3}. With no credit taken for recovery of offsite power, the CCDP is 3.24×10^{-3}; the hardware portion is 2.24×10^{-3}. In addition to the operators failing to actuate the diesel generators, there is the overall probability that the operators fail to evacuate the control room and proceed successfully to hot shutdown using the remote shutdown panel. For the control room evacuation case, the CCDP reflects the capability of the two trains on the remote shutdown panel. The conditional probability of core damage for remote shutdown panel operation was calculated to be 9.78×10^{-3}. This CCDP represents what in essence is failures of two redundant trains or crew failure to successfully bring the plant to hot shutdown and maintain it. For the human error analysis, the dynamic human error curve from the time-reliability curves (TRCs) used in the CR-3 IPE for "rule-based / conflict" was used. For the relevant time, the worst case was used: station blackout with EFP-2 failure, leaving the operators 50 minutes for recovery. Assuming ten minutes for performance of any recovery, the 40-minute number for the relevant TRC is 9.78×10^{-3}.

The probability that offsite power is recovered within four hours and 50 minutes (even after a station blackout and EFP-2 failure, it takes 50 minutes before enough coolant has been lost that recovery of offsite power will not prevent core damage) is 0.062. If credit is taken for recovery of offsite power, the CCDP is $(3.24\times10^{-3})(0.062) = 2.0\times10^{-4}$.

If no credit is taken for recovery of offsite power, the CCDP is $9.78\times10^{-3} + 3.24\times10^{-3} = 1.3\times10^{-2}$.

Electrical Plant Relay Panel

The operators must locally actuate both diesels after a fire in this panel. Application of power from the diesel generators is a dead bus transfer. Offsite power might be recoverable after EFP-2 fails on loss of control (four hours). The conditional core damage probability for a fire in this panel is identical to that for the electrical distribution panel discussed above, 1.3×10^{-2}. No recovery of offsite power is credited.

Step 4 - Determine the logical boundaries for the spread of fires initiated in a panel in the MCB (or panel section).

For the Main Control Board, an attempt was made to see if the board could be sectionalized. The MCB is large, and open at the top. Hot gases will not accumulate inside it, but rather will flow to the false ceiling area and above it. Sandia cabinet fire test insights (see Appendix H) indicate it is reasonable to assume that a fire would take time to spread from one end of the panel to another. Partitions, or even cabinet sections sometimes can not only delay fire spread from one section to the next but block the "view" of radiative heat transfer.

Figure 4.5-1 illustrates the layout of the Main Control Board. The MCB is comprised primarily of front and back panel sections. A few internal panels, many of them containing banks of relays, are between the front and back sections. The panels for which fire damage is important are those seven listed in the previous step. They are on the front of the board except for the Electrical Plant Relay Panel, which is on the back. Except for the internal ES cable trays marked in the figure, cables enter each section from below. On the front panel, each section is separated from other sections by a side panel which contains a large heat sink of cables. The likely points of ignition, switches and other electrical connections, are on the face of the panels.

Determining the possibility that fire scenarios may involve multiple MCB panel sections in the CR-3 control room requires the analysis of three different types of fire propagation scenarios:

- fire in an ES panel or the RCS Volume Control panel damaging the internal ES cable trays,
- fire in a front panel causing damage to a back panel or vice-versa, and
- fire in an internal relay panel affecting one or more front and back panels.

The above analysis was performed assuming the following data for heat release rates and damage criteria. Heat release rates were based on the Sandia cabinet fire tests and insights as summarized in Appendix E of the Fire PRA Implementation Guide. Damage criteria were based on the sources documented in Appendix F.

Heat release rates for internal relay panels:
- 65 Btu/sec for relay cabinet (representative of one qualified cable bundle, e.g., on end of a relay rack)
- 270 Btu/sec for a large fire involving more than one bundle (representative of fully involved fire in benchboard cabinet with qualified cable)

The latter release is considered a high heat release rate that will take time to develop when the panel is the likely source of ignition.

Damage criteria for components on front or back panels:
- 1 Btu/sec/ft^2 for typical equipment and cables
- 0.19 Btu/sec/ft^2 for solid-state equipment

In the case of the internal ES cable trays, it was judged that the fire would have to propagate from the likely source of ignition on the panel to the cables on the divider. The trays run over the panel dividers but not the panels. The time for such a fire to develop was judged to be comparable to the time to evacuation, i.e., the time at which the function of the circuits becomes irrelevant. The time to circuit failure would be expected to be delayed even if the fire started in the panel divider because the trays are metal boxes which were judged to provide protection similar to a shielded cable tray.

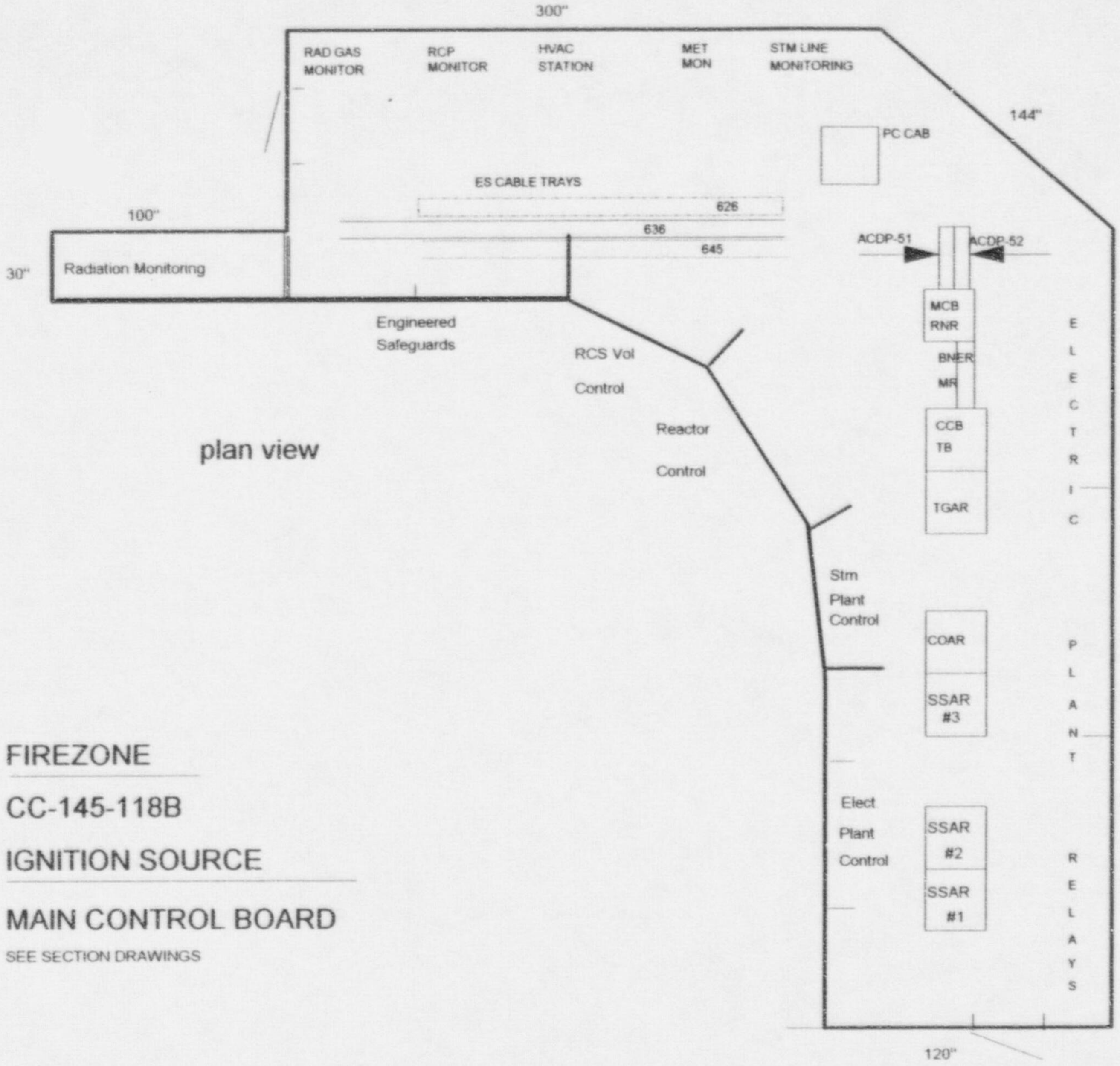


Figure 4.5-1 Main Control Board (MCB) Drawing

A similar conclusion was reached for panel fires damaging other panels. In this case, some components in the exposed panel might be subject to heat radiation damage, particularly solid-state components. A walkdown of the MCB internals indicated that components in critical cabinets, both solid-state and other types, were separated sufficiently that a high heat release rate would be required to cause damage. Again, the time for such a fire to develop was judged to be comparable to the time to evacuation, i.e., the time at which the function of the circuits becomes irrelevant.

The conclusion of this step was that the MCB fire scenarios did not need to consider multiple panel sections of the MCB. By the time multiple panel sections were damaged, the control room would probably already have been evacuated.

Step 5 - Calculate the conditional probability of core damage (CCDP) for the necessary MCB panel sections and for control room evacuation cases.

The conditional probability of core damage for the Electrical Distribution Panel and the Electrical Plant Relay Panel was calculated to be 3.24×10^{-3}. This CCDP represents a long-term loss of offsite power requiring manual actuation of the diesels. If control room evacuation is necessary, the CCDP is 1.3×10^{-2}.

Step 6 - Determine the ignition frequency for each critical cabinet.

The fire ignition frequency for the control room is 9.5×10^{-3}/yr, which essentially is the frequency of electrical cabinet fires. The eleven electrical cabinet fires in the EPRI Fire Events Database (FEDB) can be categorized as initiated by the following sources:

Ignition Source	# of Fires
Relays	6
Circuit cards	3
Other	2

Cabinets have a wide range of relays and circuit cards. The following categorization was used:

Relay/circuit card loading	Fraction of loading	Representative # of Relays	Representative # of Circuit Cards
None	0 or < 0.1	0	0
Light load	~1/3 of nominal	7	20
Moderate load	~nominal	20	60
Heavy load	~3 times nominal	60	180

For the CR-3 cabinets of concern, the MCB sections were examined during a walkdown. The loadings of each cabinet were used to develop an ignition source factor and corresponding cabinet ignition frequency.

The ignition frequency factor is the number of applicable events divided by eleven total events. For heavy and light loads, the number of applicable events is multiplied and divided by three, respectively. For "none," no events are counted. All cases have a minimum of two events corresponding to the other category. In the event data, other includes the causes "pinched cable" and "unknown."

The ignition frequency for a cabinet is divided over 85 cabinets in the control room. The number of cabinets includes the 23 sections or internal panels of the MCB and 62 other cabinet sections. The ignition frequency becomes:

$$\begin{aligned} f_{cab} &= [(9.5\text{x}10^{-3}/\text{y})/(85)](\mathit{ignfac}) \\ &= (1.12\text{x}10^{-4}/\text{y})(\mathit{ignfac}) \end{aligned}$$

The FEDB indicates that the majority of control fires are not severe. Since such a fire can fail multiple components, this analysis assumes that a full loss of offsite power will occur for any severe fires.

The results for each unscreened cabinet are summarized below.

MCB Section	**Relay/Circuit Card Loading**	**Ignition Frequency Factor *(ignfac)***	**Electrical Cabinet Severity Factor**	**Severe Cabinet Fire Ignition Frequency *(f_{cab})***
Electrical Distribution Panel	none/none	0.182	0.2	$4.1\text{x}10^{-6}$/yr
Electrical Plant Relay Panel	heavy/light	1.91	0.2	$4.3\text{x}10^{-5}$/yr

Step 7 - Evaluate probability of severe fire development.

The probability of severe fire development is included in the previous table. The value used is described in more detail in Appendix D.

Step 8 - Determine the probability of suppression failure prior to control room evacuation.

The probability of non-suppression of a control room electrical cabinet fire as a function of time was obtained by using a model to interpret the control room fire durations in the EPRI Fire Events Database. All but one of the control room fires were in electrical cabinets. The other fire was a small kitchen fire with a five-minute duration. Fire durations for five electrical cabinet fires are contained in the database, including one at one-half minute, one at one minute, two at two minutes and one at five minutes.

The model used to interpret the data was EPRI's Human Cognitive Reliability (HCR) correlation for interpreting measured operator action times in the control room (see

EPRI NP-6560L "HRA Approach Using Measurement for IPE," Reference 4-13). The model fits the event times (e.g., fire durations), to a log-normal curve to estimate the probability for non-action for times greater than that observed.

Distributions were fit to four sets of data as shown in Figure 4.5-2. The recommended curve eliminates the five-minute duration fire which was not in an electrical cabinet. This fire is not deemed appropriate for an electrical cabinet fire suppression model. A data set including the other fire was used for the upper bound estimate. A third data set was the basis for the lower bound estimate. It uses the best-estimate case but adds another fire at one minute. Adding this event accounts for the fire in the database with a suppression time of one minute, but with no specified duration. Its duration was postulated as one minute based on a review of its event description and the other short duration fires.

The fifteen-minute time for this scenario represents the time necessary for smoke from an electrically-initiated cabinet fire to obscure the control board. The probability of non-suppression at this time has a best estimate of 3.4×10^{-3}, an upper bound of 4.3×10^{-3} and a lower bound of 8.9×10^{-4}.

The probability of cabinet fire non-suppression before the need for control room evacuation is 3.4×10^{-3}. This value assumes detection at or prior to the time that visible smoke appears in the cabinet. It also assumes 15 minutes from the time of detection to the time of smoke obscuration of the control panels. Besides detection time, this time is also dependent on plant-specific factors such as room volume and room ventilation. The SNL test facility had a room volume of 48,000 ft^3 and ventilation rates ranging from one to ten room changes per hour. The CR-3 control room has a room volume of between 32,000 and 50,000 ft^3 depending on whether the area above the false ceiling is counted. The control room HVAC has a room ventilation rate of about seven room changes per volume when in smoke ejection mode. Hence, the CR-3 control room geometry and HVAC is reasonably represented by the SNL test facility, and the test results can be used directly. Regarding detection, the CR-3 control room does not have in-cabinet detectors. Automatic detection is located on the false ceiling. This analysis assumes that human detection is equivalent to or better than automatic detection.

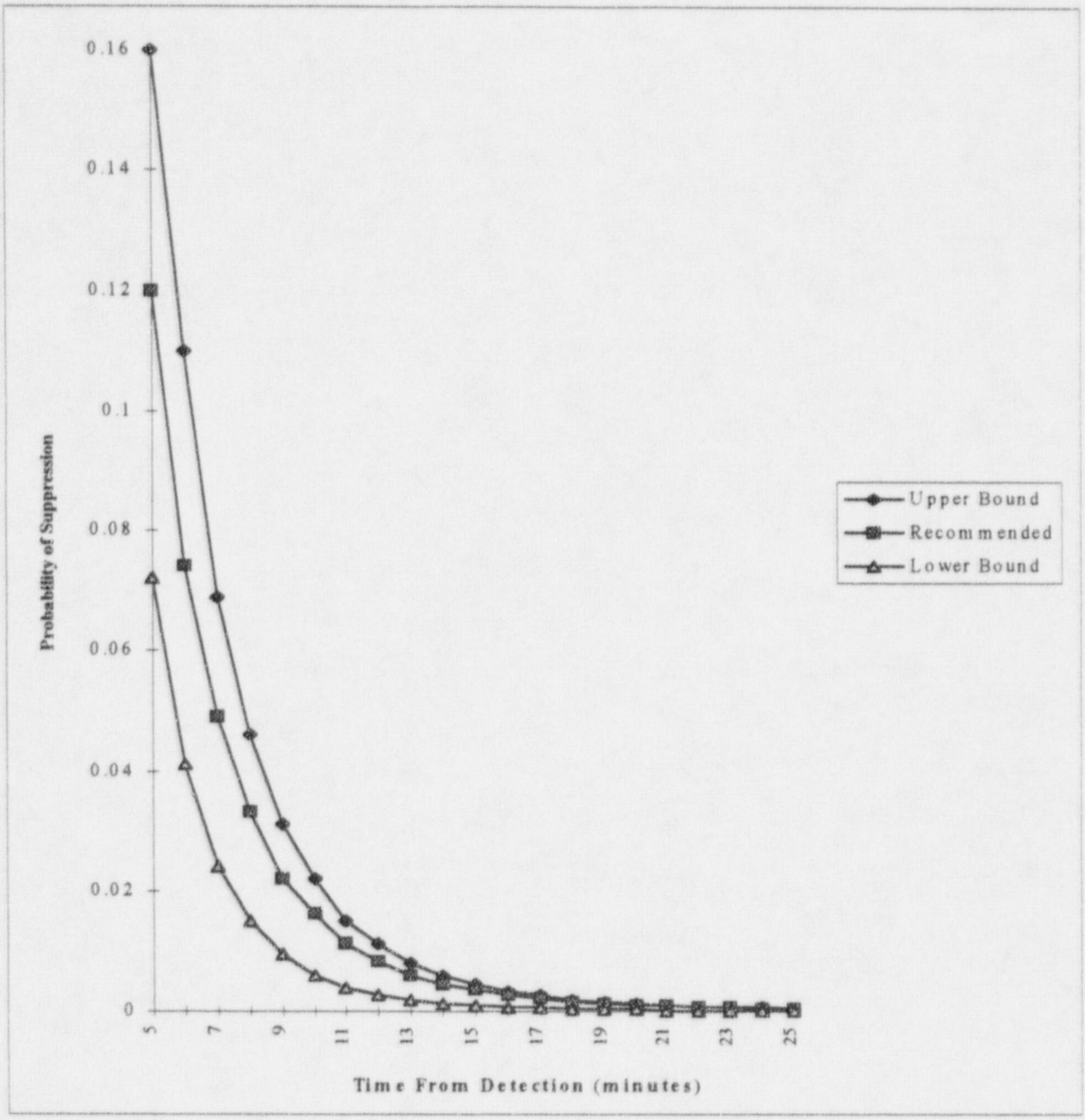


Figure 4.5-2: Control Room Fire Manual Suppression Time Reliability Curve

Step 9 - Calculate the conditional probability of core damage (CCDP) for the control room evacuation cases.

For the control room evacuation case, the CCDP reflects the capability of the two trains on the remote shutdown panel. The conditional probability of core damage for remote shutdown panel operation was calculated to be 9.78×10^{-3}. This CCDP represents what in essence is failures of two redundant trains or crew failure to successfully bring the plant to hot shutdown and maintain it when one or more safe shutdown trains is available. The hardware portion of this CCDP is 1.61×10^{-7}, and is the CCDP for CR-3 given a loss of main feedwater. If a loss of offsite power accompanied by a loss of auto-initiation of the diesel generators, then the hardware portion of the CCDP is 3.24×10^{-3}. For the control room evacuation calculation, this CCDP was used instead of the less conservative loss of main feedwater CCDP. The remote shutdown panel possesses considerable control over the functions needed to achieve and maintain a safe hot shutdown. There are, however, some human challenges associated with any evacuation scenario: the need for increased local, manual operator actions, the stress of operating from a backup control station, the complications associated with the evacuation, and the stress of the fire itself. For the human error analysis, the dynamic human error curve from the time-reliability curves (TRCs) used in the CR-3 IPE for rule-based/conflict was used. For the relevant time, the worst case was used: station blackout with EFP-2 failure, leaving the operators 50 minutes for recovery. Assuming ten minutes for performance of any recovery, the 40-minute number for the relevant TRC is 9.78×10^{-3}. For the control room analysis, this probability was used for the overall probability of the operating crew failing to accomplish a successful evacuation and successful transition to hot shutdown from the remote shutdown panel. It is very conservative since only a very small percentage of the control room fire cutsets will involve a station blackout with immediate failure of EFP-2. Combining the human and hardware CCDPs yields a total control room evacuation CCDP of 1.3×10^{-2}.

Step 10 - Evaluate fire effects on adjacent cabinets.

For the MCB, fires affecting more than one panel section were specifically evaluated and discussed in Step 4. Fires damaging adjacent cabinets outside the MCB were not considered a significant contributor to risk. First, such fires would need to be fully developed. The time to full development is very similar to the time predicted for evacuation as based on the Sandia cabinet tests. Therefore, the probability of non-suppression before damage to adjacent cabinets is also low, e.g., the probability of non-suppression at 15 minutes is 3.4×10^{-3}. Since the consequences of damage are bounded by the control room evacuation case, no analysis was deemed necessary.

Results

The control room fire core damage frequency for CR-3 is a combination of the results from the "evacuation scenario" and the "critical cabinet scenario." The evacuation scenario contribution is:

$$CDF_{evac} = (9.5 \times 10^{-3}/yr)(3.4 \times 10^{-3})(1.3 \times 10^{-2})$$

$$= 4.2 \times 10^{-7}/yr$$

The critical cabinet scenario contribution is:

$$CDF_{ccab} = (4.3\times10^{-5}/yr)(3.24\times10^{-3}) + \quad \text{(Electric Distribution Panel contribution)}$$
$$(4.1\times10^{-6}/yr)(3.24\times10^{-3}) \quad \text{(Electric Power Relay Panel contribution)}$$

$$= 1.5\times10^{-7}/yr$$

The total core damage frequency for the CR-3 control room is the sum of CDF_{evac} and CDF_{ccab}, or 5.7×10^{-7} per year. The low CDF reflects the quality of the plant's control room fire procedures as well as the plant's remote shutdown capability, specifically the ability to monitor and control the use of two redundant safe shutdown paths. The low CDF also reflects the CR-3 plant design whose multiple means of attaining plant shutdown make it particularly difficult for a fire to spread to important components in multiple divisions. The conditional core damage probabilities indicate the strength of the above two factors.

Cable Spreading Room

Fires in the cable spreading room are treated in a somewhat similar manner as the control room fires. The difference is that loss of control is caused by direct fire damage to cable rather than smoke obscuration, and that there are no fixed ignition sources in the cable spreading room, only a transient fire source.

A simplified approach was taken for the cable spreading room because of the low risk involved. A sensitivity study was performed to show one possible outcome of a more detailed analysis. The difficulty of a detailed analysis of the cable spreading room is that it involves a large amount of work to identify cable targets. As was indicated by the control room analysis, a significant amount of controls must be failed to cause evacuation due to loss of control. However, to be sure that those controls are not affected quickly by a transient source, cables in trays must be identified and evaluated. Since the cable trays in the room are close to the floor, a normal transient fuel package will damage one or more trays virtually in every location. In effect, the analysis could involve identifying a large number of fire scenarios and a time-consuming evaluation of each. As an alternative, the risk presented assumes loss of control for every fully developed transient fire, while a sensitivity study shows the risk assuming that the fraction of fires causing loss of control is similar to another PWR.

The transient fire ignition frequency for a fully-developed fire in the cable spreading room is 9.73×10^{-5}/yr. The CCDP associated with this scenario is 1.3×10^{-2}. Therefore, the total core damage frequency for a fire in the cable spreading room is:

$$CDF_{csr} = CDF_{evac} + CDF_{noevac}$$

$$CDF_{evac} = (9.73\times10^{-5}/yr)(1.3\times10^{-2})$$
$$= 1.26\times10^{-6}/yr$$

$$CDF_{noevac} = 0 \text{ (assumed)}$$

$$\begin{aligned} CDF_{csr} &= 1.26\text{x}10^{-6}/\text{yr} + 0 \\ &= 1.26\text{x}10^{-6}/\text{yr} \end{aligned}$$

Since this calculation assumes a loss of offsite power, loss of auto-initation of the diesel generators, and control room evacuation for any fire in the cable spreading room, the CDF_{csr} of $1.26\text{x}10^{-6}$/yr is considered a bounding value.

The sensitivity study presumes that only a small fraction of the cable spreading room floor area can result in a transient fire quickly causing loss of control. The Seabrook fire PRA found that less than 3% of the floor area could cause such damage. In addition to this scenario, other transient fires could cause loss of control if the fire spread significantly or if a hot gas layer occurred. Operation of the halon system would prevent such damage. Therefore, the sensitivity study considers the loss of control to be the sum of two scenarios, direct damage and hot gas layer.

The probability of non-suppression for the halon system in the cable spreading room is 0.05. Therefore, the frequency of a hot gas layer in the cable spreading room is $(9.73\text{x}10^{-5}/\text{yr})(5\text{x}10^{-2}) = 4.9\text{x}10^{-6}/\text{yr}$. The frequency of a transient fire causing loss of control, but with no resulting hot gas layer is $(9.73\text{x}10^{-5}/\text{yr})(0.03)(1-0.05) = 2.8\text{x}10^{-6}/\text{yr}$. For the non-evacuation scenarios, the CCDP is assumed to be that for the control room station blackout scenario but without the human errors associated with an evacuation, $3.24\text{x}10^{-3}$. For the hot gas layer scenarios, the control room CCDP of $1.3\text{x}10^{-2}$ was assumed.

The results of the sensitivity study are:

$$CDF_{csr} = CDF_{evac} + CDF_{noevac}$$

$$\begin{aligned} CDF_{evac} &= (9.73\text{x}10^{-5}/\text{yr})(5\text{x}10^{-2})(1.3\text{x}10^{-2}) \\ &= 6.3\text{x}10^{-8}/\text{yr} \end{aligned}$$

$$\begin{aligned} CDF_{noevac} &= (9.73\text{x}10^{-5}/\text{yr})(0.03)(1-0.05)(1.3\text{x}10^{-2}) \\ &= 3.6\text{x}10^{-8}/\text{yr} \end{aligned}$$

$$\begin{aligned} CDF_{csr} &= 6.3\text{x}10^{-8}/\text{yr} + 3.6\text{x}10^{-8}/\text{yr} \\ &= 9.9\text{x}10^{-8}/\text{yr} \end{aligned}$$

This CDF_{csr} is much more likely to be representative of the actual CR-3 cable spreading room core damage frequency than the bounding value calculated previously.

4.5.7 Multi-Compartment Fires

The risk of a multi-compartment scenario is generally associated with the risk of hot gases spreading from one compartment to another. Propagation is unlikely because compartment boundaries are generally not combustible, and combustibles, like cable trays, are generally sealed when they cross compartment boundaries.

The following steps were performed for each unscreened fire zone:

1. Fire zones capable of producing a damaging hot gas layer (HGL) with a frequency of greater than 1×10^{-6} per year were identified.
2. All applicable multi-compartment fire scenarios, i.e., adjacent zones, were identified.
3. Barrier failure probabilities were calculated.
4. Multi-compartment scenarios with combined frequencies of less than 1×10^{-6} per year were screened.
5. Unscreened multi-compartment scenarios were examined in more detail.

Hot gases cannot spread from one compartment to another if no hot gas layer (HGL) forms in the exposing compartment. In the first step, fire modeling identifies which fire zones have a HGL frequency of greater than 1×10^{-6} per year. For CR-3, these fire zones are listed in Table 4.5-8.

Table 4.5-8
CR-3 Fire Zones with HGL Frequency > 1×10^{-6}/yr

Zone	Description	HGL Ignition Frequency
CC-108-106	BATTERY CHARGER ROOM 3A	1.07E-04
CC-108-108	4160V ES SWITCHGEAR BUS ROOM 3A	4.02E-05
CC-124-117	480V ES SWITCHGEAR BUS ROOM 3A	3.17E-05
CC-124-116	480V ES SWITCHGEAR BUS ROOM 3B	2.89E-05
CC-108-107	4160V ES SWITCHGEAR BUS ROOM 3B	2.34E-05
CC-108-109	INVERTER ROOM 3B	1.42E-05
CC-108-105	BATTERY CHARGER ROOM 3B	1.00E-05
CC-108-102	HALLWAY AND REMOTE SHUTDOWN ROOM	9.14E-06
CC-124-111	CRD & COMMUNICATION EQUIP ROOM	1.58E-06

For each compartment with an HGL frequency of greater than 1×10^{-6} per year, the compartments adjacent to, above, and below the exposing compartment were identified. These compartments were examined to screen out those which could not support a hot gas layer. Walkdowns of the unscreened exposed compartments were performed to determine the number and types of fire barriers between the exposing and exposed compartments.

Barrier failure probabilities were calculated for each "exposing compartment - exposed compartment" combination. The types and number of each type of barrier were determined for each combination, and these were summed to determine a total barrier failure probability. The data for the barrier type failure probabilities were taken from NUREG/CR-4840, shown in Table 4.5-9.

Table 4.5-9
Fire Barrier Failure Probabilities

Barrier Type	Description	Barrier Failure Probability/Demand
1	Fire, security, and water tight doors	7.4×10^{-3}
2	Fire and ventilation dampers	2.7×10^{-3}
3	Penetration seals, fire walls	1.2×10^{-3}

The barrier failure probabilities for each "exposing compartment - exposed compartment" combination were multiplied by the relevant exposing compartment HGL frequencies obtained from the fire modeling to determine the multi-compartment fire frequency for each. The results of this step are shown in Table 4.5-10.

The only exposing compartment with multi-compartment fire frequencies greater than 1×10^{-6} per year was CC-108-106. The total multi-compartment fire frequency for all of the CC-108-106 combinations is 4.40×10^{-6} per year.

The results for CC-108-106 were further examined to determine the impact on plant equipment. That is, what is the impact on the CCDP of a barrier failure. Of the four scenarios, two involve hot gases spreading to rooms with "A" train equipment, two involve rooms with "B" train equipment. CC-108-106 includes unprotected "A" train equipment and Thermo-Lag wrapped "B" train equipment, the failure of both resulting in a CCDP of 1.0.

For the two scenarios involving "A" train exposed compartments, the generation of a hot gas layer causes no more damage than a hot gas layer in the exposing compartment. For the two scenarios involving "B" train exposed compartments, the generation of a hot gas layer damages circuits that are protected by Thermo-Lag in CC-108-106. Hence, failure of the barrier is functionally similar to failure of the wrap. The impact on risk from the barrier failure depends on whether suppression is more likely before the wrap fails or more likely before the "B" train circuit fails when the barrier has failed and exposed it to the spread of hot gases.

The compartments connected to CC-108-106 are much larger. Therefore, a hot gas layer occurs much later in both compartments than it does in CC-108-106 alone. Times to a 700°F hot gas layer are approximately 70 to 90 minutes versus 25 minutes. Since the wrap is presumed to last roughly 60 minutes (for three-hour Thermo-Lag) more than the time to hot gas layer development (25 minutes in CC-108-106 alone), the time to circuit failure is similar regardless of whether the barrier fails. For this reason, the barrier has little impact on risk. Consequently, multi-compartment fire risk at CR-3 is insignificant.

Table 4.5-10
Multi-Compartment Fire Frequencies

Exposing Zone	HGL Frequency	Exposed Zone	Above/ Below Exposing Zone (A/B)	Total Type 1 Barriers	Total Type 2 Barriers	Total Type 3 Barriers	Effective Type 1 Barriers	Effective Type 2 Barriers	Effective Type 3 Barriers	Composite Barrier Failure Probablity (CBFP)	Compartment Fire Frequency (IGF*CBFP)
CC-108-102	9.14E-06	CC-108-107		1		1			1	1.20E-03	1.10E-08
	9.14E-06	CC-108-105		1		1			1	1.20E-03	1.10E-08
	9.14E-06	CC-108-103		1		1			1	1.20E-03	1.10E-08
	9.14E-06	CC-124-111	A			1			1	1.20E-03	1.10E-08
		Total									4.39E-08
CC-108-105	9.14E-06	CC-108-108				1			1	1.20E-03	1.10E-08
	9.14E-06	CC-108-102		1		1			1	1.20E-03	1.10E-08
	9.14E-06	CC-108-106		1	1	1		1	1	3.90E-03	3.57E-08
	9.14E-06	CC-108-103		1	1	1		1	1	3.90E-03	3.57E-08
	9.14E-06	CC-108-106			1	1		1	1	3.90E-03	3.57E-08
	9.14E-06	CC-124-114	A			1			1	1.20E-03	1.10E-08
	9.14E-06	CC-124-115	A			1			1	1.20E-03	1.10E-08
		Total									1.51E-07
CC-108-106	1.07E-04	CC-108-104		1	1	1	1		1	8.60E-03	9.23E-07
	1.07E-04	CC-108-109		1		1	1	1	1	1.13E-02	1.21E-06
	1.07E-04	CC-108-110		1	1	1	1	1	1	1.13E-02	1.21E-06
	1.07E-04	CC-108-105		1	1	1	1		1	8.60E-03	9.23E-07
	1.07E-04	CC-124-111	A			1			1	1.20E-03	1.29E-07
		Total									4.40E-06
CC-108-107	2.34E-05	CC-108-102		1	1	1		1	1	3.90E-03	9.13E-08
	2.34E-05	CC-108-108		1	1	1			1	1.20E-03	2.81E-08
	2.34E-05	CC-124-111	A			1			1	1.20E-03	2.81E-08
		Total									1.47E-07
CC-108-108	4.02E-05	CC-108-107		1		1			1	1.20E-03	4.83E-08
	4.02E-05	CC-108-109		1		1			1	1.20E-03	4.83E-08
	4.02E-05	CC-108-105				1			1	1.20E-03	4.83E-08
	4.02E-05	CC-124-111	A			1			1	1.20E-03	4.83E-08
	4.02E-05	CC-124-117	A			1			1	1.20E-03	4.83E-08
		Total									2.41E-07
CC-108-109	1.42E-05	CC-108-110		1		1	1		1	8.60E-03	1.22E-07
	1.42E-05	CC-108-106		1		1	1		1	8.60E-03	1.22E-07
	1.42E-05	CC-108-108		1		1	1		1	8.60E-03	1.22E-07
	1.42E-05	CC-124-111	A			1			1	1.20E-03	1.70E-08
		Total									3.83E-07
CC-124-111	1.58E-06	CC-124-112				1			1	1.20E-03	1.89E-09
	1.58E-06	CC-124-113				1			1	1.20E-03	1.89E-09
	1.58E-06	CC-124-114		1		1			1	1.20E-03	1.89E-09
	1.58E-06	CC-124-115			1	1			1	1.20E-03	1.89E-09
	1.58E-06	CC-124-116		1	2	1		2	1	6.60E-03	1.04E-08
	1.58E-06	CC-124-117		1	2	1		2	1	6.60E-03	1.04E-08
	1.58E-06	CC-134-118A	A		2			2	1	6.60E-03	1.04E-08
		Total									3.88E-08
CC-124-116	2.89E-05	CC-124-117				1			1	1.20E-03	3.47E-08
	2.89E-05	CC-124-111		1	2	1		2	1	6.60E-03	1.91E-07
	2.89E-05	CC-134-118A	A			1			1	1.20E-03	3.47E-08
		Total									2.60E-07
CC-124-117	3.17E-05	CC-124-116				1			1	1.20E-03	3.81E-08
	3.17E-05	CC-124-111		1	2	1		2	1	6.60E-03	2.09E-07
	3.17E-05	CC-134-118A	A			1			1	1.20E-03	3.81E-08
		Total									2.86E-07

4.6 Analysis of Containment Performance

In Chapter 4 of NUREG-1407, it states, "For purposes of an IPEEE, a Level 1 probabilistic risk assessment (PRA) is considered acceptable to identify potential internal fire vulnerabilities at nuclear power plants." In Section 4.1.5. Perform Containment Analysis, it states, "Perform containment analysis if containment failure modes differ significantly from those found in the IPE internal events evaluation." In response to this guidance, the CR-3 fire zones with the largest contribution to the overall fire core damage risk, i.e., those listed in Table 4.5-4, were examined to see if any might border on the containment, thereby possibly causing a burn-through of an electrical penetration, a seal on a containment hatch, or some other containment penetration. Since all of the fire zones with a CDF of greater than $1x10^{-6}$ per year are located in the control complex, none are adjacent to the containment. Therefore, any fire which could possibly cause a containment integrity failure would not be in a zone in which there was a significant potential for core damage due to the fire.

4.7 Treatment of Fire Risk Scoping Study Issues

Sandia Fire Risk Scoping Evaluation

Background

Sandia National Laboratories, as part of their Fire Protection Research Project, undertook two tasks in what is now referred to as the Fire Risk Scoping Study:

1. Review and update the perspective of fire risk in light of the information developed through the Fire Protection Research Project.

2. Identify and perform initial investigations of any potential unaddressed issues of fire risk.

Sandia reviewed four previously completed fire PSAs. The PSA risk scenarios were requantified using the data and information from the Fire Protection Research Project as a basis and included plant modifications made in response to implementations of Appendix R requirements at the plants under study. In performing this second task, Sandia developed a list of issues which they felt represented potential contributors to fire risks that had not been adequately addressed in previous risk assessments. Sandia concluded from these reassessments that fire may represent a dominant contributor to plant core damage risk and that these six issues should be addressed in future risk assessments.

The draft Sandia report was made available to several plant designers, fire researchers, industry representatives, fire protection consultants and regulators. They were asked to review the report and to ensure that, as far as practical, the list of unaddressed issues was complete. The most important industry response, provided to Sandia by the Edison Electric Institute Fire Protection Committee, was that "these issues are unaddressed by the <u>selected</u> method of risk evaluation and do not (necessarily) represent unaddressed risk issues for nuclear plants . . . this document is a report on the inadequacy of current risk assessment and research methodology for fire. There is no basis presented to indicate that regulatory requirements or implemented levels of fire protection are inadequate."

Sandia/NRC Fire Risk Scoping Study Issues. The NRC staff has requested that the following six issues be addressed in any future fire evaluation methodology:

1. Seismic/Fire Interactions
2. Fire Barrier Qualifications
3. Manual Fire fighting Effectiveness
4. Total Environment Equipment Survival
5. Control Systems Interactions
6. Improved Analytical Codes

The six issues are discussed individually below.

Issue 1 - Seismic/Fire Interactions. This issue involves three concerns: (1) seismically-induced fires, (2) seismic actuation of fire suppression systems, and (3) seismic degradation of fire suppression systems. The nuclear industry feels that these types of events would not significantly contribute to an increase in external event core-damage frequency. In CR-3's case, the fact that central Florida is a region of extremely low seismicity strengthens this argument. In the EPRI Project Report, "Probabilistic Seismic Hazard Evaluation for Crystal River Nuclear Generating Plant," Project RP 101-53, April 1989 (Reference 4-14), the frequency associated with the 0.1g SSE earthquake was calculated to be 1.6×10^{-5} per year. This frequency, by itself, is so low that any consideration at all given to the probability of all of the other events which would have to occur in order to result in a core damage accident renders the threat of seismic/fire interactions relatively insignificant. Additional issue-specific insights are given below.

1. ***Seismically-Induced Fires.*** A recent survey of over 100 plant and industrial facilities after 18 major earthquakes indicates that earthquakes generally do not cause fires in such facilities (EPRI-NP 6989, "Survey of Earthquake-Induced Fires in Electrical Power and Industrial Facilities," Reference 4-15).

2. ***Seismic Actuation of Fire Suppression Systems.*** The effects of inadvertent suppression system actuation have been previously considered as part of the internal flooding design analysis.

3. ***Seismic Degradation of Fire Suppression Systems.*** A report investigating this subject, "Performance of Fire Protection Systems Under Post-Earthquake Conditions" (Reference 4-16), concluded that fire suppression systems installed in accordance with nationally-recognized codes and standards generally provide an adequate level of support for piping under seismic conditions. At CR-3, all piping for the Appendix R sprinkler system is seismically supported.

Issue 2 - Fire Barrier Qualifications. This issue is concerned with determining and quantifying the effectiveness of fire barriers to contain a fire. The NRC staff's main concern seems to be with regard to the installation and maintenance of penetrations through fire barriers that are protected by fire dampers, fire doors and fire-rated penetration seal assemblies. However, rated fire barriers should be accepted as being effective if plants demonstrate their fire barriers and associated barrier components are being adequately designed, inspected, tested and maintained. At CR-3, all fire barrier penetrations are inspected every 18 months per procedure SP-407, "Fire Barrier Penetration Seals."

The nuclear industry believes that properly designed and installed fire barriers are adequate to contain the types of fires expected in nuclear power plants and that rigorous surveillance, testing, and maintenance of fire barrier components (i.e., fire doors, fire dampers and penetration seal assemblies) provide an acceptable basis for demonstrating a high level of reliability of barrier effectiveness. Any potential installation problems with fire damper operations and fire penetration seal assemblies of concern to the NRC should be considered compliance issues.

Item II of the Sandia Fire Risk Scoping Study Evaluation (Table 4.7-1) provides a number of attributes of an acceptable fire barrier program. These attributes are addressed below.

II. FIRE BARRIER QUALIFICATIONS

Fire Barriers

1. Fire barriers and components such as fire dampers, fire penetration seals, and fire doors for fire barriers considered in the FIVE Methodology are included in the plant surveillance program.

   The penetration fire barriers are a passive element in the facility fire protection program and are subject to periodic inspection.

Fire Doors

2. A fire door inspection and maintenance program.

   Safety-related area access fire doors and those fire doors in rated fire walls required to assure safe shutdown are surveyed under SP-805A, "Annual Inspection of Plant Fire Doors." Each of the fire doors listed in SP-805A is verified to be functional by an inspection on an annual basis. Also included in SP-805A are drawings showing the location of each fire door. Inspection criteria included in SP-805A meets the guidelines provided in NFPA 80, 1983.

Penetration Seal Assemblies

3. A penetration seal inspection and surveillance program.

   Verification of the physical condition of a penetration seal is needed in order to ensure that the seal functions as an approved fire barrier. Fire barrier penetration seals separating plant fire areas or providing separation to assure safe shutdown is achieved in the event of a fire are verified to be functional by a visual check of 10% of the seals at least once per eighteen 18 months. SP-407, "Fire Barrier Penetration Seals," addresses the requirements for the eighteen (18) month surveillance inspection. SP-407 identifies physical conditions that are considered unacceptable and, as such, would require a seal to be considered inoperable.

4. Fire barrier penetration seals have been installed and maintained to address concerns such as those identified in NRC Information Notice No. 88-04.

   Procedure MP-805, "Sealing of Penetrations," addresses the installation and documentation instructions for the various penetration seal assemblies. Also included in MP-805 are acceptance criteria and limitations for the penetration seals as well as qualifications of the installers.

Fire Dampers

5. An inspection and maintenance program for fire dampers.

   Fire dampers are inspected annually in accordance with Procedure SP-607, "Fire Damper Inspection." 10% of the fire damper inventory is selectively drop-tested each inspection cycle except for fire dampers in the Cable Spreading Room which are functionally tested (ETL activation and damper drop) at least once each eighteen months in accordance with SP-501B, "Halon System Functional Check." SP-501B verifies actuation of automatic fire dampers associated with the Halon System.

6. Damper installations address concerns such as those identified in NRC Information Notice No. 89-52, "Potential Fire Damper Operational Problems," dated June 8, 1989 and NRC Information Notice No. 83-69, "Improperly Installed Fire Dampers at Nuclear Power Plants," dated October 21, 1983.

   Both of these Information Notices were evaluated. For IN 89-52, tests were run on all fire dampers. The two dampers which did not meet the test's acceptance criteria were modified. IN 83-69 reported an incident which occurred at CR-3. The improperly installed fire dampers were replaced and installed properly.

Issue 3 - Manual Fire Fighting Effectiveness. Item III of the Sandia Fire Risk Scoping Evaluation (Table 4.7-1) provides a number of attributes of an acceptable fire brigade training and preparedness program. A discussion of CR-3's fire brigade training program and preparedness program and how it accomplishes these desired attributes is given below.

III. MANUAL FIREFIGHTING EFFECTIVENESS

Reporting Fires

1. Appropriate plant personnel knowledgeable in the use of portable fire extinguishers.

   Plant personnel receive training on the use of portable fire extinguishers in fire brigade training, fire watch training, and/or general employee training, depending on their role in responding to a fire.

2. Portable extinguishers located throughout the plant.

   Portable fire extinguishers are located throughout the site area to provide incipient fire fighting capabilities. Fire extinguishers at CR-3 are any one of the following types:

   - *ABC Dry Chemical (includes portable hand and two portable wheeled 150-lb extinguishers)*
   - *Purple K-2 portable wheeled 300-lb extinguishers*
   - *Carbon Dioxide*
   - *Halon 1211*

3. A plant procedure for reporting fires in the plant.

   EM-201, "Duties of an Individual Who Discovers an Emergency" defines the actions to be taken by an individual who discovers a fire emergency. This procedure is reviewed as a part of General Employee Training.

4. A plant communication system that includes contact to the control room.

   The PAX plant-dedicated phone system can be used to report any emergency to the control room by dialing 311. Operators always carry radios. Regular phones are also available in the office spaces within the plant.

Fire Brigade

1. A fire brigade made up of at least five trained people on each shift?

   A Shift Fire Brigade team of at least five members is maintained onsite at CR-3 at all times.

2. The brigade leader and at least two other brigade members on each brigade shift are knowledgeable in plant systems and operations?

   The brigade leader is normally the assistant nuclear shift supervisor or the chief nuclear operator. At least one of the other members is an operator, and one or more of the remainder of the members is knowledgeable in plant systems and operations.

3. Each brigade member receives an annual review of physical condition to evaluate his ability to perform fire fighting activities.

   Fire Brigade members are required to be physically fit and adequately trained before they may serve on the brigade. Physical exams are conducted annually.

4. Minimum equipment provided for the brigade includes the following:

   a. Personal protective equipment such as SCBA, turnout coats, boots, gloves and hard hats.

   b. Emergency communications equipment.

   c. Portable lights.

   d. Portable ventilation equipment.

   e. Portable extinguishers.

Equipment is provided for Fire Brigade use in responding to fire emergencies. Fire brigade equipment is selected and maintained utilizing guidance included in NFPA 600-1986 (formerly NFPA 27) and OSHA Standards 29 CFR 1910 Subpart L. The Senior Nuclear Fire Protection Specialist ensures that this equipment is readily accessible to Fire Brigade members by determining the specific plant areas in which equipment should be stored in order to support the Pre-Fire Plan strategies. Lockers containing the appropriate equipment are located in these areas. Equipment essential to the function of the Fire Brigade is not shared with other organizations at CR-3.

Fire Brigade equipment includes:

- *Turnout Gear*
- *Respiratory Protection Equipment*
- *Hi Rise Packs*
- *Communications Equipment*
- *Foam Carts*
- *Fire Carts*
- *Wheeled Portable Fire Extinguishers*

Turnout Gear

Fire Brigade turnout gear meets the requirements of OSHA Title 29, Subpart L, Section 1910.155. Turnout gear is located in equipment lockers in the plant area and consists of, but is not limited to:

- *Helmet with attached shield*
- *Short boots*
- *Coat with inside liner attached*
- *Bunker pants with liner attached*
- *Gloves*
- *Hood*

Turnout gear is available in sufficient quantity to support Fire Brigade response to a fire. An inventory and inspection of the turnout gear is performed by SP-804, "Surveillance of Plant Fire Brigade Equipment," to assure acceptable quantity and condition of the turnout gear. SP-804 also identifies the location of the turnout gear equipment lockers.

Personal Alert Safety System

Each member involved in rescue, fire suppression, or other hazardous duties is provided with a Personal Alert Safety System device in the hazardous area per NFPA 1500, Standard on Fire Department Occupational Safety and Health Program

Respiratory Protection Equipment

Breathing apparatus used at CR-3 are Self-Contained Breathing Apparatus (SCBA) positive pressure units as required by OSHA Title 29, Subpart L, Section 1910.156, and B.T.P.9.5-1 Appendix A. There are at least ten SCBA units dedicated for Fire Brigade members to use in the event of a fire emergency. There are also a minimum of eleven (11) full back-up cylinders. The Senior Nuclear Fire Protection Specialist designates the appropriate location for the ten (10) required SCBA units. Specific locations are identified in SP-804, "Surveillance of Plant Fire Brigade Equipment." SCBAs with extra air cylinders are located on fire carts and brought to the fire scene during the initial response. SCBAs and spare cylinders are filled from an on-site air compressor/cascade system. Weekly inventory inspection of SCBAs is required and performed by SP-804, "Surveillance of Plant Fire Brigade Equipment." The SCBAs are functionally tested monthly. Maintenance, functional test, and repair requirements and frequencies are controlled and performed by procedure HPP502, "Respirator Inspection and Maintenance."

Hi Rise Packs

Hi rise packs consist of a pack with at least 50 feet of fire hose with a nozzle packed inside. One pack is designated for use in the event of a fire inside the Reactor Building. Other packs, located on the fire carts, are available to provide extra hose in the event an extension or replacement hose is necessary while fighting a fire.

Communications Equipment

Four portable radios dedicated for Fire Brigade use are located in the Fire Brigade equipment room or in the possession of Shift Fire Brigade Team Members during their shift. The radios are inventoried and checked for proper operation on a weekly basis. This surveillance is performed in accordance with SP-804, "Surveillance of Plant Fire Brigade Equipment."

Additional Equipment

Hose and selected fire fighting tools, including two deluge guns each capable of delivering 2000 gpm, are located in hydrant houses throughout the protected area. Also, fire carts, foam carts, and wheeled portable fire extinguishers are located within the power block.

Fire Brigade Training

5. Brigade members receive an initial classroom instruction program consisting of the following:

    a. Review of the plant fire fighting plan and identification of each individual's responsibilities.

    b. Identification of typical fire hazards and associated types of fires that may occur in the plant.

    c. Identification of the location of fire fighting equipment and familiarization with the layout of the plant, including access and egress routes.

d. The proper use of available fire fighting equipment and the correct method of fighting each type of fire. The types of fires covered include fires in energized electrical equipment, fires in cables and cable trays and fires involving flammable and combustible liquids and gases.

e. The proper use of communication, lighting, ventilation and emergency breathing equipment.

f. Fighting fires inside buildings and confined spaces.

g. Review of fire fighting strategies and procedures.

The minimum initial training requirements for a Fire Brigade Member are:

- *Completion of General Employee and Respirator Training.*
- *Thirty-two (32) hours of classroom instruction in fire fighting fundamentals.*
- *Twenty four (24) hours of Hands-On-Training.*
- *Participation in a plant fire protection familiarization walk through and an initial fire drill.*
- *Self-Contained Breathing Apparatus Training.*

Topics discussed in the Fire Brigade initial training program include, but are not limited to:

- *Fire Science and Behavior*
- *Fire Hose and Hose Handling*
- *Fundamentals of Fire Extinguishment*
- *Portable Extinguishers*
- *Ventilation*
- *Salvage and Overhaul*
- *Emergency Lighting*
- *Search and Rescue*
- *Fire Detection and Suppression Systems*
- *Hazardous Materials*
- *Pre-fire Planning*

Practice

6. Fire brigade members receive hands-on structural fire fighting training at least once per year to provide experience in actual fire extinguishment and the use of emergency breathing apparatus.

Fire brigade members receive hands-on structural fire fighting training annually using FPC's own "burn" building.

Drills

7. Fire brigade drills are performed in the plant so that each fire brigade shift can practice as a team.

   Each fire brigade shift is allowed to practice as a team during the drills.

8. Drills performed at regular intervals for each shift fire brigade.

   Fire drills are held quarterly for each operating shift.

9. At least one unannounced fire drill for each shift fire brigade performed per year.

   At least one drill per year for each shift is unannounced.

10. At least one drill per year performed on the "back-shift."

    At least one drill per year is performed on the "back-shift."

11. Drills pre-planned to establish training objectives and critiqued to determine how well the training objectives have been met?

    Drills are pre-planned and critiqued to establish that the training objectives have been met.

    AI-2205, "Administration of CR-3 Fire Brigade Organization," establishes the fire drill program at CR-3. Included in this procedure is a discussion of the purpose, scheduling, type (announced versus unannounced), evaluation and documentation of fire drills.

12. At least once every three years, an unannounced drill is performed for and critiqued by qualified individuals independent of the licensee's staff.

    At three-year intervals, a drill is reviewed by a qualified outside fire protection consultant.

13. Pre-fire plans are developed for safety-related areas of the plant (as a minimum).

    See response to 14.

14. The pre-fire plans are updated and used as part of the brigade training.

    Pre-fire plans provide tactical and strategy guidelines and information for combating fires in all areas of the CR-3 plant. The Pre-fire plans are stand alone documents and are updated periodically as conditions warrant. The Pre-fire plans contain, but may not be limited to the following subjects:

    - *Identification of major in-situ combustibles in each fire zone.*
    - *Fire extinguishment best suited for the fires associated with the combustible loading in that zone and their locations.*
    - *Ventilation, access and command posts.*
    - *Access and egress routes involving locked doors*
    - *Designation of plant systems that should be managed to reduce the damage potential during a local fire; location of local and remote controls for such management*

- *Designation of vital heat-sensitive system components that should be kept cool while fighting a local fire*
- *Critical equipment which are particularly hazardous combustible sources and should be kept cool*
- *Identification of radiological and toxic hazards in fire zones*
- *Ventilation system operation that assures desired plant pressure distribution when the ventilation flow is modified for fire containment or smoke clearing operations.*

Administration of the pre-fire plans is directed by Site Nuclear Services as detailed in AMI-06, "Preparation and Control of the CR-3 Pre-Fire Plans."

15. Fire brigade equipment is maintained.

Each portable extinguisher is inspected monthly by SP-800, Monthly Fire Extinguisher Inspection, to determine that the extinguisher is available and operable. All portable extinguishers have an annual maintenance inspection per Florida State Rules and Standards to provide assurance that they will operate effectively and safely. This inspection, performed by SP-800A, Annual Fire Extinguisher Inspection, includes a thorough examination and any necessary repair, recharging, and/or replacement.

Records

16. Records are provided for each fire brigade member demonstrating the minimum level of training and refresher training has been provided.

Training records are maintained to assure that each member received the proper training.

Issue 4 - Total Environment Equipment Survival. The NRC staff has expressed three major concerns regarding this issue:

1. The potential for adverse effects on plant equipment caused by combustion products released from the fire causing damage, and possible loss of safe shutdown functions.
2. The spurious or inadvertent actuation of fire suppression systems resulting in the loss of safe shutdown functions.
3. Operator effectiveness in performing manual safe shutdown actions and potential misdirected suppression effects in smoke-filled environments.

With regard to item 1 above, there have not been enough studies performed with respect to non-thermal fire effects on industrial plant equipment to adequately quantify the potential problems and identify solutions each utility should consider for those problems. The FIVE methodology does not currently allow for an evaluation of non-thermal environmental effects of smoke on equipment. However, the detrimental short-term effects of smoke on equipment are not believed to be significant.

With regard to item 2, NRC staff is currently investigating this concern in Generic Safety Issue (GSI) 57, "Effects of Fire Protection Systems Actuation on Safety-Related

Equipment." Industry investigation of 75 LERs cited in the Draft NUREG/CR-5432 prepared by Sandia National Laboratories as instances of inadvertent actuations found only 13 involved damage to safety-related equipment. Of these 13 events, none involved a situation where the redundant equipment was lost, much less loss of safe shutdown capability. Furthermore, all of the automatic suppression systems in the CR-3 fire zones which use water as the extinguishing agent are actuated by heat from the fire and will not spuriously actuate from smoke or combustion products.

To assist the operator in the performance of safe shutdown manual actions should he/she have to pass through or perform manual actions in plant areas where fire or smoke may be present, portable lights and SCBAs are readily available.

CR-3 procedures AP-880, "Fire Protection," AP-990, "Shutdown from Outside Control Room," and OP-880, "Fire Service System" all provide guidance to the operator in the event of a fire. Given a fire in a particular location, these procedures will inform the operator of what safe shutdown equipment may be unavailable, what safe shutdown equipment may require manual operation, and what safe shutdown equipment should be unaffected.

Issue 5 - Control Systems Interactions. The intent of this issue is to verify the ability to achieve safe shutdown from either the control room or remote shutdown panel cannot be threatened by a single fire. The primary concern is for plants which do not have independent "remote" control or monitoring circuits. The NRC staff would like to verify that one fire would not disable control room control of these circuits because they were split off from the control room feeder circuit and not run separately outside the control room fire area.

At CR-3, the remote shutdown panel serves as the independent control station at which the operators perform safe shutdown procedures given a fire in the control room. The control and monitoring circuits that serve the remote shutdown panel are independent from those of the control room. Activation of the remote shutdown panel isolates the circuits from the control room, and transfers control to the remote shutdown panel.

Issue 6 - Improved Analytical Codes. This issue involved questions regarding the adequacy of available fire models for use in IPEEE analyses for fire external events.

After a number of discussions between nuclear industry representatives and the NRC Staff regarding this issue, the NRC agreed that the COMPBRN IIIe fire modeling program as developed by UCLA and including modifications recommended by Sandia National Laboratory is adequate for analytical fire modeling and requires no further modification for application in IPE of external events.

The fire modeling techniques incorporated in Phase II of this FIVE methodology are derived from the same basic correlations used in COMPBRN IIIe.

Table 4.7-1
Attributes of Adequate Fire Protection Program from Sandia FRSS

SANDIA FIRE RISK SCOPING STUDY EVALUATION

ATTRIBUTES OF ADEQUATE FIRE PROTECTION PROGRAM

I. SEISMIC/FIRE INTERACTIONS

Seismic/Fire Interactions

1. Seismically-Induced Fires:

As part of the seismic assessment walkdown, verify that hydrogen or other flammable gas or liquid storage vessels in areas with seismic safe shutdown or safety-related equipment are not subject to leakage under seismic conditions in accordance with the requirements of EPRI NP-6041 and "Generic Implementation Procedure" (GIP). Examples would be improperly-anchored hydrogen or oxygen bottles, hydrogen tanks used for primary coolant chemistry control, etc.

2. Seismic Actuation of Fire Suppression Systems:

As part of the seismic assessment, verify that the design of water suppression systems considers the effects, if appropriate, of inadvertent suppression system actuation and discharge on that equipment credited as part of the seismic safe shutdown path in a margins assessment that was not previously reviewed relative to the internal flooding analysis or concerns such as those discussed in E Information notice 83-41.

3. Seismic Degradation of Fire Suppression Systems

As part of the seismic assessment walkdown, verify fire suppression systems have been structurally installed in accordance with good industrial practice and reviewed for seismic considerations such that suppression system piping and components will not fall and damage safe shutdown path components nor is it likely that leaking or cascading of the suppressant will result.

II. FIRE BARRIER QUALIFICATIONS

Fire Barriers

1. Fire barriers and components such as fire dampers, fire penetration seals and fire doors for fire barriers considered in the FIVE Methodology are included in the plant surveillance program.

Fire Doors

2. A fire door inspection and maintenance program.

Penetration Seal Assemblies

3. A penetration seal inspection and surveillance program.
4. Fire barrier penetration seals have been installed and maintained to address concerns such as those identified in NRC Information Notice No. 88-04.

Fire Dampers

5. An inspection and maintenance program for fire dampers.
6. Damper installations address concerns such as those identified in NRC Information Notice No. 89-52, "Potential Fire Damper Operational Problems," dated June 8, 1989 and NRC Information Notice No. 83-69, "Improperly Installed Fire Dampers at Nuclear Power Plants," dated October 21, 1983.

Table 4.7-1 (cont.)
Attributes of Adequate Fire Protection Program from Sandia FRSS

SANDIA FIRE RISK SCOPING STUDY EVALUATION

ATTRIBUTES OF ADEQUATE FIRE PROTECTION PROGRAM

III. <u>MANUAL FIREFIGHTING EFFECTIVENESS</u>

<u>Reporting Fires</u>

1. Appropriate plant personnel knowledgeable in the use of portable fire extinguishers.
2. Portable extinguishers located throughout the plant.
3. A plant procedure for reporting fires in the plant.
4. A plant communication system that includes contact to the control room.

<u>Fire Brigade</u>

1. A fire brigade made up of at least 5 trained people on each shift?
2. The brigade leader and at least two other brigade members on each brigade shift are knowledgeable in plant systems and operations?
3. Each brigade member receives an annual review of physical condition to evaluate his ability to perform fire fighting activities.
4. Minimum equipment provided for the brigade includes the following:
    a. Personal protective equipment such as SCBA, turnout coats, boots, gloves and hard hats.
    b. Emergency communications equipment.
    c. Portable lights.
    d. Portable ventilation equipment.
    e. Portable extinguishers.

<u>Fire Brigade Training</u>

5. Brigade members receive an initial classroom instruction program consisting of the following:
    a. Review of the plant fire fighting plan and identification of each individual's responsibilities.
    b. Identification of typical fire hazards and associated types of fires that may occur in the plant.
    c. Identification of the location of fire fighting equipment and familiarization with the layout of the plant, including access and egress routes.
    d. The proper use of available fire fighting equipment and the correct method of fighting each type of fire. The types of fires covered should include fires in energized electrical equipment, fires in cables and cable trays and fires involving flammable and combustible liquids and gases.

    e. The proper use of communication, lighting, ventilation and emergency breathing equipment.
    f. Fighting fires inside buildings and confined spaces.
    g. Review of fire fighting strategies and procedures.

Table 4.7-1 (cont.)
Attributes of Adequate Fire Protection Program from Sandia FRSS

SANDIA FIRE RISK SCOPING STUDY EVALUATION

ATTRIBUTES OF ADEQUATE FIRE PROTECTION PROGRAM

Practice

6. Fire brigade members receive hands-on structural fire fighting training at least once per year to provide experience in actual fire extinguishment and the use of emergency breathing apparatus.

Drills

7. Fire brigade drills are performed in the plant so that each fire brigade shift can practice as a team.
8. Drills performed at regular intervals for each shift fire brigade.
9. At least one unannounced fire drill for each shift fire brigade performed per year.
10. At least one drill per year performed on a "back shift" for each shift fire brigade.
11. Drills pre-planned to establish training objectives and critiqued to determine how well the training objectives have been met?
12. At least once every three years, an unannounced drill is performed for and critiqued by qualified individuals independent of the licensee's staff.
13. Pre-fire plans are developed for safety-related areas of the plant (as a minimum).
14. The pre-fire plans are updated and used as part of the brigade training.
15. Fire brigade equipment is maintained.

Records

16. Records are provided for each fire brigade member demonstrating the minimum level of training and refresher training has been provided.

IV. TOTAL ENVIRONMENT EQUIPMENT SURVIVAL

Potential Adverse Effects on Plant Equipment by Combustion Products

1. The FIVE methodology does not currently provide for an evaluation of non-thermal environmental effects of smoke on equipment (see Section 4.2.2).
2. However, be aware of and sensitive to potential impact of smoke and products of combustion on human performance in safe shutdown operations in application of FIVE.

Spurious or Inadvertent Fire Suppression Activation

1. Verify that the design of fire suppression systems considers the effects, if appropriate, of inadvertent, suppression system actuation and discharge on equipment credited for safe shutdown for concerns such as those discussed in NRC I&E Information Notice 83-41.

Operator Action Effectiveness

1. There are safe shutdown procedures identifying the steps for planned shutdown when necessary in the event of a fire.
2. Operators receive training on these procedures.

Table 4.7-1 (cont.)
Attributes of Adequate Fire Protection Program from Sandia FRSS

SANDIA FIRE RISK SCOPING STUDY EVALUATION

ATTRIBUTES OF ADEQUATE FIRE PROTECTION PROGRAM

Operator Action Effectiveness (Continued)

3. If in performance of these procedures operators are expected to pass through or perform manual actions in areas that may contain fire or smoke, suitable SCBA equipment and other protective equipment are available for operators to perform their function.

V. CONTROL SYSTEMS INTERACTIONS

1. Safe shutdown circuits are physically independent of, or can be isolated from, the control room for a fire in the control room fire area.

4.8 References

4-1 J. W. Hickman, *PRA Procedures Guide: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants*, American Nuclear Society and Institute of Electrical and Electronic Engineers, NUREG/CR-2300, Vols. 1 and 2, January 1983.

4-2 *Fire-Induced Vulnerability Evaluation (FIVE) Methodology Plant Screening Guide*, Professional Loss Control, EPRI TR-100370, April 1992.

4-3 *Methods of Quantitative Fire Hazards Analysis*, Frederick W. Mowrer, EPRI TR-100443, Research Project 3000-37, May 1992.

4-4 U. S. Nuclear Regulatory Commission, *Recommended Procedures for the Simplified External Event Risk Analyses for NUREG-1150*, Albuquerque, New Mexico: NUREG/CR-4840, Sandia National Laboratories, September 1989.

4-5 U. S. Nuclear Regulatory Commission, *Probabilistic Safety Analysis Procedures Guide*, NUREG/CR-2815, Washington, D.C., NRC FIN A3758., August 1985.

4-6 W. Parkinson, et al, *Fire Events Database for U.S. Nuclear Power Plants*, Electric Power Research Institute, NSAC-178L, December 1991.

4-7 J. M. Chavez. *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets - Part II: Cabinet Effects Test*, Volumes 1 and 2, Albuquerque, NM: Sandia National Laboratories, SAND86-0336. Washington, D.C.: Government Printing Office, April 1987, NUREG/CR-4527.

4-8 S. P. Nowlen, *A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories*, 1975-1987, Albuquerque, NM: U. S. Government Printing Office, NUREG/CR-5384, Sandia National Laboratories, SAND89-1359, December 1989.

4-9 W. Parkinson, et al, Automatic and Manual Suppression Reliability Data for Nuclear Power Plant Fire Risk Analyses, Science Applications Int'l Corp., Los Altos, NSAC-179L, February 1994.

4-10 *10CFR50 Appendix R Fire Study, Analysis of Safe Shutdown Equipment and Operations, Prepared for Florida Power Corporation Crystal River 3*, Gilbert/Commonwealth, Inc., Revision 4, September 10, 1993.

4-11 *FRANC, Fire Risk Analysis Code, Beta Version (0.5)*,EPRI AP-103733 January 1994.

4-12 NUMARC 91-04, *Severe Accident Issue Closure Guidelines*, January 1992.

4-13 HRA Approach Using Measurement for IPE, Palo Alto, CA: Electric Power Research Institute, December 1989. EPRI NP-6560L.

4-14 "Probabilistic Seismic Hazard Evaluation for Crystal River Nuclear Generating Plant," EPRI Project RP 101-53, April 1989.

4-15 EPRI-NP 6989, "Survey of Earthquake-Induced Fires in Electrical Power and Industrial Facilities," September 1990.

4-16 "Performance of Fire Protection Systems Under Post-Earthquake Conditions," Brookhaven National Laboratory, October 1978.

5. Assessment of High Winds, External Flooding, and Other Hazards

A systematic review was made of potential hazards associated with high winds, external flooding, and other sources (such as transportation accidents) that could conceivably affect the safety of Crystal River 3. For each of these general areas, a comparison of the plant design and site characteristics to the criteria and guidance summarized in NUREG-1407 (Reference 5-1) and NUREG/CR-5042 (Reference 5-2) was made. In many cases, it was possible to screen out the hazards without more detailed analysis. Where events could not be screened readily, a more detailed assessment was performed.

5.1 High Winds

Crystal River 3 is located adjacent to the Florida coast of the Gulf of Mexico. It is subject to potential hurricanes traveling inland from the Gulf or across Florida from the Atlantic Ocean. Tornadoes also occur with a relatively high frequency in the area. Tornadoes tend to produce higher wind loadings than do hurricanes, and are therefore more limiting with respect to the design of the structures housing equipment important to safety.

With the exceptions primarily of the offsite power supply to the plant (the switchyard and lines feeding it) and the power conversion system, for which most components are located in the turbine building, all of the systems credited in the IPE with respect to preventing core damage are located in category I structures. With two exceptions, the category I structures are designed to the following criteria (Reference 5-3):

- A tangential wind velocity of 300 mph;
- An external pressure drop of 3 psig;
- Missiles equivalent to the following:
    - A utility pole 35 ft long, 14 inches in diameter, weighing 50 lb/ft^3, and traveling at 150 mph
    - A one-ton automobile traveling at 150 mph
    - A 4-inch by 12-inch by 12-ft long wooden plank traveling end-on at 300 mph
    - A 10-ft section of 3-inch schedule 40 pipe, traveling at 100 mph.

The two exceptions are the roof of the auxiliary building and the emergency feedwater (EFW) tank enclosure. The auxiliary building roof has a steel support structure that is designed to withstand seismic loads, but that is not designed to serve as a barrier against tornado missiles. The EFW tank enclosure was the result of a modification made well after the original plant design, and it meets current design criteria. This includes the capacity to withstand a maximum wind speed of 360 mph and a somewhat different missile spectrum.

Because of the use of older design criteria for some of the critical structures, the potential for failure due to high winds cannot be screened out without further evaluation. To investigate the potential for vulnerabilities further, bounding quantitative analyses were performed for wind hazards.

5.1.1 Tornado Winds

A bounding quantitative evaluation was made of the potential for damage due to tornado winds to threaten core cooling. This evaluation consisted of the following steps:

1. Estimating the hazard from available historical data,
2. Characterizing the fragility of important plant structures and systems, and
3. Combining the hazard and fragility to estimate the frequency of damage to the important plant structures.

The results from step 3 do not necessarily imply a frequency of core damage. If the frequency is acceptably low, however, no further effort is needed to conclude that there are no severe-accident vulnerabilities that need to be considered with regard to tornado winds.

Tornado Wind Hazard

The approach used to characterize the tornado wind hazard is consistent with that outlined in NUREG/CR-3058 (Reference 5-4). A raw data base of tornado occurrences in Florida was obtained from the Storm Prediction Center for the years 1950 through 1995 (Reference 5-5). This data base was used to develop a frequency-intensity relationship for tornadoes.

The occurrences in this data base were first sorted by county so that occurrences in west central Florida (the region in which Crystal River 3 is located) could be identified. The data set was then sorted to identify the number of occurrences in each F-scale category. These intensity categories and the number of occurrences in each over the 46-year experience base are as follows:

F-Scale	Range of Maximum Wind Speeds (mph)	Number of Occurrences
F0	40 - 72	381
F1	73 - 112	215
F2	113 - 157	80
F3	158 - 206	5
F4	207 - 260	3
F5	261 - 318	0
Unknown	—	34
Total reported (1950 - 1995)	—	718

It is desirable to adjust the numbers of tornadoes in this data base to account for tornadoes that may have gone unreported for a variety of reasons. Figure 5 of NUREG/CR-3058 indicates the estimated number of unreported tornadoes in each 1° x 1° square in the lower 48 states for the 30-year period 1950 through 1979 (Reference 5-4). For the squares corresponding roughly to the counties of west central Florida included in the data base, there was a total of 129 unreported tornadoes. Reporting of tornadoes has generally improved over more recent years, due both to substantially increased population density in the region and to more careful tracking of storms. To help ensure that the tornado frequency is not underestimated, however, this value was extrapolated over the full period of 1950 through 1995, for an effective number of unreported tornadoes of 198.

The additional 232 tornadoes (34 for which no F-scale was indicated in the data base, plus an estimated 198 unreported tornadoes) were then distributed among the F-scale categories. To do this, the cumulative number of reported tornadoes exceeding the lower wind-speed value in each F-scale category was subjected to a regression analysis. The regression analysis yielded the following relationship for number of tornadoes, N, exceeding wind speed v:

$$N = 3213 * 10^{-0.015v} \text{ (basic data set)}$$

This equation was used to determine the fraction of expected tornadoes in each intensity category, including category F5 (for which no tornadoes were specifically reported). The 232 additional tornadoes were then distributed among the categories according to these fractions. A second regression analysis was then made of the resulting effective number of tornadoes. The regression based on the adjusted data obtained the following relationship between tornado occurrences and wind speed:

$$N = 6740 * 10^{-0.017v} \text{ (adjusted data set)}$$

The number of reported tornadoes, the adjusted number taking into account unreported tornadoes and those for which F-scale was not reported, and the results of the second set of regression analyses are illustrated in Figure 5-1. Note that tornadoes in excess of intensity F5 are deemed to be incredible (Reference 5-6).

As a sensitivity, the regression analysis was also made by separating the data into two wind-speed regimes (consistent with the approach used in NUREG/CR-3058). This effectively reflected a knee in the distribution. This analysis appeared to provide a somewhat better fit to the adjusted data set. The projected number of tornadoes at higher wind speeds, however, was smaller than that obtained using the single regression above. Because there was very limited data for high intensity tornadoes, it was decided to use the results of the single regression analysis that produced more conservative results.

The curve in Figure 5-1 can be used to estimate the occurrence rates of tornadoes as a function of intensity in the area covered by the data set (i.e., in west central Florida). To determine the hazard presented to Crystal River 3, it is necessary to calculate the ratio of the path area for tornadoes to the total area covered by the data set (i.e., using the point strike model).

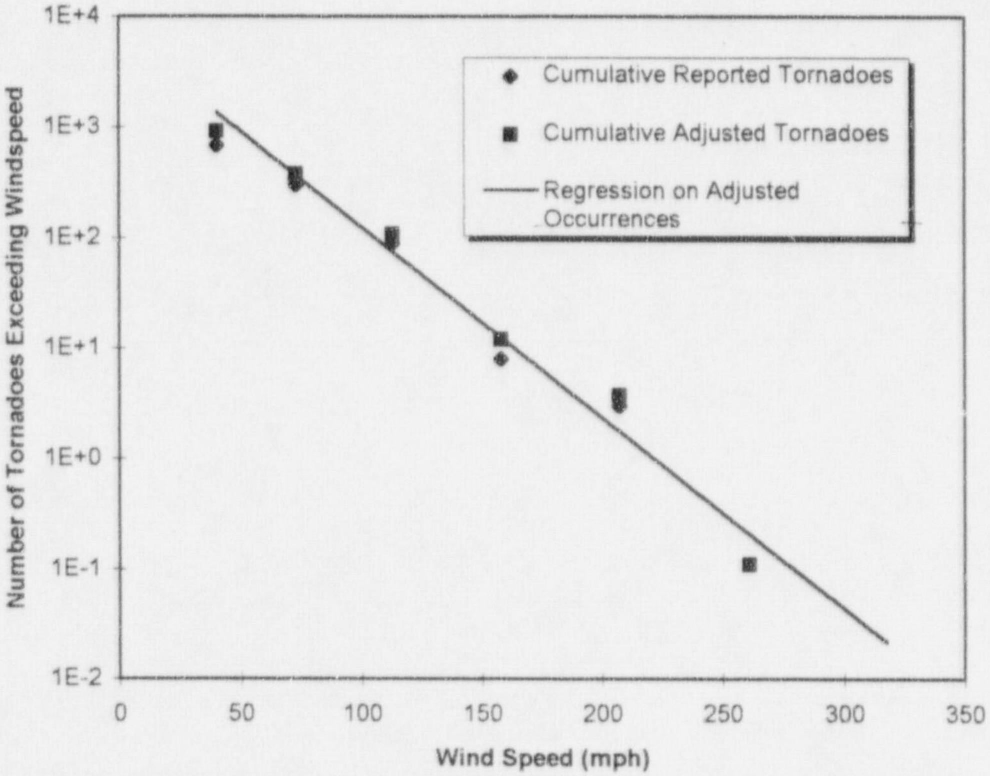


Figure 5-1. Occurrence-Intensity Relationship for Tornadoes

Although an average path area is sometimes used for tornadoes of any intensity (Reference 5-7), the data indicate that path area is correlated with tornado intensity. Because path lengths and widths were not reported for a substantial portion of the data set, the evaluation of path area was expanded to include all tornadoes that occurred in Florida over the 46-year period. A summary of the data on path lengths is provided below.

F-Scale	Range of Maximum Wind Speeds (mph)	Median Wind Speed (mph)	Average Path Area (mi^2)
F0	40 - 72	56	0.0133
F1	73 - 112	92.5	0.075
F2	113 - 157	135	0.353
F3	158 - 206	182	0.853
F4	207 - 260	233.5	7.66
F5	261 - 318	289.5	55.0*

*There were no tornadoes of intensity F5 reported in the data base. This value is from NUREG/CR-3058, for a different region of the country.

As noted above, there were no tornadoes of intensity F5 reported for this period in Florida. The average path area for intensity F5 was taken from an assessment for a different region of the country in NUREG/CR-3058. Because the average areas for F4 tornadoes are similar (7.66 mi^2 for the Florida tornadoes vs. 6.56 mi^2 from the NUREG/CR-3058 assessment), this would seem to be a reasonable approximation.

Based on this data set, a regression analysis was also performed to establish a relationship between tornado path area and intensity. The average path areas were assumed to represent observations at the median wind speed in each intensity category. The regression analysis of this data produced the following relationship:

$$A_{path} = 0.00245 * 10^{0.0149v}$$

The total area for the counties comprising west central Florida was calculated to be 11,789 mi^2. The frequency of a strike at any point can therefore be calculated as follows:

$$F(v) = \frac{A_{path}(v)}{A_{total}} * \frac{N(v)}{T}$$

where $F(v)$ = frequency of exceeding windspeed v

$N(v)$ = expected number of tornadoes exceeding windspeed v

T = length of observation period for data (46 years)

The data for path area and tornado occurrences were combined using the expression above to develop the hazard curve for tornado winds that can be used for the Crystal River site. This curve is shown in Figure 5-2. Note that the curve is relatively flat over the range of wind speeds considered (i.e., the frequency of tornado strike for wind speeds in excess of 50 mph is less than 5 times that for wind speeds exceeding 300 mph). This is because of the competing effects of decreasing exceedance frequency and increasing path area as a function of wind speed.

Effects of Tornado Winds

A bounding assessment of the fragility of the plant to tornado winds was performed. The safety-related systems relied upon to preserve core cooling are located within category I structures designed for a wind speed of 300 mph (or greater). Other systems that were also credited in the IPE are located in structures that are designed to lower standards than are the category I structures. Offsite power would also be affected at a lower wind speed. These considerations were taken into account by making two sets of calculations:

- The conditional probability of core damage was calculated for a case in which offsite power was lost, with no recovery of offsite power assumed within 24 hr. This probability was combined with the total frequency of tornadoes of intensity F1 or greater (i.e., wind speed in excess of 73 mph).
- The conditional probability of core damage was assumed to be unity for tornadoes of sufficient intensity to exceed the capacity of the category I structures.

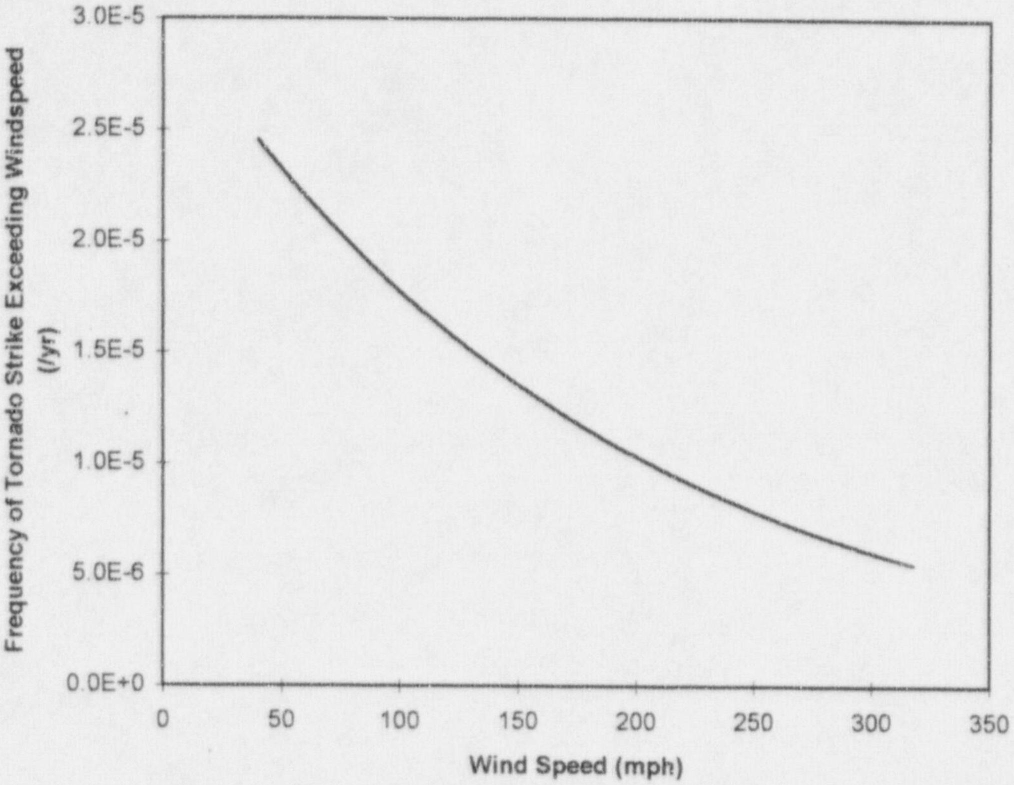


Figure 5-2. Hazard Curve for Tornado Strike Frequency

For the first of these cases, the integrated core-damage model from the IPE was evaluated to obtain the conditional probability of core damage. This was estimated to be $1.4\text{x}10^{-3}$. The exceedance frequency for site strikes corresponding to F1 tornadoes is $2.1\text{x}10^{-5}$/yr. The bounding core-damage frequency for this case is therefore as follows:

$$\begin{aligned} CDF_1 &= F(v \geq F1) * CCDP_{LOOP} \\ &= (2.1x10^{-5} / yr)(0.0014) \\ &= 2.9x10^{-8} / yr \end{aligned}$$

For the second case, it was necessary to develop a characterization of the fragility of category I structures to tornado winds. The characterization suggested by the *PRA Procedures Guide* (Reference 5-8) was adapted for this purpose. The mean fragility as a function of tornado intensity was estimated using the following expression:

$$f = \Phi\left[\frac{\ln(v/c)}{\beta_{c,r}}\right]$$

where Φ = standard Gaussian cumulative distribution

c = median windspeed capacity of structure

$\beta_{c,r}$ = composite logarithmic standard deviation of randomness

The *PRA Procedures Guide* suggests estimating the median capacity as 1.5 times the design wind speed, and suggests a value for $\beta_{c,r}$ of 0.25. Incorporating these parameters, together with the design value of 300 mph, into the expression above yielded the relationship below for the probability of failure as a function of wind speed. The corresponding fragility curve is shown in Figure 5-3.

$$f = F\left[\frac{\ln(v/450)}{0.25}\right]$$

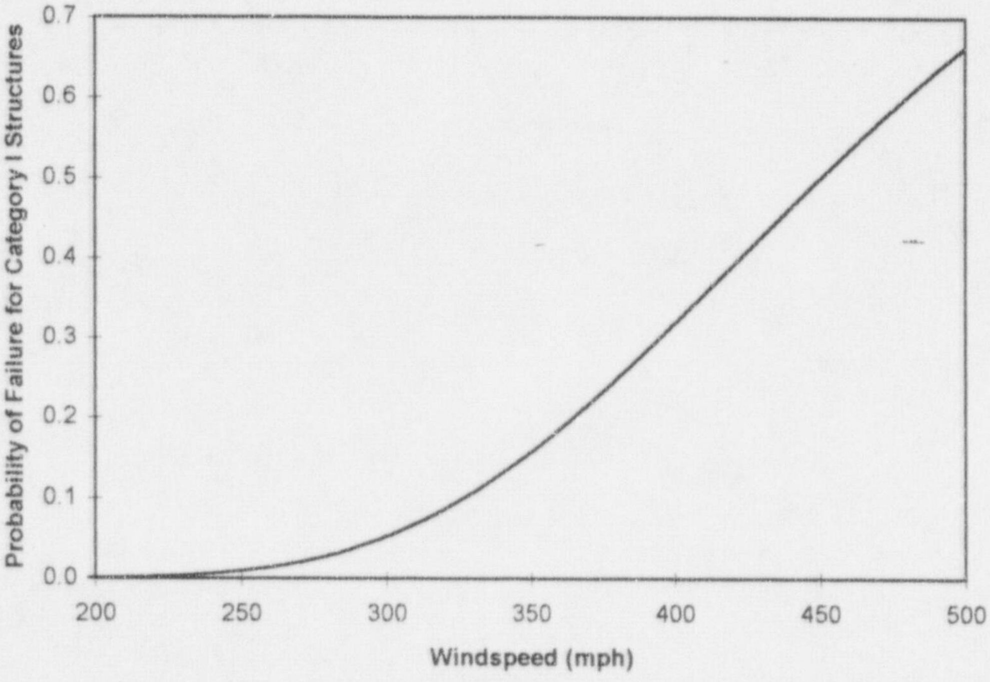


Figure 5-3. Fragility of Category I Structures for Wind Loadings

The hazard for exceedance frequency of a tornado strike (Figure 5-2) was then integrated with the fragility to produce an estimate of the overall frequency of damage sustained to category I structures at the site. This was estimated to be 6.3×10^{-8}/yr. The total frequency estimated for core damage resulting from tornado winds is therefore as summarized below. The analysis appears to confirm that tornado winds do not pose a significant hazard to Crystal River 3.

Tornado-induced sustained loss of offsite power, with failure of core cooling	$2.9\text{x}10^{-8}$ /yr
Core damage due to tornado-induced failure of category I structures	$6.3\text{x}10^{-8}$ /yr
Total core-damage frequency due to tornado winds	$9.2\text{x}10^{-8}$ /yr

Tornado Missiles

In addition to the potential for damage to occur as a direct result of the wind pressures created by tornadoes, there is the possibility that a tornado may entrain items that could become missiles that might strike the plant.

As discussed above, all of the safety-related systems are located in category I structures that are designed to withstand a spectrum of tornado missiles comparable to that required by current design standards. Included in this level of protection are the borated water storage tank (BWST) and the tank supplying suction to the EFW system. The only exception to this design basis is the roof system for the auxiliary building, which is not designed for tornado missiles. This does not present a significant potential to pose a vulnerability to severe accidents for several reasons:

- The roof constitutes a relatively small exposure area, and would be susceptible only to missiles with a significant downward velocity component.
- The auxiliary building, along with the other category I structures (except for the intake structure), is located on top of a berm approximately 20 ft above the normal site grade. This tends to limit the number of missiles that could attain sufficient altitude to threaten the roof of the auxiliary building.
- Even substantial damage to the auxiliary building would not ensure core damage. For example, the EFW pumps are located in the intermediate building, and their suction supply is in a separate, protected structure, so that at least one means of core cooling should remain available.
- Tornado missiles have only rarely been found to pose a significant threat to nuclear power plants. On these occasions, there have been significant systems that are vulnerable to potential damage from missiles.

Therefore, it is judged that tornado missiles do not pose a significant vulnerability for Crystal River 3.

5.1.2 Non-Tornado Winds

As noted above, tornado winds present the most significant threat of damage to category I structures. It is necessary, however, to consider the potential for less severe but more frequent occurrences of straight winds to cause damage. There is a negligible chance that straight winds could damage category I structures directly. It was noted, however, that there is a tall stack for the adjacent fossil-fired Unit 1. If the stack were to fall in the proper direction, it is conceivable that it could damage a portion of Crystal River 3.

An earlier assessment was made of the potential for the stack to affect core cooling for Crystal River 3 as a consequence of a hurricane (Reference 5-9). In that assessment, it was concluded that, among category I structures, only the enclosure for the EFW storage tank was both within range of the stack and potentially vulnerable to damage. This assessment made several conservative assumptions, including that the stack remained intact as it was falling (it would be much more likely that, as the stack fell out of plumb, it would collapse on itself).

For the IPEEE, this assessment was expanded to consider all non-tornado winds, not just those that resulted from a hurricane (although hurricanes would generally produce the most severe straight winds). The steps in the assessment were similar in nature to those performed for tornado winds:

- Historical data were collected and evaluated to generate a characterization of the hazard associated with straight winds;
- The potential for damage to result from the high winds (i.e., the fragility) was evaluated probabilistically; and
- The hazard and fragility were combined to obtain a bounding estimate of the frequency of core damage.

The wind hazard was assessed by assembling data for the period 1955 through 1995. This data set was available electronically from the Storm Prediction Center of the National Weather Service (Reference 5-10). This data set included the following types of information for each reported occurrence of winds greater than 50 knots (about 58 mph):

- Date and time of occurrence
- Sequential number of the occurrence
- State and county in which the high wind occurred (the data set was for the entire U.S.)
- Latitude and longitude at which the occurrence was observed
- National Weather Service office reporting the occurrence
- Number of fatalities and injuries and classification of cost of damage
- Magnitude of the wind (in knots)

The data sets (data for each year were generally contained in a separate data file) were each sorted by latitude and longitude. To obtain an estimate of the hazard most directly relevant to the Crystal River site, events occurring in ten 1° x 1° squares in West Central Florida were extracted. There were a total of 1936 observed occurrences of winds in excess of 50 knots in these squares over the 41 years for which data were available. It was assumed that high wind anywhere within the square in which Crystal River 3 is located would also be experienced at the plant. The total frequency of winds in excess of 50 knots at Crystal River was therefore taken to be as follows:

$$F_{total} = \left(\frac{1936\,occurrences}{41\,years}\right)\left(\frac{1\,square\ for\ CR3}{10\,squares\ total}\right) = 4.72\,occurrences/yr$$

It remains to distribute this occurrence rate with respect to the exceedance frequency for the spectrum of winds that are of concern. Wind speeds were reported for 536 of the events, allowing a reasonable distribution of the speeds to be made. The highest recorded wind speed in the area, however, was 113 mph. Therefore, a regression analysis was conducted on this data to provide a means for extrapolating beyond this wind speed. The results (which are represented by the expression that follows) and the frequencies based directly on historical data are presented in Figure 5-4.

$$F(v_{straight}) = 2226 * 10^{-0.0473 v_{straight}}$$

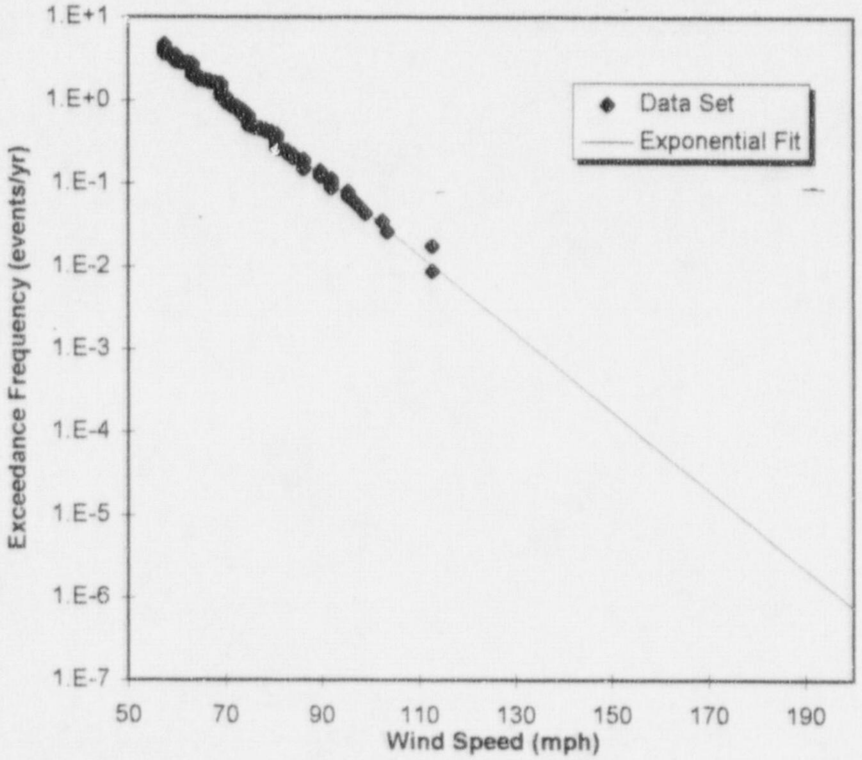


Figure 5-4. Hazard Curve for High Wind Occurrence

The stack is designed for a nominal wind speed of 100 mph. Because the plant is on a coastal site, applicable standards require a further factor of safety of 1.11, so that the design wind speed for the stack is actually 111 mph. A fragility formulation similar to that applied for the category I structures under tornado loadings was used for the stack. For the category I structures, the median wind-speed capacity was estimated by multiplying the design wind speed by a factor of safety of 1.5. Because the stack was not designed to the same criteria as safety-related nuclear structures, it was not clear that use of this overall factor of safety of 1.5 would be appropriate. To account for this, the median capacity for the stack was estimated as 1.5 times the nominal design speed of 100 mph, rather than the actual design wind speed of 111 mph. This yields a median capacity of 150 mph, rather than 167 mph, as would otherwise be obtained. The corresponding fragility curve is shown in Figure 5-5, and can be expressed as follows:

$$f_{stack} = \Phi\left[\frac{\ln(v/150)}{0.25}\right]$$

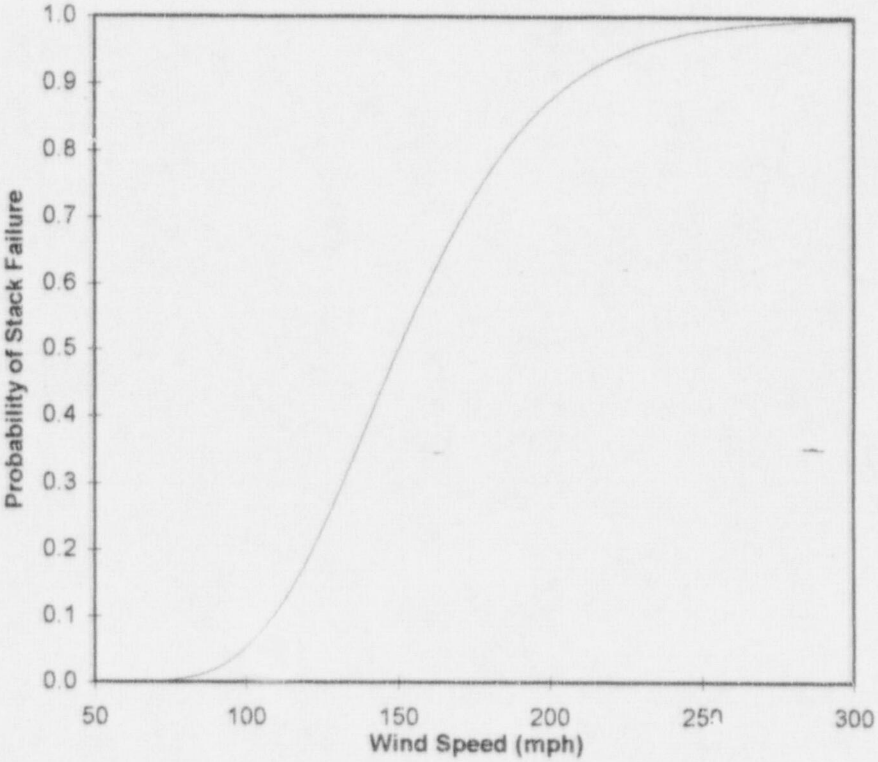


Figure 5-5. Fragility for Unit 1 Stack Under Wind Loadings

The total frequency of failure of the stack was calculated by combining the hazard curve in Figure 5-4 with the fragility curve in Figure 5-5. The result was an estimated failure rate of the stack due to high winds of 8.1 x 10^{-4} per year.

Figure 5-6 depicts the relationship between the Unit 1 stack and important structures that could conceivably be struck by it if it were to be blown down by high winds. The category I structures should actually be capable of withstanding impact from the stack if it were to fall. As noted above, in the previous assessment, it was assumed that only the enclosure for the EFW tank had a reasonable chance of being damaged by the falling stack. Although the enclosure should have capacities similar to the other category I structures conceivably within range of the falling stack (including especially the intermediate building), it is the category I structure nearest the stack. If the tank were damaged as a result of being struck by the stack at the same time that offsite power was lost (as might well be the case for these high wind conditions), all feedwater could be lost. It is somewhat less likely that the intermediate building would be struck by the stack, and also less likely that, given damage to the intermediate building, a single safety function would be completely lost. Therefore, it is assumed for purposes of this assessment as well that it is the EFW tank enclosure that is of primary concern.

No information on direction was provided in the data base on wind occurrences. Although winds in the vicinity have been observed to originate from all points of the compass, they occur with greatest frequency in a generally southwest-to-northeast pattern. The enclosure for the EFW tank is located almost directly due east from the stack. Based on the dimensions and relative locations of the stack and the EFW tank enclosure, the probability that the stack would strike the enclosure if it had an equal chance of falling in any direction would be 0.02 (Reference 5-9). Since the winds preferentially blow in a direction more or less toward the tank enclosure, this probability was adjusted upward. The adjustment was made by assuming that the stack could fall anywhere in a 90° arc that included the EFW tank enclosure, rather than randomly in a full 360° circle. This produced a conditional probability that the stack could strike the enclosure of 0.08.

Given that the stack fell and struck the EFW tank enclosure, it is by no means certain that the enclosure would be significantly damaged, or that the tank itself would be damaged sufficiently that it could not serve as a source of suction for the EFW pumps. As noted at the beginning of this section, the enclosure is designed to withstand a spectrum of tornado missiles. Therefore, the conditional probability of damage to the enclosure sufficient to affect the availability of the EFW tank was taken to be 0.1.

Thus, the frequency of an event involving loss of the EFW tank enclosure due to wind-induced toppling of the Unit 1 stack was estimated to be as follows:

$$\begin{aligned} F_{\text{tank}} &= F_{\text{stack}} * P_{\text{enclosure struck}} * P_{\text{tank failed}} \\ &= (8.1\times10^{-4})(0.08)(0.1) = 6.5\times10^{-6}\ /\text{yr} \end{aligned}$$

The conditional probability of core damage was calculated assuming the following:

- Failure of the EFW tank due to the stack impact would result in a total loss of EFW. No credit was given to transferring suction from the EFW tank to the condensate storage tank.

- Offsite power would be lost and could not be restored within 24 hours. No credit was given to the use of main feedwater or other systems that would rely on offsite power or for which important components are located in the turbine building.

The probability of core damage based on these conditions was calculated using the models developed for the IPE. The result was an estimated conditional probability of $2.5\text{x}10^{-3}$. The frequency of core damage due to stack failure under high wind conditions was therefore calculated to be the following:

$$\begin{aligned} CDF_{\text{high wind}} &= (6.5\text{x}10^{-6}\ /\text{yr})(2.5\text{x}10^{-3}) \\ &= 1.6\text{x}10^{-8}\ /\text{yr} \end{aligned}$$

Therefore, straight winds do not represent a significant hazard or the potential for a vulnerability at Crystal River 3 as well.

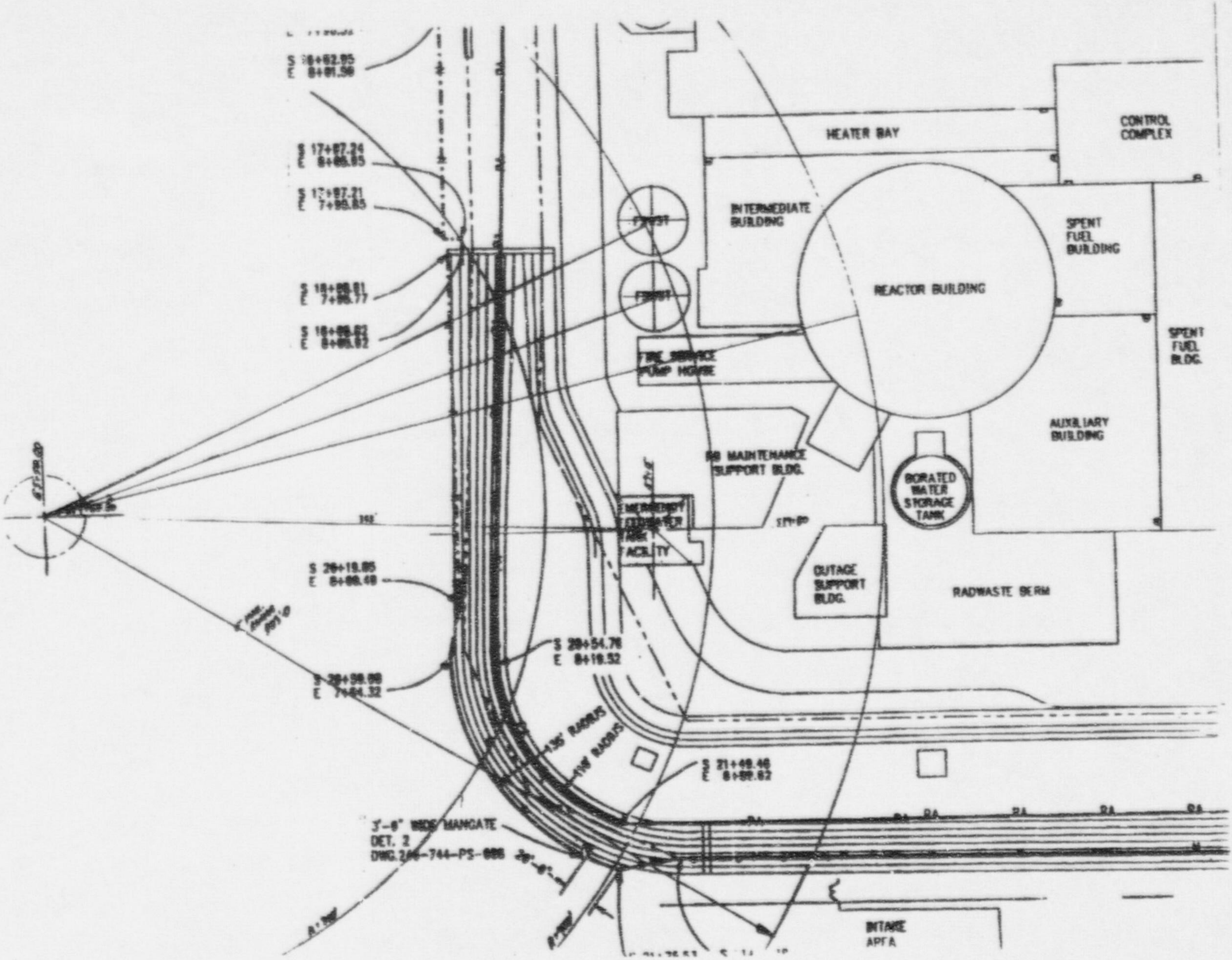


Fig. 5-6 - CR-1 Stack Impact Zone

5.2. External Flooding

Crystal River 3 is located on the Gulf Coast of Florida, between the mouths of the Withlacoochee and Crystal Rivers. Cooling water for the plant is supplied from the Gulf via an intake canal, with discharge back through a separate canal. The site is located in an area that rises gradually and relatively consistently from the Gulf to gently rolling hills about 16 miles to the east. The terrain affords adequate drainage to the Gulf to accommodate runoff from precipitation and the potential for river flooding. Furthermore, plant buildings are located on a berm that is elevated approximately 20 ft above the local grade.

Roof drain systems are designed for precipitation rates up to 6 inches per hr (Reference 5-11). Precipitation rates greater than this level will cause overflowing of the eaves, but the building roofs are designed to handle the resulting load (a depth of 3 inches on the roof).

The potential for the most severe flooding at the site is due to the effects of hurricanes. Hurricanes can produce abnormally high tides due to winds blowing onshore. This effect, coupled with run-up of waves produced by the hurricane and sustained precipitation before the full effect of the winds is realized, produces the flooding level that establishes the design basis for Crystal River 3. The plant design basis includes full protection for all components needed to function to achieve a safe shutdown for the tides and wave action produced by hurricanes of any intensity up to and including the probable maximum hurricane (PMH).

Unlike tornadoes, which sometimes develop from severe storms with relatively limited warning time, hurricanes are generally tracked from their inception, and achieve landfall with substantial warning time. This affords time to place the plant in a safe condition, if necessary, before the full effects of the storm are realized. At Crystal River 3, operation of the plant is continued until such time as the tidal surge reaches 10 ft above mean low water (MLW) to elevation 98 ft (the local grade below the berm surrounding the plant buildings. At that point, an orderly shutdown of the plant would be initiated. At that time, there remains the 20-ft margin afforded by the berm.

The plant design was generally completed prior to the issuance of the 1975 Standard Review Plan (Reference 5-12), but the evaluation of the PMH is consistent with or more restrictive than that which would be required to meet current criteria as specified in Section 2.4.5 Probable Maximum Surge and Seiche Flooding of the Standard Review Plan. With regard to defining the design basis flood for a site, the Standard Review Plan specifies the use of Regulatory Guide 1.59 (Reference 5-13). This, in turn, refers to ANSI Standard N170-1976, which has been superseded by ANSI/ANS 2.82-1992 (Reference 5-14). In fact, it appears that the current standard (ANSI/ANS 2.82-1992) drew heavily from the assessments for Crystal River in establishing criteria for considering hurricane-induced flooding. Comparing the requirements of the current standard to the evaluations actually performed to define the effects of the PMH yields the following insights:

- The hurricane winds capable of producing the maximum surge are defined by a variety of parameters, including radius, pressures at the center and periphery of the storm, its forward translational speed, and its maximum wind speed. The standard indicates the need to consider different sets of these parameters, because the higher wind speeds of relatively short duration may produce more limited flooding than would lower wind speeds that would typically be sustained for a longer period of time. Several sets of parameters were used to estimate the surge tide level and the wave run-up at the site. The set of parameters that produced the maximum wave run-up were used in establishing the design basis for the plant. These parameters included the results of work performed by the U.S. Army's Coastal Engineering Research Center (CERC), which served as a consultant to the Atomic Energy Commission (AEC). The parameters were derived from the U.S. Weather Bureau's reports HUR 7-97 and 7-97A, which continue to be cited as references for the analysis of PMH in the standard. The specific parameters suggested by the AEC are contained in a report (Reference 5-15) that is also cited as a reference in ANSI/ANS 2.82-1992.

- It is necessary to define an initial tide level upon which to superimpose the hurricane surge. The standard currently calls for using the 10% exceedance high tide for this purpose. Table 2 of ANS 2.82-1992 infers that this level would be between 2 and 3 ft above MLW for the Crystal River site. In the analysis for Crystal River 3, it was assumed that the hurricane occurred at the time of high spring tide of 4.3 ft above MLW, so that the value used is more conservative than would currently be required.

- The calculation of surge and wave run-up heights requires modeling the impact of the terrain between the plant buildings and the Gulf. Various analytical methods are acceptable for this portion of the analysis. In the initial assessment for Crystal River, a combination of analytical and experimental models and data were used to estimate the maximum wave height at the site. The AEC suggested somewhat different parameters for this calculation, which produced a higher maximum height. The design basis reflects the higher level reflected in the AEC calculations.

The calculations indicated that the maximum surge height was estimated to be 121.4 ft MLW. Taking into account wave run-up, the flood height could reach 127 ft. Therefore, measures were taken to protect the plant buildings up to a level of 129 ft MLW. These provisions include the addition of watertight doors that can be used when needed, permanent barriers in some locations, sealing some penetrations, and raising the vent lines for the diesel generator fuel tanks. Some of the doors are permanently installed and need only be closed prior to arrival of the maximum surge. Others must be mounted when needed. Because of the long warning period available, there is ample time to take these actions. A review of potential pathways into the plant was also made. For example, high level in the intake canal simultaneous with maintenance requiring opening of the main condenser could conceivably lead to flooding in the turbine building. The plant has taken special measures, however, to ensure that the condenser is properly isolated in the event that high levels are anticipated.

Appendix B of ANSI/ANS 2.82-1992 provides a calculation of the probabilities of the combined effects for various sources of flooding, including hurricane-induced surges. The appendix estimates that the annual occurrence frequency of the PMH coincident with the 10% exceedance high tide is orders of magnitude below an acceptance criterion of 10^{-6} per year. Thus, there are no vulnerabilities at Crystal River 3 due to flooding associated with the PMH.

5.3 Lightning

The Crystal River site is located in an area in which thunderstorms are relatively frequent. Lightning strikes in the switchyard have, in the past, caused partial losses of offsite power to the plant. The configuration of the loads from the switchyard has been modified so that separate startup transformers supply offsite power to each of the two engineered safeguards (ES) buses in the event that normal auxiliary power from the plant generator is not available. This measure will generally prevent a lightning strike from causing a loss of offsite power to both ES buses. The current assessment in the IPE adequately accounts for the potential for lightning-induced losses of offsite power.

Lightning strikes have not been the cause of other problems, such as disruptions within the onsite power distribution system or the generation of spurious control signals. A detailed engineering review of the adequacy of provisions for surge protection in the event of a lightning strike is currently underway (Reference 5-16). Any problems that are uncovered as a result of this review will be addressed as necessary. The plant experience, coupled with this review, provide adequate assurance that there will be no vulnerabilities to lightning strikes.

5.4 Transportation and Other Facilities

A review was made of other sources of external hazards, including the potential for impact on the plant site of a variety of accidents relating to transportation and to other facilities near the site. The nature of the hazard posed by each of these sources is discussed below. None of the hazards was determined to require more detailed analysis.

Marine Traffic

There are no major shipping lanes in the Gulf of Mexico near the plant site, and the plant is located far enough inland to preclude damage from ship or barge impact, explosions, or releases of toxic gases. The FSAR noted the potential for future modification of the Intercoastal Waterway and its connection to the Cross-Florida Barge Canal relatively near the plant site. Only a small portion of the Cross-Florida Barge Canal has been constructed, and its use is extremely limited. There are no current plans for completing the Cross-Florida Barge Canal or making it a part of the Intercoastal Waterway. The Intercoastal Waterway retains its original form approximately ten miles offshore from the plant site and has minimal marine traffic of significant size.

Aircraft Impact

The report NUREG/CR-5042 summarizes acceptance criteria that, if met, are judged to produce a site with a negligible frequency of accidents due to aircraft impact. These criteria relate to proximity of the plant site to airports, military training routes, and federal airways.

The closest commercial airport is more than 50 miles from the plant site. This is far enough that proximity to the airport is not an issue. There is a small airport servicing general aviation about 8 miles from the site. Although detailed records of aircraft activity are not available, the relevant criterion from NUREG/CR-5042 is that the annual number of operations be less than $500D^2$, where D is the plant-to-airport distance. With a value for D of 8 miles, this would set a criterion of 32,000 operations per year. This is far in excess of the level of activity judged to apply to the airport. Moreover, the damage that could be caused by the impact of a small aircraft is limited. Therefore, this source of hazard can be neglected.

There are no military facilities near the plant site. The nearest military training route is 6 miles from the site. Therefore, the acceptance criterion of 5 miles is met.

The centerline of the nearest Federal airway (designated V7-521) is about 3 miles from the site. Since the airway encompasses a width of 4 miles on either side of the centerline, the plant site falls within the edge of the boundary.

The hazard, in terms of the overall frequency of a crash at the plant site, can be expressed by the following expression (Reference 5-2):

$$P_{CA} = C * N * \left(\frac{A}{W}\right)$$

where C = inflight crash rate per mile for aircraft using airway
N = number of flights per year along the airway
A = effective area of plant in square miles, and
W = width of airway in miles

An average value of 7.7×10^{-9} fatal accidents per year per aircraft mile was reported in Table 6.A.2.2 of NUREG/CR-5042 (Reference 5-2). This represents the aircraft accident frequency over the period 1978 through 1984, but it reflects the total rate of accidents involving fatalities, including those that occurred during ground operations, takeoffs, and landings, rather than being limited to crashes of aircraft in flight. This was confirmed by reviewing data contained in a recent report (Reference 5-17). Because the relevant rate of accidents for high altitude operation far from airports was not readily available, a bounding crash rate was taken to be 10% of the value from NUREG/CR-5042. This value (that is, 7.7×10^{-10}/yr/mile) was used to infer a value for C in the equation above. The number of flights using airway V7-521 is approximately 100 per day, or 36,500 per year (Reference 5-18). It should be noted that the plant is located near one edge of the airway. Pilots attempt to stay close to the centerline, and would usually be warned by air traffic control if they strayed as close as one mile from the edge of the airway. Thus, assuming a uniform density for air traffic across the airway would tend to be conservative. On the other hand, a flight that was in imminent danger of crashing might not necessarily be under sufficient control to be assured of being centered in the airway.

Assessment of the plant area entails both considering the area of important plant buildings, as well as estimating a shadow exposure from the descending aircraft. The category I buildings (with the exception of the intake structure, which itself presents a small target) taken together form a rough square of less than 500 ft on a side. Because the buildings are located on a berm about 20 ft above local grade, and because of the generally marsh-like nature of the nearby terrain, impact from substantial portions of a skidding aircraft would not be likely unless the aircraft struck the ground very near the site. Direct impact on the plant buildings as the aircraft approached the ground would also be of concern. Therefore, a shadow length of 0.5 miles is assumed to apply, for an effective target area of approximately 0.05 mi^2. The frequency of an aircraft crash that could impact important plant buildings can therefore be estimated as follows:

$$P_{CA} = (7.7x10^{-10} crashes / aircraft - mile)(36,500\, flights / yr)\left(\frac{0.05 mi^2}{8 mi}\right)$$

$$= 1.8x10^{-7} / yr$$

Thus, the hazard posed by aircraft is very small for Crystal River 3.

Railway Accidents

The nearest railway line is approximately 9 miles from the site, so that accidents involving passing trains need not be considered. The site is served by a spur line; only cars consigned to the Crystal River plant are brought onto the site over the spur. Another spur ties into the Florida Power spur line at a point about 3.5 miles east of the site. This second spur services a small dolomite mining and processing facility about 4 miles from the plant. The mine uses relatively small amounts of explosives in its operations. The amount that could be involved in a railway accident is too small to affect the Crystal River site.

Highway Accidents

The only major highway near the plant site is U.S. Route 19, which passes approximately 4 miles east of the site. According to NUREG/CR-5042, only major highways that pass through or near the plant exclusion area and involve a heavy volume of traffic with hazardous material shipments need be considered in more detail. This highway is sufficiently far from the plant site and subject to a relatively small volume of traffic, so that it does not pose a significant hazard to the plant site.

Pipeline Accidents

There are no pipelines passing on or near the plant site, so this source of hazard need not be considered further.

Other Facilities

The mining operation referred to previously is about 4 miles from the plant site. It uses explosives up to an amount equivalent to 1000 lb of TNT. This has been evaluated and determined to be insufficient to have an impact at the Crystal River site. In addition, there is an oil storage facility approximately 4.3 miles from the plant site. The facility is no longer in use, however, and its tanks have been emptied.

Some hazardous materials are also used at Crystal River 3 and the four coal-fired units on site. The potential effects on control room habitability that might result from the accidental release of ammonia, sulfur dioxide, or chlorine have been investigated. It was determined that these accidental releases would be insufficient to produce toxic concentrations that could be inducted into the control complex (Reference 5-18).

5.5 References

5-1 *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities.* U.S. Nuclear Regulatory Commission Report NUREG-1407, June 1991.

5-2 Kimura, C. Y. and R. J. Budnitz. *Evaluation of External Hazards to Nuclear Power Plants in the United States.* U.S. Nuclear Regulatory Commission Report NUREG/CR-5042, December 1987.

5-3 *Crystal River Unit 3 Final Safety Analysis Report.* Florida Power Corporation, Section 5.2.1.2.6.

5-4 McDonald, J. R. *A Methodology for Tornado Hazard Probability Assessment.* U.S. Nuclear Regulatory Commission Report NUREG/CR-3058, October 1983.

5-5 "Florida Tornadoes 1950 - 1995". Storm Prediction Center Electronic Data Base, August 1996.

5-6 Thom, H.C.S. "Tornado Probabilities", *Monthly Weather Review.* October-December 1963, pp. 730 - 736.

5-7 *J. Atmos. Sci.* August, 1981, pp. 1517-1519.

5-8 *PRA Procedures Guide.* American Nuclear Society and U.S. Nuclear Regulatory Commission Report NUREG/CR-2300, August 1983.

5-9 Averett. M.W. "Risk Analysis of CR-1 Stack Falling on the CR-3 Site". Florida Power Corporation Memorandum FMS93-028, July 19, 1993.

5-10 "U.S. Wind Data 1955 - 1995". Storm Prediction Center Electronic Data Base, August 1996.

5-11 *Crystal River Unit 3 Final Safety Analysis Report*. Florida Power Corporation, Section 2.4.2.4.

5-12 *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition*, September 1975.

5-13 *Design Basis Floods for Nuclear Power Plants*. U.S. Nuclear Regulatory Commission Regulatory Guide 1.59, Rev. 2, August 1977.

5-14 *American National Standard for Determining Design Basis Flooding at Power Reactor Sites*. American National Standards Institute/American Nuclear Society Standard 2.8-1992, July 28, 1992.

5-15 Schwencer, A. "Regulatory Position on Crystal River Nuclear Station". U.S. Atomic Energy Commission letter to J.T. Rogers, Florida Power Corporation, October 12, 1973.

5-16 "Status of Surge Protection for Transformers". Florida Power Corporation Precursor No. 96-3543, July 29, 1996.

5-17 Aviation System Indicators: 1995 Annual Report. U.S. Federal Aviation Administration Office of Safety Services, (downloaded October 21, 1996).

5-18 Tunstill, J.W. "Aircraft Flights Within Approximately 10 Miles of Crystal River Airport". Florida Power Corporation Internal Memorandum to M.W. Averett, October 21, 1996.

5-19 *Crystal River Unit 3 Final Safety Analysis Report*. Florida Power Corporation, Section 2.2.3.

6. Licensee Participation and Internal Review Team

6.1 IPEEE Program Organization

The CR-3 IPEEE internal fire risk analysis was performed by Mark W. Averett, David N. Miskiewicz, and Michael R. Casada. The analysis was performed using the EPRI Fire PRA methodology. Guidance in the use of this methodology was provided by William Parkinson, of SAIC. The primary calculational tool, FRANC, was written by Chris Cragg, SAIC. The analysis of high winds, external floods, and transportation and nearby facility accidents was performed by Stuart Lewis of Safety and Reliability Optimization Services, Inc. (SAROS)

6.2 Composition of Independent Review Team

The primary independent review was performed by Stuart Lewis of Safety and Reliability Optimization Services, Inc. (SAROS), whose review is given below in Section 6.3. As a secondary informal review, Tony Raimondo of VECTRA verified that the CR-3 fire analysis model, consisting of the Access files, the FRANC files and the fault tree model reflected the safe shutdown train availabilities in the Appendix R Fire Study. Differences in the results were traced back to determine if their source was due to an error in the database, credit for manual actions not modeled in the PSA model, or conservatisms in the PSA model. Any errors were corrected.

6.3 Areas of Review and Major Comments

A review was conducted of the analysis of internal fires at Crystal River 3 (CR-3) performed for the Individual Plant Examination of External Events (IPEEE, Reference 1). This review focused on the following elements of the assessment:

- The overall approach selected, with regard to its ability, when applied properly, to identify severe accident vulnerabilities and to provide reasonable characterizations of risk as may be desired for applications beyond the IPEEE.

- The degree of completeness with respect to the areas of the plant subjected to qualitative or quantitative analysis.

- The appropriateness of any screening criteria used to eliminate zones of apparently low risk potential from more detailed analysis, and the applications made of those criteria.

- The manner in which unscreened areas were evaluated with respect to several factors, including the following:
    - The estimation of initiating frequencies for fires;
    - The appropriateness of the sources and targets selected, (to the extent that could be determined from available information);

- The reasonableness of timing to failure of the target, and of the corresponding failure probabilities of suppression measures (manual and automatic).
- The assessment of the conditional probability of core damage for the fire scenarios.

A probabilistic risk assessment (PRA) of fires was performed to satisfy the IPEEE. The PRA employed the methods and data developed under the sponsorship of the Electric Power Research Institute (EPRI, Reference 2).

Overall Conclusions

The fire PRA represents an appropriate approach to assessing the potential for severe accidents to result from internal fires. The overall effort required, while still substantial, is less than would have been required if the methods and data developed for the EPRI fire PRA procedure and for the Fire-Induced Vulnerability Evaluation (FIVE) program (Reference 3) had not been extensively employed.

The core-damage frequency for fires calculated for CR-3 is significantly higher than that for internal events. While there is substantial uncertainty in these results, they appear to be reasonable, and the specific fire zones that contribute most to the results make engineering sense.

The fire PRA appears to be a reasonably comprehensive analysis, and should have been more than adequate to allow for the identification of any severe-accident vulnerabilities. Most of the comments provided in this report summarize features of the analysis that contributed most to the results obtained. A few comments regarding areas that might be re-considered are identified.

Modeling of Fire-Induced Failures

The primary consideration in the study was the possible effect of fires on control and power circuits. The approach taken and assumptions made were reviewed.

1. One of the most thorough elements of the fire assessment was the development of an extensive data base to tie circuits in various locations to specific components modeled in the IPE. A generally conservative assumption was made that any control or power circuit exposed to a fire in a particular fire zone would cause unavailability of the associated equipment. It is not clear from the report whether there was any supplemental investigation and modeling of failures beyond those considered in the IPE. It is possible that the fire could cause spurious actuations that were neglected in the IPE because of the dominance of other failure modes.

2. There is some indication that the possibility of a fire that leads to spurious opening of valves in the pressure boundary for the reactor coolant system was considered, but the extent to which this was done could not be determined.. It is possible that hot shorts in some control circuits could lead to opening of the pressurizer pilot-operated relief valve, the letdown isolation valve, or other paths that could constitute a small loss-of-coolant accident. These types of failure are usually not

modeled explicitly in PRAs. If this potential was reviewed and ruled out, the review should be documented for the fire analysis.

3. With regard to failures of control circuits, no attempt was made to discriminate between open circuits and hot shorts. This is conservative, unless a hot short could lead to a worse condition than that modeled in the IPE. The probability of a hot short is typically taken to be smaller than that for an open circuit; this could be taken into account if a more careful assessment of failure modes is made.

Fire Modeling

Two levels of quantitative analysis were performed. In the first, a screening step, all equipment in a particular fire zone was assumed to be failed by any fire in the zone. The conditional probability of core damage was then calculated and combined with the initiation frequency for the zone. If the resulting core-damage frequency was below 1×10^{-6}, the zone was screened from further analysis.

For zones that did not screen using this approach, fire modeling was performed in more detail. This entailed identifying potential ignition sources and targets. Heat release rates were calculated and used, together with the geometries of the zone, to determine whether the fire sources were capable of affecting the targets.

1. Extensive walkdowns of the fire zones were performed to support the fire modeling effort. These walkdowns should have been very beneficial to the effort, and especially lend substantial credibility to the analysis.

2. The approach to characterizing the severity of the fires and the times to damage drew heavily on the FIVE models and data. This appears to be a reasonable approach, and is a more effective use of resources than performing extensive calculations with a tool such as COMPBRN.

3. The assessment of non-suppression applied data for automatic and manual suppression compiled by EPRI. It is not clear that there was any effort to review plant-specific information concerning response times for fire brigades, or to adjust the manual non-suppression probability for zones in different locations within the plant.

Fire Initiation Frequencies

Initiation frequencies were drawn from the EPRI Fire Events Data Base (Reference 4), which is the source used for both the EPRI fire PRA approach and FIVE.

1. The frequencies of various fires appear to be properly distributed among the zones in the buildings at CR-3. Frequencies associated with transients also seem to account properly for administrative controls and other measures that limit their presence.

2. The frequencies are appropriately adjusted by severity factors. It does not appear that use of the severity factors and non-suppression probabilities in any zones resulted in over-counting of reduction factors.

Assessment of Fire Barriers

The manner in which fire barriers were credited in protecting redundant trains of equipment for various fire zones was reviewed.

1. Thermo-lag is used in a number of locations at CR-3. The PRA assumed that Thermo-lag intended to provide a 1-hr fire barrier would actually provide protection for about 20 min. Similarly, where it was intended to provide 3-hr protection, 1 hr of actual protection was credited. These assumptions are consistent with industry-sponsored testing and assumptions regarding the effectiveness of Thermo-lag, and are appropriate pending further resolution of the issue.

2. The possibility of multi-compartment fires appears to have been considered in a reasonably comprehensive manner. The effects of failures of active fire-barrier elements (such as dampers and fire doors) were considered, and reasonable probabilities of failure were applied.

Quantification of Conditional Probability of Core Damage

The conditional core-damage probability was calculated by exercising the IPE model, using the FRANC computer code to facilitate accounting for the fire-induced failures.

1. The basic PRA model appears to have been used largely unchanged from its application for the IPE. As noted earlier, the extent to which other possible failures that might not have been modeled for internal sequences in the IPE is not clear.

2. Human interactions incorporated into the PRA models were reviewed with respect to the general context of fire scenarios. Credit for some types of recovery actions were removed. In other cases, the probabilities of specific events were adjusted to reflect increased potential for failure. Most human interactions were, however, left unchanged. This appears to be appropriate.

Fires in the Main Control Room

The potential for core damage to result from fires in the control room was considered with respect to both the effects of fires in specific control boards, and the possibility that any control room fire might lead to the need to evacuate the control room. In the latter case, the options available to the operators to bring the plant to stable hot shutdown conditions could be more limited. The approach taken is an appropriate means of using available information and modeling techniques in an effective manner with a reasonable level of effort.

1. The control room presents a smaller contribution to the frequency of core damage due to internal fires than is typically found for other nuclear power plants. This appears to be largely due to the existence of significant capabilities to achieve safe shutdown from outside the control room at CR-3. These capabilities resulted in a relatively small conditional probability of core damage for scenarios in which it was necessary to evacuate the control room.

2. A screening process was applied to limit the number of cabinets and panels in the control room for which detailed analysis was required. This process reduced the scope of the assessment to two sections of the main control board. Although it appears to be a reasonable conclusion that these two sections present the most severe challenges in the control room, there was not sufficient information available to confirm that the combined frequencies of core damage due to fires in other sections and cabinets would not contribute at a similar or higher level. Even so, however, these cabinets should not contribute to the overall core-damage frequency due to fires, and would not seem to have the potential to constitute vulnerabilities.

3. The non-suppression probability for fires originating in control boards is based on the EPRI interpretation of the Sandia tests, as reported in NSAC-181 (Reference 5). The value obtained reflects an assumption of 15 minutes from the time the fire is first detected to when the control boards would be sufficiently obscured to cause the need to evacuate the control room. In its review of NSAC-181, the NRC concluded that this interpretation could be optimistic, potentially substantially so (Reference 6). A re-examination of the test data, however, indicates that the EPRI interpretation is generally reasonable.

   It should be noted, however, that it is necessary to be very cautious concerning the time at which the fire is assumed to be detected. In the Sandia tests, the induced ignition location was monitored very closely for indications that a fire had initiated. The time at which there was visual evidence of the fire was generally equivalent to the time at which in-cabinet fire detection could have detected the presence of the fire. For cases in which there are no in-cabinet detectors, however (and assuming that there would not normally be such careful monitoring of the ignition source, as there was in the test), it is more reasonable to assume a period of at least 3 minutes from when the fire is detectable in the cabinet, to when it might be detected by the control room staff (e.g., because of smoke, odor, erratic instrument readings, etc.). This would infer that a more appropriate time from detection to obscuration would have been about 12 minutes. Although the difference in non-suppression probabilities is only on the order of a factor of two for these cases, the estimated core-damage frequency for the control room can be quite sensitive to this parameter.

   It should also be noted that, while the Sandia tests did not show the time to obscuration to be very sensitive to ventilation rates in the control room, they did indicate a significant sensitivity to room volume. If the volume above the false ceiling were not included in the total room volume, the time to obscuration of the control panels might be reduced to about 2/3 the time from the Sandia testing. This could correspond to a further increase in the probability of non-suppression.

Fires in the Cable Spreading Room

The cable spreading room typically presents a significant challenge in fire risk assessments due to the large number of potential targets and the variety of geometries they present. A simplified approach was employed to analyze fires in the cable spreading room at CR-3.

1. The simplified approach is facilitated by the lack of fixed ignition sources in the cable spreading room. The frequency of transient-initiated fires in a particular area is small compared to that for many fixed sources. Because of the relatively low initiation frequency, it was possible to assume conservatively that all fires would become fully developed. Even so, the operators could still leave the control room to actuate and control necessary equipment.

2. A sensitivity study was performed in which the potential that the fire could be suppressed by the halon system in the room, and that critical damage could still result even if the fire were suppressed, were evaluated. The quantification for the sensitivity study is inconsistent with the values presented in the discussion of the fire scenarios. It appears that the core-damage frequency for the case in which the control room does not need to be evacuated should have used a conditional probability of core damage of 0.0032, rather than 0.013. The core-damage frequency would therefore have been as follows:

$$\begin{aligned} CDF_{noevac} &= (9.73\times10^{-5}\ /yr)(0.03)(1-0.05)(3.24\times10^{-3}) \\ &= 9.0\times10^{-9}\ /yr \end{aligned}$$

$$\begin{aligned} CDF_{csr} &= 6.3\times10^{-8}\ /yr + 9.0\times10^{-9}\ /yr \\ &= 7.2\times10^{-8}\ /yr \end{aligned}$$

6.5 Resolution of Peer Review Comments

Responses to the comments from the IPEEE Peer Review (Section 6.4) are given below.

Modeling of Fire-Induced Failures

1. Following the development of the Access relational database tying fires to the components and basic events they affected, the impact of fires in each zone on the Appendix R safe shutdown paths as determined using the CR-3 PSA model was compared to that in the Appendix R Fire Study. Where there were differences, changes were made in the PSA model. As a rule, the CR-3 PSA determination of the availability of the safe shutdown paths tended to be more conservative than that from the Appendix R Fire Study. In addition, valve failure modes of spuriously transferring open and spuriously transferring closed were included in the CR-3 PSA fault tree models.

2. Failure of the PORV to close following pressure relief and failure of the PORV to close following HPI cooling are modeled in the CR-3 PSA. Spurious opening of the PORV due to cable damage was not included; however, the PORV is designed to fail closed on loss of control power, so that any fire damage to a cable affecting control power to the PORV will very likely eventually result in PORV closure even if there is an initial spurious actuation.

3. No response necessary. The effect is to make the model more conservative.

Fire Modeling

1. No response necessary.

2. No response necessary.

3. The plant-specific fire brigade response times were reviewed, and generally found to be typical of other utilities' participating in the EPRI Fire PSA and FIVE Tailored Collaboration projects. Credit for suppression was given according to the guidelines given in the EPRI Fire Risk Analysis Implementation Guide (Ref. 6-2). Fire brigade response times considered were the first responder arrival time and the full brigade arrival time. These times were typically about 1-3 minutes and 8-12 minutes respectively. It is difficult to take credit for the first responder suppressing a fire before damage occurs to nearby circuits due to the short times assumed in the screening analysis, i.e., the time to circuit failure due to plume damage is often calculated using the FIVE damage worksheets to be about 1 minute or less. It is straightforward, however, to take credit for both the first responders and the full brigade in the fire scenarios where redundant trains could be affected. These scenarios involve either Thermo-Lagged and unprotected circuits in the same plume, or separated circuits damaged by hot gas layers caused by large cable fires. In these scenarios, the fire brigade drill times were always less and often much less than the calculated damage time. Hence no zone-specific response times were used.

Assessment of Fire Barriers

1. No response necessary.

2. No response necessary.

Quantification of Conditional Probability of Core Damage

1. See response for "Overall Conclusions," first comment.

2. No response necessary.

Fires in the Main Control Room

1. The relatively low CCDP for control room evacuation is a direct result of the review of the controls available to the operator at the remote shutdown panel, which revealed that in most scenarios, the controls necessary for safe shutdown were present on the panel.

2. Not addressed due to low potential for significant contribution to core damage frequency.

3. No response necessary.

Fires in the Cable Spreading Room

1. No response necessary.

2. The correction to the CDF_{csr} calculation has been made.

6.4 References

6-1 Averett, M.W., et al. Crystal River 3 Individual Plant Examination of External Events. Florida Power Corporation, June 1996.

6-2 Parkinson, W.J., et al. Fire PRA Implementation Guide. Electric Power Research Institute Report TR-105928, December 1995.

6-3 Fire-Induced Vulnerability Evaluation (FIVE) Methodology Plant Screening Guide. Electric Power Research Institute Report TR-100370, April 1992.

6-4 Parkinson, W.J., et al. Fire Events Database for U.S. Nuclear Power Plants. Electric Power Research Institute Report NSAC-178L, December 1991.

6-5 Parkinson, W.J., et al. Fire PRA Requantification Studies. Electric Power Research Institute Report NSAC-181, March 1993.

6-6 Lambright, J., et al. A Review of Fire PRA Requantification Studies Reported in NSAC/181. Sandia National Laboratories for the US Nuclear Regulatory Commission Report, April 1994.

7. Plant Improvements and Unique Safety Features

Crystal River 3 is currently undergoing a revised Appendix R analysis, initiated by the Thermo-Lag issue. As a result of this analysis, some re-routing of circuits and the addition of supplemental fire protection will take place. Since this analysis reflects the current plant configuration, no plant improvements, other than the administrative limits to be placed on two of the transient fire storage areas, were or will be made as a result of this analysis. The fire risk analysis will likely be updated in the future to reflect the upcoming changes, and any potential improvements indicated by the analysis will be considered at that time.

8. Summary and Conclusions

In summary, the core damage contribution for fire initiating events at CR-3 is significant; however, the total core damage frequency from all events, internal and external, is 5.2×10^{-5} per year, still well below the NRC threshold of 1×10^{-4} per year. It is not unusual for a nuclear unit's total core damage frequency profile to be dominated by external events, and CR-3 is no exception.

The CR-3 fire PSA indicated what zones are most critical with regard to fire, specifically the zones in the control complex (see Table 1.4-1). The fire PSA also showed which zones were of less concern, even taking into account the reduced effectiveness of the Thermo-Lag. The analysis revealed that some of the dominant fire initiating events were, in fact, transient sources. A minimum of effort in the designation of the areas in the zones where transient storage is permitted will result in a significant reduction in the core damage risk due to fire.

At the time the IPEEE fire analysis was performed, final resolution of the issue of Thermo-Lag and Appendix R compliance at CR-3 had not occurred. The analysis documented herein reflects the configuration of the plant prior to Refuel 10, which began February 16, 1996. The analysis assumes that the one-hour and three-hour Thermo-Lag wraps effectively protect their circuits for 20 minutes and 60 minutes, respectively. Resolution of the Thermo-Lag issue will likely involve circuit re-routing and supplemental wrapping of selected trays and conduits. Following resolution of these issues, FPC will evaluate whether it is necessary to revise this report.

In the emergency procedures for fire initiating events, there is zone-specific guidance relative to actions to be taken in the event of fire. The operator is told which components he is likely to lose completely, the components for which he will lose remote control capability, and which components comprise his safe shutdown path(s). For those components where remote control is lost, the most vital of these are listed as candidates for manual operation should they be needed. No credit was taken in the CR-3 IPEEE fire analysis for any of these manual actions. If necessary, when Thermo-Lag resolution is complete, the CR-3 fire analysis will be requantified to credit these manual actions and their impact on fire risk. Until then, the core damage frequencies given above are likely somewhat conservative due to their exclusion of credit for these manual actions.

9. Appendices

A	Fire ACCESS Database and Query Details
B	Ignition Source / Target Drawings
C	Ignition Frequency Calculations
D	Severity Factors
E	Heat Release Rates
F	Equipment Damage Criteria
G	Walkdown Forms
H	Electrical Cabinet Fires - Effect on Adjacent Cabinets
I	Hot Gas Layer Timing Study
J	Protective Features - Coatings and Barriers

Appendix A

Fire ACCESS Database Table and Query Details

K:\PRA\ACCESS\FIRE.MDB
Table: CDF_Sources

Thursday, May 16, 1996

Properties

Date Created:	5/15/96 12:38:24 PM	Def. Updatable:	Yes
Frozen Columns:	3	Last Updated:	5/15/96 12:38:29 PM
Record Count:	1820		

Columns

Name	Type	Size
ZONE	Text	30
SOURCE	Text	40
SCEN	Text	50
DAMAGE	Text	50
IGNF	Number (Double)	8
HGL	Yes/No	1
AUTO_NSP	Number (Double)	8
MANUAL_HGL	Number (Double)	8
MANUAL_TL	Number (Double)	8
MANUAL_TLZ	Number (Double)	8
MANUAL_NSP	Number (Double)	8
TIME_700	Number (Double)	8
TIME_1000	Number (Double)	8
TIME_TL	Number (Double)	8
CCDP	Number (Double)	8
CDF	Number (Double)	8

Columns

Name	Type	Size
BE	Text	8
NOTE	Text	20
PROB	Number (Double)	8
DESC	Text	60
MODULE	Text	8

Columns

Name	Type	Size
CIRCUIT	Text	7
NATURE	Text	10
FROM	Text	60
TO	Text	60
ROUTING	Text	200

Columns

Name	Type	Size
TAG	Text	20
DESC	Text	50
TYPE	Text	20
SYSTEM	Text	2
SUBSYS	Text	5
LOC	Text	20
ELEV	Text	8
COL/ROW	Text	8
LOCDESC	Text	50
ZONE	Text	15
CIRCUITS	Yes/No	1
RRW	Number (Double)	8
RAW	Number (Double)	8

Columns

Name	Type	Size
MODULE	Text	8
NOTE	Text	20
PROB	Number (Double)	8
DESC	Text	60

Properties

Date Created:	3/14/96 8:11:18 AM	Def. Updatable:	Yes
Last Updated:	3/26/96 11:53:15 AM	Record Count:	37

Columns

Name	Type	Size
SOURCE_TYPE	Text	30
ZONE_TYPE	Text	30
TYPE_FEDB	Text	30
IGNF_FEDB	Number (Double)	8
COUNT	Number (Double)	8
IGNF_CR3	Number (Double)	8
SEVERITY_FACTOR	Number (Double)	8

Properties

Date Created:	6/9/95 7:32:01 AM	Def. Updatable:	Yes
Last Updated:	4/9/96 3:32:15 PM	Record Count:	25418
Row Height:	645		

Columns

Name	Type	Size
CIRCUIT	Text	7
NATURE	Text	10
FROM	Text	60
TO	Text	60
ROUTING	Text	200

Properties

Date Created:	6/9/95 7:33:55 AM	Def. Updatable:	Yes
Last Updated:	4/16/96 1:20:31 PM	Record Count:	3834
Row Height:	1095		

Columns

Name	Type	Size
CIRCUIT	Text	7
TAG	Text	20
REF	Memo	-
CIRCIR	Yes/No	1
SPURIOUS	Yes/No	1
COMMENTS	Memo	-
by	Text	9

Properties

Date Created:	6/9/95 7:34:13 AM	Def. Updatable:	Yes
Frozen Columns:	2	Last Updated:	4/19/96 11:16:45 AM
Record Count:	20504		

Columns

Name	Type	Size
CIRCUIT	Text	10
CONDUIT	Text	10

Properties

Date Created:	3/20/96 2:02:14 PM	Def. Updatable:	Yes
Last Updated:	4/22/96 7:54:46 AM	Record Count:	2023

Columns

Name	Type	Size
CONDUIT	Text	150
ZONE	Text	50
PROTECT	Text	255
Comments	Text	50

Properties

Date Created:	3/20/96 11:20:30 AM	Def. Updatable:	Yes
Last Updated:	3/20/96 12:24:13 PM	Record Count:	373842

Columns

Name	Type	Size
TRAY	Text	15
COORD	Number (Integer)	2
CIRCUIT	Text	15
Comments	Text	100

Properties

Date Created:	3/20/96 1:55:08 PM	Def. Updatable:	Yes
Last Updated:	3/20/96 4:20:12 PM	Record Count:	5440

Columns

Name	Type	Size
TRAY	Text	255
COORD	Number (Single)	4
ZONE	Text	15
PROTECT	Text	255
X-Column_Line	Text	4
X-Distance_Feet	Number (Integer)	2
X-Distance_Inches	Number (Integer)	2
Y-Column_Line	Text	4
Y-Distance_Feet	Number (Integer)	2
Y-Distance_Inches	Number (Integer)	2
Z-Elevation	Number (Single)	4
Width	Number (Single)	4
Depth	Number (Single)	4
Intersection-1	Number (Integer)	2
Intersection-2	Number (Integer)	2
Intersection-3	Number (Integer)	2
Hanger_Support-1	Text	15
Hanger_Support-2	Text	15
Hanger_Support-3	Text	15
Coordinate_Pct_Area	Number (Single)	4
Coordinate_Weight	Number (Single)	4
Comments	Text	100

Columns

Name	Type	Size
BE	Text	8
BEMOD	Text	255
BETAG	Text	20

Properties

Date Created:	11/14/95 2:18:36 PM	Def. Updatable:	Yes
Last Updated:	4/11/96 7:11:15 AM	Record Count:	112

Columns

Name	Type	Size
ZONE	Text	15
ZONE_TYPE	Text	255
DESC	Text	60
AREA	Number (Double)	8
LOADING	Number (Double)	8
TEMP	Number (Double)	8
DURATION	Number (Double)	8
CFF	Number (Double)	8
DETECTION	Text	20
AUTO	Text	60
MANUAL	Text	120
HOSE_STA	Text	2
NSP	Number (Double)	8
TL_1hr	Text	255
TL_3hr	Text	255

Properties

Date Created:	5/10/96 10:30:08 AM	Def. Updatable:	Yes
Last Updated:	5/10/96 1:45:22 PM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Select		

SQL

```
SELECT DISTINCT SOURCE.SOURCE, SOURCE.ZONE, SOURCE.SOURCE_TYPE, ZONE.ZONE_TYPE,
IIf(Left$([SOURCE].[SOURCE],6)="TRANS-
",([IGNF_GENERIC].[IGNF_FEDB]/[countSOURCESperZONE].[SumOfCOUNT])*[IGNF_GENERIC].[SEVERIT
_FACTOR],[IGNF_GENERIC].[IGNF_CR3]*[IGNF_GENERIC].[SEVERITY_FACTOR]) AS IGNF_SOURCE
FROM ((SOURCE INNER JOIN ZONE ON SOURCE.ZONE = ZONE.ZONE) INNER JOIN IGNF_GENERIC ON
(ZONE.ZONE_TYPE = IGNF_GENERIC.ZONE_TYPE) AND (SOURCE.SOURCE_TYPE =
IGNF_GENERIC.SOURCE_TYPE)) INNER JOIN countSOURCESperZONE ON (SOURCE.SOURCE_TYPE =
countSOURCESperZONE.SOURCE_TYPE) AND (SOURCE.ZONE = countSOURCESperZONE.ZONE)
ORDER BY SOURCE.SOURCE;
```

Columns

Name	Type	Size
SOURCE.SOURCE	Text	50
ZONE	Text	30
SOURCE_TYPE	Text	30
ZONE_TYPE	Text	255
IGNF_SOURCE	Number (Double)	8

Properties

Date Created:	6/3/96 8:47:12 AM	Def. Updatable:	Yes
Frozen Columns:	3	Last Updated:	6/3/96 2:30:26 PM
ODBC Timeout:	60	Record Locks:	Edited Record
Returns Records:	Yes	Type:	Select

SQL

```
SELECT DISTINCTROW [CDF_20/60].SOURCE, Sum([CDF_20/60].CDF) AS CDF_FINAL
FROM [CDF_20/60]
GROUP BY [CDF_20/60].SOURCE
ORDER BY Sum([CDF_20/60].CDF) DESC;
```

Columns

Name	Type	Size
SOURCE	Text	40
CDF_FINAL	Number (Double)	8

Properties

Date Created:	5/15/96 12:38:46 PM	Def. Updatable:	Yes
Frozen Columns:	3	Last Updated:	6/3/96 2:30:49 PM
ODBC Timeout:	60	Record Locks:	Edited Record
Returns Records:	Yes	Type:	Select

SQL

```
SELECT DISTINCTROW [CDF_20/60].ZONE, Sum([CDF_20/60].CDF) AS CDF_FINAL
FROM [CDF_20/60]
GROUP BY [CDF_20/60].ZONE
HAVING (((Sum([CDF_20/60].CDF))>0.000001))
ORDER BY Sum([CDF_20/60].CDF) DESC;
```

Columns

Name	Type	Size
ZONE	Text	30
CDF_FINAL	Number (Double)	8

Properties

Date Created:	5/16/96 11:04:54 AM	Def. Updatable:	Yes
Last Updated:	5/16/96 11:04:54 AM	Record Count:	5569

Columns

Name	Type	Size
FREVENT	Text	255
TOEVENT	Text	20
TOTYPE	Text	255
SOURCE	Text	50

A

Properties

Date Created:	3/25/96 10:01:02 AM	Def. Updatable:	Yes
Last Updated:	5/16/96 10:54:27 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT "S"+[SOURCE_ID] AS FREVENT, CIRTAG.TAG AS TOEVENT, "1" AS TOTYPE,
SOURCE.SOURCE INTO tmpSOURCETAG
FROM ((SOURCE_TARGET INNER JOIN SOURCE ON SOURCE_TARGET.SOURCE = SOURCE.SOURCE)
INNER JOIN ((TRAYCIR INNER JOIN CIRTAG ON TRAYCIR.CIRCUIT = CIRTAG.CIRCUIT) INNER JOIN
TRAYZONE ON TRAYCIR.TRAY = TRAYZONE.TRAY) ON (TRAYZONE.COORD = TRAYCIR.COORD) AND
(SOURCE_TARGET.TARGET = TRAYZONE.TRAY) AND (SOURCE.ZONE = TRAYZONE.ZONE)) INNER
JOIN francZONESCENARIOS_UNSCREENED ON SOURCE.ZONE =
francZONESCENARIOS_UNSCREENED.Zone
ORDER BY "S"+[SOURCE_ID], CIRTAG.TAG;
```

Query Parameters

Name	Type
IGNF_ZONE.ZONE	Text

Properties

Date Created:	3/21/96 3:49:19 PM	Def. Updatable:	Yes
Last Updated:	5/16/96 11:03:55 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Append		

SQL

```
INSERT INTO tmpSOURCETAG ( FREVENT, TOEVENT, TOTYPE, SOURCE_SOURCE )
SELECT DISTINCT "S"+[SOURCE_ID] AS FREVENT, CIRTAG.TAG AS TOEVENT, "1" AS TOTYPE,
SOURCE.SOURCE
FROM (((SOURCE_TARGET INNER JOIN (CONDCIR INNER JOIN CIRTAG ON CONDCIR.CIRCUIT =
CIRTAG.CIRCUIT) ON SOURCE_TARGET.TARGET = CONDCIR.CONDUIT) INNER JOIN CONDZONE ON
CONDCIR.CONDUIT = CONDZONE.CONDUIT) INNER JOIN SOURCE ON SOURCE_TARGET.SOURCE =
SOURCE.SOURCE) INNER JOIN francZONESCENARIOS_UNSCREENED ON SOURCE.ZONE =
francZONESCENARIOS_UNSCREENED.Zone;
```

Query Parameters

Name	Type
IGNF_ZONE.ZONE	Text

Properties

Date Created:	3/29/96 1:45:45 PM	Def. Updatable:	Yes
Last Updated:	5/16/96 11:04:44 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT tmpSOURCETAG.FREVENT, tmpSOURCETAG.TOEVENT, tmpSOURCETAG.TOTYPE,
tmpSOURCETAG.SOURCE_SOURCE AS SOURCE INTO francSOURCETAG
FROM tmpSOURCETAG
ORDER BY tmpSOURCETAG.SOURCE_SOURCE;
```

K:\PRA\ACCESS\FIRE.MDB
Table: francSOURCETAGTL B

Thursday, May 16, 1996

Properties

Date Created:	5/16/96 11:14:11 AM	Def. Updatable:	Yes
Last Updated:	5/16/96 11:14:11 AM	Record Count:	4856

Columns

Name	Type	Size
FREVENT	Text	255
TOEVENT	Text	20
TOTYPE	Text	255
SOURCE	Text	50

K:\PRA\ACCESS\FIRE.MDB
Query: francSOURCETAG_TL_1 B

Properties

Date Created:	3/25/96 10:32:48 AM	Def. Updatable:	Yes
Last Updated:	5/16/96 10:25:14 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT "S"+[SOURCE_ID] AS FREVENT, CIRTAG.TAG AS TOEVENT, "1" AS TOTYPE,
SOURCE.SOURCE INTO tmpSOURCETAGTL
FROM ((SOURCE_TARGET INNER JOIN SOURCE ON SOURCE_TARGET.SOURCE = SOURCE.SOURCE)
INNER JOIN ((TRAYCIR INNER JOIN CIRTAG ON TRAYCIR.CIRCUIT = CIRTAG.CIRCUIT) INNER JOIN
TRAYZONE ON TRAYCIR.TRAY = TRAYZONE.TRAY) ON (TRAYZONE.COORD = TRAYCIR.COORD) AND
(SOURCE_TARGET.TARGET = TRAYZONE.TRAY) AND (SOURCE.ZONE = TRAYZONE.ZONE)) INNER
JOIN francZONESCENARIOS_UNSCREENED ON SOURCE.ZONE =
francZONESCENARIOS_UNSCREENED.Zone
WHERE ((TRAYZONE.PROTECT Is Null))
ORDER BY CIRTAG.TAG;
```

Query Parameters

Name	Type
IGNF_ZONE.ZONE	Text

B

Properties

Date Created:	3/21/96 3:54:36 PM	Def. Updatable:	Yes
Last Updated:	5/16/96 11:10:57 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Append		

SQL

```
INSERT INTO tmpSOURCETAGTL ( FREVENT, TOEVENT, TOTYPE, SOURCE_SOURCE )
SELECT DISTINCT "S"+[SOURCE_ID] AS FREVENT, CIRTAG.TAG AS TOEVENT, "1" AS TOTYPE,
SOURCE.SOURCE
FROM ((SOURCE_TARGET INNER JOIN ((CONDCIR INNER JOIN CIRTAG ON CONDCIR.CIRCUIT =
CIRTAG.CIRCUIT) INNER JOIN CONDZONE ON CONDCIR.CONDUIT = CONDZONE.CONDUIT) ON
SOURCE_TARGET.TARGET = CONDCIR.CONDUIT) INNER JOIN SOURCE ON (SOURCE.ZONE =
CONDZONE.ZONE) AND (SOURCE_TARGET.SOURCE = SOURCE.SOURCE)) INNER JOIN
francZONESCENARIOS_UNSCREENED ON SOURCE.ZONE =
francZONESCENARIOS_UNSCREENED.Zone
WHERE ((CONDZONE.PROTECT Is Null));
```

Query Parameters

Name	Type
IGNF_ZONE.ZONE	Text

K:\PRA\ACCESS\FIRE.MDB
Query: francSOURCETAG_TL_3 B

Thursday, May 16, 1996

Properties

Date Created:	3/29/96 1:55:03 PM	Def. Updatable:	Yes
Last Updated:	5/16/96 11:13:58 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT tmpSOURCETAGTL.FREVENT, tmpSOURCETAGTL.TOEVENT,
tmpSOURCETAGTL.TOTYPE, tmpSOURCETAGTL.SOURCE_SOURCE AS SOURCE INTO
francSOURCETAGTL
FROM tmpSOURCETAGTL
ORDER BY tmpSOURCETAGTL.SOURCE_SOURCE;
```

K:\PRA\ACCESS\FIRE.MDB
Table: francSOURCEZNTLTAG

Thursday, May 16, 1996

Properties

Date Created:	5/16/96 11:19:26 AM	Def. Updatable:	Yes
Last Updated:	5/16/96 11:19:26 AM	Record Count:	31376

Columns

Name	Type	Size
FREVENT	Text	255
TOEVENT	Text	20
TOTYPE	Text	255
SOURCE	Text	50

Properties

Date Created:	5/16/96 9:37:55 AM	Def. Updatable:	Yes
Last Updated:	5/16/96 10:33:47 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCTROW francSOURCETAG.FREVENT, francSOURCETAG.TOEVENT,
francSOURCETAG.TOTYPE, francSOURCETAG.SOURCE INTO tmpSOURCEZNTLTAG
FROM francSOURCETAG;
```

K:\PRA\ACCESS\FIRE.MDB
Query: francSOURCEZNTLTAG_2 ✓

Properties

Date Created:	5/16/96 8:57:36 AM	Def. Updatable:	Yes
Last Updated:	5/16/96 10:34:06 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Append		

SQL

```
INSERT INTO tmpSOURCEZNTLTAG ( FREVENT, TOEVENT, TOTYPE, SOURCE )
SELECT DISTINCT francSOURCETAG.FREVENT, francZONETAGTL.TOEVENT,
francZONETAGTL.TOTYPE, francSOURCETAG.SOURCE
FROM (francSOURCETAG INNER JOIN SOURCE ON francSOURCETAG.SOURCE = SOURCE.SOURCE)
INNER JOIN francZONETAGTL ON SOURCE.ZONE = francZONETAGTL.FREVENT;
```

K:\PRA\ACCESS\FIRE.MDB
Query: francSOURCEZNTLTAG_3

Thursday, May 16, 1996

Properties

Date Created:	5/16/96 9:41:36 AM	Def. Updatable:	Yes
Last Updated:	5/16/96 9:41:38 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT tmpSOURCEZNTLTAG.FREVENT, tmpSOURCEZNTLTAG.TOEVENT,
tmpSOURCEZNTLTAG.TOTYPE, tmpSOURCEZNTLTAG.SOURCE INTO francSOURCEZNTLTAG
FROM tmpSOURCEZNTLTAG;
```

Properties

Date Created:	4/26/96 9:05:47 AM	Def. Updatable:	Yes
Last Updated:	4/26/96 9:05:47 AM	Record Count:	5611

Columns

Name	Type	Size
FREVENT	Text	15
TOEVENT	Text	20
TOTYPE	Text	255

K:\PRA\ACCESS\FIRE.MDB
Query: francZONETAG_1 A

Thursday, May 16, 1996

Properties

Date Created:	3/5/96 4:15:23 PM	Def. Updatable:	Yes
Last Updated:	4/26/96 9:00:46 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT TRAYZONE.ZONE, CIRTAG.TAG INTO tmpZONETAG
FROM (TRAYZONE INNER JOIN TRAYCIR ON (TRAYZONE.COORD = TRAYCIR.COORD) AND
(TRAYZONE.TRAY = TRAYCIR.TRAY)) INNER JOIN CIRTAG ON TRAYCIR.CIRCUIT = CIRTAG.CIRCUIT
ORDER BY TRAYZONE.ZONE, CIRTAG.TAG;
```

K:\PRA\ACCESS\FIRE.MDB
Query: francZONETAG_2 A

Thursday, May 16, 1996
Page: 1

Properties

Date Created:	3/5/96 4:15:32 PM	Def. Updatable:	Yes
Last Updated:	4/26/96 9:04:18 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Append		

SQL

```
INSERT INTO tmpZONETAG ( ZONE, TAG )
SELECT DISTINCT CONDZONE.ZONE, CIRTAG.TAG
FROM (CONDZONE INNER JOIN CONDCIR ON CONDZONE.CONDUIT = CONDCIR.CONDUIT) INNER
JOIN CIRTAG ON CONDCIR.CIRCUIT = CIRTAG.CIRCUIT
ORDER BY CONDZONE.ZONE, CIRTAG.TAG;
```

Properties

Date Created:	3/26/96 4:44:21 PM	Def. Updatable:	Yes
Last Updated:	4/26/96 9:05:38 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT tmpZONETAG.ZONE AS FREVENT, tmpZONETAG.TAG AS TOEVENT, "1" AS TOTYPE
INTO francZONETAG
FROM tmpZONETAG
ORDER BY tmpZONETAG.ZONE, tmpZONETAG.TAG;
```

Properties

Date Created:	4/26/96 8:59:56 AM	Def. Updatable:	Yes
Last Updated:	4/26/96 8:59:56 AM	Record Count:	4788

Columns

Name	Type	Size
FREVENT	Text	15
TOEVENT	Text	20
TOTYPE	Text	255

Properties

Date Created: 3/20/96 2:22:31 PM
Last Updated: 4/26/96 8:45:57 AM
Record Locks: Edited Record
Type: Make-table
Def. Updatable: Yes
ODBC Timeout: 60
Returns Records: Yes

SQL

```
SELECT DISTINCT TRAYZONE.ZONE, CIRTAG.TAG INTO tmpZONETAGTL
FROM (TRAYZONE INNER JOIN TRAYCIR ON (TRAYZONE.COORD = TRAYCIR.COORD) AND
(TRAYZONE.TRAY = TRAYCIR.TRAY)) INNER JOIN CIRTAG ON TRAYCIR.CIRCUIT = CIRTAG.CIRCUIT
WHERE ((TRAYZONE.PROTECT Is Null))
ORDER BY TRAYZONE.ZONE, CIRTAG.TAG;
```

K:\PRA\ACCESS\FIRE.MDB

Query: francZONETAG_TL_2 B

Properties

Date Created:	3/20/96 2:18:40 PM	Def. Updatable:	Yes
Last Updated:	4/26/96 8:56:15 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Append		

SQL

```
INSERT INTO tmpZONETAGTL ( ZONE, TAG )
SELECT DISTINCT CONDZONE.ZONE, CIRTAG.TAG
FROM (CONDZONE INNER JOIN CONDCIR ON CONDZONE.CONDUIT = CONDCIR.CONDUIT) INNER
JOIN CIRTAG ON CONDCIR.CIRCUIT = CIRTAG.CIRCUIT
WHERE ((CONDZONE.PROTECT Is Null))
ORDER BY CONDZONE.ZONE, CIRTAG.TAG;
```

B

Properties

Date Created:	3/26/96 5:01:04 PM	Def. Updatable:	Yes
Last Updated:	4/26/96 8:59:50 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT tmpZONETAGTL.ZONE AS FREVENT, tmpZONETAGTL.TAG AS TOEVENT, "1" AS
TOTYPE INTO francZONETAGTL
FROM tmpZONETAGTL
ORDER BY tmpZONETAGTL.ZONE, tmpZONETAGTL.TAG;
```

Properties

Date Created:	4/26/96 8:44:26 AM	Def. Updatable:	Yes
Last Updated:	4/26/96 9:08:30 AM	Record Count:	224

Columns

Name	Type	Size
ID	Number (Long)	4
Hide	Yes/No	1
Run	Yes/No	1
Zone	Text	15
ZoneDesc	Text	60
Auto	Text	60
Scen	Text	255
ScenDesc	Text	255
MapTable	Text	50
CreditWrap	Yes/No	1
BEC	Yes/No	1
BF	Yes/No	1
TRC	Yes/No	1
TRMCUB	Number (Single)	4
TRTrunc	Number (Single)	4
ORC	Yes/No	1
ORMCUB	Number (Single)	4
ORTrunc	Number (Single)	4
GTC	Yes/No	1
GTMCUB	Number (Single)	4
GTTrunc	Number (Single)	4
IGF	Number (Double)	8
NSP	Number (Double)	8
CCDP	Number (Single)	4
CDF	Number (Single)	4
Screened	Yes/No	1
Notes	Memo	-

Properties

Date Created:	4/1/96 4:03:13 PM	Def. Updatable:	Yes
Last Updated:	5/16/96 3:48:53 PM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT francZONESCENARIOS_EMPTY.Hide, francZONESCENARIOS_EMPTY.Run,
ZONE.ZONE AS [Zone*], ZONE.DESC AS ZoneDesc, ZONE.AUTO AS Auto, "A" AS Scen, "" AS ScenDesc,
francZONESCENARIOS_EMPTY.MapTable, francZONESCENARIOS_EMPTY.CreditWrap,
francZONESCENARIOS_EMPTY.BEC, francZONESCENARIOS_EMPTY.BF,
francZONESCENARIOS_EMPTY.TRC, francZONESCENARIOS_EMPTY.TRMCUB,
francZONESCENARIOS_EMPTY.TRTrunc, francZONESCENARIOS_EMPTY.ORC,
francZONESCENARIOS_EMPTY.ORMCUB, francZONESCENARIOS_EMPTY.ORTrunc,
francZONESCENARIOS_EMPTY.GTC, francZONESCENARIOS_EMPTY.GTMCUB,
francZONESCENARIOS_EMPTY.GTTrunc, IGNF_ZONE.IGNF_ZONE AS IGF,
IIf([ZONE].[AUTO]="none",1,[ZONE].[NSP]) AS [NSP*], francZONESCENARIOS_EMPTY.CCDP,
francZONESCENARIOS_EMPTY.CDF, francZONESCENARIOS_EMPTY.Screened INTO
tmpZONESCENARIOS
FROM (ZONE LEFT JOIN francZONESCENARIOS_EMPTY ON ZONE.ZONE =
francZONESCENARIOS_EMPTY.Zone) LEFT JOIN IGNF_ZONE ON ZONE.ZONE = IGNF_ZONE.[ZONE*]
ORDER BY ZONE.ZONE;
```

Properties

Date Created:	4/1/96 4:14:17 PM	Def. Updatable:	Yes
Last Updated:	5/16/96 3:49:18 PM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Append		

SQL

```
INSERT INTO tmpZONESCENARIOS ( Run, [Zone*], ZoneDesc, Auto, Scen, ScenDesc, MapTable, CreditWrap,
BEC, BF, TRC, TRMCUB, TRTrunc, ORC, ORMCUB, ORTrunc, GTC, GTMCUB, GTTrunc, IGF, [NSP*]
CCDP, CDF, Screened )
SELECT DISTINCT francZONESCENARIOS_EMPTY.Run, ZONE.ZONE AS [Zone*], ZONE.DESC AS
ZoneDesc, ZONE.AUTO AS Auto, "B" AS Scen, "" AS ScenDesc, "ZONETL" AS MapTable,
francZONESCENARIOS_EMPTY.CreditWrap, francZONESCENARIOS_EMPTY.BEC,
francZONESCENARIOS_EMPTY.BF, francZONESCENARIOS_EMPTY.TRC,
francZONESCENARIOS_EMPTY.TRMCUB, francZONESCENARIOS_EMPTY.TRTrunc,
francZONESCENARIOS_EMPTY.ORC, francZONESCENARIOS_EMPTY.ORMCUB,
francZONESCENARIOS_EMPTY.ORTrunc, francZONESCENARIOS_EMPTY.GTC,
francZONESCENARIOS_EMPTY.GTMCUB, francZONESCENARIOS_EMPTY.GTTrunc,
IGNF_ZONE.IGNF_ZONE AS IGF, 1-[ZONE].[NSP] AS [NSP*], francZONESCENARIOS_EMPTY.CCDP,
francZONESCENARIOS_EMPTY.CDF, francZONESCENARIOS_EMPTY.Screened
FROM (ZONE LEFT JOIN francZONESCENARIOS_EMPTY ON ZONE.ZONE =
francZONESCENARIOS_EMPTY.Zone) LEFT JOIN IGNF_ZONE ON ZONE.ZONE = IGNF_ZONE.[ZONE*]
ORDER BY ZONE.ZONE, ZONE.ZONE;
```

Query: francZONESCENARIOS_3

Properties

Date Created:	3/29/96 11:07:39 AM	Def. Updatable:	Yes
Last Updated:	4/26/96 8:43:34 AM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT tmpZONESCENARIOS.* INTO francZONESCENARIOS
FROM tmpZONESCENARIOS
ORDER BY tmpZONESCENARIOS.[Zone*], tmpZONESCENARIOS.Scen;
```

Properties

Date Created:	4/3/96 3:41:41 PM	Def. Updatable:	Yes
Last Updated:	5/10/96 1:36:09 PM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Select		

SQL

```
SELECT DISTINCTROW ZoneScenarios.Zone, ZoneScenarios.ZoneDesc, Sum(ZoneScenarios.CDF) AS
CDF_OLD, Sum(([CDF]/[IGF])*[IGNF_ZONE]) AS CDF_NEW
FROM ZoneScenarios INNER JOIN IGNF_ZONE ON ZoneScenarios.Zone = IGNF_ZONE.ZONE
GROUP BY ZoneScenarios.Zone, ZoneScenarios.ZoneDesc
HAVING ((ZoneScenarios.Zone<>"CC-145-118B" And ZoneScenarios.Zone<>"CC-134-118A") AND
((Sum(([CDF]/[IGF])*[IGNF_ZONE]))>0.000001))
ORDER BY Sum(([CDF]/[IGF])*[IGNF_ZONE]) DESC;
```

Query Parameters

Name	Type
IGNF_ZONE.ZONE	Text

Columns

Name	Type	Size
Zone	Text	15
ZoneDesc	Text	60
CDF_OLD	Number (Double)	8
CDF_NEW	Number (Double)	8

Properties

Date Created: 4/26/96 12:09:10 PM
Last Updated: 4/26/96 12:09:52 PM
Def. Updatable: Yes
Record Count: 728

Columns

Name	Type	Size
ID	Number (Long)	4
Hide	Yes/No	1
Run	Yes/No	1
Zone	Text	255
Source	Text	50
ZoneZone	Text	15
ZoneDesc	Text	60
AUTO	Text	60
Scen	Text	255
MapTable	Text	255
CreditWrap	Yes/No	1
BEC	Yes/No	1
BF	Yes/No	1
TRC	Yes/No	1
TRMCUB	Number (Single)	4
TRTrunc	Number (Single)	4
ORC	Yes/No	1
ORMCUB	Number (Single)	4
ORTrunc	Number (Single)	4
GTC	Yes/No	1
GTMCUB	Number (Single)	4
GTTrunc	Number (Single)	4
IGF	Number (Double)	8
NSP	Number (Double)	8
CCDP	Number (Single)	4
CDF	Number (Single)	4
Screened	Yes/No	1
Notes	Memo	-

Properties

Date Created:	3/29/96 2:18:02 PM	Def. Updatable:	Yes
Last Updated:	5/10/96 12:47:10 PM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT francZONESCENARIOS_EMPTY.Hide, francZONESCENARIOS_EMPTY.Run,
"S"+[SOURCE_ID] AS [Zone*], SOURCE.SOURCE AS [Source*],
francZONESCENARIOS_UNSCREENED.Zone AS ZoneZone, ZONE.DESC AS ZoneDesc, ZONE.AUTO, "A"
AS Scen, "" AS MapTable, francZONESCENARIOS_EMPTY.CreditWrap,
francZONESCENARIOS_EMPTY.BEC, francZONESCENARIOS_EMPTY.BF,
francZONESCENARIOS_EMPTY.TRC, francZONESCENARIOS_EMPTY.TRMCUB,
francZONESCENARIOS_EMPTY.TRTrunc, francZONESCENARIOS_EMPTY.ORC,
francZONESCENARIOS_EMPTY.ORMCUB, francZONESCENARIOS_EMPTY.ORTrunc,
francZONESCENARIOS_EMPTY.GTC, francZONESCENARIOS_EMPTY.GTMCUB,
francZONESCENARIOS_EMPTY.GTTrunc, IGNF_SOURCE.IGNF_SOURCE AS IGF,
IIf([ZONE].[AUTO]="None",1,[ZONE].[NSP]) AS [NSP*], francZONESCENARIOS_EMPTY.CCDP,
francZONESCENARIOS_EMPTY.CDF, francZONESCENARIOS_EMPTY.Screened INTO
tmpSOURCESCENARIOS
FROM (((ZONE LEFT JOIN francZONESCENARIOS_EMPTY ON ZONE.ZONE =
francZONESCENARIOS_EMPTY.Zone) RIGHT JOIN francZONESCENARIOS_UNSCREENED ON
ZONE.ZONE = francZONESCENARIOS_UNSCREENED.Zone) LEFT JOIN SOURCE ON
francZONESCENARIOS_UNSCREENED.Zone = SOURCE.ZONE) LEFT JOIN IGNF_SOURCE ON
SOURCE.SOURCE = IGNF_SOURCE.SOURCE.SOURCE
WHERE ((SOURCE.SOURCE Is Not Null));
```

Query: francSOURCESCENARIOS_2

Properties

Date Created:	3/29/96 2:21:52 PM	Def. Updatable:	Yes
Last Updated:	5/10/96 12:47:45 PM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Append		

SQL

```
INSERT INTO tmpSOURCESCENARIOS ( Hide, Run, [Zone*], [Source*], ZoneZone, ZoneDesc, AUTO, Scen,
MapTable, CreditWrap, BEC, BF, TRC, TRMCUB, TRTrunc, CRC, ORMCUB, ORTrunc, GTC, GTMCUB,
GTTrunc, IGF, [NSP*], CCDP, CDF, Screened )
SELECT DISTINCT francZONESCENARIOS_EMPTY.Hide, francZONESCENARIOS_EMPTY.Run,
"S"+[SOURCE_ID] AS [Zone*], SOURCE.SOURCE AS [Source*],
francZONESCENARIOS_UNSCREENED.Zone AS ZoneZone, ZONE.DESC AS ZoneDesc, ZONE.AUTO, "B"
AS Scen, "SOURCETL" AS MapTable, francZONESCENARIOS_EMPTY.CreditWrap,
francZONESCENARIOS_EMPTY.BEC, francZONESCENARIOS_EMPTY.BF,
francZONESCENARIOS_EMPTY.TRC, francZONESCENARIOS_EMPTY.TRMCUB,
francZONESCENARIOS_EMPTY.TRTrunc, francZONESCENARIOS_EMPTY.ORC,
francZONESCENARIOS_EMPTY.ORMCUB, francZONESCENARIOS_EMPTY.ORTrunc,
francZONESCENARIOS_EMPTY.GTC, francZONESCENARIOS_EMPTY.GTMCUB,
francZONESCENARIOS_EMPTY.GTTrunc, IGNF_SOURCE.IGNF_SOURCE AS IGF, 1-[ZONE].[NSP] AS
NSP, francZONESCENARIOS_EMPTY.CCDP, francZONESCENARIOS_EMPTY.CDF,
francZONESCENARIOS_EMPTY.Screened
FROM (francZONESCENARIOS_UNSCREENED LEFT JOIN ((SOURCE LEFT JOIN ZONE ON
SOURCE.ZONE = ZONE.ZONE) LEFT JOIN francZONESCENARIOS_EMPTY ON ZONE.ZONE =
francZONESCENARIOS_EMPTY.Zone) ON francZONESCENARIOS_UNSCREENED.Zone =
SOURCE.ZONE) LEFT JOIN IGNF_SOURCE ON SOURCE.SOURCE = IGNF_SOURCE.SOURCE.SOURCE
WHERE ((SOURCE.SOURCE Is Not Null));
```

Properties

Date Created:	5/14/96 2:38:11 PM	Def. Updatable:	Yes
Last Updated:	5/14/96 2:40:12 PM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Append		

SQL

```
INSERT INTO tmpSOURCESCENARIOS ( Hide, Run, [Zone*], [Source*], ZoneZone, ZoneDesc, AUTO, Scen,
MapTable, CreditWrap, BEC, BF, TRC, TRMCUB, TRTrunc, ORC, ORMCUB, ORTrunc, GTC, GTMCUB,
GTTrunc, IGF, [NSP*], CCDP, CDF, Screened )
SELECT DISTINCT francZONESCENARIOS_EMPTY.Hide, francZONESCENARIOS_EMPTY.Run,
"S"+[SOURCE_ID] AS [Zone*], SOURCE.SOURCE AS [Source*],
francZONESCENARIOS_UNSCREENED.Zone AS ZoneZone, ZONE.DESC AS ZoneDesc, ZONE.AUTO, "C"
AS Scen, "SOURCEC" AS MapTable, francZONESCENARIOS_EMPTY.CreditWrap,
francZONESCENARIOS_EMPTY.BEC, francZONESCENARIOS_EMPTY.BF,
francZONESCENARIOS_EMPTY.TRC, francZONESCENARIOS_EMPTY.TRMCUB,
francZONESCENARIOS_EMPTY.TRTrunc, francZONESCENARIOS_EMPTY.ORC,
francZONESCENARIOS_EMPTY.ORMCUB, francZONESCENARIOS_EMPTY.ORTrunc,
francZONESCENARIOS_EMPTY.GTC, francZONESCENARIOS_EMPTY.GTMCUB,
francZONESCENARIOS_EMPTY.GTTrunc, IGNF_SOURCE.IGNF_SOURCE AS IGF, 1-[ZONE].[NSP] AS
NSP, francZONESCENARIOS_EMPTY.CCDP, francZONESCENARIOS_EMPTY.CDF,
francZONESCENARIOS_EMPTY.Screened
FROM (francZONESCENARIOS_UNSCREENED LEFT JOIN ((SOURCE LEFT JOIN ZONE ON
SOURCE.ZONE = ZONE.ZONE) LEFT JOIN francZONESCENARIOS_EMPTY ON ZONE.ZONE =
francZONESCENARIOS_EMPTY.Zone) ON francZONESCENARIOS_UNSCREENED.Zone =
SOURCE.ZONE) LEFT JOIN IGNF_SOURCE ON SOURCE.SOURCE = IGNF_SOURCE.SOURCE.SOURCE
WHERE ((SOURCE.SOURCE Is Not Null));
```

K:\PRA\ACCESS\FIRE.MDB
Query: francSOURCESCENARIOS_4

Properties

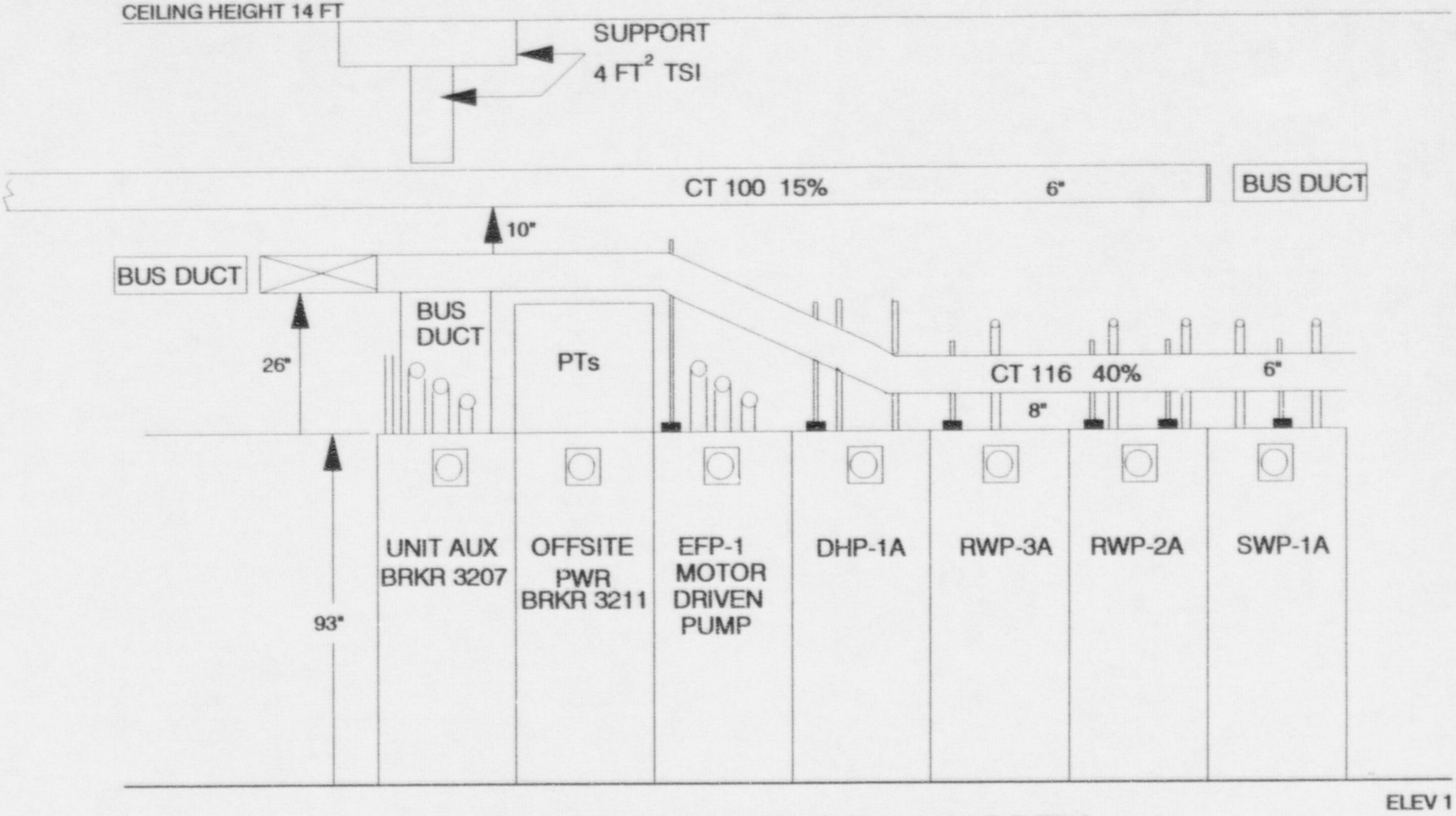
Date Created:	4/2/96 9:58:41 AM	Def. Updatable:	Yes
Last Updated:	5/14/96 2:37:50 PM	ODBC Timeout:	60
Record Locks:	Edited Record	Returns Records:	Yes
Type:	Make-table		

SQL

```
SELECT DISTINCT tmpSOURCESCENARIOS.* INTO francSOURCESCENARIOS
FROM tmpSOURCESCENARIOS
ORDER BY tmpSOURCESCENARIOS.ZoneZone, tmpSOURCESCENARIOS.[Zone*],
tmpSOURCESCENARIOS.Scen;
```

Appendix B

Ignition Source / Target Drawings



4160 V ES SWGR 3A NORTH

FIREZONE : CC-108-108

EFFECTIVE AREA : 652 FT^2

DAMAGE HEIGHT FOR 700 F = 5.0 FT

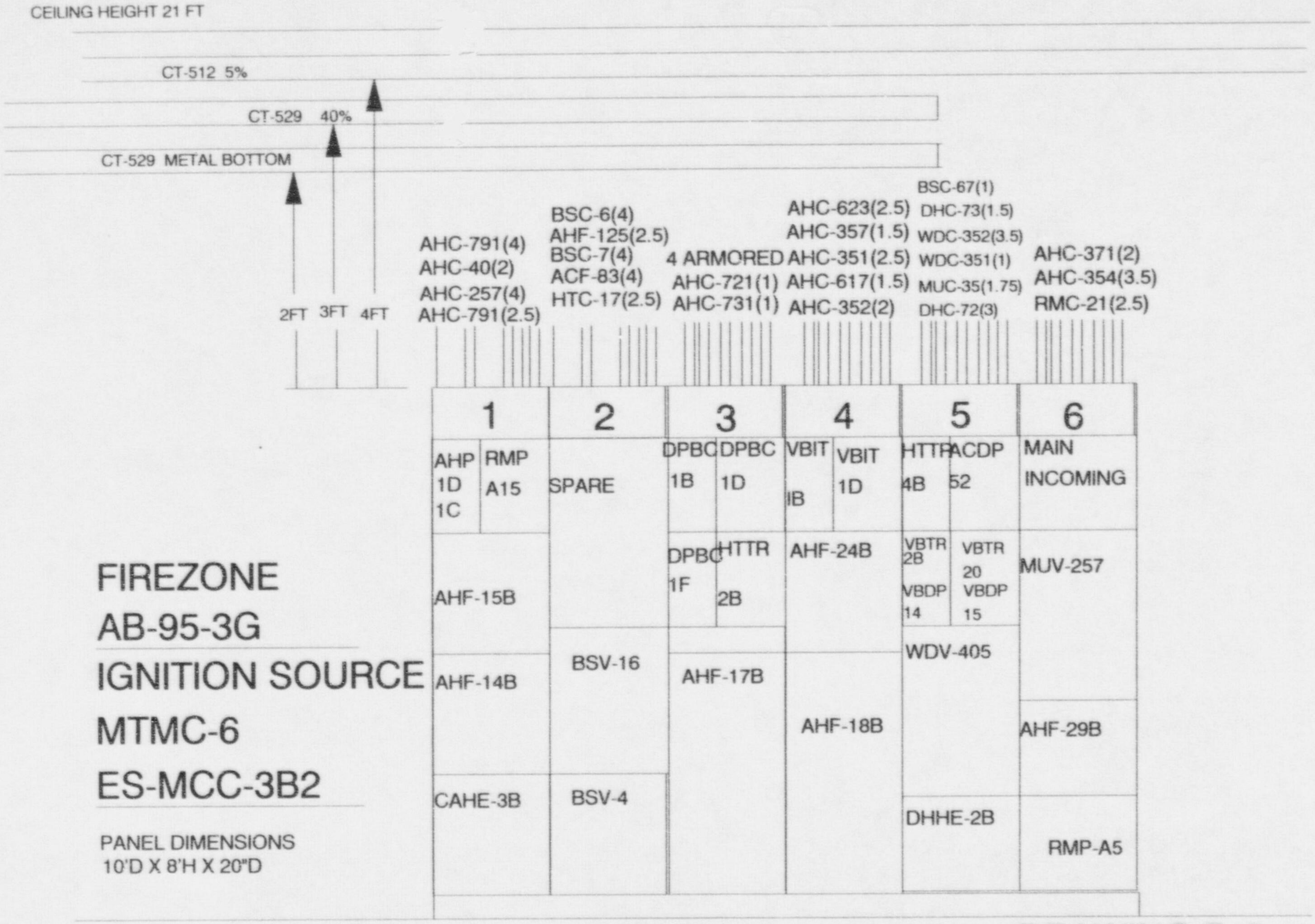
IGNITION HEIGHT FOR 1000 F = 3.5 FT

IGNITION HEIGHT FOR 936 F = 3.7 FT

DRAWING D-1

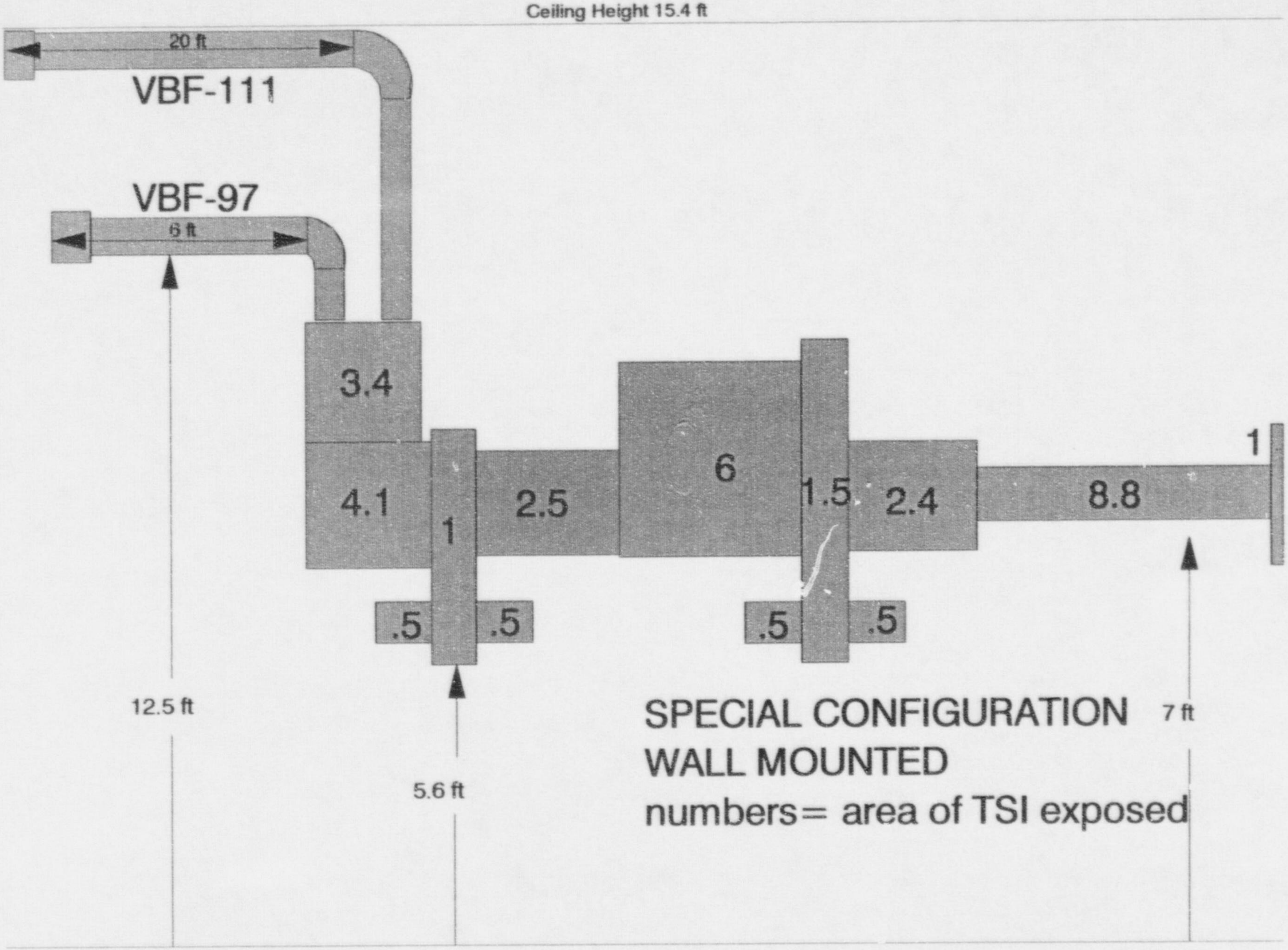
FIREZONE
AB-95-3G
IGNITION SOURCE
MTMC-6
ES-MCC-3B2

PANEL DIMENSIONS
10'D X 8'H X 20"D



ELEV 95

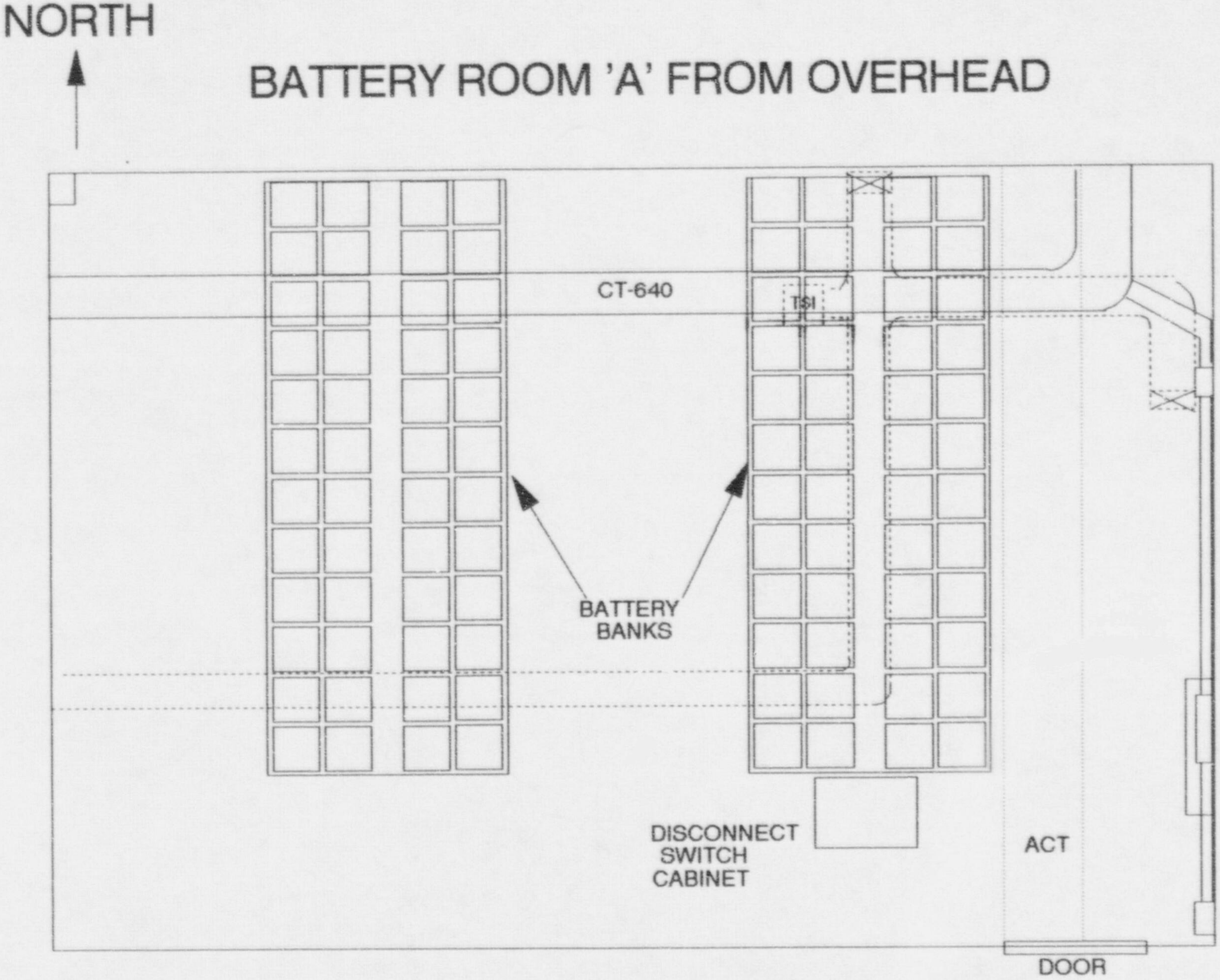
DRAWING D-2



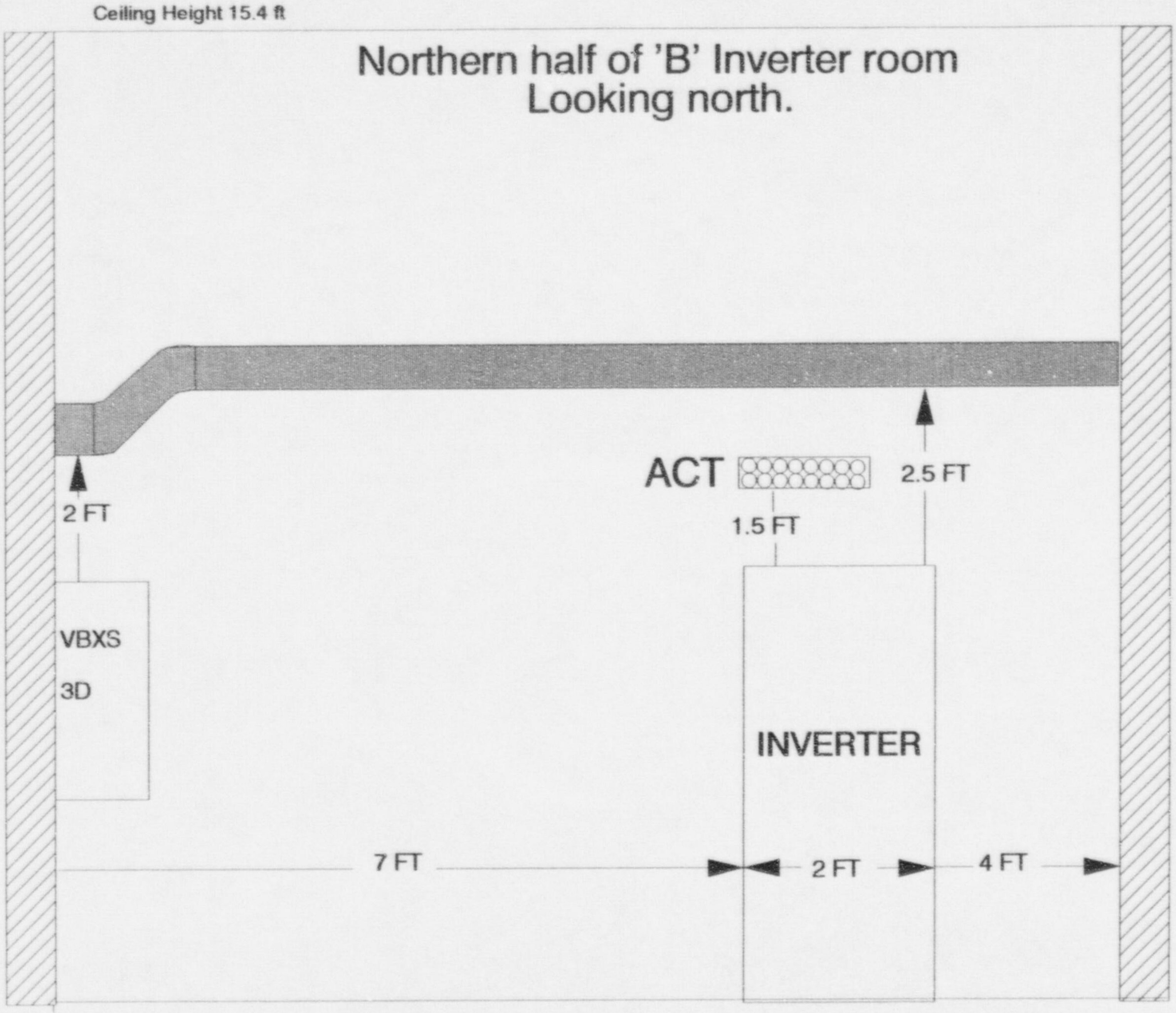
SPECIAL CONFIGURATION
WALL MOUNTED
numbers= area of TSI exposed

CC-108-108

DRAWING O-3


NORTH
BATTERY ROOM 'A' FROM OVERHEAD
CT-640
TSI
BATTERY
BANKS
DISCONNECT
SWITCH
CABINET
ACT
DOOR

DRAWING D-4

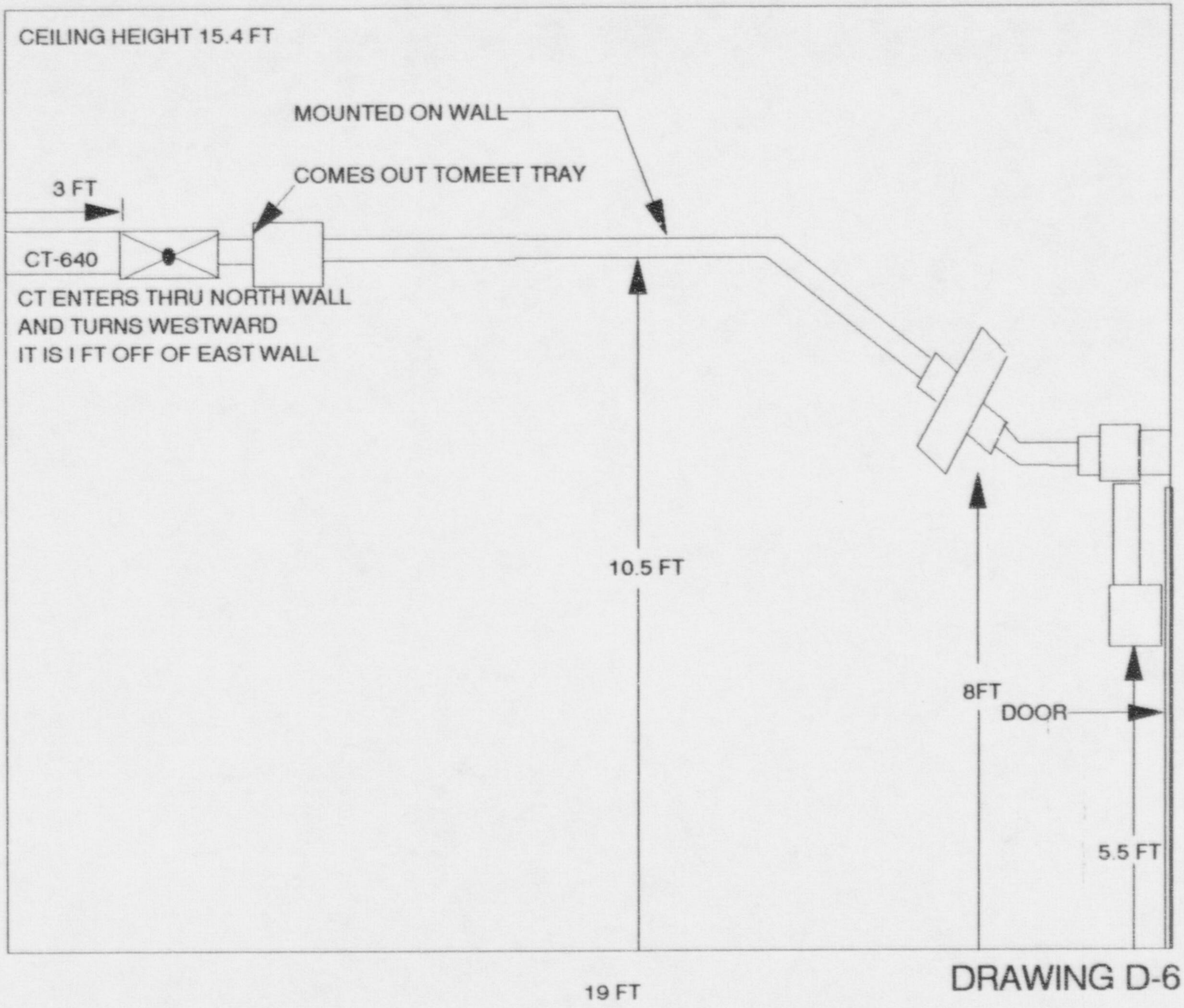


Northern half of 'B' Inverter room
Looking north.

DRAWING D-5

BATTERY 'A' EAST WALL

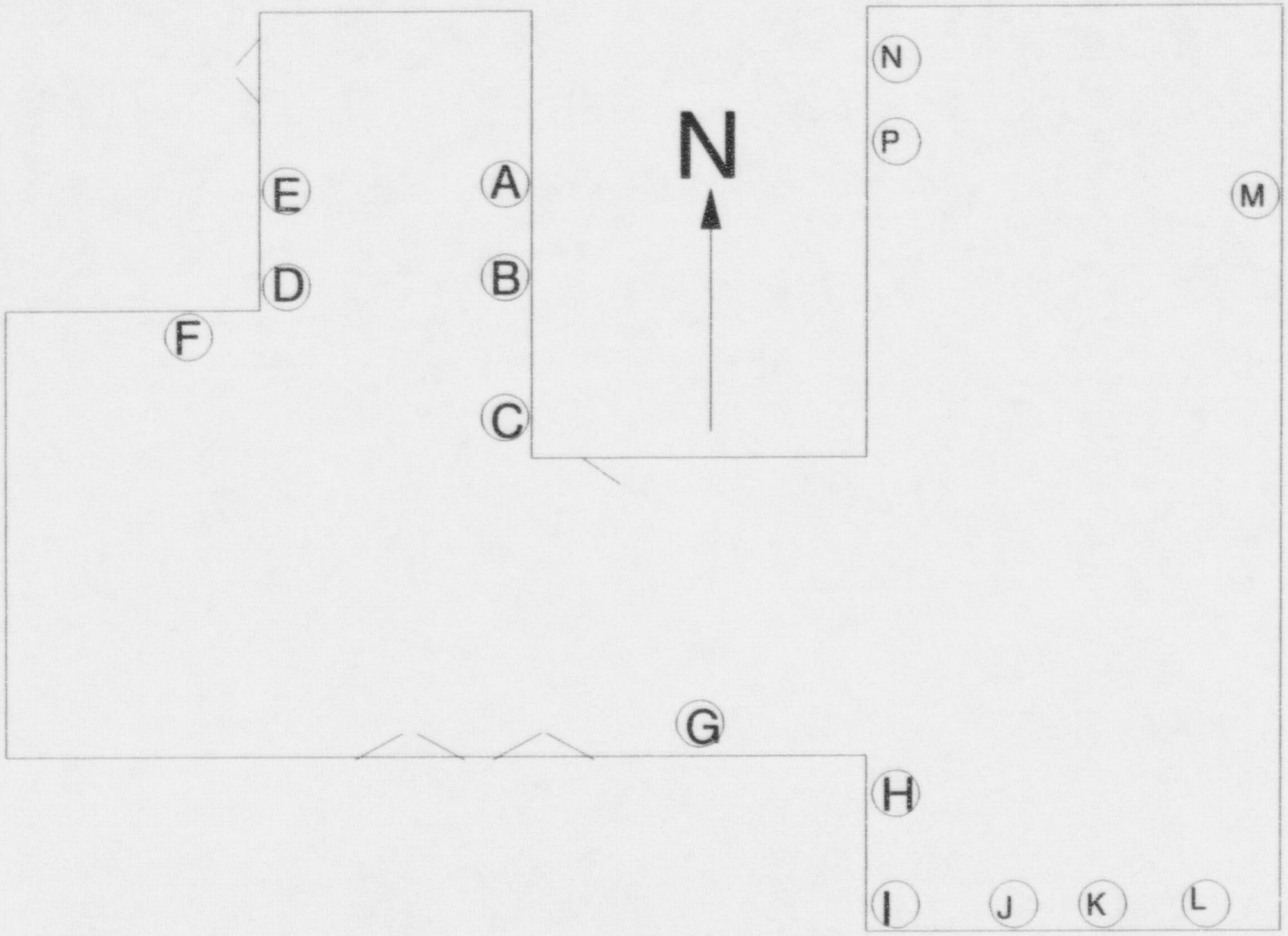
BAEW



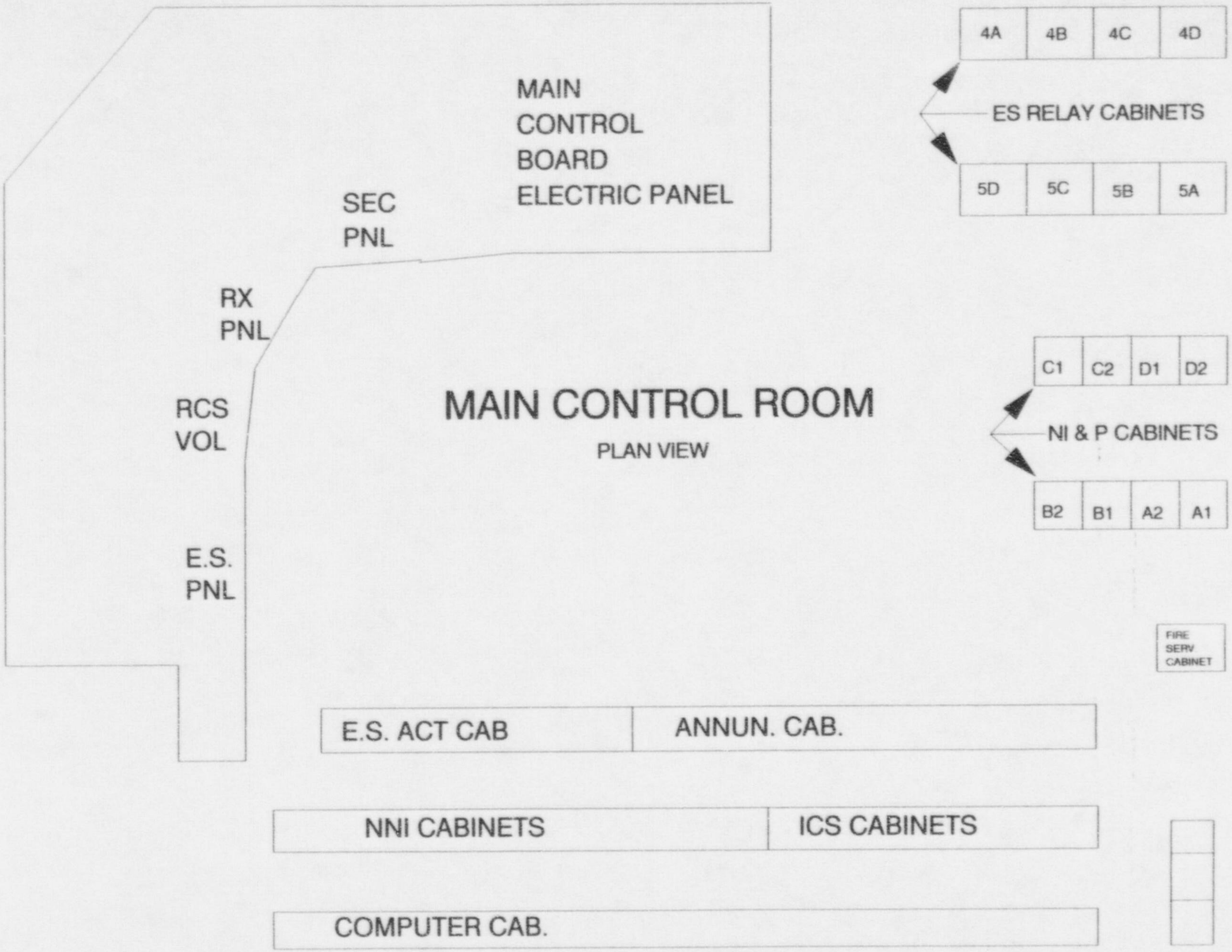
DRAWING D-6

PROBABLE DAMAGING TRANSIENT FUEL PACKAGE LOCATIONS

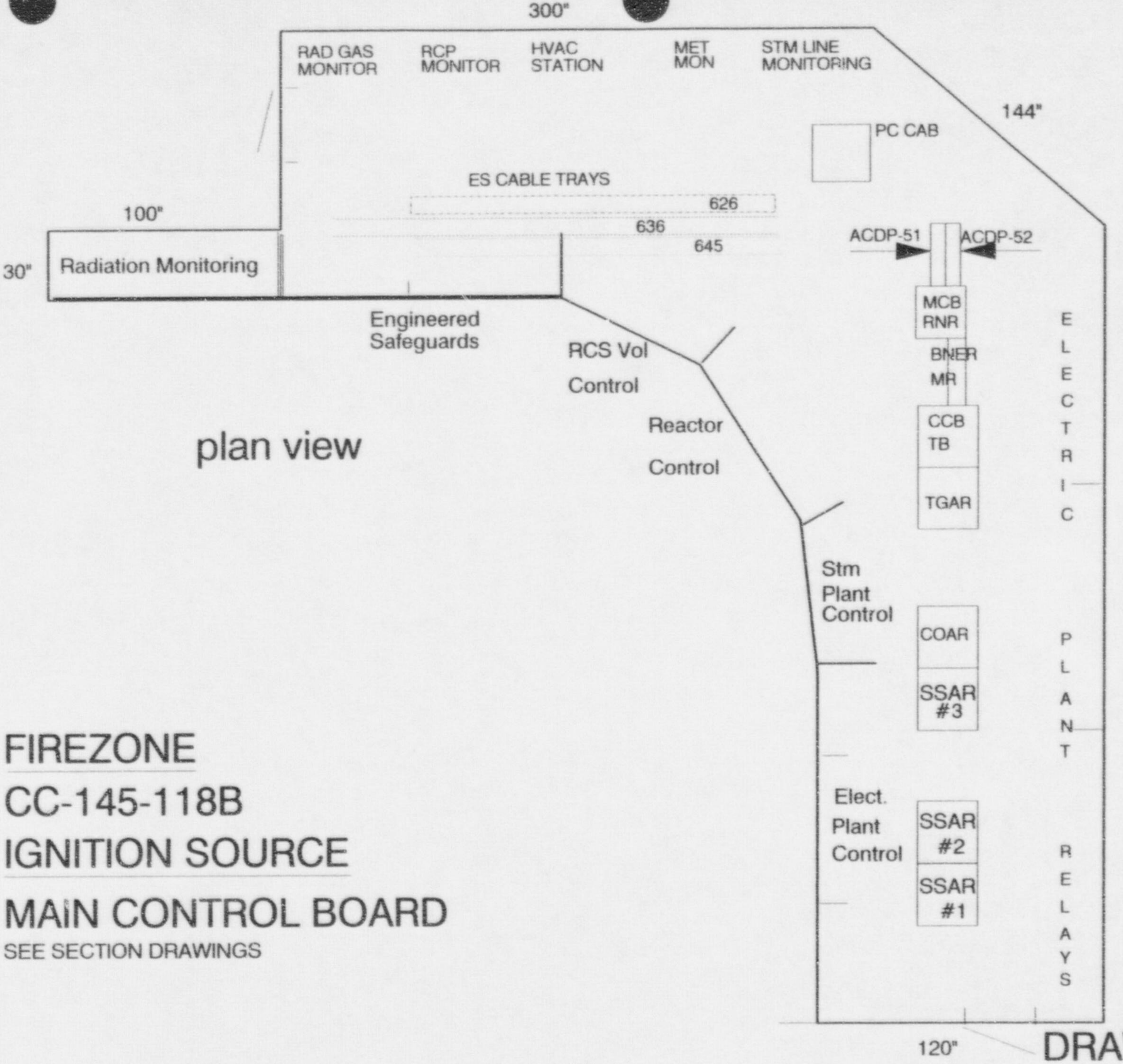
CC-124-111



DRAWING D-7


MAIN CONTROL BOARD ELECTRIC PANEL
SEC PNL
RX PNL
RCS VOL
E.S. PNL
4A
4B
4C
4D
ES RELAY CABINETS
5D
5C
5B
5A
C1
C2
D1
D2
NI & P CABINETS
B2
B1
A2
A1
MAIN CONTROL ROOM
PLAN VIEW
FIRE SERV CABINET
E.S. ACT CAB
ANNUN. CAB.
NNI CABINETS
ICS CABINETS
COMPUTER CAB.

DRAWING D-8



FIREZONE
CC-145-118B
IGNITION SOURCE
MAIN CONTROL BOARD

SEE SECTION DRAWINGS

DRAWING D-9

Appendix C

Guidance for Fire Ignition Frequency Calculation

(from EPRI Fire Risk Implementation Guide)

This appendix provides additional guidance for counting fire ignition sources and calculating plant-specific fire frequencies. Frequencies will be developed for compartments, and then compartment frequencies may be combined, if necessary, to determine area frequencies.

C.1 Equipment Counting Methods

There are two principal approaches to counting equipment:

- Visual examination (drawings and/or walk down), or
- Use of an electronic database

The more cost-effective approach is probably to count equipment by relying on visual examination. Experience indicates that a knowledgeable individual can estimate the number of components with the level of accuracy desired (e.g., ± 25%). A computerized equipment location database can be used as an aid if one is available. Note that an Appendix R database containing only safe-shutdown equipment is not very useful, since both safety-related and non-safety-related components may be potential fire sources.

Plant drawings may also be used for equipment counting. However, for some equipment, it may be desirable to use visual inspection to obtain an accurate count (e.g., electrical cabinet panels and breaker cubicles). For areas that are inaccessible, drawings, may be the only aids available.

Electronic databases may also be used directly for equipment counting. An electronic database may provide more precise counting of equipment that would otherwise be assumed to be distributed evenly using the location weighting factor. For example, electrical cabinets in the switchgear room are distributed evenly among each switchgear room while a more precise count with a database may indicate some variations from room to room. An electronic database, however, is not necessarily more efficient. Counting rules are must be implemented using fields available in the database. For example, differences in equipment size e.g., for pumps or transformers may not be indicated in the database. It may be difficult then to exclude smaller components which operating experience has often indicated are not risk-significant ignition sources.

C.2 Specific Guidance for Counting

Guidance on how to count selected ignition sources is provided in the following paragraphs.

Electrical Cabinets. Count individual panels and breaker cubicles and both AC and DC sources. An average number of cubicles may be estimated for cabinets such as motor control centers and DC distribution panels instead of counting cubicles in each cabinet individually. If there are no electrical cabinets in the Cable Spreading Room, delete the electrical cabinet contribution to the compartment ignition frequency.

Pumps. Count large pumps in core heat removal systems and associated support systems. Note, however, that small pumps can be ignition sources but with less severe heat release rates. During plant walk downs, look for special situations where a small pump is close to important equipment. In this case, count the pump.

Batteries. Cells are not counted individually. If there are "A" and "B" batteries, each with 60 cells, these are counted as 2 batteries.

Diesel Generators. Diesel generator sub-components are counted as part of the diesel. For example, diesel generator air start compressors are considered as part of the diesel generator and not counted as air compressors.

T/G Excitor, T/G Oil, and T/G Hydrogen. Number of ignition sources for the T/G Excitor, T/G Oil, and T/G Hydrogen categories will normally be one.

Radwaste Area Miscellaneous Components. No counting is required in the radwaste area except for dryers. Transients allowed in radwaste areas need to be indicated.

Transformers. Count all transformers except control power transformers and other small transformers which are sub components in major electrical equipment. Examples of transformers which are counted are 4160/480 transformers attached to AC load centers, low voltage regulators, and essential service lighting transformers. Yard transformers are considered separately.

Cable. The calculation requires the amount of cable insulation in the area, expressed either as weight or heat of combustion (Btu).

Dryers. Include clothes dryers in the count for dryer equipment. Instrument air dyers are counted as part of air compressors.

Junction Boxes/Splices. The number of junction boxes in an area may be difficult to determine. If so, the frequency can be apportioned based on ratio of cable in the area to the total cable in the plant.

Miscellaneous H_2 Fires. This category includes hydrogen (and propane) fires in miscellaneous systems other than hydrogen cylinder storage, generator cooling, and battery rooms, which are considered in other categories. No counting of ignition sources is required unless one area contains a disproportionate amount of regulators and tubing. For additional guidance, read the section on Miscellaneous Hydrogen Fires in the database report.

Ventilation Subsystems. This category includes components such as AC units, fan motors, air compressors, etc.. A fan motor and compressor housed in the same cabinet are counted as one component.

Transients. Ignition source weighting factors will be based on the transients allowed in the area. This information is asked for in the upper right-hand corner of the worksheet. Transient and welding sources are considered applicable to all areas unless they are precluded by administrative controls or practices or design features essentially eliminate the possibility. Welding fires (and junction box fires) in qualified cable can be ignored as they are unlikely to be self-sustaining and, consequently are not expected to be risk significant.

Transients are allowed unless they are precluded by procedure during power operation. "Open flames" refers to use of candles to check the integrity of penetration seals. "Heating of combustibles" refers to use of band type heaters or other heaters to warm lubricants or battery terminal grease in preparation for maintenance operations.

Other tips for counting components relate to selecting applicable location:

- When counting components, exclude components in areas of a building which are applicable to another location. For example, do not count equipment in radwaste areas in the Auxiliary Building.
- Consider Control Buildings as part of the Auxiliary Building (PWR) or Reactor Building (BWR) locations.
- Do not consider the primary containment as part of the Reactor Building.

Ignition sources other than those listed in table 4-2, do not need to be counted unless there is history of such fires occurring at the site being analyzed. If such sources are modeled derive the generic frequency from FEDB (no. of fires/rx-yr). If not in the FEDB, i.e., no such fires occurred anywhere else, ignore. The heat release rate may be obtained from a similar component, e.g., 65 Btu/s for MOVs, oil HRR for grease (use size of the motor because of high viscosity).

C.3 Comparison of Equipment Counts

A useful means of checking the outcome of equipment counts is by comparison with other plants. Comparing the plant-wide equipment counts with those from other plants provides an easy method of sanity checking the results. Table C-1 includes the equipment counts for several plants. While a variance does exist between plants, the data could help spot potential gross miscounts of equipment. Equipment subject to miscounting includes electrical cabinets in the Cable Spreading Room and transformers.

C.4 Equipment Counting for a Single Unit at a Multi-Unit Site

The ignition frequency method is easiest to apply for an entire site or a single, completely separated unit. When the application addresses only a portion of a site, it is possible to make mistakes when counting equipment shared by more than one unit. The best way to avoid mistakes is to test the results of any application against the two basic assumptions used to generate the results:

- The ignition frequency for all equipment in one unit is the same as the ignition frequency for all equipment in another unit.
- The ignition frequency in any compartment in a unit is proportioned to the types of ignition sources and their relative fraction of the total in the plant.

If the units at a site are "mirror image" or generally believed to contain the same types and numbers of equipment, the method can be implemented relatively effectively using a single assumption:

- The number of ignition sources and plant locations in the "uncounted unit" is the same as the number in the counted unit.

As an example, consider a two unit site in which some areas contain equipment for both units. The units are "mirror imaged" units. There are four RPS MG sets in each Unit for a total of 8 sets. Two of the switchgear rooms are Unit 1 specific and one is common to both units. There is a Unit 1 RPS MG set in one of the Unit 1 switchgear rooms and another in the common switchgear room. (The remaining 2 Unit 1 RPS MG sets are elsewhere in the plant.) There is a Unit 2 RPS MG set in the common switchgear room.

Using the assumption for the "uncounted unit," the location weighting factor for the switchgear rooms is:

- Number of units at the site/Number of SWGR rooms at the site = 2/5

The number of switchgear rooms at the site is determined by adding the two switchgear rooms at Unit 1, one switchgear room shared by both units plus the two switchgear rooms assumed and uncounted at Unit 2. No ignition source weighting factor is required for the electrical cabinets in the switchgear rooms.

The location weighting factor for the plant-wide components is:

- Number of units at the site = 2

The ignition weighting factor for the RPS MG sets is:

- Number of ignition sources in compartment/number of ignition sources at the site

For the switchgear rooms, the RPS MG sets ignition source weighting factors are:

- 0 for the Unit 1 switchgear room without an RPS MG set
- 1/8 for the Unit 1 switchgear room with a single RPS MG set
- 2/8 for common switchgear room

The number of RPS MG set ignition sources at the site is determined by adding the four counted at Unit 1 plus the four assumed and uncounted at Unit 2.

In summary, equipment counts for a single unit at a multi-unit site should be done using the following rules:

- Count equipment and locations for one unit NOT in common with the other unit.
- Assume the mirror image unit has the same number of equipment or locations.
- Count equipment and locations in common areas.
- Use the sum for plant-wide and location equipment counts.
- Use location weighting factors based on two units.

Table C-1
Total Plant-Wide Equipment Counts Used in Ignition Frequency Method for FIVE and Fire PRA Tailored-Collaboration Projects

Component	PWR/W (2 Units)	BWR-6	PWR CE	BWR-4	BWR-6	PWR W	PWR CE	High per unit	Low per unit	Average per unit (1)
Air Compressor	9	10	9	44	11	14	5	15	5	8
Battery Chargers	35	8	6	34	6	14	5	18	3	8
Dryers	4	14	0	0	5	-	15	15	0	6
Electrical Cabinets (2)	1,975	903	2,058	630 (4)	1,847	2,335	129 (4)	1,847	988	1,187
Elevator Motor	3	1	3	0	6	-	1	6	0	2
Fire Protection Panels	50	6	75	40	115	16	8	115	6	30
Pumps (except MFW or Fire)(2)	283	117	414	24 (4)	101	103	148	207	52	128
RPS MG Sets	4	2	2	31	2	4	0	10	0	3
Transformers	329	48	28	55	178	109	71	178	14	78
Ventilation Subsystems	332	171	441	289	636	22	128	636	11	204
Offgas Recombiners (BWR)	NA	0	NA	3	0	NA	NA	3	0	0

(1) Calculated by taking the average per unit for each site, then summing the averages per unit and dividing by the number of sites.

(2) Auxiliary or Reactor Building and Turbine Building only.

(3) Entry is for one of three reactor building only. This entry was not included in high, low and average per unit.

(4) This entry was not included in the high, low and average values.

C.5 Specific Guidance for Applying Ignition Source Weighting Factor Method A

Ignition source weighting factor method "A" applies to diesel generator rooms, switchgear rooms, battery rooms, control rooms, cable spreading rooms, intake structures, radwaste areas, and transformer yards.

The ignition frequency method is based on the assumption that the same type of equipment is equally likely to cause a fire. Weighting factor method "A" assumes that the equipment of interest is evenly distributed among the compartments comprising the location. For example, in a plant with four switchgear rooms method "A" assumes that each switchgear room contains one-fourth of the electrical cabinets normally found in switchgear rooms. When method "A: is applied, the location weighting factor (i.e., number of units / number of rooms) apportions the ignition frequency among the four rooms, and the ignition source weighting factor for the component type (e.g., cabinets, pumps) is 1.0.

However, there may be locations at some plants where this assumption does not apply. If this assumption does not apply, the location weighting factor should be adjusted to reflect the actual distribution of equipment.. Consider a case in which there are three switchgear rooms at a certain plant. It is estimated that 90% of the plant switchgear equipment is divided equally between switchgear rooms A and B, which are similarly configured, and the remaining 10% is in switchgear room C. In this case the location weighting factor for switchgear rooms should be adjusted to account for the uneven distribution of equipment. The location weighting factor for switchgear rooms (i.e., number units / number of switchgear rooms) should be replaced by the following:

number of units * percent total equipment in the room

The location weighting factor for switchgear rooms A and B for this example would then be:

number of units * 0.45.

The location weighting factor for switchgear room C would be:

number of units * 0.10.

Appendix D

Guidance for Estimating Fire Severity

(from EPRI Fire Risk Implementation Guide)

This appendix describes how severity factors can be used to incorporate more realism in fire risk estimates. First, this appendix describes the use of severity factors in past fire PRA methods and the limitations posed by operating experience in developing new ones. Next, the technical approach used to develop and apply severity factors is described. Finally, development of severity factors for selected fire sources is presented

D.1 Background

D.1.1 Severity Factors in Fire PRAs

Fire risk is calculated based on the frequency with which fires occur and the damage that they cause. Traditionally, methodologies have estimated ignition frequency from event experience and damage from fire models. Experience from EPRI fire risk methods testing indicates that limitations in each method combine to compromise the realism that can be obtained from fire PRA methodologies.

PRA technology is designed to predict rare events that have not occurred in nuclear experience. In the course of these predictions, PRAs also predict a set of intermediate events. As the amount of nuclear plant operating experience has increased, a number of such intermediate events have occurred. Consequently, PRA predictions of intermediate events can be compared to operating experience to determine if PRA methods need to be altered to better predict rare events.

In the case of fire PRA technology, methods have traditionally tried to overcome the weaknesses of fire models and ignition frequency data by the use of "severity factors". A severity factor is simply a conditional probability that the ignition source is sufficiently severe to cause the conditions represented by the model. In past PRAs which were based on limited operating experience, the factor was completely based on judgment with the actual tie to operating experience being quite vague. For example, the factor might represent the fraction of Auxiliary Building fires which caused fires so severe as to be equivalent to a one-foot diameter oil pool fire.

In the case of the EPRI fire PRA methodology, some of this problem has already been addressed. For each of the ignition sources there are one or more heat release rates. Because the heat release rates are now more realistic, some of the severity factor has already been estimated. For example, a vertical electrical cabinet with qualified cable has been shown to not reach the heat release rates corresponding to the abovementioned oil pool. Originally, it was hoped that the additional preciseness in ignition sources and realism in heat release rates would reduce the dependence on severity factors. However, as fire modeling results were obtained, it appeared that fire modeling damage predictions were still much higher than fire event experience implied.

D.1.2 Limitations in Operating Experience

Providing a sanity check of fire modeling based on operating experience poses a number of problems. If not, it might have been more efficient to predict risk directly based on operating experience rather than use fire modeling. The following compares operating experience insights to modeling results and describes the difficulties encountered in making them match.

A fire event may not result in damage for a variety of reasons. These are:

1. The fire might be severe, but nothing is nearby to be damaged.
2. Because of restricted ventilation, not enough oxygen can enter the component to allow combustibles to burn.
3. The amount of energy in the ignition source and/or fuel proximity and geometry in the component are insufficient for the fire to grow.
4. The fire is detected early by plant personnel and suppressed before it grows.
5. The fire is detected by fast response detectors and, because it grows slowly, is suppressed by an "open head" fixed suppression system.

Fire modeling is quite effective in identifying the first reason but not the others. In the EPRI Fire PRA method the second reason is addressed by engineering judgment. The remaining three reasons are addressed poorly by fire PRAs because heat release data is based on "simulated" fires in which the fuel geometry or ignition energy is optimized to ensure ignition occurs. For example, in Sandia's electrical cabinet fire tests (1,2), qualified cable handles were untied and spread out and then ignited with acetone because electrical ignition had failed. Similarly, in EPRI's cable tray fire tests (3), #2 fuel oil and Pennzoil pilot fires were ignited by pouring heptane on the pool surface and igniting the heptane.

These simulations ignore many ignition conditions that involve long heat-up periods to volatilize the combustible before either ignition-significant fuel involvement occurs. Because these heat-up periods often involve degrading component operation or distinctive smells, human detection can be an effective preventive factor. (For these reasons, fire codes sometimes do not require detection when locations are always occupied.) Indeed, when plant operating experience was evaluated in NSAC-179L (4), it was noted that manual detection is about six times more likely than automatic detection.

For these reasons, an important objective of an operating experience review to sanity check fire modeling is to identify and better understand the reasons fires do not damage other components. In this way, two important results can be obtained. First, location-specific attributes that make manual or automatic detection more likely can be credited where they apply. Second, a sensible and explainable technical basis for severity factors can be provided to regulators and users of fire risk estimates.

Even if variations in the geometry of source and target, component ventilation, and detection and suppression capability were known for each event, plant-specific factors can still affect the results. Components differ from plant to plant as do the operations and maintenance practices that affect them. These factors can influence the size and energy of the ignition source and the combustibility of the materials in the source. For example, if breakers includes materials that are combustible, a fire is more likely to grow. If cables are not qualified, cable ignition may be much more likely. Because of such concerns, it is important that recurring causes of fires at a particular plant are evaluated separately and that the presence of uniquely combustible materials, such as non-qualified cable, be identified for severe fires.

The last and possibly most significant difficulty to overcome in the use of event experience is the uncertainty in event information. A number of fire events have short descriptions and blank entries to key fields that indicate severity. (See discussion below.) A large portion of these events have no clear reference (e.g., plant name) that would allow further investigation. Because severe fires appear to be rare, assumptions regarding the use of incomplete information can significantly affect severity factor development. For example, in the case of electrical cabinet fires in switchgear rooms, six of the seventeen events had key fields left blank. Of these six, four had no plant name. When only a few events at most are expected to be severe, results can vary significantly depending on whether or not these "unknown" events are counted as severe in the numerator or minor in the denominator.

For these reasons, it is important that plant-specific information is pursued to the maximum possible degree and that the results depend primarily on the best understood data. Because the lead time is often long for obtaining additional details, we expect our understanding of them to change and such changes may result in increases or decreases in the severity factor. Because the principal objective is to attain more realistic conditions, judgment is used in this approach in lieu of conservative assignments. Since our judgments might change as information changes, the severity factor may change. Uncertainties will be estimated so that our understanding of the likelihood that the severity factor might change is understood by users.

D.2 Technical Approach

The technical approach for determining severity factors was developed in light of the abovementioned limitations. The basic approach involves comparing the fraction of fire modeling calculations that predict damage to an estimate of the fraction of operating experience events that caused damage. As the evaluation proceeded, certain complicating and simplifying factors were identified and the overall approach became more complex. The remainder of this section describes the resulting approach. In the next section, an example for switchgear room electrical cabinets is presented to illustrate the fundamentals of the approach.

D.2.1 Technical Approach for Evaluating Fire Data

At first, all the fire events in the EPRI Fire Events Database (NSAC 178L) (5), also called the FEDB, are examined following these steps:

1. Evaluate fire data
    set criteria
    classify events based on FEDB
    determine information desired
    obtain additional information
    select final severe fires
    - certain
    - potential

    estimate range and mean of observed damage
    provide basis, open issues and plans to resolve

2. Evaluate fire modeling results
    identify representative cases
    tabulate damage results and bases for screening
    evaluate ranges in plant specific results and potential significance
    estimate range and mean of calculated damage

3. Compare data to modeling results

4. Evaluate application conditions for severity factor
    manual detection
    automatic suppression
    recurring fires

5. Determine severity factor

6. Describe data insights which justify severity factor

Because of the uncertainty in information and the difficulty in obtaining additional details, a method is required to determine which fire events need to be carefully evaluated. Specifically, a set of criteria for fully-developed fires needed to be identified. The following criteria are used to identify potentially fully-developed fires:

1. Use of hose streams subsequent to the use of portable extinguishers or fixed systems,
2. Damage to components outside the ignition source (e.g., overhead cables),
3. Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets),
4. Automatic detection or suppression actuation,
5. Duration or suppression time greater than or equal to 10 minutes,
6. Significant economic loss,
7. All of the above fields empty, and
8. Description implies a severe fire occurred.

Items 1 through 3 are the strongest measures of severity. These events are usually classified as potentially fully developed even if damage did not occur. Items 4 through 6 indicate the possibility of a severe fire. However, they do not guarantee severity. For example, long durations or automatic detection can result if the fire is detected long before it becomes fully developed. Sometimes this is the case for low-severity fires that produce a lot of smoke but very little heat. Significant economic loss can result for low-severity fires solely due to the cost of component replacement or plant shutdown. Item 7 is not an indication of severity as much as it is an indication of uncertainty. It is important to tabulate these events and provide a basis for classifying them. Finally, the description of the fire (item 8) may provide insights that are not otherwise indicated by other database fields.

D.2.2 Technical Approach for Applying Severity Factors

The basic approach for implementing the severity factor model involves the following steps.

1. Select the ignition source
2. Identify plant locations for the ignition source
3. Determine manual detection and automatic suppression factors that apply to the location
4. Select the severity factor model
5. Determine severity factors

The following provides an overview of how the severity factor method is provided.

Select the ignition source. Only certain severity factors will be developed for the EPRI method. The severity factors have been selected based on the lessons learned from the EPRI Fire PRA and FIVE Tailored Collaboration programs. The ignition sources to be evaluated are:

- Electrical cabinets, including switchgear, MCCs, and panels in locations other than the control room
- Electrical cabinets in the control room
- Indoor transformers, particularly oil filled transformers in the plant
- Diesel generators
- Pumps, excluding containment (e.g., RCPs) and Main Feedwater pumps
- Ventilation subsystems
- Motor Generator Sets

Identify plant locations for the ignition source. The ignition sources that are risk significant may exist in different plant locations which in turn imply different response to fire. Whether a location is occupied or whether it contains an automatic suppression system is important to the application of the model. Therefore, the locations need to be tabulated in a form such as the following:

Ignition Source Type	Location name
Electrical cabinet (panels and MCCs)	AB-1
Electrical cabinet (panels)	AB-2
Electrical cabinet (panels and MCCs)	AB-3
Electrical cabinet (panels)	Control room
Electrical cabinet (switchgear and MCCs)	4160 v Switchgear room

Determine manual detection and automatic suppression factors that apply to the location. Fire events data indicates the potential effectiveness of manual detection (and manual suppression) and, in certain instances, of automatic suppression which involves fast response detectors. In some cases, these attributes will be different at different locations within the plant. Hence, a model is required to reflect these differences.

Location name	Occupied continuously	Automatic suppression with fast response detectors
AB-1	no	none
AB-2	yes (aux operator station)	no, pre-action system
AB-3	no	yes
Control room	yes	none
4160 v Switchgear room	no	yes

Select the severity factor model. The severity factor model will vary depending on the component and manual detection and automatic suppression attributes. In the case of the first examples performed, the severity factor attributes have been limited because all plants have similar attributes. Specifically, all switchgear rooms are not continuously occupied and control rooms are always continuously occupied.

Determine severity factors. In this step, the severities are calculated based on model attributes. Additionally, plant specific data is reviewed to determine if certain recurring fire conditions exist. For example, control power transformer fires in MCCs dominate the BWR Reactor Building Electrical Cabinet ignition source bin. Nearly, half of all MCC fires occurred at one utility and 85% of those at one site. This step includes a check to ensure that such fires which are deleted for the generic model do not apply to a plant specific application.

D.3 Evaluation of Severity Factors for Selected Fire Sources

The approach discussed in the previous sections was used to develop severity factors for selected ignition sources. The results of this investigation is presented here.

Ignition Source	No. of Applicable Events in the FEDB	Severity Factor
Control Room Electrical Cabinets	10	0.2
Switchgear Room Electrical Cabinets	17	0.12
Indoor Transformers	10	0.1
Diesel Generators	65	0.4*
Motor Generator Sets	7	0.14
Pumps**	46	0.20
Ventilation Subsystems	12	0.08

* Diesel Generator Skid Fires

** Excluding Containment (e.g. RCPs) and Main Feedwater Pumps

The bases for these values are discussed in the following sections in detail.

D.3.1 Control Room Electrical Cabinet Fires

A review of the control room fires in the EPRI Fire Events Database (NSAC 178L) was performed to estimate what fraction of these fires was severe, i.e., fires that could have caused damage beyond the ignition source. Table D.3-1 describes the results of the review. The database lists 12 control room fires, one a grease fire in the kitchen. One fire occurring outside the control room (9/7/85) and one recurring fire (3/30/83) were eliminated from further consideration. Following are important characteristics of the ten remaining fires:

- None of the database events report the use of hose stations. Two (2) fires self extinguished, and six (6) were suppressed with portable extinguishers. No information was provided for the other two (2) events.
- In five (5) of these fires damage was confined to one or few relays or circuit cards. One (1) was a grease fire not affecting any circuits, and one (1) was due to a wire that shorted when pinched in the door. Only two (2) reported possible involvement of wiring and damage to other circuits. No information on one event was available.
- Of the 10 fires, five (5) were detected by control room personnel and two (2) by smoke detectors (one in-cabinet). The means of detection was unreported for the remaining three events.

As the result of this review, only one fire is considered to be potentially severe (10/14/88). A potentially severe fire was taken to be one causing damage to wiring or adjacent cabinets prior to being extinguished. Inadequate information was available on two events (3/12/83 and 7/26/85). Weighing each unknown event as one-half of a severe event the fraction of severe fires becomes 2/10 or 0.2.

D.3.2 Switchgear Room Electrical Cabinet Fires

A preliminary evaluation of switchgear room electrical cabinet fires has been performed. Table D.3-2 describes the results of the evaluation. (The incident numbers (INO) for each event from the FEDB are listed in this and the following tables for traceability of the evaluation.) The evaluation indicates that one event was severe and that two events might be severe, out of a total of 17 events. Weighing each potentially severe event as one-half of a severe event, the fraction of severe fires becomes 2/17 or 0.12.

The data also appears to indicate that at least 50% of these fires would actuate automatic suppression systems with fast response detectors before a high heat release rate is expected.

D.3.3 Indoor Transformer Fires

The Fire Events Database includes ten (10) indoor transformer fires. Our preliminary evaluation turned up three events meeting some or all of our criteria for identifying potentially severe events One event describes an explosion in a neutral ground transformer. The record indicates a "Class B" fire, i.e., one involving a liquid combustible, and also indicates that automatic detection (smoke/heat) and suppression (deluge system) were actuated. This record describes an event similar to fires investigated by Altmann and Pfeiffer (6). The authors of this report attempted to induce fires in transformers with high-energy arcing faults. They concluded that unless the transformer insulant is preheated beyond its fire point temperature, it can be ignited by an arc but cannot be made to sustain burning independently. Since neutral ground transformers typically see high voltages only for very brief periods when they are called upon to perform their protective functions, we concluded that this event probably was not severe (i.e., did not result in a self-sustaining fire). Our conclusion is consistent with the event report which does not indicate damage to any equipment other than the transformer. Table D.3-3 contains the details of the severity factor analysis for Indoor Transformer fires.

Another event, occurring in a low voltage transformer (paging system transformer), meets three of our criteria for a potentially severe event: 1) the event duration is given as 13 minutes; 2) there was >$5K in damage 3) the automatic (halon) suppression system was actuated. In addition, portable extinguishers were used by the plant fire brigade subsequent to actuation of the halon system. On the other hand the report indicates that only the transformer was affected. We think the amount of combustible material associated with the paging transformer is small.. However, because portable extinguishers were used in addition to the halon system, we concluded that this fire may have been self-sustaining.

A third event occurred in a high voltage (4160/480 kV) dry type transformer, and appears to meet a number of the criteria for a severe fires: 1) the event resulted in loss of function of the bus as well as the transformer; 2) the combustible involved is listed as insulation; 3) the halon system was actuated; 4) the event duration is given as 29 minutes (with a suppression time of 10 minutes); and 5) there was more than $5K in damage However, the description states that "no fire was actually observed". In addition, fires in dry-type transformers were also investigated by Alber, Altmann and Pfeiffer (References 1 and 2). Authors of these investigations report that 1) high energy arcing faults could not be made to induce self-sustaining and stable combustion in dry-type transformers; and 2) even when exposed to an external exposure fire, little escalation beyond the original external fire took place. The authors attribute the failure of dry-type transformers to burn to the low combustible load and to mineral fillers in the transformer insulation which impede the access of oxygen to the flammable constituents of the insulation. We therefore concluded that this event probably did not result in self-sustaining combustion.

Weighing each potentially severe event as one-half of a severe event, the fraction of severe indoor transformer fires becomes 1/10 or 0.10.

D.3.4 Diesel Generator Fires

An evaluation of the database events for diesel generator fires was performed to obtain insights into the behavior of DG fires and to develop a severity factor for DG fires. The FEDB contains sixty-five (65) diesel generator fires, encompassing fires occurring in the engine, generator, shaft assembly, turbocharger, exhaust manifold, exhaust stack, calrod lube oil heaters, electrical components, pumps, fans, and batteries. Details of the severity factor analysis are provided in Table D.3-4.

The evaluation used the criteria for identifying potentially fully-developed fires, described in Section 2, with the following exception. Many DG fires involve oil (41 out of 54 events for which this information is reported). Fires involving oil are usually assumed to have high heat release rates. But, in more than a third (15) of the DG events where oil was involved, the event reports indicated the fire was small. So it is clear from the operating experience review that for diesel generator fires, the presence of oil does not necessarily indicate a serious fire. For this reason the presence of oil as a combustible was not in itself considered a strong measure of severity.

DG fire events in the data represent fires in a variety of locations within the DG room, as well as fires with markedly different characteristics. If we are to represent diesel generator fires realistically, the model must recognize this variation in DG fires. Sixty-two (62) of the sixty-five (65) DG events in the FEDB provide information allowing us to group DG fires into the following categories 1) diesel generator skid fires, 2) exhaust stack fires, 3) heater fires, 4) other diesel generator fires. Severity of fires in these categories is discussed in the paragraphs that follow.

Diesel Generator Skid Fires

This category includes events occurring in the engine, generator, shaft assembly, turbocharger, and exhaust manifold. Forty-eight (48) of the reported events occurred in one of these components. Therefore, 77% of the generic fire frequency for diesel generator fires should be apportioned to fires occurring at the skid.

Forty (40) of the forty-eight (48) events occurring at the skid involved oil. The most likely cause of fires in this category is oil leaking onto the exhaust manifold (19 events). Three (3) events involved fuel oil leaks or ruptures. Four (4) events involved oil spray. On the other hand, a number of the fires appear to have been contained within the diesel engine, turbocharger or exhaust manifold, and many of the events in this group are described in the reports as small fires. Some small fires self-extinguished as soon as the fuel source was removed, while severe fires had durations ranging up to 2 hours. A summary of the findings regarding severity for fires at the DG skid is as follows:

Severity category	Number (n)	Severity weighting factor (WF)	n * WF
Severe	12	1.0	12
Potentially severe	14	0.5	7
Not severe	18	0.0	0
Insufficient information*	4	NA	
Sum	48		19

* This calculation assumes that fires for which there is insufficient information are distributed among the other three categories in proportion to those for which we have information.

Severity Factor for Engine/Generator fires = 19/48 = 0.40.

Exhaust Stack Fires

Four fires occurred in the exhaust stack (downstream of the exhaust manifold). Therefore 6% of the generic fire frequency for diesel generator fires should be apportioned to fires occurring at the exhaust stack. These fires are considered separately from fires in the exhaust manifold because of differences in the locations and the combustibles involved.

None of the exhaust stack fires involved oil. These fires all appear to involve transient materials in direct contact with the hot exhaust stack or in the path of hot exhaust gases at the outlet. The possibility of exhaust stack fires should be considered in all compartments through which the exhaust stack is routed. Exhaust stack fires may be modeled like transient combustible fires elsewhere in the plant. No severity factor was determined for this category.

Heater Fires

One fire was initiated by a calrod heater. Therefore 2% of the generic fire frequency for diesel generator fires should be apportioned to fires occurring at calrod heaters. This event occurred when oil in the reservoir of an air intake filter was ignited by calrod heaters inadvertently left on while the oil was being drained. This fire was probably severe, as there was a large inventory of oil available, the event had a duration of 15 minutes, and there was sufficient heat to actuate the automatic suppression system.

The fraction (3%) of the diesel generator fire frequency for calrod heaters should be apportioned among all calrod heaters associated with the diesels (typically found in lube oil reservoirs and jacket water heaters). Units in jacket water systems can be screened if an evaluation of the combustibles available at the jacket water heaters shows that it is appropriate to do so. The severity of calrod heater fires in oil systems should be assumed to be 1.0.

Other diesel generator fires

Six fires occurred in DG electrical components, two occurred in DG pumps, and one occurred in a DG supply/exhaust system fan. Therefore (10%) of the frequency of DG fires should be apportioned to fires occurring at electrical components (e.g., excitors, solenoids, coils, voltage regulators), 3% at DG pumps, and 2% at supply/exhaust system fans. The descriptions of fires in this category are similar to fires associated with these ignition sources occurring elsewhere in the plant. None of the fires in this category was judged to be severe. These fires should be modeled similar to electrical cabinets, pumps, fans and batteries elsewhere in the plant. The severity factors for cabinets, pumps and ventilation subsystems discussed in this Appendix may be applied as appropriate to the fires in this category.

D.3.5 Motor Generator Set Fires

An evaluation of fires in motor-generator sets, as reported in the FEDB, has been performed. Table D.3-5 describes the results of the evaluation. The database lists seven (7) fires occurring in CRD or RPS motor generator sets. None of the events reports clearly indicates the fire was severe. However, two events might have been severe. Both were extinguished using portable extinguishers. One had a duration time of 30 minutes; however, this may be attributable to the fact that the alarm failed to actuate. The other flashed when the back panel of the unit was removed to apply extinguishing agent, then reflashed when the extinguisher was removed the first time. Weighing each potentially severe event as one-half of a severe event, the fraction of severe fires becomes 1/7 or 0.14.

D.3.6 Pump Fires (Excluding Containment and Feedwater Pumps)

An evaluation of the events in the FEDB for pump fires was performed to obtain insights into the behavior of pump fires and to develop a severity factor for pump fires. The primary containment (e.g., RCP) and main feedwater pumps were excluded from this investigation. Containment pumps are excluded because fires in containment are not significant to risk (discussed in section 4.1). Main feedwater pumps are excluded due to their size and fire characteristics. This examination identified forty-six (46) pump fires in the FEDB. Table D.3-6 presents a summary of these events.

Ten (10) of these pump fires self-extinguished. These fires are not considered severe. Another seventeen (17) fires were manually suppressed using portable extinguishers or by deenergizing equipment. These are classified as low severity based on duration, small damage and/or description. There were seven fires with indeterminate methods of extinguishment, but whose descriptions indicated non-severe fires.

Six (6) fires required a combination of hose stream and other manual suppression means to put out. Four (4) of these fires involved oil; two (2) were severe motor fires. These six (6) events are classified as severe.

Six (6) fires did not contain enough information to be considered not severe. These fires are considered potentially severe and not weighted as one-half of a severe event. The severity factor for pumps is then 9/46 or 0.20.

D.3.7 Ventilation Subsystem Fires

An evaluation of fires in ventilation subsystems in the FEDB has been performed. Table D.3-7 describes the results of the evaluation. The database lists twelve (12) fires occurring in ventilation subsystems. None of the events reports clearly indicates a severe fire, and none indicates there was damage to anything other than the initiating component. However, two events required more than 10 minutes to suppress (one 40 minutes and the other 20 minutes, using portable extinguishers) suggesting these events might have been severe. Weighing each potentially severe event as one-half of a severe event, the fraction of severe fires becomes 1/12 or 0.08.

D.4 References

1. J. Chavez. *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets - Part 1: Cabinet Effects Tests,*, Volume 1, Albuquerque, NM: Sandia National Laboratories. SAND86-0336. Washington, D.C.: Government Printing Office, April 1987. NUREG/CR-4527

2. J. Chavez. *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets - Part II: Cabinet Effects Test,* Volume 2. Albuquerque, NM: Sandia National Laboratories, SAND86-0336. Washington, D.C.: Government Printing Office, April 1987. NUREG/CR-4527.

3. *Categorization of Cable Flammability,* Immediate-Scale Fire Test of Cable Tray Installations, EPRI NP-1881, Research Project 1165-1, August 1982.

4. W. Parkinson, et al, *Fire Events Database for U.S. Nuclear Power Plants*, Electric Power Research Institute, NSAC-178L, December 1991.

5. W. Parkinson, et al, *Automatic and Manual Suppression Data for Nuclear Power Plant Fire Risk Analyses*, Electric Power Research Institute, NSAC-179L, February 1994.

6. G. Altmann and R. Pfeiffer, *Fire Protection Aspects of Transformers in Electrical Plants*, Siemans Power Engineering VI, No. 3, 1984, pp. 194-198.

Table D.3-1
Evaluation of the Severity of Control Room Fires

Fire Events	Severity Screening Criteria*								Initiating	Detection	
INO #/date	1	2	3	4	5	6	7	8	Component	Means	Comments
CR cabinet											
163 (7/12/79)	No	Yes	No	No	No	no info	No	No	Circuit card	Personnel	Panel still in service after fire
329 (8/11/82)	No	no info	No	No	No	No	No	No	Cable	Personnel	Caused by personnel
369 (3/12/83) & 374 (3/30/83)	No	no info	No	No	no info	no info	No	No	Relay	Personnel	RPS relays remained operable after each fire
425 (6/3/84)	No	No	No	No	No	no info	No	No	Relay	no info	
464 (3/29/85)	No	No	No	no info	No	no info	No	No	Oven grease	no info	
480 (7/14/85)	No	No	No	no info	No	no info	No	No	Circuit card	Personnel	Suppressed quickly although no time given
481 (7/26/85)	no info	no info	no info	no info	no info	no info	X	no info	no info	no info	No description
537 (9/4/86)	No	no info	no info	X	No	No	No	No	Circuit card	Personnel, Smoke detector	
659 (12/30/87)	No	No	No	X	No	No	No	No	Relay	Personnel, Smoke detector	
756 (10/14/88)	No	Yes	no info	No	No	no info	No	May be	Relay	Personnel	Four relays plus wiring damaged

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-2
Evaluation of the Severity of Switchgear Room Electrical Cabinet Fires

Fire Events (INO #)	Severity Screening Criteria*								Initiating Component	Detection Means	Voltage	Severity	Comments
	1	2	3	4	5	6	7	8					
Switchgear													
65						X			Bus	CR			Self-extinguishing
127			X		X	X		X	Relay	Local	4160		Fire not significant until door opened
195							X		Bus	CR			Description implies minor
214							X		Breaker	CR			Fire apparently limited to breaker
221							X		Bus	Personnel			Probably not severe because suppressed by untrained workers
475							X	X	Bus		4160	Small fire	Small electrical fire
498					X			X	Breaker	CR	6.9	Explosion	No flames observed
516									Trip coil	Local			No criteria met
634				X		X			Bus	Halon, personnel	4160		"Fire" apparently did not involve switchgear

*** Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-2
Evaluation of the Severity of Switchgear Room Electrical Cabinet Fires (Continued)

Fire Events	Severity Screening Criteria*								Initiating	Detection			
(INO #)	1	2	3	4	5	6	7	8	Component	Means	Voltage	Severity	Comments
MCCs													
173							X		Bus		480		Probably self-extinguishing, may be duplicate of 175
175				X	X			X	Bus	Smoke-heat detector	480	Explosion	Self-extinguishing
349							X	?	Breaker	Local			Signs of fire outside breaker
434		X	X	X		X			Breaker	Halon actuated	480	Explosion	Control cable ignited
642					X				Breaker	Fire watch			No propagation outside of breaker
663									CPT				No criteria met
671									Breaker	CR			No criteria met
678						X			Bus			Explosion since badly damaged	Circuit protection de-energized bus and terminated fire

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-3
Evaluation of the Severity of Indoor Transformer Fires

INO	SWF	Location	Severity Screening Criteria*								Initiating Component	Detection Means	Voltage	Comments
			1	2	3	4	5	6	7	8				
155	insuff. info.	Switchgear Room	no info	no info	no info	no info	no info	no info	YES	no	Med or High voltage xfmr			Insufficient information.
300	1	Turbine Bldg	no	no info	YES	YES	no info	no info	no	YES	High voltage xfmr	Smoke, heat detector	> or = 6900	"Explosion" in a neutral ground xfmr. "Class B" fire type indicates involvement of liquid combustibles.
333	0.5	Cable Spr Room	no	no info	no info	YES	YES	YES	no	no	Low voltage xfmr	Halon	Other low voltage	13 min. duration, actuated halon system
363	0	Turbine Bldg	no	no info	no info	no info	no	no info	no	no	Med voltage xfmr		480	Fire extinguished by deenergizing the xfmr. Suppression time given as 0 min.
389	0	Rx/Aux Bldg	no	no info	no info	no info	no info	no info	no	no	Med voltage xfmr		460	Fire extinguished by deenergizing the component.
421	1	Switchgear Room	no	YES	YES	YES	YES	YES	no	no	Med voltage xfmr	Smoke detect. Halon	4160/480	No fire was actually observed.
500	0	Rx/Aux Bldg	no	no info	no info	no	no	no info	no	no	Low voltage xfmr	Personnel	Other low voltage	5 min duration, smoke only.
551	0	Rx/Aux Bldg	no	no info	no info	no	no	no info	no	no	Low voltage xfmr	Personnel	Other low voltage	Smoke and sparks. Extinguished by deenergizing xfmr. 1 min duration.
614	0	Turbine Bldg	no	no	no	no	no	YES	no	no	Size unknown	Control Rm Observ.	Unknown	Smoke, sparks
762	0	Switchgear Room	no	no info	no info	no	no	no	no	no	Lighting xfmr	Personnel	ltg	<$5K loss. 2 min duration

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-3
Evaluation of the Severity of Indoor Transformer Fires (Continued)

INO	SWF	Location	Severity Screening Criteria*								Initiating Component	Detection Means	Voltage	Comments
			1	2	3	4	5	6	7	8				
846	no info	Unknown	no info	no info	no info	no info	no info	no info	YES	no	Low voltage xfmr		120	New event,
871	no info	Unknown	no info	no info	no info	no info	no info	no info	YES	no	Low voltage xfmr		Other low voltage	New event, Smoke. Xfmr used to power plant rad monitors,
877	no info	Rx/Aux Bldg	no info	no info	no info	no info	no info	no info	YES	no	Med voltage		480/120	New event,
916	0	Rx/Aux Bldg	no	no info	no info	no	no info	no info	no	no	Med voltage xfmr	Personnel	480	New event, Extinguished by deenergizing the component.
918	1	Turbine Bldg	YES	YES	no	YES	YES	no info	no	no	High voltage xfmr	Smoke, heat detector	26/4 kV	New event, 16 min duration. Hoses were charged but may not have actually been used.

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-4
Evaluation of the Severity of Diesel Generator Fires

				Severity Screening Criteria*								
INO	**SWF**	**Initiating Component**	**Detection Means**	**SSC1**	**SSC2**	**SSC3**	**SSC4**	**SSC5**	**SSC6**	**SSC7:**	**SSC8**	**Comment:**
49	0	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	No	No		No	"Immediately extinguished"
50	0	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	No	No		No	"No damage occurred"
51	0	Oil leak onto exh. manifold	No info		No	Yes					No	"No damage was apparent."
53	0	Exhaust stack (transient fire)	Security guards	No	No	No	No	Yes	No		No	Self extinguishing
54	1.0	Crankcase explosion	Personnel	No	No	Yes	No	Yes	Yes			Judged to be serious based on the 45 min. duration. Event occurred during pre-op testing.
63	No info	Exhaust manifold	No info							Yes	No info	
67	1.0	Heating element (oil reservoir)	Smoke, heat detector	No	No	Yes	Yes	Yes	No		Yes	Event occurred during maintenance activities.
68	0	Oil leak onto exh. manifold	Smoke, heat detector	No	No	Yes	Yes	Yes	No		No	Described as a small fire
71	0	Oil leak onto exh. manifold	Personnel	No	No	Yes	No				No	Described as a small fire
73	0.5	Oil leak onto exh. manifold	Personnel	No	No	Yes	No				No	
75	0	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	No	Yes		No	Described as a small fire
79	0.5	Oil leak onto exh. manifold	No info		No	Yes					No info	
85	0	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	Yes	Yes		No	Description indicates a small fire. (This event looks suspiciously like a duplicate of event # 75. Parts of the descriptions used nearly identical wording.)
86	1.0	Generator	No info		No			Yes			No	Classified as severe due to the long suppression time. (1:18)

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-4

Evaluation of the Severity of Diesel Generator Fires (Continued)

				Severity Screening Criteria*								
INO	SWF	Initiating Component	Detection Means	SSC1	SSC2	SSC3	SSC4	SSC5	SSC6	SSC7:	SSC8	Comment:
87	0.5	Exhaust manifold	No info		No	Yes					No	
89	1.0	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	Yes	No		No	Oil spray fire, 20 min duration.
115	0.5	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	No	No		No	Oil spray fire. Described as a small fire. Preaction system tripped but insufficient heat to open heads.
126	0	Turbocharger	Personnel	No	No	No	No				No	Self-extinguishing. Carbon buildup in the exhaust path due to intermittent short duration operation. Description indicates visible flames
129	0.5	Exhaust stack (transient fire)	Security guards	No	No	No	No	Yes	No		No	This is more properly considered a transient fire. It was a structure fire started in combustible materials left too close to the diesel exhaust stack. 20 min duration.
134	1.0	Turbocharger	Smoke, heat detector	Yes	No	Yes	Yes				No info	
144	0	Electrical (control cab)	Personnel	No	No	No	No				No	Self extinguishing. Description suggests smoke only.
146	No info	Pump (motor)	Personnel	No	No	No	No				No	
150	No info	Exhaust manifold	No info							Yes	No info	
165	0.5	Exhaust manifold	Personnel		No	Yes						Description indicates visible flames.
166	No info	Electrical (excitor ctrl cab)	Personnel							Yes	No info	
171	No info	Exhaust manifold	Personnel							Yes		
172	1.0	Turbocharger	Smoke, heat detector	Yes	No	Yes	Yes	Yes	Yes		No	Fire smoldered for 2 hours
186	1.0	Bearing	Control Rm Observ.	Yes	No	Yes	No	Yes	No			
189	0	Unknown	Personnel	No		Yes	No	No	No		No	Description indicates small fire.
204	No info	Electrical (exciter cubicle)	Personnel							Yes		
215	No info	Turbocharger	No info							Yes	No info	

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-4
Evaluation of the Severity of Diesel Generator Fires (Continued)

				Severity Screening Criteria*								
INO	SWF	Initiating Component	Detection Means	SSC1	SSC2	SSC3	SSC4	SSC5	SSC6	SSC7:	SSC8	Comment:
222	0.5	Oil leak onto exh. manifold	Personnel	No	No	Yes	No				No	Fire was contained in the exhaust piping.
244	0.5	Exhaust manifold	Personnel		No	Yes					No	
246	0	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	No	No		No	Description indicates small fire.
252	0	Pump (motor)	Personnel	No	No	No	No				No	Self extinguishing. Description implies small fire.
260	0.5	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	No	No		No	Extinguished w/in 5 min
262	1.0	Oil leak onto exh. manifold	Fire Watch	Yes		Yes	No	No			Yes	Oil spray fire. Description indicates damage to components other than the DG.
263	0	Exhaust manifold	Personnel	No	No	Yes	No	No	No		No	Description indicates small fire.
268	0.5	Exhaust manifold	Personnel	No	No	Yes	No	No	No		No	Extinguished w/in 5 min
270	0	Oil leak onto exh. manifold	Personnel	No	No	Yes	Yes				No	Description indicates small fire.
286	0.5	Turbocharger	No info			Yes					No	
308	No info	Unknown	Personnel							Yes	No info	
327	0	Turbocharger	No info							Yes	No	Description indicates small fire.
328	1.0	Turbocharger	No info	Yes	No	Yes	Yes	Yes	No		No	External fire. Oil leaked onto turbocharger.
330	1.0	Oil leak onto exh. manifold	Personnel	No	No	Yes	Yes				No	External fire, possible oil spray fire.
396	1.0	Turbocharger	Personnel	Yes	Yes	Yes	No	Yes	Yes		Yes	Fuel line rupture. Pre-action system failed to operate.
397	0.5	Exhaust manifold	Personnel	No	No	Yes	No				No	
410	0	Crankcase explosion	No info	No	No	Yes					No	Self extinguishing
428	No info	Electrical (voltage regulator)	No info							Yes	No info	Event occurred during pre-op testing
454	1.0	Turbocharger	Personnel	No	No	Yes	No	Yes			No	Classified as severe because it involved oil and had 22 minute duration.

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-4
Evaluation of the Severity of Diesel Generator Fires (Continued)

				Severity Screening Criteria*								
INO	**SWF**	**Initiating Component**	**Detection Means**	**SSC1**	**SSC2**	**SSC3**	**SSC4**	**SSC5**	**SSC6**	**SSC7:**	**SSC8**	**Comment:**
457	0	Exhaust manifold	Personnel	No	No	No		No	No		No	External exh. manifold fire.
508	0.5	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	No	No		No	Extinguished w/in 1 min. Event occurred during pre-op testing.
514	0	Unknown	No info	No		No		No			No	Description implies minor fire.
535	0	Exhaust manifold	Personnel	No	No	Yes	No	Yes	No		No	Self extinguishing. Event occurred during cold shutdown.
558	0	Fan motor (supply/exhaust fan)	Personnel							Yes	No	Not counted. This is a ventilation subsystem event (supply and exhaust fans to the DG room).
559	1.0	Engine	Smoke, heat detector	Yes	No	Yes	Yes	Yes	Yes		Yes	Fuel oil leak; spray onto hot engine.
561	0.5	Crankcase explosion	No info		No	Yes					No info	Event occurred during start-up.
629	0	Exhaust manifold	No info	No	No	Yes			No		No	No damage occurred
644	0	Electrical (solenoid)	No info	No	No	No		Yes			No	Description implies minor fire.
680	0.5	Oil leak onto exh. manifold	Personnel	No	No	Yes	No	No	No		No	Self extinguishing once fuel source was removed. Event occurred during refueling outage.
710	1.0	Exhaust stack (structure fire)	Personnel	Yes		No	No	Yes			No	Smoldering fire in insulation beneath fire barrier protective boot. Event occurred during refueling outage. 27 min duration
736	0.5	Exhaust stack (transient fire)	Personnel	No	No	No	No	Yes	No		No	
741	0	Electrical (closing coil)	Personnel	No		No	No	No	No		No	
746	0	Engine	No info	No	No	Yes		No	No		No	"No damage was incurred."
765	0	Engine	Smoke, heat detector	No	No	Yes	Yes	No	No		No	Description implies minor (extinguished w/in 3 min.) Fuel oil leak. Event report implies self-extinguished when equip. was deenergized. Event occurred during refueling outage.

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-5
Evaluation of the Severity of MG Set Fires

INO	SWF	Initiating Component	Detection Means	Severity Screening Criteria*								Comment:
				1	2	3	4	5	6	7	8	
196	0	Breaker	Personnel	No	No	No	No				No	Self extinguishing. Description implies minor.
217	0.5	Panel	Personnel	No	No	Yes	No	Yes	No		No	Visible flames when back panel was removed in order to apply extinguishing agent. Fire reflashed when extinguisher was removed.
530	0	Motor	Control Rm Observ.							Yes	No	
532	0	Motor	Control Rm Observ.							Yes	No	
557	0	Breaker	Personnel	No	No	No	No	Yes	Yes		No	Description implies minor (smoke only).
611	0	Breaker	Control Rm Observ.	No	No	No	No	Yes			No	Smoke only, Report states that no open flaming was reported.
656	0.5	Generator	Personnel	No	No	No	No	Yes	Yes		No	Duration given as 30 min. Fire alarm failed. Plant FB responded and portable extinguishers were applied.

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-6
Evaluation of the Severity of Pump Fires

INO	SWF	Detection Means	Initiating Component	Severity Screening Criteria*								Comment
				ssc1	ssc2	ssc3	ssc4	ssc5	ssc6	ssc7	ssc8	
20	0	Plant Personnel	Pump	No	No	No	No	Yes	No	No	No	self-extinguishing; oil on pump lagging
21	0	Plant Personnel	Pump (Forced Circulation Pump)	No	No	No	No	No	No	No	No	manually suppressed; short duration
27	0	Construction Workers	Motor (RHR Service Water Pump)	No	No	No	No		No	No	No	manually suppressed; short duration
29	0.5		Pump (RHR)							Yes	No	little information
37	0.5	Smoke, Heat Detectors	Motor (RHR Pump)	No	No	Yes	Yes		Yes	No	No	motor bearing fire
84	0		Motor (Recirculation Pump - 3B)		No	No				No	No	small electrical fire
93	0	Plant Personnel	Valve (MSIV), Pipe	No	No	No	No			No	No	self-extinguishing; oil on hot piping
137	0	Plant Personnel	Breaker (Fire Pump)	No	No	No	No	No		No	No	self-extinguishing; oil on hot piping
145	0.5	Control Room Observation	Motor (LPSI)	Yes	No	No	No			No	No	motor fire
147	0	Plant Personnel	Motor (Recir. Pump)	No	No	No	No	No		No	No	self-extinguishing
159	1	Plant Personnel	Pipe (Rupture of Hydraulic System)	Yes	No	Yes	No	Yes	Yes	No	No	oil on hot pipes
176	0	Smoke Detectors (Ion)	Motor (Service Water Pump)	No	No	No	Yes	No		No	No	self-extinguishing
190	0		Motor (Cooling Water Pump)	No	No	No	No	No		No	No	manually suppressed; short duration
209	0		Motor	No	No	No	No	No		No	No	manually suppressed; short duration
219	0	Plant Personnel	Motor (Diesel Driven Fire Pump)	No	No	No	No		No	No	No	manually suppressed; short duration
223	0	Fire Watch	Motor (Valve)	No	No	No	No	No	No	No	No	manually suppressed; short duration
235	0		Motor (Fire Pump)	No	No	No	No			No	No	small electrical fire
238	0.5	Plant Personnel	Motor (CCW)	No	No	No	No	No	Yes	No	No	motor fire; motor replaced
266	0.5		Motor (Condensate)	No	No	Yes	No	Yes	Yes	No	No	motor windings and bearings
269	0	Plant Personnel	Motor (SI)	No	No	No	No			No	No	manually suppressed; short duration
298	0		Pump (Hot water recirc)	No	No	No	No			No	No	manually suppressed; short duration
305	0	Plant Personnel	Pipe (Turbine - RCIC)	No	No	No	No			No	No	self-extinguishing
322	0	Plant Personnel	Motor (DG Cooling Water Pump)	No	No	No	No			No	No	self-extinguishing
340	0	Plant Personnel	Motor (Valve)	No	No	No	No	No	No	No	No	manually suppressed; short duration

* **Severity Screening Criteria (SSC)**

1. Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2. Damage to components outside the ignition source (e.g., overhead cables).
3. Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4. Actuation of automatic detection or suppression systems.
5. Duration or suppression time greater than or equal to 10 min.
6. Economic loss greater than or equal to $5K
7. No information available for criteria 1 through 6.
8. Description implies a severe fire occurred.

Table D.3-6 (cont.)
Evaluation of the Severity of Pump Fires

INO	SWF	Detection Means	Initiating Component	Severity Screening Criteria*								Comment
				ssc1	ssc2	ssc3	ssc4	ssc5	ssc6	ssc7	ssc8	
346	0		Pump	No	No	No	No	No		No	No	manually suppressed; short duration
365	0	Smoke-Heat Detector	Motor	No	No	No	No			No	No	self-extinguishing
370	0		Breaker (Radwaste Pump)	No	No					No	No	small electrical fire
388	0		Engine (Fire Pump)	Yes	No	No	No	No	Yes	No	Yes	manually suppressed; short duration
435	0	Plant Personnel	Motor (Make-up)	No	No	No	No			No	No	smoke and fumes
444	0	Plant Personnel	Motor (CCW)	No	No	No	No			No	No	self-extinguishing
468	0		Motor Bearing	No	No	Yes	No	No		No	No	manually suppressed; short duration
491	0.5		Pump (Heater Drain Tank Pump)	No	No	No				No	No	oil fire on suction line insulation
495	1	Smoke Detector	Motor (RHR Pump)	No	No	Yes	Yes	Yes		No	No	motor fire
505	0		Motor (Containment Spray Pump)	No	No	No	No	Yes		No	No	small electrical fire with long duration
518	0		Motor (Charging Pumps)	No	No	No	No	No		No	No	manually suppressed; short duration
519	0	Smoke Detector	Motor (Pump)	No	No	No	No			No	No	self-extinguishing
526	0	Smoke Detectors	Motor (Boric Acid Transfer Pump)	No	No	No	Yes	No		No	No	deenergized; short duration
555	0		Belt	No	No	No	No	No	No	No	No	deenergized; short duration
566	1		Motor (Shutdown Coolong Pump)	No	No	Yes	No	Yes	Yes	No	No	oil fire
572	0	Control Room Obs., Plant Pers.	Motor (FWP - Seal failure)	No	No	No	No	No	Yes	No	No	no other equipment affected
645	0	Plant Personnel	Motor (Fire Pump Relay Contacts)	No	No	No	No	No		No	No	manually suppressed; short duration
679	0	Smoke Detectors	Motor (Charging Pump)	No	No	No	Yes	No	No	No	No	small, smoking motor fire
714	1	Detector	Motor (Heater Drain Pump)	Yes	No	Yes	Yes	No	Yes	No	Yes	severe oil fire
735	1	Smoke Detectors (Ionization)	Motor (Heater Drain Pump)	No	No	Yes	Yes	No	Yes	No	Yes	heater drain tank motor
755	1	Fire Watch	Pump (CCW)	Yes	No	Yes	No	No	No	No	No	oil fire
760	0	Plant Personnel	Motor (Water Pump)	No	No	No	No	No	No	No	No	manually suppressed; short duration

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Table D.3-7
Evaluation of the Severity of Ventilation Subsystem Fires

	Severity Screening Criteria*								Initiating Component	Detection Means	Severity
Fire Event No.	1	2	3	4	5	6	7	8			
130									Blower Motor	Personnel	0
220									Fan Motor	Personnel	0
296					x				Bearing		.5
302									Fan Belt		[illegible]
439				x					Fan	Detector	0
459									Fan Belts		0
544					x				Fan	Personnel	0
602					x				Demister		.5
625				x	x				compressor motor	Smoke Detector	0
633									AC Unit	Personnel	0
658				x					Fan Motor		0
749									Fan Motor	Control Room	0

* **Severity Screening Criteria (SSC)**

1 Use of hose streams subsequent to the use of portable extinguishers or fixed systems.
2 Damage to components outside the ignition source (e.g., overhead cables).
3 Ignition of combustibles associated with the predicted heat release rate (e.g., cables in electrical cabinets, oil in pumps).
4 Actuation of automatic detection or suppression systems.
5 Duration or suppression time greater than or equal to 10 min.
6 Economic loss greater than or equal to $5K
7 No information available for criteria 1 through 6.
8 Description implies a severe fire occurred.

Appendix E

Heat Release Rates

(from EPRI Fire Risk Implementation Guide)

This appendix provides guidance for selection of Heat Release Rate (HRRs) for both fixed and transient fire sources. Extensive data has been collected from tests and experience. This data is presented in the following sections with appropriate technical bases.

E.1 Heat Release Rates for Typical Fire Sources in U.S. Commercial Nuclear Power Plants

Extensive review of U.S. commercial nuclear power plant experience compiled in EPRI's Fire Events Database (1) resulted in a list of credible fire ignition sources. The HRR data for all these sources is documented in Table E-1. To help the user in selection of the appropriate HRR value, the data explains the characteristics of the fuel, range of values and their reference.

Separate, detailed discussions are provided in Sections E.2 and E.3 for electrical cabinets and transients, respectively.

E.2 Electrical Cabinets

Electrical cabinet fire heat release rates are particularly important in a fire risk study. NSAC-181 (2) is a prime example of the impact of realistic heat release rates on fire risk. The topic is also important because the analyst might otherwise conclude that high heat release rates are generally recommended. NUREG/CR-4840 (3), a method approved by NRC for IPEEE, also suggests high heat release rates for typical fires (e.g., approximately 1000 Btu/sec). While not specifically assigning such a heat release rate to electrical cabinet fires, these heat release rates were used in switchgear room electrical cabinets fires during applications of the method for NUREG-1150.

FIVE displays example heat release rates from selected electrical cabinet fire tests performed by Sandia, the same source for this Appendix and NSAC-181. However, FIVE neither requires nor recommends those heat release rates. The heat release rate graphs reproduced in FIVE are representative of only a few selected cases, namely benchboard cabinets found in the control room. The following evaluation of the test data in NUREG/CR-4527(4,5) for vertical cabinets indicates quite different results.

For vertical cabinets, heat release rates differ dramatically for qualified and unqualified cable. The following describes different results for each. The Sandia tests provide various heat release rate results for different cable qualifications and combustible loads. They also present results for open and closed vertical cabinets and benchboard cabinets.

Table E-1, Part 1, Heat Release Rates

Ignition Source from FEDB	Fire Source Type	Characteristic Combustible	Range of Values	Heat Release Rate Method/Reference
Electrical Cabinets Fire Protection Panels Battery Chargers Electrical Cabinets T/G Excitor Dry-type Transformers	Qualified Cable in vertical cabinets	Qualified Cable	65 Btu/s	See Section E.2
	Non-Qualified Cable	Non-Qualified Cable	65 to 850 Btu/s	See Section E.2
	Transformers	Cast Resin	<65 Btu/s	Dry-type, cast-resin transformers hardly experience any escalation of fire beyond the original external fire because fire load. Also, there is no comparable risk of explosion
Pumps Pumps (Aux. Bldg. or Reactor Bldg.) Fire Pumps Other Pumps MFW Pump	Motor	Motor Windings	< 65 Btu/s	Heat Release Rates should be smaller than a small cabinet fire.
	Lube Oil	Oil	110-135 Btu/s-ft^2	For a confined spill, multiply the HRR times the area of the confined space. If unconfined, use FIVE Table 3 for spill Pennzoil)
	Pressurized Oil	Oil	HRR of 124 to 242 Btu/s Pressure of 246 - 1000 psi Mass Flow Rates of 6.63 E-03 to 1.26 E-02 lbs./s	See attached Table HRR-1: Table requires an estimation of pressure of exiting fluid or the mass flow rate of the oil through the aperture.
Engines Gas Turbines Boiler Diesel Generator	Diesel Engine Fuel	Diesel Fuel	133 (Btu/s-ft^2)	See FIVE Table 2E. #1 and #2 fuel oil are approximated as Kerosene For a confined spill, multiply the HRR times the area of the confined space. If unconfined, use FIVE Table 3for spill area of pool (#2 Fuel Oil).

Table E-1, Part 1, Heat Release Rates

Ignition Source from FEDB	Fire Source Type	Characteristic Combustible	Range of Values	Heat Release Rate Method/Reference
Engines (Con't) Gas Turbines Boiler Diesel Generator	Turbine Fuel	Jet Fuel (Kerosene)	133 (Btu/s-ft^2)	For a confined spill, multiply the HRR times the area of the confined space. If unconfined, use FIVE Table 3 for spill area of pool (#2 Fuel Oil).
	Boiler Fuel	Heavy Fuel Oil	110 Btu/s/ft^2	For a confined spill, multiply the HRR times the area of the confined space. If unconfined, use FIVE Table 3 for spill area of pool (#2 Fuel Oil).
Other Electrical Equipment Containing Flammable Liquids RPS MG Sets Transformers Yard Transformers (propagation to Turbine Building) T/G Oil	Oil	Mineral Oil	135 Btu/s/ft.^{2}	For a confined spill, multiply the HRR times the area of the confined space. If unconfined, use FIVE Table 3 for spill area of pool (#2 Fuel Oil).
	Oil	Transformer Oil	135 Btu/s/ft^2	For a confined spill, multiply the HRR times the area of the confined space. If unconfined, use FIVE Table 3 for spill area of pool (#2 Fuel Oil).
	Motor	Lube Oil	110-135 Btu/s/ft^2	For a confined spill, multiply the HRR times the area of the confined space. If unconfined, use FIVE Table 3 for spill area of pool (Pennzoil).
Electrical Motors Air Compressors Ventilation Subsystems Elevator Motors	Motor	Motor Windings	< 65 Btu/s	Heat Release Rates should be smaller than a small cabinet fire.
	Pressurized Oil	Pressurized Oil	HRR of 124 to 242 Btu/s Pressure of 246.5-1000.5 psi Mass Flow Rates of .00663-.0126 lb/s	See attached Table HRR-1: Table requires an estimation of pressure of exiting fluid or the mass flow rate of the oil through the aperture.

Table E-1, Part 1, Heat Release Rates

Ignition Source from FEDB	Fire Source Type	Characteristic Combustible	Range of Values	Heat Release Rate Method/Reference
Equipment Containing Hydrogen T/G Hydrogen Off Gas/Hydrogen Recombiner Hydrogen Tanks Miscellaneous Hydrogen Fires Battery Chargers	Hydrogen	Hydrogen	Not Applicable	SFPE Handbook of Fire Protection Engineers (pp. 1-298 through 1-305)
Cable-Non-Qualified Cable Junction Box/Splice In Non-Qualified Cable Cable Fires Caused By Welding	Cable	Non-Qualified Cable	11-94 Btu/s/ft.2	FIVE Methodology Table 1-E. Damage Threshold Criteria page 10.4-67
Dryers	Motor	Motor Windings		Heat Release Rates should be smaller than a small cabinet fire.
Transients Transient Fires caused by welding transients	Transient Combustibles	Various	20-333 Btu/s	See Section E.3
Battery	Battery Casing	Polycarbonate	68 (Btu/s-ft^2)	see ref. #4 & 5
	Battery Casing	Polystyrene	129 (Btu/s-ft^2)	see ref. #4 & 5

Table E-1, Part 2
Approximation of Pressurized Oil Fires

METRIC UNITS (Diameter of the nozzle used in test: 0.38mm)

Fluid	Nozzle Pressure (MPa)	Mass flow rate m_f (g/s)	Chemical HRR Q_{ch} (kW)	Net Heat of Combustion ΔH_T (kJ/g)	Ave. heat of Combustion ΔH_{ch} (kJ/g)	Combustion Efficiency x_{ch}	Visible flame height L_f (m)
Mineral Oil	6.9	5.71	255	46.0	44.6	0.97	2.18
	5.2	5.18	230	46.0	44.3	0.96	1.96
	3.5	4.45	202	46.0	44.1	0.96	1.91
	1.7	3.0	131	46.0	41.4	0.90	1.50

ENGLISH UNITS (Diameter of the nozzle used in the test: 0.015in)

Fluid	Nozzle Pressure (PSI)	Mass flow rate m_f (lb/s)	Chemical HRR, Q_{ch} (Btu/min)	Net Heat of Combustion ΔH_T (Btu/lb)	Ave. heat of Combustion ΔH_{ch} (Btu/lb)	Combustion Efficiency x_{ch}	Visible flame height L_f (ft)
Mineral Oil	1000.9	1.3E-02	14515	9.6E-02	9.3E-02	0.97	6.89
	754.3	1.1E-02	13092	9.6E-02	9.3E-02	0.96	6.43
	507.7	9.8E-03	11498	9.6E-02	9.2E-02	0.96	6.27
	246.6	6.6E-03	7457	9.6E-02	8.7E-02	0.90	4.92

References for Heat Release Rate Table E-1, Parts 1 and 2

1. Altman, G., Pfiffer, R.: Fire Protection Aspects of Transformers in Electrical Plants. Siemens Power Engineering VI (1984), pp. 194-198.
2. Khan, M.M., Characterization of Liquid Fuel Spray Fires: Factory Mutual Research Corporation Norwood, Massachusetts, HTD-Vol. 223, Heat and Mass Transfer in Fire and Combustion Systems, The Winter Annual Meeting of ASME, Anaheim, California, Nov. 8-13, 1992.
3. Alber, Friedrich, Altman, Gerhard, and Pfiffer, Richard, "Fire Behavior of Liquid-Immersed Distribution Transformers.", Siemens Power Engineering & Automation , vol. 8, no. 3, May-Jun. 1986, pg. 198-204.
4. Przybyla, Leon, Gandhi, Pravinray, "Flammable Liquids in Plastic Containers", Fire Journal (Boston), vol. 84, no. 3, May-Jun. 1990, pg. 38-39, 41-43.
5. Tewarson, A., Pion, R.F., "Flammability of Plastics. I. Burning Intensity.", Combustion and Flame, vol. 26, pg. 85-103.
6. Cote, Arthur E. (editor), Linville, Jim L. (Editor), Fire Protection Handbook 16th Edition, NFPA, Quincy, MA, 1986, pg. 5-120.

The test data was separated according to these characteristics (open, closed, vertical and benchboard) and the heat release rates were evaluated. Peak values for heat release rates were used except for those cases where a transient ignition source was used to ignite cables in the cabinets. Because the transient source heat release rate was relatively consistent throughout the test (peak HRR varying from 23 Btu/s to 30 Btu/s), its contribution (25 Btu/s) was subtracted from the reported heat release rate.

Peak values were considered appropriate even though they were sometimes only sustained for a few minutes. The breadth of these shorter peaks is sufficiently large to cause damage in qualified cable at higher than threshold temperatures, e.g., 840 degrees F. (See Appendix G for further explanation.) For other conditions, i.e., when sustained high temperatures and heat release rates are required, other values may be more appropriate (e.g., for ignition of qualified cable).

Cabinet tests involving qualified cable could only achieve self-sustained propagation when ignited by a transient source; electrical ignition always failed to do so. Heat release rate values from the tests range from 50 to 71 kW in six tests. Two tests recorded heat release rates of 24 and 27 kW (ST1 and ST2, respectively); however, those HRRs represented only the transient source. Similar HRRs were found regardless of whether the door was open or closed and the amount of fuel load. Similar HRRs were probably due to the fact that the fires never propagated throughout cabinets; rather they stayed in the ignited cable bundle. Based on these results, we recommend a <u>65 Btu/sec</u> HRR for <u>vertical electrical cabinets</u> known to contain only qualified cable.

The SNL report documents four tests of benchboard cabinets with combustible load of between 1.4 - 1.5 MBtus. The tests report HRRs ranging from 170 - 1140 Btu/s (qualified) and 750 - 1200 Btu/s (non-qualified).

In the case of non-qualified cable, both ignition sources (i.e., transients and electrical), ignited cable bundles in the cabinet. Fires propagated throughout the cabinet, including past internal barriers. HRR values range much more widely (i.e., from a low of 100 to a high of 918 Btu/s for vertical cabinets and 750-1232 Btu/s for benchboard-type cabinets). The results varied significantly based on the amount of fuel load and whether the door was open or closed. Figures E-1 and E-2 document these variations. Consequently, we recommend the following model for vertical cabinets, which contains screening values independent of fuel load as well as final values if fuel loads are obtained. It is often very difficult to know the fuel load within a cabinet. Values are rarely documented and it is not practical to open cabinet doors during most plant operating conditions.

Analysis of the control room fires, where benchboard-type cabinets are typically used, is described in Section 4.2 of this report.

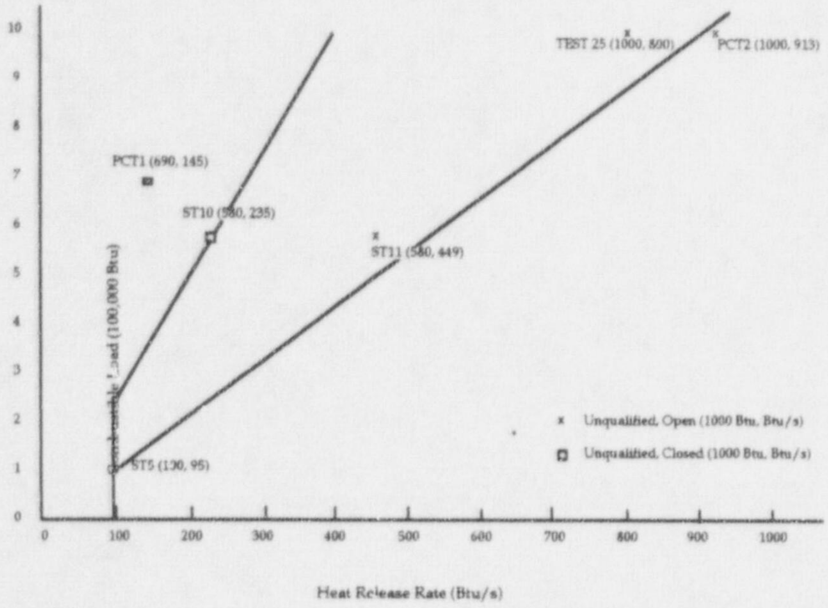


Figure E-1 HRR Values for Vertical Cabinets with non IEEE-383 Qualified Cabinets

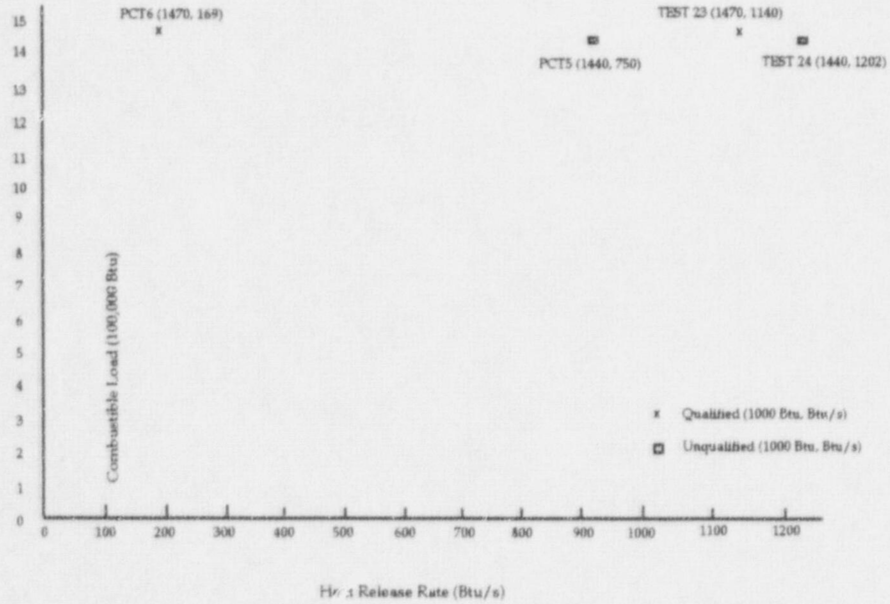


Figure E-2 HRR Values for Benchboard Cabinets with non IEEE-383 Qualified Cabinets

Screening Values

- Open door 850 Btu/sec (based on PCT2 and Test 25)
- Closed door 400 Btu/sec (based on ST10)

Final Values

- Open door 8.5E-4 x FL (Btu) (but no less than 95 based on ST5)
- Closed door 4E-4 x FL (Btu) (but no less than 95 based on ST5)

If documentation is not available on fuel loads for unqualified cable and a cabinet-specific HRR is desired, the following criteria is suggested based on the Sandia report:

- Assume 125,000 BTUs for each cable bundle

Table E-2 documents a summary of SNL's cabinet fire tests (NUREG/CR-4527).
The above model for heat release rates does not consider certain other factors related to applying the heat release rate in fire modeling, specifically:
when should the cabinet be considered open,
where should the virtual source of the fire be located, and
how should radiative heating be considered for fires in enclosed cabinets.
The following provides insights into these questions based on our findings from testing the model during the TC process. Typical cabinet openings observed in the field include:

Vents:	Louvers on the front, back and /or sides Grilles on the front, back, sides and/or top Open top Open top with shield Fans (typical on solid state equipment)

Penetrations:	Air drop with flange and water seal Air drop with open conduit Air drop with rated fire seal (not common) Sealed conduit

Electrical cabinets that are not vented do not propagate a fire. Penetrations described above are not considered to be vents. It is assumed that in the absence of other ventilation, penetrations will not allow sufficient air exchange to replace oxygen being consumed by the fire, and an incipient fire will self-extinguish when there is no longer enough oxygen to support combustion.

Table E-2
Summary of Sandia Cabinet Fire Tests (NUREG/CR-4527)

Test No.	Ignition Source	Cabinet	Cable Type	Combustible Load (MBtu)	Ventilation Method	Peak Temperatures (°F)		Smoke Obscuration (min)		Test	
	Type	Type				Room	Adjacent Cabinet	Visual Observation	Measured Optical (to 1 m^{-1})	Objectives	Results
Qualified, Open											
ST1	Transient	Vertical	Q	0.11	No doors	N/A	N/A	N/A	N/A	Single cable bundle. To evaluate if the transient ignition source could ignite the cable bundle and propagate a fire in it.	Cable bundle did not burn.
ST2	Transient	Vertical	Q	0.11	No doors	N/A	N/A	N/A	N/A	Single cable bundle. To evaluate if the transient ignition source could ignite the cable bundle and propagate a fire in it.	The ignition source was not enough to ignite and propagate a fire through the cable bundle.
ST3	Transient	Vertical	Q	0.11	No doors	N/A	N/A	N/A	N/A	Single cable bundle . Increased the source from ST1 & ST2 to ignite the cables and lossened up the bundle to allow additional air flow and flames through the cables.	The cable bundle ignited and fire propagated up the bundle. Entire bundle consumed
ST4	Transient	Vertical	Q	0.11	No doors	N/A	N/A	N/A	N/A	Single cable bundle. Increased the source from ST1 & ST2 to ignite the cables. The bundle was even more loosened up compared to ST3.	The cable bundle ignited and burned quickly.
ST9	Transient	Vertical	Q	0.22	Doors open	N/A	N/A	N/A	N/A	This test was conducted to investigate if internal horizontal barriers (e.g., strip chart recorders, mounting plates, etc.) would enhance the potential for the fire to propagate.	The fire did not propagate horizontally even with the partition. Peak HRR reached at about 10 min.
ST6	Transient	Vertical	Q	0.33	No doors. 2 - 19"*84" openings.	N/A	N/A	N/A	N/A	To determine if fire in a corner cable bundle will propagate to another cable bundle in the cabinet.	No horizontal propagation of the fire in any cable bundles. It took about 8 min to reach the peak HRR.
PCT3	Transient	Vertical	Q	1	Doors open	122	140	10	N/A	Although ST6 thru ST9 had shown a fire in qualified cable and vertical cabinet would not spread, this test was conducted to determine what effect a larger fuel loading of qual. cable in a vertical cabinet would have on ignition and propagation of a fire.	No propagation. Obscuration at 10 minutes. Peak HRR reached at about 10 min.
PCT6	Transient	Benchboard	Q	1.47	Doors open front grill	239	95	11	N/A	This test was done to investigate how the fires propagate in benchboard cabinets with unqualified cables.	Propagation 1.22m up. Obscuration at 11 min. Peak HRR reached after 15 minutes.
Test 23	Transient	Benchboard	Q	1.47	Front ventilation grill & open backdoor	279	522 (Wall) 237 (Air)	9	9	Configuration similar to PCT 5. Except qualified and room ventilation at 1 rm ch/hr (800 ft3/min)	Obscuration of the room at about 9 min (at optical density of 1.83-m). Peak HRR reached at 10:45 min.

Table E-2 (continued)
Summary of Sandia Cabinet Fire Tests (NUREG/CR-4527)

Test No.	Ignition Source	Cabinet	Cable Type	Combustible Load (MBtu)	Ventilation Method	Peak Temperatures (°F)		Smoke Obscuration (min)		Test	
	Type	Type				Room	Adjacent Cabinet	Visual Observation	Measured Optical (to 1 m^{-1})	Objectives	Results
Qualified, Closed											
ST7	Transient	Vertical	Q	0.33	Doors closed	N/A	N/A	N/A	N/A	Same as ST6 except doors were put on the cabinet. The doors each had two vent grills, one on the top of the door and one near the bottom.	Only the main bundle above the fuel was consumed. No horizontal propagation to other bundles. Peak HRR reached in 17 min.
ST8	Transient	Vertical	Q	0.55	Doors closed	N/A	N/A	N/A	N/A	Similar to ST7 but fuel loading and configuration more representative of NPP control room cabinets (based on actual pictures).	The main cable bundle directly above the source burned. The cable bundle and plastic wireway to the left of the main bundle also burned. No other bundle burned. Peak HRR reached in about 10 min. The room did not fill with smoke.
Unqualified, Open											
ST5	Transient	Vertical	UQ	0.11	No doors	N/A	N/A	N/A	N/A	Single cable bundle. Similar to ST3 and ST4 but with unqualified cables to evaluate the ability to ignite and propagate a fire through a single bundle.	Entire bundle consumed with peak HRR of 100 Btu/s in less than 9 min.
ST11	Transient	Vertical	UQ	0.58	Doors open	N/A	N/A	8	N/A	Same as ST10 except the doors were left open to evaluate the effect of ventilation.	Propagated. All burned. The fire burned much quicker than ST10. The peak HRR of 480 Btu/s wa reached at 19 min. It took longer than 5 min to reach 70 Btu/s. The smoke level quickly decended to the to the floor obscuring the cabinets in the enclosure.
Test25	Electrical	Vertical	UQ	1	Doors open	144	77	20	13	In situ fuel arrangement and amount the same as PCT2. Except for electrical ignition source and room ventilation maintained at 8 rm ch/hr (6400 ft3/min).	Smoke first visible (very small amount) from elect source 6 min before ignition at 15.5 min. In-cab detector activated at 10.5 min after ignition.
PCT2	Transient	Vertical	UQ	1	Doors open	320	180	6	N/A	After PCT1 increased the loading (from 690,000 to 1000,000 Btu) and left the door open. As a result of discussions with NRC, this was considered representative of cabinets in operating plants.	Propagated. Flames out cabinet door in 5 min. Visual obscuration in 6 min with total obscuration of the cabinets 9 min after ignition. About 11 min to reach the peak HRR (took ~7 min from 99.5 to 995 Btu/s).

Table E-2 (continued)
Summary of Sandia Cabinet Fire Tests (NUREG/CR-4527)

Test No.	Ignition Source	Cabinet	Cable Type	Combustible Load (MBtu)	Ventilation Method	Peak Temperatures (°F)		Smoke Obscuration (min)		Test	
	Type	Type				Room	Adjacent Cabinet	Visual Observation	Measured Optical (to 1 m^{-1})	Objectives	Results
PCT5	Electrical	Benchboard	UQ	1.44	Doors open front grill	410	212	13	N/A	This test was done to investigate how the fires propagate in benchboard cabinets with unqualified cables.	Ignition occurs15.33 min after electrical ignition is turned on. Smoke was visible for approximately 4 min before ignition and obscured the view in the room at 9 min after ignition. Peak HRR at 30 min, 15 minutes after fire ignition.
Test 24	Electrical	Benchboard	UQ	1.44	Front ventilation grill & open backdoor	250	606 (Wall) 194 (Air)	16.5	13.5	Similar configuration as PCT5. Room ventilation at 1 rm ch/hr (800 ft3/min)	Complete obscuration at 6' level began in approx. 15 min and optical density of 1m-1 reached at 12 min after ignition. Smoke from electrical ignition was visible 1.5 min before ignition. Peak HRR reached at about12.5 min after ignition.
Unqualified, Closed											
ST10	Transient	Vertical	UQ	0.58	Doors closed. Vent grills on door	N/A	N/A	<11	N/A	Same as ST8 except for UQ instead of Q cable. Same as ST11 except the doors were left open to evaluate the effect of ventilation.	Propagated. All burned. Obscuration faster than PCT1 (11.66 min). Reached the first peak HRR (255 Btu/s) at ~11 min and the second (265 Btu/s) at ~28 min. It took longer than 5 minutes to reach 70 Btu/s.
PCT1	Transient	Vertical	UQ	0.59	Doors closed. Vent grills on door	140	126	11	N/A	Similar to ST10. Higher total fuel loading due to larger cabinet floor area. Loading per square meter of the cabinet floor area was the same.	Propagation. Peak HRR and obscuration at ~12 min. Fire did not burn as fast as ST10.

Table E-2 (continued)
Summary of Sandia Cabinet Fire Tests (NUREG/CR-4527)

Test No.	Ignition Source	Cabinet	Cable Type	Combustible Load (MBtu)	Ventilation Method	Peak Temperatures (°F)		Smoke Obscuration (min)		Test	
	Type	Type				Room	Adjacent Cabinet	Visual Observation	Measured Optical (to 1 m^{-1})	Objectives	Results
Heptane pool, propylene burner, no circuits.											
Test 21	Gas burner	Benchboard	Propylene	N/A	Front ventilation grill and open backdoor.	212	455 (Wall) 172 (Air)	10	7.5	To provide data with known heat source and rate to use in validating enclosure inst, previous test results and fire models.	Peak HRR of 489 Btu/s was reached within 4 min.
Test 22	Gas burner	Benchboard	Propylene	N/A	Front ventilation grill and open backdoor.	225	680 (Wall) 176 (Air)	10		Same as test 21 except the burner was programmed to grow to 1000 kw in 8 min.	Peak HRR of 948 Btu/s was reached within 8 min.
PCT4	Heptane	Vertical	Heptane	N/A	Doors open	572	1040	N/A	N/A	This test was done to evaluate the effect of a very large fire on room and adjacent cabinet temp. Since it was impractical (and unrealistic) to put twice as many cables as PCT2, 15 gallon of heptane with surface area of 10 ft2 was used.	a) Radiation from the cabinet walls to adjacent cab. dominates, b) single cabinet will burn differently than a cabinet with adjacent cabinets, c) cabinets with a single wall (as opposed to double with air gap) result in damaging temp in adjacent cabinet.

If there are no vents in the cabinet and the only openings are penetrations of the kind listed above, combustion products from an incipient fire (carbon monoxide, carbon dioxide, soot) will accumulate inside the cabinet. The increasingly dense particulate matter will block radiative feedback, thus reducing external flux to the incipient fire (necessary to support combustion in qualified cable). In addition, as combustion products increase, the available oxygen will decrease. Buoyancy forces will cause warming air inside the cabinet to rise and try to exit through the top penetrations. Replacement air will compete with exiting air for access to the same opening. Therefore, air exchange through the top penetrations for typical nuclear power plant cabinet configurations listed above is not expected to be sufficient to support combustion.

One could postulate that hot gases accumulating at the top of the cabinet could ignite the penetrating cables, which could then afford a propagation path to overhead cable trays. SNL cabinet fire tests indicate that this does not occur in closed cabinets with qualified cable. NUREG/CR-4527: Part 1 reports the following results for tests with qualified cable and closed doors:

Test ST7: cables at the top of the cabinet showed only slight deterioration and discoloration;
Test ST8: heat damage to cables in the top of the cabinet was observed, but no ignition occurred.

Conditions in the SNL tests were less restrictive than our assumed configuration, in that the test cabinets had ventilation grilles top and bottom, and ignition was induced by a transient source rather than an electrical fault. Even so, only the cables near the ignition source burned in the two tests involving closed cabinets with qualified cable.
Table F-3 identifies the factors and their implication to fire modeling. To ease application of the model, these factors are identified on the walkdown forms contained in Appendix E.

Heat Release Rate for High Energy Electrical Cabinets

The SNL tests used to derive cabinet heat release rates (HRRs) were conducted simulating control (low voltage) type cabinets. This discussion provides guidance in use of these values for high energy switchgear and motor control center (MCC) cabinets, i.e., voltage greater than or equal to 480v.

The HRR is determined by figuring out how much of which combustible is available to burn and how fast it is burning. Cable insulation is the main source of combustion for low-voltage control cabinets and high-voltage switchgear or MCCs. Cabinets with similar types and amounts of combustibles and configurations (i.e., how the combustibles are arranged in the cabinet) will produce similar HRRs once the electrical fault is removed and the cabinet is deenergized.

Table E-3
Electrical Cabinet Heat Release Rate Factors

Cabinet Configuration	Fire Modeling Assumption
No ventilation	Cannot propagate
No top penetration	Source at height of ventilation louvers no radiation, subtract 20% of HRR (FIVE, p. 10.4-22)
Open top penetration	Source at top of cabinet Open cabinet HRR for non-qualified cable
Sealed top penetration	"Fire-rated" (same as no top penetration) "not-rated" (same as open top penetration)
Top penetration is conduit (D < 2", L > 1' or D = 2", L > 3' or conduit has a rated seal)	Same as no top penetration if otherwise ventilated, same as no ventilation if not otherwise ventilated

Judgment probably required for rating decision and to estimate time delay from no-top to open-top release (i.e., time to failure of seal)

However, an electrical fault in a switchgear or MCC is likely to produce an explosive fire with significantly more damage resulting from the explosion than from the ensuing fire. The severity factors developed for the switchgear and MCCs (Appendix D) should provide a basis for what fraction of these fires could result in explosive and damaging fires. An explosive switchgear/MCC fire is likely to have the following distinct characteristcs, which may be applicable to indoor transformers as well:

Initiates automatic suppression systems with fast response detectors before a high heat release rate is expected;
Damages the cabinet internals and adjacent cubicles;
Opens the cabinet door and allows for spread to adjacent cabinets; and
Creates life safety concerns and delays fire brigade response.

These factors should be considered when modeling high energy electrical cabinet fires.

E.3 Transient Combustibles

Table E-4 summarizes the heat release rate data for transient fires from experiments by Von Volkinburg (LBL, 1978) as reported in Nowlen (6), Lee (NBS 1982) (7), Cline (SNL 1983) as reported in Lee (7), Nowlen (SNL 1986) (8), and Chavez (SNL 1987) (4). This data comprises the results of a literature survey for characterizing fires involving typical nuclear power plant plant transient combustibles. Four of Von Volkinburg's experiments are the basis for the "trash bag" heat release rates referenced in FIVE (9,10). The table on the following pages does not include experiments by Alpert and Ward, as reported in Lee. Alpert and Ward's experiments involved stacks of wood pallets 3 to 16 feet high, constructed of untreated wood. Such configurations are not considered typical for nuclear plant fire areas containing safety related equipment.

Implementation Guidelines for Assigning Heat Release Rates for Transient Fuels

1. With the help of plant personnel, select one or more of the six transient fuel bins in the table that are most appropriate for the room under consideration.

2. For screening calculations, apply the highest heat release rate in the table for the bin or bins selected. For the worker radiation protection (WRP) clothing bin see the guidance in the next step.

3. Heat release rates for WRP clothing depend on whether or not there are significant amounts of plastic materials present. The following guidance is provided for selecting heat release rates for WRP clothing:

- **WRP clothing and plastic storage materials :** The fuel package in SNL Test #9 can be considered representative of configurations where a significant amount of plastic would contribute to the heat release rate (e.g., WRP clothing stored in plastic bins, or in polyethylene bags near a polyethylene roll). Based on Test #9, a heat release rate of 113 kW (107 Btu/s) is considered appropriate for fuel packages consisting of WRP clothing and plastic.
- **WRP clothing without plastic storage materials:** The fuel packages in Lee's tests can be considered representative of configurations where plastic would not contribute significantly to the heat release rate (e.g., WRP clothing stored in metal bins or in polyethylene bags if there is no other plastic (such as a polyethylene roll) stored nearby. A polyethylene bag alone would not be expected to contribute significantly to the heat released from such a fuel package. Lee's fuel packages contain amounts of material comparable to the amount in Nowlen's 30 gallon trash container. Based on Lee's tests, a heat release rate of 60 kW (57 Btu/s) is considered appropriate for WRP clothing without plastic storage materials (except a polyethylene bag). Note that there is little difference in the heat release rate for Lee's two tests, even though one fuel package weighs almost twice as much as the other.

4. For final calculations, determine the conditional probability (mean and distribution) that the heat release rate is sufficient to damage the target(s). The conditional probability is 1.0 if the lowest heat release rate in the table for the bin is sufficient to cause damage. If the lowest estimate does not cause damage (either using COMPBRN IIIe or the FIVE worksheets and tables 4E and 5E) estimate the lowest heat release rate required to cause damage. Develop a conditional probability that this heat release rate occurs for the scenario, based on:

- the range of heat release rates in the appropriate bin or bins,
- the types of fires in the operating experience reported in the FEDB, and
- if incidences exist, of the types of fires reported in the plant specific operating experience.

Table E-4
HEAT RELEASE RATES FOR TRANSIENT FUELS

Test	Fuel Package	Composition	Peak Heat Release Rate	Total Heat Content	Bin	Comment
SNL - Nowlen Test #5	12" x 16" x 12" cardboard box(.395 kg) 3" stack folded computer paper (6.8 kg) Crumpled paper (.680 kg)	Total 7.9 kg (17.4 lb) 5% cardboard 86% folded paper 9% crumpled paper	26 kW (25 Btu/s)	12,350 (Btu)	Folded or stacked paper	Very little of the folded paper burned.
SNL - Nowlen Test #6	12" x 16" x 12" cardboard box(.395 kg) 3" stack folded computer paper (6.8 kg) Crumpled paper (.680 kg)	Total 7.9 kg (17.4 lb) 5% cardboard 86% folded paper 9% crumpled paper	21 kW (20 Btu/s)	9,500 (Btu)	Folded or stacked paper	Very little of the folded paper burned.
LBL - Von Volkinburg, 3 airline trash bags	Three 11 gal. polyethylene trash bags (.035 kg, estimated) 36 polystyrene cups (.21 kg, estimated) 51 paper cups (.45 kg, estimated) paper towels (2.73 kg)	Total 3.5 kg (7.7 lb) 3% polyethylene 6% polystyrene 13% paper cups 78% paper towels	351 kW (333 Btu/s)		Human occupancy trash	One of four tests used as the basis for FIVE's recommended heat release rate for transient fires.
LBL - Von Volkinburg, 2 airline trash bags	Two 11 gal. polyethylene trash bags (07 kg, estimated) 24 polystyrene cups (.14 kg, estimated) 38 paper cups (.30 kg, estimated) paper towels (1.82 kg)	Total 2.3 kg (5.2 lb) 3% polyethylene 6% polystyrene 13% paper cups 78% paper towels	297 kW (282 Btu/s)	70,678 (Btu)	Human occupancy trash	One of four tests used as the basis for FIVE's recommended heat release rate for transient fires.
LBL - Von Volkinburg, 1 airline trash bag	11 gal. polyethylene trash bag (.035 kg, estimated) 12 polystyrene cups (07 kg, estimated) 17 paper cups (.15 kg, estimated) Paper towels (.91 kg)	Total 1.2 kg (2.6 lb) 3% polyethylene 6% polystyrene 13% paper cups 78% paper towels	159 kW (151 Btu/s)	45,941 (Btu)	Human occupancy trash	One of four tests used as the basis for FIVE's recommended heat release rate for transient fires.
SNL - Nowlen Test #8	5 gal. polyethylene trash can (.771 kg) Polyethylene liner (.035 kg) Cotton rags (.46 kg) Paper (.34 kg)	Total of 1.6 kg (3.5 lb) ~50% polyethylene ~28% cotton rags ~21% paper	24 kW (23 Btu/s)	23,911 (Btu)	Human occupancy trash	Fire developed quickly in the crumpled paper packing. This caused melting of the plastic wastebasket and eventual development of a fairly steady plastic pool fire.
SNL - Nowlen Test #7	5 gal. polyethylene trash can (.771 kg) Polyethylene liner (.035 kg) Cotton rags (.46 kg) Paper (.34 kg)	Total of 1.6 kg (3.5 lb) ~50% polyethylene ~28% cotton rags ~21% paper	12 kW (11 Btu/s)	53,200 (Btu)	Human occupancy trash	The trash can overturned during the test and approximately 1/2 the paper and packing material spilled out. It was primarily this material which actually burned during the test.

Table E-4 (Continued)
HEAT RELEASE RATES FOR TRANSIENT FUELS

Test	Fuel Package	Composition	Peak Heat Release Rate	Total Heat Content	Bin	Comment
SNL - Nowlen Test #3	2.5 gal polyethylene bucket (.788 kg) 16 oz box of Kimwipes (.562 kg) 1 qt acetone (.747 kg) Polyethylene wash bottle (.079 kg)	Total 2.2 kg (4.8 lb) 40% polyethylene 26% tissue paper 34% acetone	145 kW (138 Btu/s)	23,750 (Btu)	Maintenance refuse	During test 3 the acetone spilled from the bucket approximately 6 minutes after ignition, resulting in a large flash of burning acetone. This type of behavior was not observed in test 4, or any of the cabinet fire tests (Chavez) which used this ignition source. When this spike in the heat release rate is removed (See NUREG/CR-4679, Figure 50b) the peak heat release rate is about 34 kW (32 Btu/s).
SNL - Nowlen, Test #2	12" x 16" x 12" cardboard box (.395 kg) 16 oz box of Kimwipes (.562 kg) 1 qt acetone (.747 kg) Polyethylene wash bottle (.079 kg)	Total of 1.78 kg (3.9 lb) 22% cardboard 32% tissue paper 42% acetone 4 % polyethylene	109 kW (104 Btu/s)	35,150 (Btu)	Maintenance refuse	
SNL - Nowlen, Test #1	12" x 16" x 12" cardboard box (.395 kg) 16 oz box of Kimwipes (.562 kg) 1 qt acetone (.747 kg) Polyethylene wash bottle (.079 kg)	Total of 1.78 kg (3.9 lb) 22% cardboard 32% tissue paper 42% acetone 4 % polyethylene	97 kW (92 Btu/s)	45,600 (Btu)	Maintenance refuse	
SNL - Nowlen Test #4	2.5 gal polyethylene bucket (.788 kg) 16 oz box of Kimwipes (.562 kg) 1 qt acetone (.747 kg) Polyethylene wash bottle (.079 kg)	Total 2.2 kg (4.8 lb) 40% polyethylene 26% tissue paper 34% acetone	34 kW (32 Btu/s)	46,550 (Btu)	Maintenance refuse	
SNL - Chavez Screening Test #5	2.5 gal polyethylene bucket (.788 kg, estimated) Polyethylene wash bottle (.079 kg, estimated) 16 oz box of Kimwipes (.455 kg) 1 qt acetone (.747 kg, estimated)	Total 2.1 kg (4.6 lb) 40% polyethylene 22% tissue paper 36% acetone	32 kW (30 Btu/s)	68,500 (Btu)	Maintenance refuse	Chavez performed 5 screening tests involving two fuel packages. Only the heat release rate for Test #5 is reported in the reference document. Heat release rates for the other tests are reported to be less severe than test #5.
SNL - Chavez Screening Test(s)	Computer paper box (.395 kg, estimated) 16 oz box of Kimwipes (.455 kg) 1 qt acetone (.747 kg, estimated)	Total 1.6 kg (3.5 lb) 25% cardboard 28% tissue paper 47% acetone	<32 kW (<30 Btu/s)	29,200 (Btu)	Maintenance refuse	This fuel package may also contain a polyethylene container for the acetone. Chavez performed 5 screening tests involving two fuel packages. Only the heat release rate for Test #5 is reported in the reference document. Heat release rates for the other tests are reported to be less severe than test #5.

Table E-4 (Continued)
HEAT RELEASE RATES FOR TRANSIENT FUELS

Test	Fuel Package	Composition	Peak Heat Release Rate	Total Heat Content	Bin	Comment
LBL - Von Volkinburg 30 lb wood crib	Wood pieces, White fir (13.65 kg) Wood excelsior, shredded and fluffed (.45 kg) Absolute ethyl alcohol (.118 l) (~ .75 kg, estimated)	Total ~14.9 kg, estimated (32.8 lb) 92% wood 3% excelsior (wood shavings) 5% ethyl alcohol	327 kW (311 Btu/s)	30,811 (KCal)	Wood	The wood pieces were 1-1/4" x 1-1/4" x 15" in size. The precise arrangement of the sticks is not reported. The wood excelsior was spread on the floor under the wood crib and soaked in alcohol to provide a uniform ignition source for the wood.
LBL - Von Volkinburg 20 lb wood crib	Wood pieces, Douglas fir (9 kg) 100 cc (.95 qt) JP-4 (~.75 kg, estimated)	Total 9.75 kg (21.5 lb) 92% wood 8% JP-4	217 kW (206 Btu/s)	26,752 (KCal)	Wood	The wood pieces were 1-1/4" x 1-1/4" x 15" in size, arranged in eight layers of 5 sticks each.
LBL - Von Volkinburg, 14 lb wood crib	Wood pieces, Douglas fir (6.36 kg) 100 cc (.95 qt) JP-4 (~.75 kg, estimated)	Total 7.1 kg (15.6 lb) 90% wood 10% JP-4	186 kW (177 Btu/s)	17,590 (KCal)	Wood	The wood pieces were 1-1/4" x 1-1/4" x 14" in size, arranged in eight layers. The two bottom layers have 2 sticks each, and the other six layers have 4 sticks each.
NBS - Lee, clothing	4.5 kg clothing	4.5 kg (9.9 lb) 100% textile	60 kW (57 Btu/s)	N/A	WRP clothing	Clothing piled .3 m high on the floor. Lee notes that this heat release rate is low compared to fuel packages with similar packing densities. He states: "The reason for this low rate was that fire penetration into the piles of clothes and fabrics was limited by the pile height of 0.3 m. Consequently, pyrolysis of the combustibles at depths greater than 0.3 m, which certainly happened for the other trash fires [i.e., Cline and Von Volkinburg] could not occur and contribute to these fires."
NBS - Lee, fabric	2.7 kg fabric	2.7 kg (5.9 lb) 100% textile	50 kW (48 Btu/s)	N/A	WRP clothing	Fabric piled .3 m high on the floor. See comment about heat release rates for Lee, clothing.
SNL - Nowlen Test #9	30 gal. polyethylene trash can (3.6 kg) Polyethylene liner (.035 kg) Cotton rags (1.3 kg) Paper (1.5 kg)	Total of 6.4 kg (14.1 lb) 57% polyethylene 20% cotton rags 23% paper	50 kW (48 Btu/s) during the first 15 minutes when the fuel was paper, cotton and plastic 113 kW (107 Btu/s) in the last 40 minutes when the fuel was primarily a liquid plastic pool	192,000 (Btu)	WRP clothing	Within 15 minutes of ignition, the waste basket had melted away almost entirely leaving a pile of burning paper, cotton ,and plastic . . . Shortly thereafter, this pile of burning material toppled resulting in a surge in fire intensity. As the packing material burned away a liquid plastic pool fire became the dominant mode of burning. This pool fire continued to burn for an additional 40 minutes, flaring up to high intensities twice during that period.

Table E-4 (Continued)
HEAT RELEASE RATES FOR TRANSIENT FUELS

Test	Fuel Package	Composition	Peak Heat Release Rate	Total Heat Content	Bin	Comment
LBL - Von Volkinburg, Rubbish bag	Straw and grass cuttings (1.55 kg) Eucalyptus duff (2.47 kg) 32 gal polyethylene trash bag (.04 kg)	Total 4.1 kg (9 lb) 38% straw and grass cuttings 61% eucalyptus duff >1% polyethylene	343 kW (325 Btu/s)	93,000 (Btu)	Yard refuse	One of four tests used as the basis for FIVE's recommended heat release rate for transient fires.
LBL - Von Volkinburg, 121 liter wastebasket	32 gal. polyethylene waste container (3.8 kg, estimated) 72 quart size paper milk cartons coated with polyethylene (2.7 kg, estimated)	Total 6.5 kg (14.3 lb) 59% polyethylene 41% poly-coated paper	610 kW (580 Btu/s)	N/A	Discarded	Half the milk cartons were opened and stacked upright in the trash container to form tubes. The other half were torn into pieces and placed within the tubes formed by the upright milk cartons. Nowlen thinks this datum is not representative of typical transient fires in nuclear plants. "In these previous tests, the trash fuel configuration used included a highly flammable waxed paper fuel configured in a manner such that fire growth rates would be maximized. In these previous tests peak heat release rates of as high as 600 kW had been recorded. In the FPRP [SNL Fire Protection Research Program] tests [of] a similarly sized fuel package involving plain paper and cotton rags displayed a peak heat release of only 145 kW. As a result, the previously tested fuel packages were concluded to represent worst case configurations for such fuel packages. The FPRP packages were considered to represent more realistic best estimate configurations. (Nowlen, NUREG/CR-5384)
SNL - Cline Test #4	Rags (11.4 kg) Paper towels (7.7 kg) Plastic products (gloves and tape) (5.9 kg) Methyl alcohol (5.9 kg) Two 40 gal. polyethylene trash bags (.07 kg, estimated)	Total of ~31 kg (68 lb) ~37% rags ~25% paper towels ~19% plastic products ~19% methyl alcohol <1% polyethylene	119 kW (113 Btu/s)	N/A	Discarded	Contents divided equally between the two trash bags. See comment for Cline Test #3.
SNL - Cline Test #11	Rags (11.4 kg) Paper towels (7.7 kg) Plastic products (gloves and tape) (5.9 kg) Methyl alcohol (5.9 kg) Two 40 gal. polyethylene trash bags (.07 kg, estimated)	Total of ~31 kg (68 lb) ~37% rags ~25% paper towels ~19% plastic products ~19% methyl alcohol <1% polyethylene	119 kW (113 Btu/s)	N/A	Discarded	Contents divided equally between the two trash bags. See comment for Cline Test #3.

Table E-4 (Continued)
HEAT RELEASE RATES FOR TRANSIENT FUELS

Test	Fuel Package	Composition	Peak Heat Release Rate	Total Heat Content	Bin	Comment
SNL - Cline Test #3	Crumpled computer paper (9.1 kg) 2 polyethylene trash bags (.07 kg, estimated)	Total 9.2 kg (20 lb) 99% paper 1% polyethylene	109 kW (104 Btu/s) See comment.	N/A	Discarded	Nowlen says that Cline's heat release rates are unreliable. "The data gathered and reported as a part of the Ignition Source Fire Tests [Cline] included the oxygen depletion levels in the test enclosure. However, subsequently identified problems with the test setup have indicated that these values are in significant error. The oxygen concentration values reported by Cline are considered to significantly underestimate the actual levels of oxygen depletion during these tests. [Low oxygen depletion values would result in underpredicted heat release rates.] It is therefore inappropriate to attempt to use these values to estimate the heat release rates of the test fires." (Nowlen, NUREG/CR-4679)
SNL - Cline Test #5	Crumpled computer paper (13.6 kg) Two 50 gal. plastic trash cans (15 kg)	Total 28.6 kg (63 lb) 48% paper 52% plastic	109 kW (104 Btu/s)	N/A	Discarded	See comment for Cline Test #3.
SNL - Cline Test #10	Crumpled computer paper (13.6 kg) Two 50 gal. plastic trash cans (15 kg)	Total 28.6 kg (63 lb) 48% paper 52% plastic	109 kW (104 Btu/s)	N/A	Discarded	See comment for Cline Test #3.
LBL - Von Volkinburg, 6.6 liter wastebasket	6.6 liter polyethylene trash container (.23 kg) 12 quart size paper milk cartons coated with polyethylene (.45 kg)	Total .68 kg (1.5 lb) 34% polyethylene 66% poly-coated paper	64 kW (61 Btu/s)	N/A	Discarded	Half the milk cartons were opened and stacked upright in the trash container to form tubes. The other half were torn into pieces and placed within the tubes formed by the upright milk cartons. This datum was discarded for the same reasons as LBL - Von Volkinburg 121 liter wastebasket. If this datum had not been discarded, it would have been classified as "human occupancy trash". It's omission does not significantly change the heat release rate profile for that bin.
SNL - Cline Test #9	Crumpled computer paper (4.6 kg) Folded computer paper (31.8 kg) Two polyethylene trash bags (.07 kg estimated)	Total 36.5 kg (80 lb) 13% crumpled paper 87% folded paper <.5% polyethylene	40 kW (38 Btu/s)	N/A	Discarded	See comment for Cline Test #3.

Eight of the twenty-eight heat release rates found in this survey are considered to be unreliable. These heat release rates were discarded for the reasons noted in the comments provided in the table. Our judgment is consistent with evaluations by Nowlen (8,11). The remaining heat release rates were sorted into six bins based on the composition of the fuel packages: (1) human occupancy trash, (2) maintenance refuse, (3) stacked or folded paper, (4) wood pieces, (5) WRP clothing, (6) yard litter. All of the transient combustible bins, except those classified as maintenance refuse, consist of Class A material fuels. However, these five bins may involve mixed fuels, i.e., they may include two or more Class A materials, such as paper and plastic. The fuel packages in the maintenance refuse bin are also mixed. They consist of both Class A materials such as paper and rags, and small amounts of Class II or III liquids such as cleaning solvents.

E.4 References

1. Parkinson, et al, *Fire Events Database for U.S. Nuclear Power Plants*, Electric Power Research Institute, NSAC-178L, December 1991.
2. Parkinson, et al, *Fire PRA Requantification Studies*, NSAC-181, Electric Power Research Institute, Palo Alto, CA, March 1993.
3. *Recommended Procedures for the Simplified External Event Risk Analyses for* NUREG-1150, Albuquerque, NM: NUREG/CR-4840, Sandia National Laboratories, September 1989.
4. M. Chavez. *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets - Part 1: Cabinet Effects Tests,*, Volume 1, Albuquerque, NM: Sandia National Laboratories. SAND86-0336. Washington, D.C.: Government Printing Office, April 1987. NUREG/CR-4527
5. M. Chavez. *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets - Part II: Cabinet Effects Test,* Volume 2. Albuquerque, NM: Sandia National Laboratories, SAND86-0336. Washington, D.C.: Government Printing Office, April 1987, NUREG/CR-4527.
6. Nowlen, S., *Quantitative Data on the Fire Behavior of Combustible Materials Found in Nuclear Power Plants: A Literature Review*, NUREG/CR-4679, Sandia National Laboratories, Albuquerque, NM, February 1987.
7. Lee, B., "Heat Release Rate Characteristics of Some Combustible Fuel Sources in Nuclear Power Plants," NBSIR 85-3195, U.S. Department of Commerce, National Bureau of Standards, Gaithersburg, MD, July 1985.
8. Nowlen, S., *Heat and Mass Release for Some Transient Fuel Source Fires: A Test Report*, NUREG/CR-4680, Sandia National Laboratories, Albuquerque, NM, October 1986.
9. *Fire-Induced Vulnerability Evaluation (FIVE) Methodology Plant Guide,* Professional Loss Control, EPRI TR-100370, April 1992.
10. *Methods of Quantitative Fire Hazards Analysis*, Frederick W. Mowrer, EPRI TR-100443, Research Project 3000-37, May 1992.
11. P. Nowlen, *A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories,* 1975-1987, Albuquerque, NM: U. S. Government Printing Office, NUREG/CR-5384, Sandia National Laboratories, SAND89-1359, December 1989.

Appendix F

Equipment Damage Criteria

(from EPRI Fire Risk Implementation Guide)

Selection of damage criteria (i.e., temperature, heat flux and time-to-failure) is a key element of modeling fire-induced risk. Information is provided in this appendix to help this process.

Summaries of damage thresholds for cables and IEEE-qualified cables are presented in Tables F-1(1 - 2) and F-2. The data is derived from testing and analysis at Sandia National Laboratories and generally confirms FIVE's temperature criteria for IEEE-qualified cables (700°F) (3) and values used in the NUREG/CR-4840 (NUREG-1150) (4). Only a few types of XPLO insulated, IEEE-qualified cables have lower damage temperatures. One test result is available for non-qualified cables that also confirms FIVE's suggested value of 450°F. Limited data is available for damage to sensitive electronics, switchgear cabinets and electrical motors. A summary of this data is documented in Table F-3.

Table F-1
Time-To-Damage (Electrical Failure) for Cables[1]

Temp (°F)	Temp (°C)	IEEE-384-74 Insulation/ Jacket Age	Fail PE/PVC (new)	Pass XPE/XPE (new)	Pass XPLE/ Neoprene (new)	Pass XPLE/ Neoprene (aged)	Pass EPR/ Hypalon (new)	Pass EPR/ Hypalon (aged)
482	250	(see	7[2,3]	NF[4]				
527	275	Table G-2)		57				
572	300							
617	325				NF			NF
662	350		4	13	12	NF	NF	57
707	375				7	19	16	13
752	400				6	10	7	9
797	425					7	5	6
842	450[5]		2	4				

[1] Based on SNL oven tests reported in NUREG/CR-5384 (1) and NUREG/CR-5546 (2).
[2] No failure in PE/PVC below 250°C (482°F).
[3] Time expressed in minutes
[4] No failure
[5] 500°C (932°F) is the assumed piloted ignition temperature for cable of any qualification.

Table F-2
Threshold Failure Temperature for IEEE-384-74 Qualified Cables[1]

Cable Type	Temperature[2]	
	°C	°F
XPLO[3]		
Samuel Moore Decovon Polyset	299-307	570-585
Rockbestos Firewall III	320-322	608-612
Others	385-388	725-730
EPR	370-400	698-752
Silicone Rubber	396-400	745-752
Kerite FR	372-382	702-720
Polyimide or Kapton	399	750
Contemporary Fire Risk Values		
FIVE	371	700
NUREG/CR-4840 (1150)	350	662

[1] Calculated based on cable aging data reported in NUREG/CR-5384 and NUREG/CR-5546.

[2] Time at temperature not provided by calculation. Threshold values from qualified cable tests ranged from 48 to 57 min. for all but one cable type. New EPR/Hypalon was 18 minutes, approximately the same time for the other cable types when the temperature was 5 to 15°C (9 to 27°F) higher.

[3] Manufacturer and product name provided because of the wide range of values.

Table F-3
Damage Criteria for Other Equipment

Equipment	Damage Criteria	Source
Switchgear cabinet	248°F (0.88 Btu/sec/ft^2*)	IP-2 FRA (5)
Electrical logic (qualified to 104°F)	150°F (0.19)	Limerick FRA (6)
Electrical components temp-induced damage	115°F	Zion FRA (7)
permanent but not extensive damage	150°F	Zion FRA (7)
50% fail	190°F	Zion FRA (7)
Electrical equipment	150°F	USI A-45 FRAs (8)
Oscilloscope amplifier	failed for peak of 230°F	SNL cabinet tests** (9,10)
Solid-state counters	no failure at 333°F peak	SNL cabinet tests (9,10)
Agastat relay	320°F to 410°F	SNL oven test (1)
GE relay	662°F	SNL oven test (1)
Motors	20% above operating limit	USI A-45 FRAs (8)
Process Equipment	3.75 Btu/sec/ft^2	NUREG/CR-2815 (11)

* T_{air} in cabinet = $0.81\ q^{0.55}$ (temperature in °C, incident heat flux in w/m^2)

** SNL cabinet tests provide other "no failure" data

References

1. S. P. Nowlen, *A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories,* 1975-1987, Albuquerque, NM: U. S. Government Printing Office, NUREG/CR-5384, Sandia National Laboratories, SAND89-1359, December 1989.

2. *An Investigation of the Effects of Thermal Aging on the Fire Damageability of Electric Cables,* Sandia National Laboratories, Albuquerque, NM: NUREG/CR-5546 SAND90-0696, May 1991

3. *Fire-Induced Vulnerability Evaluation (FIVE) Methodology Plant Guide,* Professional Loss Control, EPRI TR-100370, April 1992.

4. *Recommended Procedures for the Simplified External Event Risk Analyses for* NUREG-1150, Albuquerque, NM: NUREG/CR-4840, Sandia National Laboratories, September 1989.

5. *Indian Point Probabilistic Safety Study,* New York Power Authority of the State of New York and Consolidated Edison Company of New York, Inc., March 1982.

6. *Severe Accident Risk Assessment - Limerick Generating Station,* Philadelphia Electric Company, Report #4161, April 1983.

7. *Zion Probabilistic Safety Study,* Commonwealth Edison Company, 1981.

8. *EPRI/WOG Analysis of Decay Heat Removal Risk at Point Beach,* Science Applications International Corp., and Westinghouse Electric Corp., Electric Power Research Institute, NSAC-113, March 1988.

9. J. M. Chavez. *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets - Part 1: Cabinet Effects Tests,,* Volume 1, Albuquerque, NM: Sandia National Laboratories. SAND86-0336. Washington, D.C.: Government Printing Office, April 1987. NUREG/CR-4527

10. J. M. Chavez. *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets - Part II: Cabinet Effects Test,* Volume 2. Albuquerque, NM: Sandia National Laboratories, SAND86-0336. Washington, D.C.: Government Printing Office, April 1987. NUREG/CR-4527.

11. *Probabilistic Safety Analysis Procedures Guide,* Brookhaven National Laboratory, Upton, NY, August 1985.

Appendix G

Walkdown Forms

(from EPRI Fire Risk Implementation Guide)

WALKDOWN IGNITION SOURCE SCREENING FORM
SUPPORTING CALCULATIONS

Page ___ of ___
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USER INPUT			FORM A
Plant			
Building			
Fire Zone			
Compartment			
Floor Area		ft2	
Ceiling Height		ft	
Ambient Temperature		F	
Damage Temperature		F	
Ignition Temperature		F	
Heat Loss Factor		unitless	
Ignition Source	Est. HRR	Est. Btu	Height of Virtual Surface of the Fire (Ft)
electrical cabinets		#VALUE!	
small pumps			
transformers		#VALUE!	
transients			
PC's		#VALUE!	
transformers @ 6'		#VALUE!	
transformers @ 8'		#VALUE!	
transformers @ 10'		#VALUE!	
To convert the heat release rate to net heat, estimate a duration of			
combustion in units of time and multiply by the time. (e.g. Btu/min*min)			

WALKDOWN
IGNITION SOURCE SCREENING FORM

Page ______ of ______

Plant: ______________ Fire Zone ______________

Building ______________ Compartment ______________

FORM B

Physical Characteristics of the Room

	value	units
Floor Area		ft2
Ceiling Height		ft
Ambient Temperature		F
Damage Temperature		F
Ignition Temperature		F
Heat Loss Factor		none

Amount of fuel req'd to form HGL @ 700F

Linear Ft. of Cable Tray	Btu
N/A	N/A

Pre-Calculated Critical Heights for Damage and Ignition

	USER		DAMAGE				IGNITION		
	HRR	Btu	Plume			Rad	Plume		
	▨	▨	LF 1	LF 2	LF 4	▨	LF 1	LF 2	LF 4
electrical cabinets		#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
small pumps			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
transformers		#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
transients			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
PC's		#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
transformers @ 6'		#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
transformers @ 8'		#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
transformers @ 10'		#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!

		SCREENING CRITERIA							
		WHEN SOURCE IS A CABINET				NO TARGET DAMAGED			
IGNITION SOURCE TAG NO./TRANSIENT COMBUSTIBLE NO.	TYPE	NO VENTS	CONDUIT W/FIRE SEAL	CONDUIT D < 2", L > 1'	CONDUIT D – 2", L > 3'	NONE OVERHEAD	OUTSIDE DAMAGE HEIGHT	OUTSIDE CRITICAL RADIAL DISTANCE	COMMENTS
								X	

FORM C-1

WORKSHEET 3: RADIANT EXPOSURE

electrical cabinets

1	Critical Radiant Flux to the Target (Representative value = 1)	Btu/s/ft2	1
2	Peak Fire Intensity	Btu/s	
3	Radiant Fraction of Heat Release (Representative value = 0.4)		0.4
4	Radiant Heat Release Rate	Btu/s	#VALUE!
5	Critical Radiant Flux Distance	ft	#VALUE!

WORKSHEET 3: RADIANT EXPOSURE

small pumps

1	Critical Radiant Flux to the Target (Representative value = 1)	Btu/s/ft2	1
2	Peak Fire Intensity	Btu/s	
3	Radiant Fraction of Heat Release (Representative value = 0.4)		0.4
4	Radiant Heat Release Rate	Btu/s	#VALUE!
5	Critical Radiant Flux Distance	ft	#VALUE!

WORKSHEET 3: RADIANT EXPOSURE

transformers

1	Critical Radiant Flux to the Target (Representative value = 1)	Btu/s/ft2	1
2	Peak Fire Intensity	Btu/s	
3	Radiant Fraction of Heat Release (Representative value = 0.4)		0.4
4	Radiant Heat Release Rate	Btu/s	#VALUE!
5	Critical Radiant Flux Distance	ft	#VALUE!

FORM C-2

WORKSHEET 3: RADIANT EXPOSURE

transients

1	Critical Radiant Flux to the Target (Representative value = 1)	Btu/s/ft2	1
2	Peak Fire Intensity	Btu/s	
3	Radiant Fraction of Heat Release (Representative value = 0.4)		0.4
4	Radiant Heat Release Rate	Btu/s	#VALUE!
5	Critical Radiant Flux Distance	ft	#VALUE!

WORKSHEET 3: RADIANT EXPOSURE

PC's

1	Critical Radiant Flux to the Target (Representative value = 1)	Btu/s/ft2	1
2	Peak Fire Intensity	Btu/s	
3	Radiant Fraction of Heat Release (Representative value = 0.4)		0.4
4	Radiant Heat Release Rate	Btu/s	#VALUE!
5	Critical Radiant Flux Distance	ft	#VALUE!

WORKSHEET 3: RADIANT EXPOSURE

transformers @ 6'

1	Critical Radiant Flux to the Target (Representative value = 1)	Btu/s/ft2	1
2	Peak Fire Intensity	Btu/s	
3	Radiant Fraction of Heat Release (Representative value = 0.4)		0.4
4	Radiant Heat Release Rate	Btu/s	#VALUE!
5	Critical Radiant Flux Distance	ft	#VALUE!

FORM C-3

WORKSHEET 3: RADIANT EXPOSURE

transformers @ 8'

1	Critical Radiant Flux to the Target (Representative value = 1)	Btu/s/ft2	1
2	Peak Fire Intensity	Btu/s	
3	Radiant Fraction of Heat Release (Representative value = 0.4)		0.4
4	Radiant Heat Release Rate	Btu/s	#VALUE!
5	Critical Radiant Flux Distance	ft	#VALUE!

WORKSHEET 3: RADIANT EXPOSURE

transformers @ 10'

1	Critical Radiant Flux to the Target (Representative value = 1)	Btu/s/ft2	1
2	Peak Fire Intensity	Btu/s	
3	Radiant Fraction of Heat Release (Representative value = 0.4)		0.4
4	Radiant Heat Release Rate	Btu/s	#VALUE!
5	Critical Radiant Flux Distance	ft	#VALUE!

FORM C-4

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 1
electrical cabinets

1	Target Damage Threshold Temperature	F	
2	"Z" Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
5	Esitmate of Actual Qtot	Btu	#VALUE!
6	Heat Loss Factor	unitless	
7	Calculation of Qnet	Btu	#VALUE!
8	Calculation of the Change in Temperature with	F	#VALUE!
9	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

* distance from the virtual surface of the fire to the ceiling

Maximum ambient temperature F ____________
Floor Area ____________

Plume Damage Calculation
Fire Location Factor 1
small pumps

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-5

Maximum ambient temperature F ______________
Floor Area ft2 ______________

Plume Damage Calculation
Fire Location Factor 1
transformers

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	[illegible]	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ______________
Floor Area ft2 ______________

Plume Damage Calculation
Fire Location Factor 1
transients

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-6

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation Fire Location Factor 1 PC's			
1	Target Damage Threshold Temperature	F	
2	"Z"Height "	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation Fire Location Factor 1 transformers @ 6'			
1	Target Damage Threshold Temperature	F	
2	"Z"Height "	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-7

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation Fire Location Factor 1 transformers @ 8'			
1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation Fire Location Factor 1 transformers @ 10'			
1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-8

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 2
electrical cabinets

1	Target Damage Threshold Temperature	F	
2	"Z" Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2
5	Esitmate of Actual Qtot	Btu	#VALUE!
6	Heat Loss Factor	unitless	
7	Calculation of Qnet	Btu	#VALUE!
8	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
9	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

* distance from the virtual surface of the fire to the ceiling

Maximum ambient temperature F ____________
Floor Area ____________

Plume Damage Calculation
Fire Location Factor 2
small pumps

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-9

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 2
transformers

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 2
transients

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-10

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 2
PC's

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 2
transformers @ 6'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

WALKDOWN IGNITION SOURCE SCREENING FORM
SUPPORTING CALCULATIONS

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FORM C-11

Maximum ambient temperature F __________
Floor Area ft2 __________

Plume Damage Calculation
Fire Location Factor 2
transformers @ 8'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F __________
Floor Area ft2 __________

Plume Damage Calculation
Fire Location Factor 2
transformers @ 10'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-12

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 4
electrical cabinets

1	Target Damage Threshold Temperature	F	
2	"Z" Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
5	Esitmate of Actual Qtot	Btu	#VALUE!
6	Heat Loss Factor	unitless	
7	Calculation of Qnet	Btu	#VALUE!
8	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
9	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

* distance from the virtual surface of the fire to the ceiling

Maximum ambient temperature F ____________
Floor Area ____________

Plume Damage Calculation
Fire Location Factor 4
small pumps

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-13

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation Fire Location Factor 4 transformers			
1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation Fire Location Factor 4 transients			
1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-14

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 4
PC's

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 4
transformers @ 6'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

WALKDOWN IGNITION SOURCE SCREENING FORM
SUPPORTING CALCULATIONS

FORM C-15

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 4
transformers @ 8'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Damage Calculation
Fire Location Factor 4
transformers @ 10'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-16

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 1
electrical cabinets

1	Target Damage Threshold Temperature	F	
2	"Z" Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
5	Esitmate of Actual Qtot	Btu	#VALUE!
6	Heat Loss Factor	unitless	
7	Calculation of Qnet	Btu	#VALUE!
8	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
9	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

* distance from the virtual surface of the fire to the ceiling

Maximum ambient temperature F ____________
Floor Area ____________

Plume Ignition Calculation
Fire Location Factor 1
small pumps

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-17

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 1
transformers

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 1
transients

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-18

Maximum ambient temperature F __________
Floor Area ft2 __________

Plume Ignition Calculation
Fire Location Factor 1
PC's

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F __________
Floor Area ft2 __________

Plume Ignition Calculation
Fire Location Factor 1
transformers @ 6'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-19

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 1
transformers @ 8'

1	Target Damage Threshold Temperature	F	
2	"Z"Height "	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 1
transformers @ 10'

1	Target Damage Threshold Temperature	F	
2	"Z"Height "	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	1.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-20

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 2
electrical cabinets

1	Target Damage Threshold Temperature	F	
2	"Z" Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
5	Esitmate of Actual Qtot	Btu	#VALUE!
6	Heat Loss Factor	unitless	
7	Calculation of Qnet	Btu	#VALUE!
8	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
9	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

* distance from the virtual surface of the fire to the ceiling

Maximum ambient temperature F ____________
Floor Area ____________

Plume Ignition Calculation
Fire Location Factor 2
small pumps

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-21

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 2
transformers

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 2
transients

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-22

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation Fire Location Factor 2 PC's			
1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation Fire Location Factor 2 transformers @ 6'			
1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-23

Maximum ambient temperature F __________
Floor Area ft2 __________

Plume Ignition Calculation
Fire Location Factor 2
transformers @ 8'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F __________
Floor Area ft2 __________

Plume Ignition Calculation
Fire Location Factor 2
transformers @ 10'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	2.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-24

Maximum ambient temperature F __________
Floor Area ft2 __________

Plume Ignition Calculation
Fire Location Factor 4
electrical cabinets

1	Target Damage Threshold Temperature	F	
2	"Z" Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
5	Esitmate of Actual Qtot	Btu	#VALUE!
6	Heat Loss Factor	unitless	
7	Calculation of Qnet	Btu	#VALUE!
8	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
9	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

* distance from the virtual surface of the fire to the ceiling

Maximum ambient temperature F __________
Floor Area __________

Plume Ignition Calculation
Fire Location Factor 4
small pumps

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-25

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 4
transformers

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 4
transients

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-26

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 4
PC's

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 4
transformers @ 6'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

FORM C-27

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 4
transformers @ 8'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

Maximum ambient temperature F ____________
Floor Area ft2 ____________

Plume Ignition Calculation
Fire Location Factor 4
transformers @ 10'

1	Target Damage Threshold Temperature	F	
2	"Z"Height *	ft	#VALUE!
3	Peak Fire Intensity	Btu/s	
4	Fire Location Factor	unitless	4.00
6	Esitmate of Actual Qtot	Btu	#VALUE!
7	Heat Loss Factor	unitless	
8	Calculation of Qnet	Btu	#VALUE!
9	Calculation of the Change in Temperature with Given Qnet	F	#VALUE!
10	Temperature of Plume	F	#VALUE!
10	Calculation of Qeff	Btu/sec	#VALUE!
11	Estimation of Damage Height	ft	#VALUE!

SCENARIO INFORMATION FORM

Plant Crystal River Unit 3

Location Florida Power Corp.

Reference Area ____________________

Compartment ____________________

FORM S

Ignition Source Tag Number ____________________

Type ____________________

Normally Occupied ____________________

HEAT RELEASE RATE									
OTHER DESCRIBE	ELECTRICAL CABINETS					TRANSIENT		PUMPS	
	OPEN TOP	TOP PENETRATIONS			FUEL LOAD	COMB. #	LOC. #	BERMS/ DRIP PAN	TRAY
	YES/NO	SEALED	RATED	NONE					
	NO	PARTIAL	N/A		N/A	N/A	N/A	N/A	N/A

RACEWAY/CONDUITS NO.	INTERVENING SPRINKLER HEAD	NEARBY DETECTOR	PROTECTIVE FEATURES				COMMENTS
	YES/NO	YES/NO	CONDUIT/TRAY			CABLE	
			SOLID BOTTOM	WRAPPED	OTHER	COATED	

DETECTOR TYPE										
	DETECTOR LOCATION					INTERVENING SPRINKLER TYPE				
NONE	IN-CABINET	IN-PLUME	IN-CEILING JET	LINE OF SIGHT	OTHER	SOLDER	BULB	OPEN HEAD	OTHER	REFERENCE NUMBER

S IN THE COMPARTMENT (LIMITS ON HOT GAS SPREAD)			
INTERIOR WALL(S)			
YES/NO	PARTIAL CEILING		OTHER/COMMENT
NO	YES/NO	HEIGHT	
	YES	26 FT	

WALKDOWN
SCENARIO FORM
SCENBLNK.XLS
6/10/96 10:46 AM

CALCULATION OF TIME TO DAMAGE/IGNITION BY HGL	**FORM H-1**
PLANT CR-3 COMPARTMENT	
IGNITION SOURCE	
GIVEN	
qtc -specific heat content of TSI on conduit of interest (BTUs/linear ft) ****	0.00
3.5"qtc=60900 4"qtc=70700 5"qtc=95200 6"qtc=116900 7"qtc=139500 8"qtc=161000	***************
qct -specific heat content of cable tray (BTU/linear foot for 24 inch CT) 257712	257712.00
qtp -specific heat content of TSI 3 Hr panel BTU/ft2 73500	73500.00
qo -heat of combustion for oil 125656	125656.00
XL -heat loss factor (from FIVE methodology) .94	0.94
hrrct -specific heat release rate for cable tray (BTUs/sec/square foot) 18.9	18.90
hrrtsi - specific heat release rate for TSI (BTU/sec/ft2) 8.8	8.80
hrr for qualified cable - 42 BTU/sec/ square foot	42.00
hrrg - specific heat release rate for generic trash (BTU/sec) - 145	145.00
hrrx - specific heat release rate for PMMA(plexiglass) BTU/sec/ft2	63.00
one ft2 of 1/4 inch PMMA is 1/48 th of 1 3.3 lbm -	0.28
1ft2 of PMMA - 10732 btu/lbm times .28 lbm - BTUs	3005.00
specific hrr for oil - 135 BTU/s-ft2	135.00
ASSUMED	
Ceiling Height - ****	0.00
Effective Room Area - ****	0.00
VIRTUAL SURFACE OF THE FIRE - ****	0.00
DAMAGE TEMP - (For cable use 700, for TSI use 1000) ****	1000.00
IGNITION TEMP - (For cable use 932, for TSI use 1000) ****	1000.00
Qnet/V (found in Table 7E of FIVE) ****	9.60
HRR of the exposure fire (BTUs/sec) - ****	0.00
DURATION of the exposre fire (minutes) - ****	15.00
Qexp - Heat released by the exposure fire(BTUs) - ****	0.00
Cable Tray fill (40% is normal. Enter value) - ****	0%
LGTHb - Length of cable tray burned (in feet) - ****	0.00
TRAY WIDTH (in inches) - ****	0.00
Ap - Area (ft2) of TSI panel ignited - ****	0.00
Lc - Length of TSI conduit ignited (ft) - ****	0.00
Conduit of interest has an outside diameter (including wrap) - ****	0.00
Ax - Area of the plexiglass ignited - ft2 ****	0.00
If a TRASHBAG is involved enter the number of bags, if not, enter 0 ****	0.00
Amount of oil spilled (UNCONFINED) gals ****	0.00
Amount of oil spilled (CONFINED) gals ****	0.00
Area of the spill (if UNCONFINED) ft2 ****	0.00
Area of the spill (If CONFINED input the basin area) ****	0.00
Amount of oil not allowed to burn (captured in collection system, floor drains, etc.) ****	0
CALCULATION	
"Z" Height -	0.00
HRRtc = hrrtsi*Lc*3.14*diameter/12	0.00
HRRtp = hrrtsi*Ap	0.00
HRRct - hrrct (area of cable tray burned)(%FILL/40)	0.00
HRRx = hrrx*Ax	0.00
HRRo - 135 BTU/s-ft2 * (area of confined + unconfined spill)	0.00
HRRtot - TOTAL INITIAL HRR (DO NOT Assume any delays in source ignition) -	0.00
Qo - specific heat of combustion * gals of spill	0.00
Qg = hrrg*900sec	0.00
Qnet - (Qnet/V)(V) -	0.00
Qcrit - Qnet/(1-XL) -	0.00
Qic - TOTAL heat input from INSTALLED INTERVENING COMBUSTIBLES	0.00
Qtot = Qexp + Qic + Qg + Qo	0.00
Qtot > Qcrit HGL COULD DEVELOP. If "FALSE" ignore all further calculations	FALSE
HGL COULD DEVELOP WITHIN THE burn duration of the exposure fire.	#DIV/0!
If "FALSE", "TIME TO DAMAGE" (TTD) is calculated below. IF "TRUE", then TTD -	**#DIV/0!**
If the last statement is "FALSE" then "TIME TO DAMAGE " - minutes	**#DIV/0!**

CALCULATION OF TIME TO DAMAGE/IGNITION BY HGL	**FORM H**
PLANT CR-3 COMPARTMENT CC-108-108	
IGNITION SOURCE	
GIVEN	
qtc =specific heat content of IC on conduit of interest (BTUs/linear ft) For Armaflex 4" = 5388	5388.00
For TSI 3.5"qtc = 60900 4" = 70700 5" = 95200 6" = 116900 7" = 139500 8" = 161000	***************
qct =specific heat content of cable tray (BTU/linear foot for 24 inch CT) 257712	257712.00
qtp =specific heat content of : TSI 3 Hr panel BTU/ft2 73500 Armaflex 1 ft2 by 1" thick = 5388	5388.00
qo =heat of combustion for oil 125656	125656.00
XL =heat loss factor (from FIVE methodology) .94	0.94
hrrct =specific heat release rate for cable tray (BTUs/sec/square foot) 18.9	18.90
hrrtsi = specific heat release rate (BTU/sec/ft2) for TSI = 8.8 for Armaflex = 32.0	32.00
hrr for qualified cable = 42 BTU/sec/ square foot	42.00
hrrg = specific heat release rate for generic trash (BTU/sec) = 145	145.00
hrrx = specific heat release rate for PMMA(plexiglass) BTU/sec/ft2	63.00
one ft2 of 1/4 inch PMMA is 1/48 th of 1 3.3 lbm =	0.28
1ft2 of PMMA = 10732 btu/lbm times .28 lbm = BTUs	3005.00
specific hrr for oil = 135 BTU/s-ft2	135.00
ASSUMED	
Ceiling Height = ****	0.00
Effective Room Area = ****	0.00
VIRTUAL SURFACE OF THE FIRE = ****	0.00
DAMAGE TEMP = (For cable use 700, for TSI use 1000) ****	700.00
IGNITION TEMP = (For cable use 932, for TSI use 1000) ****	932.00
Qnet/V (found in Table 7E of FIVE) ****	7.44
HRR of the exposure fire (BTUs/sec) = ****	0.00
DURATION of the exposre fire (minutes) = ****	0.00
Qexp = Heat released by the exposure fire(BTUs) = ****	0.00
Cable Tray fill (40% is normal. Enter value) = ****	0%
LGTHb = Length of cable tray burned (in feet) = ****	0.00
TRAY WIDTH (in inches) = ****	0.00
Ap = Area (ft2) of TSI panel ignited = ****	0.00
Lc = Length of IC covered conduit ignited (ft) = **	0.00
Conduit of interest has an outside diameter (including wrap) = ****	0.00

CALCULATION OF TIME TO DAMAGE/IGNITION BY HGL	**FORM H**
PLANT CR-3 COMPARTMENT CC-108-108	
IGNITION SOURCE	
Ax = Area of the plexiglass ignited = ft2 ****	0.00
If a TRASHBAG is involved enter the number of bags, if not, enter 0 ****	0.00
Amount of oil spilled (UNCONFINED) gals ****	0.00
Amount of oil spilled (CONFINED) gals ****	0.00
Area of the spill (if UNCONFINED) ft2 ****	0.00
Area of the spill (If CONFINED input the basin area) ****	0.00
Amount of oil not allowed to burn (captured in collection system, floor drains, etc.) ****	0.00
CALCULATION	
"Z" Height =	0.00
HRRtc = hrric*Lc*3.14*diameter/12	0.00
HRRtp = hrric*Ap	0.00
HRRct = hrrct (area of cable tray burned)(%FILL/40)	0.00
HRRx = hrrx*Ax	0.00
HRRo = 135 BTU/s-ft2 * (area of confined + unconfined spill)	0.00
HRRtot = TOTAL INITIAL HRR (DO NOT Assume any delays in source ignition) =	0.00
Qo = specific heat of combustion * gals of spill	0.00
Qg = hrrg*900sec	0.00
Qnet = (Qnet/V)(V) =	0.00
Qcrit = Qnet/(1-XL) =	0.00
Qic = TOTAL heat input from INSTALLED INTERVENING COMBUSTIBLES	0.00
Qtot = Qexp + Qic + Qg + Qo	0.00
Qtot > Qcrit HGL COULD DEVELOP. If "FALSE" ignore all further calculations	FALSE
HGL COULD DEVELOP WITHIN THE burn duration of the exposure fire.	#DIV/0!
If "FALSE" , "TIME TO DAMAGE" (TTD) is calculated below. If "TRUE", then TTD =	#DIV/0!
If the last statement is "FALSE" then "TIME TO DAMAGE " = minutes	#DIV/0!

Appendix H

Electrical Cabinet Fires - Effect on Adjacent Cabinets

(from EPRI Fire Risk Implementation Guide)

Fire models were not designed to be applicable to all types of fires propagation and damage scenarios. A particularly important scenario that fits this category is the effect of an electrical cabinet fire on adjacent cabinets. However, the Sandia electrical cabinet fire tests offer some insights. In this Appendix, these fire tests are evaluated and specific guidelines are suggested for their evaluation to fire PRA.

Note: This Appendix applies to vertical cabinets only.

H.1 Fire Propagation to Adjacent Cabinets

Fires may either damage adjacent cabinets or, possibly, propagate to adjacent cabinets. With regard to fire propagation some limited, but important insights can be drawn from the fire tests:

1. Fire spread to an adjacent cabinet was prevented if the cabinets were separated by a double wall with an air gap.
2. Fire spread was delayed by 15 minutes, even when there was no internal barrier between the cabinets.

In case 2, the cabinet design was such that hot gases collected in a plenum area at the top of the cabinet. A hot gas layer formed and contributed to ignition of cable in the second cabinet. Diagonal cable bundle also appeared to contribute to fire spread. That is, a cable bundle ignited low in the initial cabinet and climbed slowly until it reached the adjacent cabinet.

Based on these results, the implementation guidance for fire PRA is:

- Assume no fire spread if either:
    1. Cabinets are separated by a double wall with an air gap, or
    2. Either the exposed or exposing cabinet has an open top, ***and*** there is an internal wall, possibly with some openings, ***and*** there is no diagonal cable run between the exposing and exposed cabinet.
- If fire spread cannot be ruled out, assume that no significant heat release occurs from the adjacent cabinet for 15 minutes.

There may also be other conditions for which the fire protection engineer is aware of applicable tests, analytical results, or other insights. Engineering judgment should be applied to consider other configurations not favorable for propagation.

H.2 Damage to Adjacent Cabinets

The fire test data also provide insights regarding damage to components or cables in adjacent cabinets. The test results implied that damage could only be prevented by a double wall and an air gap. Even these cases were not definitive with regard to sensitive electronics.

Tests did indicate the following results for the adjacent cabinet:

- no electrical shorts, and
- switches and meters functioned.

Because other tests (NUREG/CR-4356) showed that relays had about the same damage criteria as switches and meters, relays should function in adjacent cabinets.

However, temperatures in some cases did appear to exceed limits for sensitive electronic equipment. Specifically, for a vertical cabinet with unqualified cable, the peak temperature in the adjacent cabinet was 180 degrees F, slightly higher than the 150 degrees F damage criteria for sensitive electronics reported in Appendix G.

The time to reach this temperature was delayed somewhat. The test enclosure and the adjacent cabinet temperatures peaked at least 5 minutes after the high heat release rate occurred in the exposing cabinet. The temperature inside the adjacent cabinet further lagged the enclosure by 7 minutes. Consequently, damage to sensitive electronics should not occur for at least ten minutes after high heat release rate.

This conclusion requires two qualifications. The only test for qualified cable showed temperatures lower than the damage criteria and a further delayed peak temperature in the adjacent cabinet. However, the test occurred in a cabinet with the door open. It is not clear whether the door open decreased the effect of the adjacent fire or increased the effect of the enclosure temperature. Nevertheless, based on the test data available, it seems unlikely that no damage would occur to sensitive electronics in the adjacent cabinet if the exposing cabinet contained qualified cable.

Also, if a compartment being modeled was smaller than the test enclosure (xxx ft^3), the enclosure temperature may increase faster than the test case. If fire modeling calculations for the compartment indicate that a hot gas layer temperature of greater than 150 degrees F would occur in less than 5 minutes, this ten minute time may require adjustment downward. For larger compartments experiencing a slower hot gas layer increase, the test data reported seems insufficient to determine the relative influence of the adjacent cabinet wall and the enclosure. Hence, times to damage longer than ten minutes are not recommended unless other data is available.

The following approach is recommended for the fire PRA:

- Assume loss of function in an adjacent cabinet if there is not a double wall with an air gap.

- Assume no damage in the second adjacent cabinet occurs until after the fire propagates to the adjacent cabinet. Assume damage can occur earlier if there are large openings in a wall and plenum areas in which a hot gas layer is likely to form. That is, the two walls of the intervening cabinet can be credited as a double wall with a (large) air gap.

- Assume no damage to an adjacent cabinet if:
  - there is a double wall with an air gap, and
  - there are no sensitive electronics in the adjacent cabinet (or the sensitive electronics have been "qualified" above 180 degrees F).

- Assume damage to sensitive electronics occurs at ten minutes if there is a double wall with an air gap.

- Assume damage to sensitive electronics can be prevented before ten minutes if the fire is extinguished and the cabinet is cooled, e.g., by CO2 extinguishers.

Appendix I

Hot Gas Layer Timing Study

(from EPRI Fire Risk Implementation Guide)

I.1 Overview

If a fire is of sufficient intensity, the hot gas layer temperature may reach cable damage temperature, e.g., 700°F. In this case widespread damage can result, including to separated trays containing cables for safety equipment. Generally, such a scenario requires a stack of cable trays to burn. If such a fire damaged sequence is calculated to be important, the analyst must determine the likelihood of manual suppression.

Fire modeling tools are generally inadequate for such a calculation. That is, when they can perform the calculation, they predict physically unrepresentative times, e.g., COMPBRN IIIe. The FRSS (2) and our own findings from use of COMPBRN IIIe (C3e) indicate that C3e's inability to model transient phenomena results in a rapid increase in burning. Since a cable tray fire reaches peak intensity at time zero, trays propagate up a stack in intervals based on the code timestep. That is, when one tray ignites, it reaches peak intensity at the start of the next time step and ignites the next tray. The process is repeated until the entire tray stack is burning in just a few time steps. The result is, for the recommended one minute time step, fires ignite whole stacks in a few minutes. As will be described below, such behavior is inconsistent with experiment.

Unfortunately, FIVE (3,4) is not even structured to perform such a calculation. Because of this limitation, a model was developed based on a portion of FIVE, i.e., its heat balance calculation. The model uses experimental data to determine fire propagation times in cable tray stacks. The following describes the basic model and its basis, a procedure for implementing it, and a sample calculation for use of the tool to predict damage times.

I.2 Model

The model accounts for fire propagation in a simple, yet conservative fashion. The total area of cable tray shown to burn in fire tests is assumed to burn at the start of a fire scenario (time = 0). This simplified approach eliminates the need to account for time-dependent fire propagation, yet is conservative in that it includes all cables that burn in the scenario. The properties of cable tray fires are described below. The ignition temperature is 932°F, which is consistent for a variety of sources, e.g., (1, 5-8).

The heat release rate for cable fires is 0.45 times the values repeated in Table 1-E of FIVE. If plant specific cable types are not known or not found in the table, the highest value for (qualified or non-qualified) cable should be used. The initial affected area for a horizontal tray is the area (footprint) of the plume, unless the ceiling jet causes a larger region to be above 932°F.The heat content per unit weight for cable should be the value used in the FHA times 0.7, to account for incomplete burning.

For calculating the tray area involved in a fire, assume the following:

In vertical trays, assume propagation from the point of ignition to the tray top. Inclined trays are treated as vertical trays. In horizontal trays, the fire is modeled differently for qualified and non-qualified cable. For qualified cable, assume horizontal spread only when fire spreads from one tray to the next, and then at a 35 degree angle on either side of the vertical according to the description in "A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories 1975-1987" (9). The tested configuration was a 7 x 2 array of cable trays separated per Regulatory Guide. 1.75. Trays with less separation would have tray covers to meet the requirements of R.G. 1.75, and would exhibit substantially less propagation. Trays with any greater separation would exhibit less propagation. A statement of the findings follows: "It was also noted, based on infrared thermography, that the fire grew primarily in an upward direction, spreading horizontally only as it progressed from level to level. The rate of the fire spread was observed to accelerate as the fire progressed. The angle of the horizontal spread from level to level was 35 degree to either side of the vertical. Very little flame spread in any given tray beyond this angle of flame progression was noted." This test provides a realistic yet conservative basis for a horizontal flame spread model for the following reasons:

- The ignition source was approximately 40 Btu/s, which is representative of actual potential fire plant scenarios in which the cables are near the source.
- The cables used in the test were XPE/XPE jacketed. These are one of the more common cable types.
- The purpose of the test was to evaluate cables under exposure fire conditions. Most of the other cable tray tests were created to judge extinguishment methods, so steps were taken to create fully involved fires which unfairly skew the results.
- The SNL test mentioned above clearly states observations regarding the extent of horizontal fire spread, circumventing the need to derive spread rates from secondary test data.

Other testing by EPRI documented in report NP-1881 (10) provides good insight regarding the difficulty involved in igniting IEEE-383 qualified cables. These tests were designed to evaluate extinguishment methods and employed an ignition fire with a heat release rate on the order of 1650 Btu/s for approximately 6.5 minutes in order to ensure a fully developed fire. This size ignition fire, which was placed only 8 inches below the cable trays, is extremely large when compared with common plant ignition sources, such as electrical cabinets (HRR = 65 Btu/s). Fire test numbers 10 through 12 on EPR/Hypalon cables in EPRI NP-1881 show that these cables were very difficult to ignite even with a such robust source. Ignition was only achieved when the cables were loosely arranged in the trays with alternating layers of one-cable, S-shaped rows interspersed, maximizing surface area and air supply (a configuration similar to wood cribbing). An ignition fire of this magnitude and duration tended to volatilize the cables being tested, exaggerating fire propagation.

In addition to explicitly accounting for the burn area as described in the SNL test, this approach employs other conservative simplifying assumptions to account for variations in plant specific configurations:

- Ignited cable trays are assumed to be fully involved at time zero. Tests show a considerable time interval before full development is reached, especially for IEEE-383 qualified cables. Even the extremely severe tests 10-12 in the EPRI NP-1881 report indicate that it takes cable tray fires at least 10 minutes to become fully developed.

- 70% of the cable insulation is assumed to burn. NUREG/CR-4566 (11) reports that 50%-70% of the cable insulation will burn, while EPRI NP-1881 reports fractions less than 50%.
- The full footprint of the source is considered to burn in the lowest cable tray, even for sources with only small openings, e. g. cabinets.
- Self sustaining ignition is always assumed, even though data shows that cable fires are difficult to ignite.

For non-qualified cable, propagation should be allowed beyond that calculated for qualified cable. Spread rates of 10 linear feet per hour should be used based on EPRI NP-7332 (12).

I.3 Procedure for Determining Whether a 700°F Hot Gas Layer Can Be Caused by a Cable Tray Fire and/or an Ignition Source

1. Calculate heat content from the ignition source (Btu's) based on plant specific data and Appendix E.

2. Calculate the area (ft^2) in which the hot gas layer (HGL) can be confined.

   This area is typically the floor area of the compartment. (NOTE: Walkdown ignition source screening form contains the floor area of the compartment.) In some cases, the HGL may be confined to a region less than the full area of the compartment. A hot gas layer should be assumed to be confined by any substantially enclosed barrier. The barrier need not be rated. If small openings in the barrier exist, the most conservative interpretation for the range of scenarios should be selected.

   The barrier need only be "enclosed" for the region of a room that is between the ceiling and virtual surface of the fire. For example, a fire with a virtual surface above the floor (e.g., cable tray or electric cabinet), that is above an open doorway can generate an HGL in a confined space above the doorway. In this case, the corresponding area of the confined space should be used instead of the compartment floor area.

3. Determine if ignition of cables is possible.

   Consider ignition for exposed cables (e.g., in trays (not conduits) directly above the source or within the ceiling jet). If ignition of cables is not possible, skip Step 4 and assume no heat content from cables.

4. Obtain the total heat content (Btu's) from ignited cable as follows:

   - Determine the footprint of the ignition source by estimating the floor area of the ignition source. For oil, estimate oil spread based on guidance provided in Table 3 of FIVE, but limit the spread as appropriate if berms, drip pans, drains or other plant features will confine the oil spread.

   - Determine the length of cable tray intersected by the floor area of the ignition source (footprint) projected upward onto the cable tray. The full length of any vertical or diagonal runs of cable tray within the footprint should be included in the length. If a diagonal cable tray lies only partially within the projected area, include the entire diagonal length of the tray.

   - If additional cable trays are located above the tray directly above the ignition source, their contribution must be included. The footprint of the cable tray should be projected upward through each tray. The footprint of the lowest tray is determined by assuming the full width of the tray is involved (even if the ignition source footprint only partially intersects the tray). The footprint of higher trays is determined by projecting the footprint upward, but assuming the length of the footprint increases on each end. The increase in length (on each end) is obtained by projecting a 35° angle off the vertical, intersecting with the next highest tray. In general, the increase in length will be 2 * 0.7 * h, where h is the distance between cable trays and 0.7 is the tangent of 35°. (If varying width trays are involved, again assume the full width of each tray is involved. Also, the full length of any vertical or diagonal trays within the projected area should be included.)

     The above process should be repeated for each tray in a stack until the total area of the involved trays is determined. (See figure attached).

   - Obtain the total Btu's by multiplying the area of involved tray by a total heat release of 128,856 Btu/ft^2.

5. Add total Btu's from Steps 1 and 4.

6. Determine the depth of the hot gas layer based on the virtual surface of the cable fire.

   - For floor-based fires (e.g., transients and pump oil fires) that do not ignite cable trays, assume the depth of the HGL is the ceiling height.

   - For other fires (e.g., electrical cabinets) that do not ignite cable trays, assume the depth of the HGL is the distance from the top of the ignition source to the ceiling.

- For fires that ignite cable trays, assume the depth of the HGL is the distance from the lowest cable tray to the ceiling.

7. Use the FIVE fire modeling tools (1) to determine the heat (Btu) required to form hot gas layer to determine whether a hot gas layer of 700° can form.

    - For the floor area from Step 2 and the depth of hot gas layer from Step 6, determine the critical combustible load for HGL formation.

    - If the total Btu's from Step 6 are larger than the critical combustible load for HGL formation, assume an HGL of 700°F can form within the depth of the HGL.

8. Check critical targets outside the hot gas layer formed by the cable tray fire.

    - If a critical target is below the lowest cable tray (but above the virtual surface of the exposure fire, e.g., top of the electrical cabinet), and Step 7 predicts sufficient combustibles are available, repeat Steps 6 & 7 assuming the depth of the hot gas layer is equal to the distance from the virtual surface of the fire to the ceiling. If a 700°F HGL can form for this depth, assume the critical target is damaged.

9. If a 700°F HGL can form, the time-to-damage can be conservatively estimated by the following process:

    - Obtain the total Btu's required from the FIVE fire modeling tool.

    - Obtain a conservative heat release rate by summing the ignition source heat release rate (from Step 1) and the cable heat release rate.

      The cable heat release rate is 19 Btu/sec/ft^2 times the area of cable tray involved (from Step 4).

    - Divide the heat release into the total Btu's to determine the minimum time to form a 700°F HGL. (NOTE: This is not a fire duration.)

A more realistic time to damage can be determined for cases involving IEEE-383 qualified cables in trays by performing the HGL timing evaluation described in the next section.

I.4 Hot Gas Layer Timing Evaluation

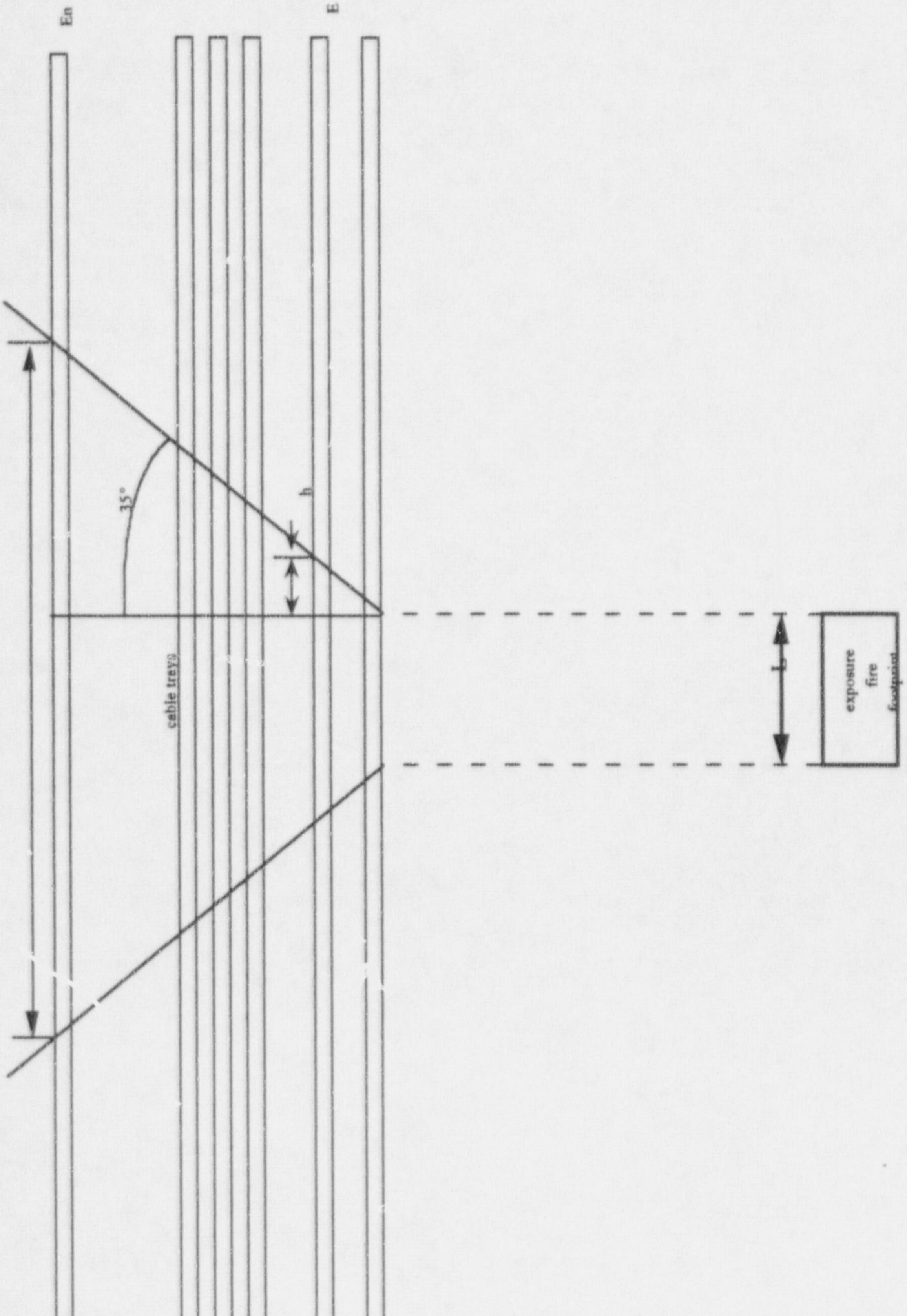
The hot gas layer timing model was developed in lieu of COMPBRN IIIE. It reflects less conservative results, uses more generic data, and incorporates experimental results and findings. The hot gas layer timing study estimates the time required for a specific scenario to reach critical damage temperatures. Time to damage depends on room volume and the amount of cable tray involved. Calculation of manual suppression probability depends on the results of the hot gas layer timing study. The assumptions employed in the development of the model, the data requirements, and a selected sample problem are described below. Figures I-1 and I-2 depict selected model input and results..

Model Description. The key assumptions/characteristics of this model are:

- Heat release rates at each stages are assumed to reach their peak value instantaneously.
- Feedback from the cable tray fire to the exposure fire is ignored in this model. Feedback would intensify the exposure fire, resulting in a higher heat release rate and shorter duration. This is non-conservative but is compensated for by conservatism in the first assumption.
- Fire in a cable tray stack grows primarily in an upward direction, spreading horizontally only as it progresses from level to level. The angle of horizontal spread from level to level is assumed to be 35° to either side of the vertical (NUREG/CR-5384 (6).
- Assume that the mass burnout occurs when 30% of the fuel is remaining (e.g., 30% of the fuel mass remains as char after the fire burns out). (NUREG/CR-4566, p. 47 (8).
- The timing study was based on the experimental data from NUREG/CR-5384 (pp. 33-40). Ignition data is available for the first four trays. Subsequent trays are assumed to ignite during the same interval as the fourth tray.

Model Input. User inputs to the model are as follows:

- Physical characteristics of the zone or compartment
  - dimensions of the room
  - height from the first tray to the ceiling
  - fire location factor
  - estimated heat loss fraction
  - total number of trays
  - elevation of each tray
  - unit heat release rate per length of cable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footprint

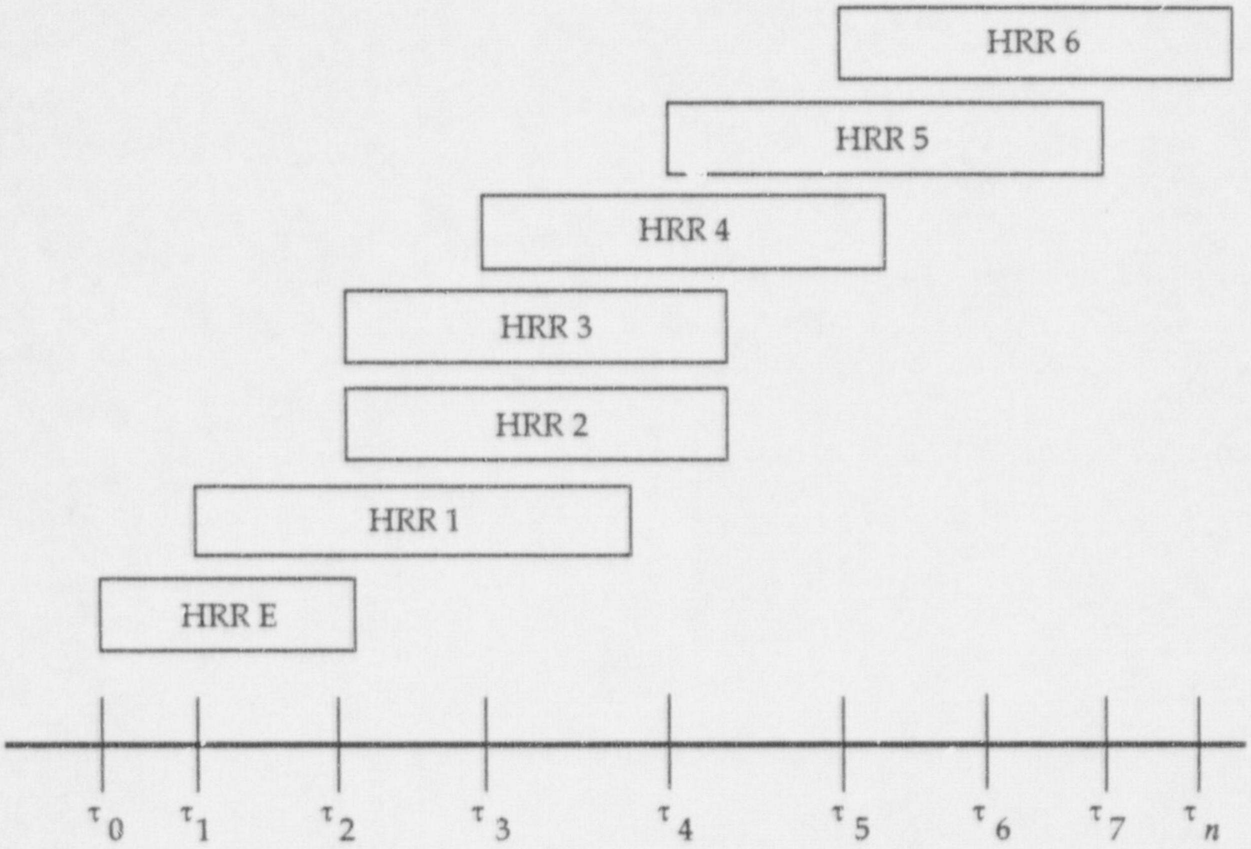

Figure I-2. Hot Gas Layer Timing Study Timeline

Model Output. The model, which was developed in EXCEL 4.0, calculates the following:

- Supporting information
  - critical temperature difference
  - net energy addition to achieve damage temperature
  - total heat contribution of each cable tray
  - estimation of cable tray heat release rate per cable tray
- Final scenario result
  - critical total energy release
  - calculation of the fire spread through the cable trays
  - estimation of the time to damage for the system

Sample problems for hot gas layer timing evaluation. The following summarizes the inputs and calculations performed in a sample problem using the hot gas layer timing study model.

GENERIC ROOM

Floor Area (user input)	$A_s = 9888\ f^2$
Height from Fire Source to Ceiling (user input)	$h = 10$ ft
Height from Virtual Plane of the Fire to Ceiling (user input)	$z = 10$ ft
Ambient Temperature (user input)	$T_{ambient} = 100°F$
Target Damage Threshold Temperature	$T_{damage} = 700°F$
Critical Damage Temperature	$\Delta T = T_{damage} - T_{ambient}$ $\Delta T = 600°F$

Net energy addition per unit volume to achieve critical damage temperature rise is calculated using the equation found in the FIVE methodology (p. 10.4-14) (3).

Net energy	$Q_{net} = V * 9.54 * 1n (\Delta T(k)/ T_{ambient} + 1)$ or $Q_{net} = 765{,}271.75$ Btu
where	V = volume of the room k denotes temperature in absolute scale
Heat Loss Factor (user input)	$X_L = 0.85$
Critical Total Energy Release	Qcrit = Qnet/(1-XL) Qcrit = 5,101,811.69 Btu
Peak Fire Intensity (user input)	Qpeak = q * As Qpeak = 380 Btu/sec

Fire Location Factor (user input)	ff = 1 for fires located in the open ff = 2 for fires located against wall ff = 4 for fires located in corners
Fire Location Factor (user input)	ff = 1 in this problem
Effective Heat Release Rates	Qeff = ff * Qpeak = Qeff = 380 Btu/sec
Total number of trays (user input)	n = 6
Elevation of each tray above virtual plane of fire (user input)	$E_1, E_2, E_3, \ldots, E_n$
Elevation of Each Tray in Sample Problem (user input)	16, 17.17, 18.50, 19.83, 21.00, 22.17
Exposure Fire Footprint at Floor Level (user input)	L = 3.0 ft
Length of tray involved in fire due to horizontal flame spread (B_n)	$B_1 = L$ $B_n = B_{n-1} + 2(h_{n-1} * \tan \Theta)$, n = 2, 3, 4...
where (see Figure K-1)	Θ = angle of upward fire propagation $h_{n-1} = E_n - E_{n-1}$ B_{1-6} = 2.5, 4.14, 6.0, 7.86, 9.5, 11.90

Using the experimental value of heat content per pound of cable tray, calculate the heat content per foot-length of cable tray.

Heat content of cable trays (user input)	h_c = 13806 Btu/lb
Mass of combustibles in a typical 18"-wide cable tray	C_m = 20 lb/ft (estimated)
Heat content per inch-width per foot-length of cable tray	$H_c = h_c * C_m * (l/18)$
where	l is the width (in inches) of cable tray l = 24 inches for the example scenario

This experiment value includes an adjustment for a combustion efficiency of 70% (user input.

The heat content per linear foot of cable tray	$H_c = h_c * C_m * (l/18) * 0.7$ or H_c = 257,712 Btu/ft
The heat contributed by the cable trays	$Q_n = H_c * B_n$

The heat contributed by the cable trays

$Q_1 = 773{,}136$ Btu
$Q_2 = 1{,}195{,}268$ Btu
$Q_3 = 1{,}675{,}128$ Btu
$Q_4 = 2{,}154{,}988$ Btu
$Q_5 = 2{,}577{,}120$ Btu
$Q_6 = 2{,}000{,}252$ Btu

Heat release rate for each cable tray (value of heat flux for qualified cable)

$q = 41.85$ Btu/ft^2/sec

Values of the heat release rate for various types of cables may be obtained from the FIVE methodology, Table 1E.

Heat release rates for cable tray

$HRR_n = q * Sa_n$ Btu/sec

where

$SA_n = B_n * 1$ ft^2

$SA_n = 6, 9.28, 13, 16.72, 20, 23.28$ ft^2

Values of heat release rates for sample problem

$HRR_{1\text{-}6} = 167.4, 260.0, 376.7, 493.4, 596.4$ and 747.0 (Btu/sec)

From experiment, time steps from t_0 t_5 are known (see Figure I-2). Subsequent time steps are taken at regular intervals (user-specified) until convergence.

Experiment Time Steps

$\tau_0 = \tau_1 = 0$ sec
$\tau_2 = 5$ min $= 300$ sec
$\tau_3 = 10$ min $= 600$ sec
$\tau_4 = 15$ min $= 900$ sec
$\tau_5 = 18$ min $= 1080$ sec
$\tau_6 = 22$ min $= 1320$ sec

Also, experimental observations indicated that trays two and three became involved in the fire together; therefore the heat release rates of the two trays were summed and analyzed at the τ_2 time step.

Energy of exposure fire (user input)

$Q_{exposure} = 93{,}000$ Btu

Taking into account the combustion frequency	$Q^{adj.}_{exposure} = 65,100$ Btu

Simulation of the scenario is achieved by summing the amount of heat contributed at each step of the timing study by adding the appropriate contributions of energy from each tray at each corresponding time step. At the same time, deduct the available amount of heat remaining in each tray with each time step. When a tray has exhausted its available fuel, discontinue summing its contribution in the overall study. Tally the accumulation of heat at each step. When the contributions of heat released in the room nears the critical total energy value, Q_{crit} , the time for emitting the remainder of heat to the scenario is interpolated using the following method:

Difference between Q_{tot} of last time step and Q_{crit}	$\Delta Q = Q_{crit} - Q_{tot}$
Sum of all the contributing heat sources	$HRR_{tot} = S\ HRR_i$
Time required to accumulate DQ	$\Delta\tau = \Delta Q/HRR_{tot}$

The necessary time to achieve the critical energy content in the scenario is:

Total time required to reach Q_{crit}	$\tau_{crit} = S\ t_i + \Delta\tau$
	$\tau_{crit} = 36.06$ min

I.5 References

1. *COMPBRN IIIE: An Interactive Computer Code for Fire Risk Analysis* , University of California, Los Angeles, EPRI NP-7282, Research Project 3000-39, May 1991.

2. J. A. Lambright, S.P. Nowlen, V. F. Nicolette, and M. P. Bohn, *Fire Risk Scoping Study: Current Perception of Unaddressed Fire Risk Issues,* U. S. Government Printing Office, NUREG/CR-5088, Sandia national Laboratories, Albuquerque, NM, SAND88-0177, December 1988.

3. *Fire -Induce Vulnerability Evaluation (FIVE) Methodology Plant Screening Guide*, Professional Loss Control, EPRI TR-100370, April 1992.

4. *Methods of Quantitative Fire Hazard Analysis* , Frederick W. Mowrer, EPRI TR-100443 Research Project 3000-37, May 1992.

5. *Fire Protection Handbook,* Sixteenth Edition, NFPA, March 1986.

6. D. K. Beller, et al., *Fire Risk Assessment Technology Studies,* Factory Mutual Research Corporation, NSAC-192 (to be published).

7. *Recommended Procedures for the Simplified External Event Risk Analyses for NUREG-* Albuquerque, New Mexico: NUREG/CR-4840, Sandia National Laboratories, September 1989.

8. *Peach Bottom 2 External Events Analysis,* , Albuquerque, New Mexico: NUREG/CR-4550, Sandia National Laboratories, SAND86-2084, December 1990.

9. S. P. Nowlen, *A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories, 1975 - 1987,* Albuquerque, New Mexico: U.S. Government Printing Office, NUREG/CR-5384, Sandia National Laboratories, SAND89-1359, December 1989.

10. *Categorization of Cable Flammability,* Immediate-Scale Fire Test of Cable Tray Installations, EPRI NP-1881, Research Project 1165-1, August 1982.

11. V. Ho, N. Siu and G. Apostolakis, *COMPBRN III - A Computer Code for Modeling Compartment Fires,,* NUREG/CR-4566, U.S. Nuclear Regulatory Commission, November 1985.

12. *Design Guide for Fire Protection of Grouped Electrical Cables,* EPRI NP-7332, ResearchProject 2969-4, May 1991

Appendix J

Protective Features - Coatings and Barriers

(from EPRI Fire Risk Implementation Guide)

Passive protective features can prevent or delay fire damage; however, the available experimental data is limited. Predictive tools like COMPBRN III are difficult to use and sometimes inapplicable. However, data from the Sandia fire test program does offer some insights regarding time to ignition and time to damage.

J.1 COATINGS

Sandia performed tests to evaluate the effects of cable coatings in:

- reducing the flammability of cable material;
- preventing or delaying the spread of fire; and
- preventing fire-induced cable failures.

Thirty-three full-scale tests were performed using trays loaded with either qualified or non-qualified cables. The cable tray configurations included both a single cable tray and two-tray stack. Exposure fires included either a gas burner or a diesel fuel liquid pool fire.

Five coatings were evaluated; however, because the names of manufacturers were withheld, use of the data is limited. Flammability was evaluated by measuring time to ignition, time to maximum heat release rate, and cumulative heat release at various times after initiation of the exposure fire.

The diesel fuel pool fire was selected for use by the EPRI fire PRA. The diesel fuel pool exposure fire was more intense, and therefore, conservative. More importantly, aspects of the gas burner tests were less representative to conditions typical of the most likely ignition sources. A barrier was placed between the two trays during the gas burner test, thereby preventing exposure of both trays.

The gas burner operated five minutes 'on' and five minutes 'off,' whereas the diesel fuel pool fire burned continuously for approximately 13 minutes. Consequently, the diesel fuel fire tests are indicative of the actual response of a coated two-tray stack to a relatively severe exposure fire that bounds the heat release rate for most ignition sources found in an area containing important cables. The results of those tests are presented in Table J-1.

For application in the EPRI Fire method, assume coated, non-qualified cables will not ignite for at least 12 minutes, and coated, non-qualified cables will not be damaged for at least 3 minutes for large exposure fires and for cable tray fires, more likely about 10 minutes.

Table J-1
Summary of Principal Two-Tray Diesel Fuel Fire Cable Fire Retardant Coatings Tests Involving Non-Rated 3-Conductor Cables

Coating	Time to Ignition (min)	Time to Damage (min)
Lower Tray Response:		
A	13	10
B	13	6
C	12	3
E	No	10
G	12	11
Upper Tray Response		
A	No	11
B	No	11
C	12	7
E	No	19
G	12	11

J.2 BARRIERS

Cable tray fire barrier tests were also performed by Sandia. Thirteen tests were conducted in a manner identical to that used in the single tray and two-tray gas burner cable coating tests. The same cable types and the same gas burner exposure fire sources were used. Five potential fire barrier systems were tested:

1. Ceramic wool blanket wrap,
2. Solid tray bottom covers,
3. Solid tray top cover with no vents,
4. Solid tray bottom cover with vented top cover, and
5. One-inch insulating barrier between cable trays.

The barrier test findings are as follows. Propagation of the fire to the second tray was prevented in each case. That is, each barrier prevented ignition of a cable tray when exposed to a cable tray fire in a lower tray. Barriers seem to substantially delay cable damage for qualified cable. However, the barriers did not delay cable damage for non-qualified cable. For application to the EPRI Fire PRA, the barrier test findings are considered most appropriate to exposure fires with smaller heat release rates and to cable trays in a stack that are threatened by fires in lower trays. In these cases, each barrier prevents cable tray ignition until well after the fire brigade reaches the scene (i.e., greater than 20 minutes), and damage in <u>qualified</u> cable with solid tray bottom covers until well after the fire brigade reaches the scene.