ENCLOSURE

TENNESSEE VALLEY AUTHORITY
BROWNS FERRY NUCLEAR PLANT (BFN)
UNITS 1, 2, AND 3

# RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION REGARDING BROWNS FERRY NUCLEAR PLANT INDIVIDUAL PLANT EXAMINATION FOR EXTERNAL EVENTS

(Report Attached)

9812080124

# RESPONSE TO

# REQUEST FOR ADDITIONAL INFORMATION

# ON

# INDIVIDUAL PLANT
# EXAMINATION FOR EXTERNAL EVENTS

- Seismic
- Fire
- High Winds, Floods, and Other External Events

NOVEMBER 1998
Revision 0

BROWNS FERRY NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY

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## SEISMIC QUESTIONS



**NOTE: The calculations contained in this report are current as of the submittal date. Future revisions as may be required will be available for review on-site.**

## SEISMIC QUESTIONS

### SEISMIC QUESTION 1 - SAFE SHUTDOWN EQUIPMENT LIST

*System analysis for the development of the safe shutdown equipment list (SSEL) is discussed in Section 3 of the Seismic IPEEE [Internal Plant Examination for External Event] Report and Section 4 of the USI A-46 Seismic Evaluation Report of the submittal. It is noted that only low pressure injection systems are selected in the Browns Ferry Nuclear plant IPEEE; high pressure injection systems (i.e., reactor core isolation cooling (RCIC) and high-pressure coolant injection (HPCI) are not included in the SSEL.*

*For success path and system selection, Electric Power Research Institute (ERPI) NP-6041-SL states this: "In general, the selected path for performing the safety functions to shut down the reactor will be the one consisting of the front line systems (and their necessary support systems) that were provided as a 'first line of defense,' and designed to respond automatically (at least in the short time during and after the SME [seismic margin earthquake] to the types of transients and/or accidents that might be induced by a margin earthquake." Based on this criterion, the high pressure injection systems i.e., (HPCI and RCIC) seem to provide a better choice for coolant injection. However, high pressure injection systems are not included in the Browns Ferry SSEL, and low pressure systems (i.e., core spray and low pressure coolant injection) are used for the success paths for inventory control. Manual reactor coolant system depressurization is therefore required for both paths, and consequently, the demands on the depressurization system and operator actions are more significant.*

a. Please provide the basis for not including any high pressure injection system in the SSEL (other than the reason given in the submittal that they are only moderately reliable based on industry experience). Please address the EPRI NP-6041-SL criterion on system selection, quoted above, in your discussion.

b. Based on plant procedures, please provided a detailed description of expected operator actions following a seismic margin earthquake (SME). Please describe in more detail the operator actions and their failure probabilities under SME conditions for reactor coolant system depressurization and decay heat removal.

c. Please describe the major equipment included in the Browns Ferry high pressure systems, and describe any known or suspected weal links in the systems under SME conditions.

### Response to Question 1

[Later]

## SEISMIC QUESTION 2 - NONSEISMIC FAILURES AND HUMAN ACTIONS

*Nonseismic failures and human actions are not specifically addressed in the submittal. The only statement made in the submittal related to these issues is this: "The SPLDs [success path logic diagrams] were reviewed and agreed upon by Browns Ferry Operations personnel." Both nonsesimic failures and human actions are especially important at Browns Ferry because of the reliance of the success path on a single-train system(or a single loop of a system) and the lack of automatic systems in the success path for coolant injection and decay heat removal.*

*Regarding nonseismic failures and human actions, NUREG-1407 states that "Success paths are chosen based on a screening criterion applied to nonseismic failures and needed human actions. It is important that the failure modes and human actions are clearly identified and have low enough probabilities to not affect the seismic margins evaluation."*

*Please describe how nonseismic failures and human actions were treated in the analysis and address the concerns of the above quoted statement from NUREG-1407.*

### Response to Question 2

[Later]

## SEISMIC QUESTION 3 - EXTERNAL FLOODING

*Seismic induced fire/floods are briefly discussed in Section 8 of the Seismic IPEEE Report. For seismic-induced floods, it is simply stated that the probability of plant and equipment flooding associated with rupture of fire protection systems has been previously addressed by Tennessee Valley Authority. No references are provided in the submittal on the source of this information. Furthermore, only flooding associated with the fire protection system is mentioned in the submittal. This does not seem to be consistent with NUREG-1407 which states that the effects of seismically induced external flooding due to a failure of upstream dams and flooding due to failure of tanks have not been addressed. Please provide a discussion on this issue consistent with the statement in NUREG-1407.*

### Response to Question 3

[Later]

## SEISMIC QUESTION 4 - QUANTITATIVE RLE INFORMATION

*No quantitative information is provided in the submittal pertaining to the development of the review-level-earthquake (RLE) in-structure response spectra and comparison to the design basis earthquake (DBE) in-structure response spectra. It appears that this detailed information is contained in Reference 9 to the submittal. Please submit Reference 9, so that our review of the seismic input can be completed.*

Response to Question 4

A copy of calculation CD-Q0000-940339 R1, "Calculation of Basic Parameters for A46 and Individual Plant Examination of External Events (IPEEE) Seismic Program," is provided in Attachment 6.

## SEISMIC QUESTION 5 - HCLPF EVALUATIONS

*Section 6 of the submittal discusses 22 bounding calculations for high-confidence-of-low-probability-of-failure (HCPLF) evaluations. Please provide references for these calculations, and also submit the calculation for the transformers which have an estimated HCLPF capacity of 0.26g.*

Response to Question 5

The bounding calculations for high-confidence-of-low-probability-of-failure (HCLPF) evaluations are contained in calculations *50147-C-003 R0, -004 R0, -005 R0, and -011 R*1. The requested calculation references are provided in Attachment 7. The calculations for the transformers which have an estimated HCPLF capacity of 0.26g are documented on calculation 50147-C-011 R1. This calculation is enclosed as Attachment 8. The HCPLF calculation appears on pages 18 and 19 of the calculation.

## SEISMIC QUESTION 6 - MASONRY WALLS

*Section 5.9.1 of the submittal discusses masonry walls. Three reinforced walls are identified as having an estimated HCPLF capacity of 0.27g. Please submit the calculation for these walls and also provide additional description of the assessment of their failure mode and potential interaction with SSEL equipment.*

Response to Question 6

The calculation for these walls is contained in calculation 50147-C-012 R1, which is enclosed as Attachment 9. The requested information is found on pages 18-20.

The evaluation of the failure mode of the subject block walls and their potential interaction with SSEL equipment appears on pages 18, 19, 20, and 23 of calculation 50147-C-012 R1. The following SSEL equipment is in the vicinity of the subject block walls.

| | |
|---|---|
| Panel 2-9-9 | SSEL No. 9045 |
| Panel 3-9-54 | SSEL No. 39133 |
| Panel 3-9-55 | SSEL No. 39134 |

The calculation discloses that this equipment is approximately 5-7 feet from the block walls. The mode of failure of the propped cantilever walls is the result of the formation of plastic hinges in their span which would cause only some spalling of the surface of the walls. Therefore, there is no interaction between the block walls and SSEL equipment.

SEISMIC QUESTION 7 - SCREENING OF THE REINFORCED CONCRETE CHIMNEY

*Section 5.5.4 of the submittal discusses the reinforced concrete chimney which stands 600 feet high. Please clarify the basis for screening the chimney for the 0.3g RLE. If this is based on a calculation of HCPLF capacity, please submit the calculation.*

Response to Question 7

[Later]

**FIRE QUESTIONS**

FIRE QUESTION 1 - CONSIDERATION OF HOT SHORTS AND SPURIOUS ACTUATIONS IN THE IPEEE ANALYSIS

*From the submittals it cannot be determined that the licensee has considered hot shorts and spurious actuations as a failure mode for control or instrumentation cables. In particular, considerations should include the treatment of conductor-to conductor shorts within a given cable. Hot shorts in control cables can simulate the closing of control switches leading, for example, to the repositioning of valves, spurious operation of motors and pumps, or the shutdown of operating equipment. These types of faults might, for example, lead to a loss-of coolant accident (LOCA), diversion of flow within various plant systems, deadheading and failure of important pumps, premature or undesirable switching of pump suction sources, undesirable equipment operations, and unrecoverable damage to motor operated valves. For main control room (MCR) abandonment scenarios, such spurious operations and actions may not be indicated at the remote shutdown panel(s), may not be directly recoverable from remote shutdown locations, or may lead to the loss of remote shutdown capability (e.g. through loss of shutdown panel power sources). In instrumentation circuits, hot shorts may cause misleading plant readings potentially leading to inappropriate control actions or generation of actuation signals for emergency safeguard features.*

*Please discuss to what extent these issues have been considered in the IPEEE. Of particular interest are potential vulnerabilities of the automatic depressurization, HPCI, and RCIC systems to spurious actuation signals. If they have not been considered, please provide an assessment of how inclusion of potential hot shorts and spurious actuations would impact the quantification of fire core damage scenarios in the IPEEE.*

Response to Question 1

Hot shorts and spurious actuations have not specifically been considered in the analyses. Fires were assumed to occur at specific locations or compartments resulting in either an engulfing fire (initial screening) causing damage to all power and control cables and components in the area or the fire damage is confined within a zone of influence (detailed screening) based on the fire size. A damage to cables translates to incapacitation of the associated equipment (i.e. core injection pumps, HVAC systems to vital areas, etc.). The plant PSA model is modified accordingly and the core melt frequency is calculated based on specific initiating events likely to

have occurred due to the fire. The methodology is focused on the effects of fires on control and power cables and determines the impact of their failure to operate (i.e. functional failure) but not their spurious operation. Also recovery from fire related damage was specifically not considered. For example, those scenarios that could impact the operability of a 480VAC board for which the plant risk model allows recovery (i.e. top event R480), this top event was set to disallow recovery of the affected board. In summary the BFN IPEEE-Fire methodology is typical of how fire risk analysis is performed in nuclear plants.

While the potential exists for other than functional failures, in most cases these form of failures would not be detrimental to safe plant shutdown. Following are some examples:

- ADS Accumulators (MSRV air supply) - The accumulators are mechanical devices located inside the inert drywell. They would not experience spurious actuations during a fire.
- ADS/MSRV - Spurious operation of one MSRV can be mitigated by a minimum set of safe shutdown equipment, e.g. one RHR pump, one RHRSW pump, two EECW pumps, etc. The minimum set is likely to be available from the diverse set of equipment in the plant. .
- MSIV - The valves are of fail safe design and will thus close when the circuits are subjected to the affects of fire.
- HPCI - Spurious operation of HPCI is mitigated by operator action in the control room if high water trip does not occur automatically.
- RCIC/CRD - spurious operation of these system is not a concern because of their relatively low flow. Plant procedures allow adequate time to prevent water intrusion into the main steam lines.

It should be noted that only a fraction of fires that occur will be in the appropriate location and only fraction of these fires will have the appropriate severity to cause damage. The BFN methodology assumes a fully developed fire with peak heat release rates at the inception of fire for most locations and does not apply the probability factors. However, when circuit faults are considered (i.e. conductor to conductor shorts within the same cable, cable to cable shorts, etc.), the probabilities of these occurrences have to be considered. Currently, circuit faults cannot be adequately modeled due to lack of accrued experience and availability of quantitative PRA methods. It is recognized that these circuit faults can occur in a fire situation and cause spurious actuations, their probability of occurring is assumed to be very low.

The ability to recover from fire-related impacts in the Main Control Room was within the design intent of the remote shutdown capability effort. While "hot short" or instrumentation impacts could occur prior to the enablement of the remote shutdown capability, they are considered to the extent as described in response to Question 6.

## FIRE QUESTION 2 - CONTROL ROOM EVACUATION SCENARIO

*Fires in the MCR are potentially risk-significant because they can cause instrumentation and control failures (e.g., loss of signals or spurious signals) for multiple redundant divisions, and because they can force control room abandonment. Although data from two experiments concerning the timing of smoke induced, forced control room abandonment are available [2.1], the data must be carefully interpreted, and the analysis must properly consider the differences in configuration between the experiments and the actual control room being evaluated for fire risk. In particular, the experimental configuration included placement of smoke detectors inside the cabinet in which the fire originated. as well as an open cabinet door for that cabinet. In one*

*case, failure to account for these configuration differences led to more than an order of magnitude underestimate in the conditional probability of forced control room fire abandonment [2.2]. In addition, another study raises questions about control room habitability due to room air temperature concerns [2.3]. The submittals appear to assume a control room abandonment probability based on the manual non-suppression probability of 3.4 x $10^{-3}$. This value is traceable to NSAC/181, the work reviewed in Reference 2.2.*

*Please provide the detailed assumptions (including the assumed fire frequency, any frequency reduction factor, and the probability of abandonment) used in analyzing the MCR and justifications for these assumptions. In particular, if the probability of abandonment is based on a probability distribution for the time required to suppress the fire, please justify the parametric form of the distribution and specify the data used to quantify the distribution parameters.*

*Ref 2.1 J. Chavez, et al., "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Cabinets, Part II-Room Effects Tests," NUREG/CR-4527/V2, October 1988.*

*Ref. 2.2 J. Lambright, et al., "A Review of Fire PRA [Probabilistic Risk Assessment] Requantification Studies Reported in NSAC/181," prepared for the United States Nuclear Regulatory Commission, April 1994.*

*Ref. 2.3 J. Usher and J. Boccio, 'Fire Environment Determination in the LaSalle Nuclear Power Plant Control Room," NUREG/CR-5037, prepared for the United States Nuclear Regulatory Commission,* October 1987.

Response to Question 2

Based on additional industry guidance available since the original submittal, the Control Rooms (Fire Compartment 16-3) fire PRA is being re-quantified. Following is the re-quantification discussion. Specific response to the question follows the re-quantification analysis.

Re- Quantification

The following two cases of control room abandonment are evaluated in the current Fire IPEEE submittal:

Case 1 - Unit 2 Control Room abandonment following an unsuppressed fire in the Unit 1 control area.

Case 3 - Unit 2 Control Room abandonment following an unsuppressed fire in the Unit 2 control area.

For Case 1, all Unit 2 equipment remains available, except that disabled by the Control Room Abandonment procedure (2-AOI-100-2 for Unit 2).

Case 3 shown in the submittal could be evaluated as failing if the shift to remote shutdown is unsuccessful, as described in Table M-3 of the EPRI Fire PRA Implementation Guide. Using a human error rate of 0.064 (NSAC/181, NUREG-1521) for successfully performing the Control Room Abandonment procedure, the frequency for this type of scenario would become:

| | | | | |
|---|---|---|---|---|
| CDF = Ignition Frequency | x | probability of non-suppression | x | failure of remote shutdown capability |
| = 0.0118 | x | 0.0034 | x | 0.064 |
| = 2.57E-6 | | | | |

Which is above the FIVE screening cutoff of 1E-6. Note that this assumes that any fire in the Unit 2 control area that is not suppressed will result in Control Room abandonment, even for fires in non-critical panels. A more detailed evaluation considering critical and non-critical panels is shown below.

*Evaluation of Current Scenarios Using EPRI Fire PRA Implementation Guide*

In Appendix M of the EPRI Fire PRA Implementation Guide (EPRI TR-105928, Final Report), each of the Control Room scenario core damage frequency equations given in Table M-3 is bounded by the ignition frequency, multiplied by the likelihood of suppression prior to control room abandonment, multiplied by the likelihood of failing to enable the remote shutdown capability. Several of the equations then include a failure term for the hardware operated from the remote shutdown panel. For Browns Ferry, this term is dominated by RCIC failure, which has a nominal value of 0.0662 (split fraction RCI1 in the BFNU2M plant model). In essence this acts to double the scenario core damage frequency when one uses an operator failure rate of 0.064 for performing the action to enable the remote shutdown capability.

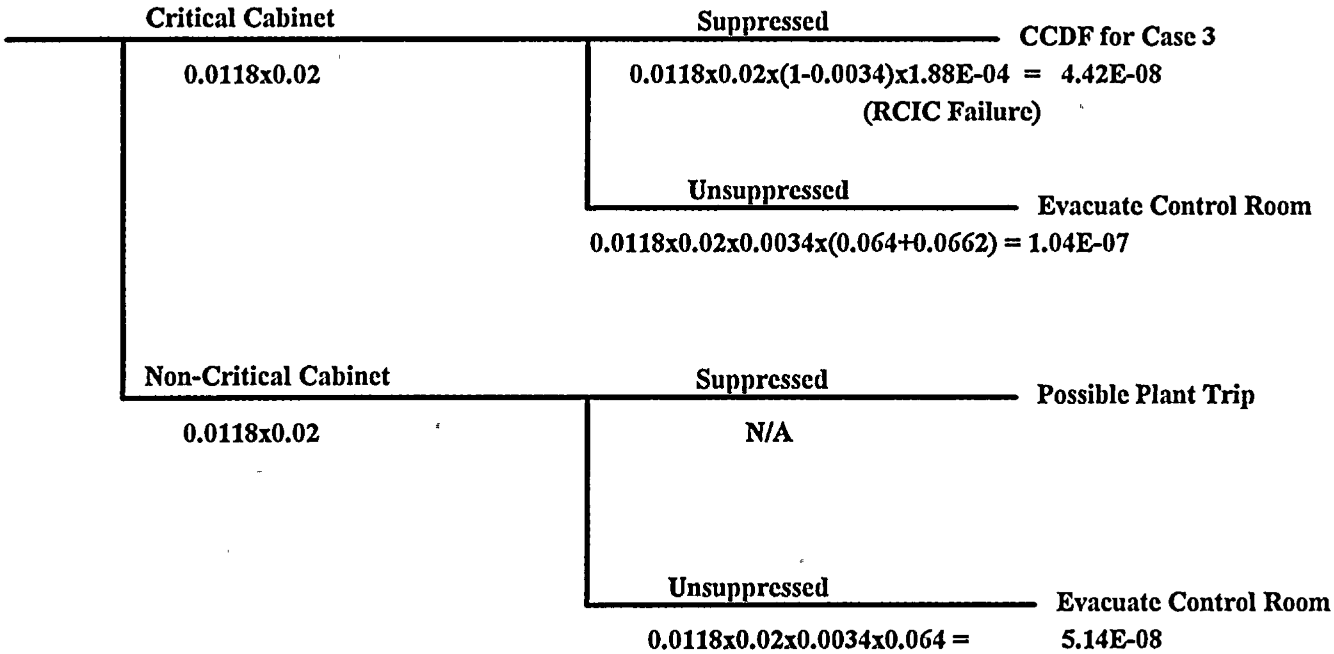
These values are then multiplied by the panel ignition frequency (0.0118 per control room for the BFN IPEEE submittal, 0.00233 in NUREG-1521, multiplied by 0.02 to account for the panel population) and the suppression factor (0.0034). This generates a scenario frequency of :

| | |
|---|---|
| 0.0118 x 0.02 x 0.0034 x (0.064) | for each non-critical cabinet |
| 0.0118 x 0.02 x 0.0034 x (0.064 + 0.0662) | for each critical cabinet |

The other scenario concerns fires that develop in a critical cabinet and self-extinguish or are suppressed. The equation for this scenario (for successful suppression) becomes:

$0.0118 \times 0.02 \times (1- 0.0034) \times CCDF_{(\text{Case 3 from BFN IPEEE})}$
$= 2.35E-4 \times 1.88E-4$
$= 4.42E-8$

Graphically, these scenarios can be shown in an event tree format as:




Using the Browns Ferry IPEEE submittal value for Control Room ignition frequency of 0.0118, this generates a fire related core damage frequency of

5.14E-8 for each non-critical cabinet
1.04E-7 for each critical cabinet (unsuppressed)
4.42E-8 for each critical cabinet (suppressed)
1.48E-7 total for each critical cabinet

While each individual scenario remains screened, the total core damage frequency for all Control Room scenarios will exceed the FIVE cutoff of 1E-6 (i.e. 2.31E-6 for 45 non-critical panels and 7.40E-7 for 5 critical panels, or 3.05E-6 total).

This evaluation is conservative in that it does not address recovery of the Main Control Room after 60 minutes (see Step 2.5 in Appendix M of the Fire PRA Implementation Guide). Also, this evaluation assumes that any fire that is not suppressed will require control room abandonment.

***Scenarios Identified by NUREG-1521***

Appendix B of NUREG-1521 (Technical Review of Risk-Informed, Performance-Based Methods for Nuclear Power Plant Fire Protection Analyses – Draft report for comment) gives two primary scenarios for control room fires. The first addresses fire in a critical panel, requiring control room evacuation. The second addresses fire in other cabinets, but still requires control room evacuation. Each of these scenarios is described quantitatively below (values obtained from Tables B.4 and B.5 of NUREG-1521).

| Term | Description | Value |
|---|---|---|
| a | Frequency of control room fires | 0.0118 |
| b | Area ratio of sensitive cabinet to total cabinet area within the control room | 0.020 |
| c | Failure of remote shutdown capability | 0.064 |
| d | Probability that smoke will force abandonment of control room, given a fire | 0.10 |
| e | Fire induced core damage frequency for Control Room Scenario 1 (a x b x c x d =) | 1.51E-06 |

For the case of a fire in a non-sensitive cabinet, the probability of core damage can be bounded by the MSIV closure case. As shown in NUREG-1521, core damage can occur as a result of failure to enable the remote shutdown panel, but only if the backup automatic systems (in this case HPCI and RCIC) fail to operate.

| Term | Description | Value |
|---|---|---|
| a | Frequency of control room fires | 0.0118 |
| b | Area ratio of non-sensitive cabinet to total cabinet area within the control room | 0.98 |
| c | Failure of remote shutdown capability | 0.064 |
| d | RCIC failure | 0.0662 |
| e | HPCI failure, given RCIC failure | 0.110 |
| f | Probability that smoke will force abandonment of control room, given a fire | 0.10 |
| g | Fire induced CDF for Control Room Scenario 1 (a x b x c x d x e x f =) | 5.39E-07 |

Therefore, by this methodology, the total core damage frequency due to control room fires for Browns Ferry would be (1.51E-6 + 5.39E-7 =) 2.05E-6. This value is slightly above the FIVE screening cutoff of 1E-6. Please note that this evaluation is conservative in that it assumes that one in ten Control Room fires results in Control Room abandonment. If this were the case, the fire events database, which has 12 Control Room fires listed, should have at least one evacuation, whereas ten of the entries did not even result in a plant trip and none of the fires led to a control room abandonment situation.

<u>Detailed Response to Question 2</u>
(Response to this question is primarily based on Response to Generic RAI on Fire-IPEEE, Question 4*)*

The question deals with detailed assumptions used in analyzing the MCR and justifications for those assumptions, including:

1. Fire frequency
2. Fire reduction factors
3. Probability of abandonment, including specifically
    - Justification for the parametric form of the distribution
    - Data used for quantification

Fire Frequencies The fire frequencies for the control room (Compartment 16-3) is calculated in Attachment B of the submittal and is based on the FIVE methodology. The fire frequency is dominated by the electrical cabinets (approximately 80% of the total). The generic electric cabinet fire frequency is multiplied by a weighting factor of 3 to account for 3 control rooms. Therefore, the fire frequency for the control room is based on generic data as identified in the FIVE methodology and no other assumptions or factors were used.

Frequency Reduction Factors The factors used in the re-quantified analysis include the area ratio of the critical cabinet to total cabinet area (0.02), probability that operators will fail to recover the plant from the remote shutdown panel (0.064), probability that smoke will force abandonment of the control room given a fire (0.1) and probability of non-suppression. (0.0034). These generic factors have been derived from NUREG-1521, NSAC/181 and the EPRI Fire PRA Implementation Guide.

Probability of Non-Suppression and Abandonment The RAI specifically questions control room non-suppression probability and the time of fire detection.

The following discussion includes the selection of the detection time and its basis, conservatisms in the timeline, sensitivity of the results to the operating experienced used, the functional form of the suppression curve and its basis, and discusses the BNL report.

Detection Time. To best evaluate the probability of non-suppression, the analysis should consider a timeline of opportunities for detection. For each opportunity in the timeline, the analysis should consider the associated plant specific factors that might impact the effectiveness of detection at that point. Given an agreed upon probability of non-suppression that is a function of time available to suppress the fire, the control room non-suppression time can then be calculated on a plant specific basis.

The detection time assumed is neither the earliest opportunity for detection, namely when the initiating electrical malfunction occurs, nor the latest opportunity, namely the time when rapid smoke generation occurs.

Photo-Electric smoke detectors are installed inside the electrical/control panels at BFN control rooms. Human detection will provide increased capability to detect fire.

Eleven of twelve control room fires in the FEDB are electrical cabinet fires. (There is one kitchen fire listed in the control room area.). Due to limited amount of transient combustible inventories or other unique sources, it is assumed that electrical cabinet fires are the only significant fires that have the potential to cause control room evacuation.

Control room electrical fires do not involve high-energy electrical circuitry because the control room contains only instrumentation and control circuitry. Fire events experience with low voltage electrical fires indicates that these fires are slowly developing and are most often diagnosed by local personnel, even when such fires occur in areas outside of the constantly manned control room. For this reason, it is assumed that the electrically ignited cabinet fire tests (Test 24 and Test 25 at SNL) are representative of the expected timeline of fire development in a control room electrical cabinet. Similarly, it is assumed that human detection is the most likely means of fire detection in the control room. In the case of the control room

fires reported in NSAC-179L, only two of ten applicable fires were detected by smoke detectors. Even in these cases, the event description lists local personnel in conjunction with automatic detection. This experience provides strong qualitative evidence that detection of control room fires is a "competition" between human and automatic means that is often "won" by the human.

The following table lays out the time line for a control room fire based on SNL tests 24 and 25. The table indicates that substantial time is available for detection prior to the time selected in NSAC-181. It indicates that the number of means by which detection can occur increases substantially over time.

Timeline of Control Room Fire Events

| Representative Event from SNL Tests | Time(s) from SNL Tests (24, 25) | Scenario Event | Available Means of Detection |
|---|---|---|---|
| Time ignition source was energized | 0:00, 0:00 | Electrical malfunction occurs | Control board indication<br>Ozone smell in CR |
| Time smoke became visible | 10:30, 9:30 | Electrical item (relay, resistor on circuit board or cable) overheats and starts smoking | Control board indication<br>Ozone smell in CR<br>Smoke observed inside the cabinet with direct viewing<br>In-cabinet detector actuates |
| Time cable ignition was observed | 15:20, 15:40 | Electrical item (relay, resistor on circuit board or cable) ignites | Control board indication<br>Ozone smell in CR<br>Smoke observed inside the cabinet with direct viewing<br>In-cabinet detector actuated<br>Flaming visible with direct viewing<br>Smoke visible outside the cabinet<br>Ceiling detector actuates? |
| Not addressed by test scenario | NA | Fire propagates from electrical item to cables or other combustibles (e.g., adjacent plastic - relay cover or circuit board) | Same as above |
| Rapid growth in measured heat release rate and smoke generation rate | 22:20, 20:00 | Cables fully involved in burning, dense smoke accumulates at the ceiling | Same as above<br>Flame visible outside the cabinet<br>Smoke level begins to descend from ceiling |
| Time control panels are no longer visible | 27:00, 23:00 30:00, 30:00 (1) | Smoke begins to obscure full length of control board panels | Same as above |

(1) First set of times is the point of measured obscuration and the second set of times is the point when obscuration was observed.

- Starting with the electrical malfunction, the opportunity for detection begins. As time grows, the amount of ozone will increase and this means of detection will correspondingly grow rapidly. Once visible smoke is produced, a similar condition will occur. That is, the continuous puffs of smoke mentioned in the review will accumulate and be more likely to be noticed. From a practical perspective, it is difficult with the information available to date to predict detection rates for each of these time periods. In lieu of that, the time selected is consistent with operating experience and SNL test described above.

The SNL tests document how actual observations seemed to indicate that the control board was visible even when measured values indicated that it should not be. The detection time and the "observed" time for forced evacuation, allow about 15 minutes for suppression.

Functional Form of the Distribution. The functional form of the manual suppression distribution selected is lognormal. This distribution form was selected because it was found by EPRI to be the best fit for extrapolating human response data collected from simulators. EPRI considered at one time the Weibull distribution but finally concluded that the lognormal was the best selection for post accident human events.

In reviewing the simulator data it collected at a number of different power plants, EPRI found that goodness of fit tests generally were comparable or better for the lognormal distribution. In addition, the lognormal distribution had been selected by a number of other interpreters of simulator data and found acceptable. Finally, the lognormal distribution tends to give a higher probability at longer times, i.e., on a relative basis it is conservative. A lognormal distribution with a mean of 3.4E-03 and an error factor of seven was used in the uncertainty analysis for manual suppression within 15 minutes.

The BNL Report. The Review mentions a BNL report (NUREG/CR-5037) and indicates that control room temperature effects may even be more limiting than smoke in causing evacuation. The excerpts of the BNL report contained in the Critique do not seem to be consistent with the SNL cabinet fire tests. In SNL test 24, the time of assumed evacuation occurs while room temperature is still at its nominal value at the 6-foot elevation (Figure 31, p. 37). In SNL test 25, the temperature at 6 foot elevation was only slightly above nominal at the assumed time of evacuation and never even reached 40 degrees C (Figure 38, p. 43). Test 25 involved operation of the facility with 8 room changes per hour (versus 1 room change per hour in test 24). The SNL report speculates that cooling from the ventilation system probably kept the temperature low. Hence, we would conclude that as long as operators initiated the smoke removal system in the control room, it is unlikely that room temperature would become a significant concern.

FIRE QUESTION 3 - HEAT LOSS FACTOR (HLF)

*The heat loss factor is defined as the fraction of energy released by a fire that is transferred to the enclosure boundaries. This is a key parameter in the prediction of component damage, as it determines the amount of heat available to the hot gas layer. A larger heat loss factor means that a larger amount of heat (due to a more severe fire, a longer burning time, or both) is needed to cause a given temperature rise. It can be seen that if the value assumed for the heat loss factor is unrealistically high, fire scenarios can be improperly screened out. Figure 3.0 provides a representative example of how hot gas layer temperature predictions can change* *assuming different heat loss factors. Note that: (1) the curves are computed for a 1000 kW fire in a 10m x 5m x 4m compartment with a forced ventilation rate of 1130 cfm; (2) the fire induced vulnerability evaluation (FIVE)-recommended damage temperature for qualified cable is 700°F for qualified cable and 450°F for unqualified cable; and, (3) the Society for Fire Protection Engineers (SFPE) curve in the figure is generated from a correlation provided in the SFPE Handbook [3-1].*

*Based on evidence provided by a 1982 paper by Cooper, et al. 3.2, the EPRI Fire PRA Implementation Guide recommends a heat loss factor of 0.94 for fires with durations greater than five minutes and 0.85 for "exposure fires away from a wall and quickly developing hot gas layers." However, as a general statement, this appears to be a misinterpretation of the results. Reference 3.2, which documents the results of multi-compartment fire experiments, states that the higher heat loss factors are associated with the movement of the hot gas layer from the burning compartment to adjacent, cooler compartments. Earlier in the experiments, where the hot gas layer is limited to the burning compartment, Reference 3.2 reports much lower heat loss factors (on the order of 0.51 to 0.74). These lower heat loss factor are more appropriate when analyzing a single compartment fire. In summary, (a) hot gas layer predictions are very sensitive to the assumed value of the heat loss factor; and (b) large heat loss factors cannot be justified for single room scenarios based on the information referenced in the EPRI Fire PRA Implementation Guide.*

*The submittals indicates that a heat loss factor of 0.85 was used in the Browns Ferry study. In light of the preceding discussion, please either: (a) justify the value used and discuss its effect on the identification of fire vulnerabilities, or (b) repeat the analysis using a more justifiable value and provide the resulting change in scenario contribution to core damage frequency.*

*Figure 3.0 - Sensitivity of the hot gas layer temperature predictions to the assumed heat loss factor.*

*3.1 P.J. Dinenna, et al, eds "SFPE Handbook of Fire Protection Engineering," 2nd Edition, National Fire protection Association, p. 3-140, 1995.*

*3.2 L. Y. Cooper, M. Harklemad, J. Quintiere, W. Rinkinen, " An Experimental Study of Upper Hot Layer Stratification in Full-Scale Multiroom Fire Scenarios,' ASME [American Society of Mechanical Engineers] Journal of Heat Transfer, 104,741-749, November 1982.*

Response to Question 3

The Heat Loss Factor (HLF) is a parameter used in the FIVE methodology in the prediction of hot gas layer (or the compartment environment) temperatures, if a fire burns without intervention and consumes all of the available fuel. If the combustible loading of the compartment is found to be sufficient enough to develop damaging temperatures, then all contents of the room are considered damaged and specific source/target evaluations are not necessary. Therefore, the HLF has no direct relationship in the calculation of plume or ceiling jet temperatures or radiant heat flux to determine target damage. However, the BFN analyses conservatively adjusts the critical temperature rise based on hot gas layer temperatures, considering all the available fuel in the compartment is consumed. This method effectively assumes instantaneous consumption of all fuel resulting in higher ambient temperatures and

therefore, higher fire plume/ceiling jet sublayer temperatures (i.e. superimposed fire plume/ceiling jet sublayer). The calculated damage envelop is thus increased.

Heat loss factors typically range between 70 and 95 percent of the total energy released in enclosure fires (EPRI-TR100443, Section 7.7.2) . The variables expected to influence the hot gas layer temperatures in a single compartment are the heat release rates; duration of fire; the room size; air flow rate to the fire, reflected in the size of the opening; and the thermal properties of floor, ceiling and walls. The FIVE methodology simplifies the analysis by utilizing the Heat loss Factor (HLF) which accounts for the heat loss to the boundaries. The FIVE methodology also assumes fires to be fuel controlled. Therefore, it can be seen that HLF will in affect vary from compartment to compartment (i.e. higher values for larger compartments). HLF will also be higher during early stages of a fire and reduce as the boundaries heat up. It will be extremely difficult to justify a single value of HLF for all compartments and for all stages of a fire. For this very reason, the fire protection literature refrains from the use of HLF. However, it can also be reasonably concluded that compartments with large surface areas; large openings to allow for vent flows; and higher thermal conductivity and specific heat are expected to have higher HLF values (i.e. larger compartments have the ability to loose more heat). Most of the fire scenarios evaluated at BFN are in the Reactor Buildings which are very large open areas with concrete boundaries and large openings. Therefore, BFNs use of the higher value of 85 percent in its analysis is justified.

Due to the uncertainties involved in the selection of the HLF, an alternate method to determine compartment temperatures is being performed. Unlike FIVE methodology, this method includes most of the parameters described above in computing compartment temperatures. These temperatures will then be compared to the compartment temperatures computed by the FIVE methodology. Temperatures in compartments are calculated using the method of MQH for naturally ventilated fires (Reference: SFPE Handbook 2$^{nd}$ edition, Page 3-139, Equation 12). As an example, the electrical cabinet 480V RMOV Board 2C located in Unit 2 Reactor Building EL 565 will be evaluated using the MQH method. The HRR for the cabinet is taken as 190 Btu/sec (200 kW); the fire duration is approximately 1800 sec based on the combustible loading of 372,000 Btu. The openings and surface areas are conservatively approximated. The thermal properties of concrete are from SFPE Handbook. See Attachment 1 for the computations.

The compartment temperatures calculated by this method are very close to the hot gas layer temperature calculated using the FIVE method with 0.7 HLF (Attachment 2). Increase in surface areas and opening size results in lower temperatures corresponding to higher HLF.

Based on the results of the alternate method, all significant fire sources including electrical cabinets are being re-evaluated using a HLF of 0.7 (Attachment 2). Note that the heat release rate (HRR) for electrical cabinets is taken as 190 Btu/sec as suggested in RAI Question # 4. The table below depicts the summary of current IPEEE values and the re-calculated values based on 0.7 HLF and 190 Btu/sec for electrical cabinets. Also provided is the walked down zone of influence used in determining cable damage envelop.

| Ignition Sources (Unit 2) | Current IPEEE Values HLF=0.85 & HRR=106 Btu/sec for Elect. Cabinets | | Re-calculated Based on HLF=0.7 and HRR=190 Btu/sec for Elect. Cabinets | | Current Zone of Influence (ZOI) Used in Determining Damage Envelop | |
|---|---|---|---|---|---|---|
| | Damage Ht. (ft) | Critical Radial Distance (ft) | Damage Ht. (ft) | Critical Radial Distance (ft) | Damage Ht. (ft) | Critical Radial Distance (ft) |
| 480V RMOV BD 2C | 6.77 | 2.60 | 8.7 | 3.5 | 8.0 | 3.0 |
| 480V RB Vent BD 2B | 6.77 | 2.60 | 8.7 | 3.5 | 8.0 | 4.0 |
| 250V RMOV BD 2C | 6.82 | 2.60 | 8.8 | 3.5 | 9.0 | 4.0 |
| 2-PNLA-25-340/341 | 6.70 | 2.52 | 6.9 | 2.5 | 7.0 | 3.0 |
| Drywell Torus Comp. | 11.85 | 5.35 | 12.0 | 5.4 | 12.0 | 6.0 |
| 480V RMOV BD 2D | 6.82 | 2.60 | 8.9 | 3.5 | 9.0 | 4.0 |
| U2 Pref. AC Trans. | 9.13 | 3.78 | 9.2 | 3.8 | 9.5 | 4.0 |
| RBCCW Pump 2A/2B | 4.01 | 1.38 | 4.0 | 1.4 | 4.0 | 2.0 |
| 480V RMOV BD 2E | 11.81 | 2.60 | 15.2 | 7.0 | 12.0 | 2.0 |
| MG Sets 2DN & 2EA | 7.04 | 2.67 | 7.3 | 2.7 | 7.0 | 3.0 |
| 4KV-480V Trans. | 9.29 | 3.78 | 9.7 | 3.8 | 10.0 | 3.0 |
| 2-LPNL-025-0031 | 7.26 | 2.60 | 10.4 | 3.5 | 10.0 | 4.0 |
| 4KV RPT BD 2-1/2-2 | 6.9 | 2.60 | 9.1 | 3.5 | 7.0 | 3.0 |
| MG Sets 2DA and 2EN | 6.99 | 2.67 | 7.2 | 2.7 | 7.0 | 3.0 |
| LPNL-25-23/24 | 7.13 | 2.60 | 9.8 | 3.5 | 10.0 | 4.0 |
| 240V Lighting BD 2B | 6.74 | 2.60 | 8.6 | 3.5 | 7.0 | 2.0 |
| SLC Pumps A and B | 12.19 | 5.35 | 12.6 | 5.4 | 13.0 | 6.0 |

Comparison of the re-calculated damage threshold elevations and the critical radial distances with the walked-down zone of influence (ZOI) indicates that the increase in distances were within the margin available for most of the non-electrical cabinet ignition sources; for some electrical cabinets the increase in damage height and radial distance was minimal and did not involve additional components; 480V RMOV BD 2E depicted the most significant increase in damage height and critical radial distance due to its location in the corner (location factor 4). This electrical board was again walked down to determine the impact of a larger damage envelop. No additional electrical cables were identified within the expanded ZOI. 4KVRPT BD 2-1/2-2 and 240V Lighting BD 2B also depicted slightly larger ZOI, however, no additional components were identified.

The above evaluation was done for unit 2. Unit 3 results are expected to be similar.

Therefore, the above analysis shows that the changes in ZOI due to higher HLF and cabinet HRR are not significant to cause appreciable changes to the calculated core damage frequencies (CDF).

FIRE QUESTION 4 - ELECTRICAL CABINET HEAT RELEASE RATE

*The analysis of the maximum rate of burning in a closed but ventilated electrical panel under oxygen-limited burning conditions (Submittal Attachment A: Heat Release Rates) appears optimistic in comparison to experimental data. The cited air flow correlation from Drysdale (Submittal Reference 21) only applies to one-direction (out) flow through a single opening in a large room under post-flashover conditions. These conditions are not consistent with the postulated panel fire conditions because: (1) the postulated fire is assumed to be in the pre-flashover stage, (2) the electrical panels apparently have openings near both the top and bottom of the panels allowing for both inlet and outlet flow and the development of a significant "chimney effect" due to buoyancy driven air flow, and (3) warping of the panel doors during the fire will likely allow for the area available for air flow to increase in size as compared to the assumed she of the ventilation grills based on the testing experiences of both Sandia National Laboratories (SNL) (ref 4.1) and, more recently, the Technical Research Center (VTT) of Finland (refs. 4.2 and 4.3). Further, the cited maximum heat release rate (HRR) of 53 BTU/s Is optimistic in comparison to the measured heat release rates for closed panels as tested both by SNL and VIT. In the SNL tests closed/ventilated panel HRR values up to 265 BTU/s were measured (i.e., Considering SNL Scoping Test 10) and in the VTT Finland tests, maximum HRR values of up to 380 BTU/s were measured (i.e., considering VTT panel test #1).*

*Please assess the changes in the IPEEE fire analysis results and insights if the maximum HRR of a closed but ventilated electrical panel is increased to 190 BTU/s, the midrange of the available test data.*

*4.1 Chavez, J. M., "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets. Part I: Cabinet Effect Tests," NUREG/CR4527, April 1987.*

*4.2. Mangs, Johan and Keski-Rahkonen, Olavi, "Full Scale Fire Experiments on Electronic Cabinets," Technical Research Center of Finland (Valtion Teknillinen Tutkimuskeskus, VIT), VTT publication 186, Espoo, Finland, 1994 (ISBN 951-384924-5; ISSN 1235-0621; UDC 614.84:699.81:621.3.05).*

*4.3 Mangs, Johan and Keski-Rahkonen, Olavi, "Full Scale Fire Experiments on Electronic Cabinets II," Technical Research Center of Finland (Valtion Teknillinen Tutkimuskeskus, VTT), VTT publication 269, Espoo, Finland, 1996 (ISBN 951-384927-9; ISSN 12350621; UDC 614.842:621.3.04:53.083).*

Response to question 4

The air flow correlation cited in Attachment A of the submittal is valid for stoichiometric burning utilizing all available air if the vent flow rate is fully choked (Equation 1). Using 3 MJ/kg as the heat released per unit mass of air consumed, this yields a stoichiometric rate of heat release as depicted in Equation 2 and is similar to the correlation used in the BFN submittal. Using a compartment energy balance and a simple energy loss model, Babrauskas, V ("Estimating Room Flashover Potential", Fire Technology, 16(2), 1980) developed a relationship between the ventilation parameter and the rate of heat release required to cause flashover. Based on the database of 33 compartment fire tests, he found that the rate of heat release required to

cause flashover, is described by Equation 3. This corresponds to half the heat release rate which would occur for stoichiometric rate of heat release (Equation 2). Therefore, the methodology used in the submittal is conservative, as it uses the stoichiometric burning and is consistent with HRR calculation correlation's found in the fire protection literature. Since the ratio of the heat of complete combustion to the air mass is nearly constant (3 MJ/kg) for most fuels; by specifying the opening size, one can obtain the HRR instantaneously.

$$\dot{m}_a = 0.5 A_o \sqrt{H_o}\,[kg/s] \ldots\ldots\ldots Equation \quad 1$$

$$\dot{Q}_{stoich} = 1500 A_o \sqrt{H_o}\,[kW] \ldots\ldots Equation \quad 2$$

$$\dot{Q}_{fo} = 750 A_o \sqrt{H}\,[kW] \ldots\ldots\ldots\ldots Equation \quad 3$$

Most electrical cabinets have no ventilation openings as described in Attachment C of the submittal. 480V RMOV BD 2E does have small openings at the top and bottom. However, since the calculated HRR is based on choked air flow conditions as discussed above, maximum HRR is calculated for the opening size specified.

The HRR calculation method as described above is valid and conservative. However, we agree that during actual fire scenarios, warping of the panel doors is likely. This will increase the area available for air flow and thus increase the HRR. Therefore, all electrical cabinets have been re-evaluated using the HRR of 190 Btu/sec as suggested by the reviewer. The resulting changes in the damage threshold elevations/distances and corresponding CDF impacts are addressed in response to question number 3 and Attachment 2.

FIRE QUESTION 5 - DESCRIPTION OF INITIATING EVENTS

*The initiating events and systemic or functional sequences identified for each fire source location in a compartment are crucial to the evaluation of conditional core damage probability. The selection influences both the complement of equipment and the human actions that are assumed to be required to prevent core damage. The human error probabilities (HEPs) used in the analysis must properly reflect the potential effects of fire (e.g., smoke, heat, loss of lighting), even if these effects do not directly cause equipment damage in the scenarios being analyzed. A review of the reasonableness of the quantitative screening calculations in the Browns Ferry fire IPEEE cannot be made because the accident sequences, analytical assumptions, functional or systemic event trees associated with fire-initiated sequences, and human actions have not been provided in accordance with NUREG-1407 (page C-4, Items 9, 10, and 11).*

*Quantification of the fire core damage frequency (CDF) and screening relied on a limited set of initiating events whose selection was not justified in the submittals (Table 5-1 in the Unit 2 submittal, and Table 5-4 in the Unit 3 submittal). Several boiling water reactor-typical initiating events are not included among the table entries, e.g., loss of heating, ventilation, and air condition, loss of service or component cooling water, or inadvertent safety relief valve actuation.*

*Please provide the following for each unscreened compartment: (1) the initiating events analyzed, (2) the accident sequences and a word description of the accident sequences that does not rely upon knowledge of the top event identifiers in the event trees, (3) a list of key analytical assumptions used in the development of the conditional probability of core damage, (4) the functional or systemic event trees used in the fire analysis with a description of the top events, (5) the key human actions of each sequence and the HEPs (descriptions and numerical values) for each. For the HEPs, describe how the effects of the postulated fires were treated.*

<u>Response to Question 5</u>

[Later]

<u>FIRE QUESTION 6 - REMOTE SHUTDOWN CAPABILITY</u>

*NUREG-1407, Section 4.2 and Appendix C, and Generic Letter (GL) 86-20, Supplement 4, request that documentation be submitted with the IPEEE submittal with regard to the Fire Risk Scoping Study (FRSS) issues, including the basis and assumptions used to address these issues, and a discussion of the findings and conclusions. NUREG-1407 also requests that evaluation results and potential improvements be specifically highlighted. Control system interactions involving a combination of fire-induced failures and high probability random equipment failures were identified in the FRSS as potential contributors to fire risk.*

*The issue of control systems interactions is associated primarily with the potential that a fire in the plant (e.g., the MCR) might lead to potential control systems vulnerability. Given a fire in the plant, the likely sources of control systems interactions are between the control room, the remote shutdown panel, and shutdown systems. Specific areas that have been identified as requiring attention in the resolution of this issue include:*

*Electrical independence of the remote shutdown control systems: The primary concern of control systems interactions occurs at plants that do not provide independent remote shutdown control systems. The electrical independence of the remote shutdown panel and the evaluation of the level of indication and control of remote shutdown control and monitoring circuits need to be assessed.*

*a.* *Loss of control equipment or power before transfer. The potential for loss of control power for certain control circuits as a result of hot shorts and/or blown fuses before transferring control from the MCR to remote shutdown locations needs to be assessed.*

*b.* *Spurious actuation of components leading to component damage, LOCA, or interfacing systems LOCA: The spurious actuation of one or more safety-related to safe-shutdown-related components as a result of fire-induced cable faults, hot shorts, or component failures leading to component damage, LOCA, or interfacing systems LOCA, prior to taking control from the remote shutdown panel, needs to be assessed. This assessment also needs to include the spurious starting and running of pumps as well as the spurious repositioning of valves.*

c. *Total loss of system function: The potential for total loss of system function as a result of fire-induced redundant component failures or electrical distribution system (power source) failure needs to be addressed.*

*Please describe your remote shutdown capability, including the nature and location of the shutdown station(s), as well as the types of control actions which can be taken from the remote panel(s). Describe how your procedures provide for transfer of control to the remote station(s). Provide an evaluation of whether loss of control power due to hot shorts and/or blown fuses could occur prior to transferring control to the remote shutdown location and identify the risk contribution of these types of failures (if these failures are screened, please provide the basis for the screening). Finally, provide an evaluation of whether spurious actuation of components as a result of fire-induced cable faults, hot shorts, or component failures could lead to component damage, a LOCA, or an interfacing systems LOCA prior to taking control from the remote shutdown panel (considering both spurious starting and running of pumps as well as the spurious repositioning of valves).*

Response to Question 6

The Backup Control System (BCS) provides backup control features for the systems needed to fulfill the shutdown function from outside the main control room (MCR) and bring the reactor to a cold shutdown condition in an orderly fashion irrespective of shorts, opens, and/or grounds in the MCR circuits. The BCS also provides the overriding controls for (1) those items not needed for actual shutdown operation but which have the potential through operation to cause a loss of coolant and possible damage to the reactor system and core, and (2) those items which could jeopardize the reliability of the 4160 volt shutdown board system by overloads due to spurious load and transfer breaker operation. The BCS also meets the 10CFR50 Appendix R requirements for Alternate Shutdown capability for a fire in the Control Bay (including compartments 16-1, 16-2, 16-3, 17, 18 & 19).

The system provides alternative shutdown capability for equipment which may be damaged in the control bay (CB). The backup system is physically and electrically separated from the damaging influence from any affected areas in the CB. The system provides the ability to achieve cold shutdown with equipment which is redundant or diverse to that which is in the MCR (or the affected area in the CB). It is in this sense that the Backup Control equipment is associated with the single-failure criteria, not that all features of Backup Control are, in themselves, single-failure proof.

The Backup Control Panel (Panel 25-32) is physically located in the Shutdown Board Room (within the Reactor Building) for each unit and is thus physically separated from the control bay. Transfer switches of the maintained contact type are located on the backup control panel and are used to transfer control from the MCR to the backup control panel. Other BCS functions take place at the 4KV Shutdown Boards, 480V Reactor MOV Boards and 250V DC Reactor MOV Boards via transfer switches. An example would be the manual controls for the Diesel Generators which are located on the respective 4160 volt shutdown boards (and locally at the diesel generators) as backup for automatic or manual initiation from the control room.

Procedures are in place to effect an orderly transfer of control from the MCR to the backup control locations. Abnormal Operating Instructions (AOI) are provided for evacuation from the control room for all but an Appendix R event. Safe Shutdown Instructions (SSI) are provided for evacuation resulting from an Appendix R event.

Only essential systems are provided at the BCS and include the following:

Main Steam System

The controls and appropriate instrumentation for monitoring the following functions/components of the main steam system are provided on the 480V Reactor MOV Board or the 250V DC Reactor MOV Board or the backup control panel:

a. Main Steam Safety Relief Valves (MSRV)
b. Main Steam Line Isolation Valves (control for closure only)
c. Main Steam Line Drain Valves

The evaluations of associated circuits, including the evaluation of high-low pressure interfaces concluded that the MSRV is the limiting component whose spurious operation could adversely affect plant shut down. Therefore, analyses were performed to demonstrate that spurious operation of one MSRV could be mitigated by the minimum safe shutdown systems.

Feedwater System

Reactor pressure and water level indication is provided on the appropriate board(s) or the backup control panel for monitoring the reactor condition regardless of the condition of the control room or spreading room circuits.

RHR Service Water System

The service water supply to the EECW System and to the two RHR heat exchangers that serve the appropriate RHR backup control loop on each unit have controls for the service water pumps and associated valves, and appropriate instrumentation for monitoring operation of the system are provided on the backup control panel and/or the appropriate boards. Transfer switches and control switches for the pumps and valves are located on the appropriate 4160 volt AC boards and 480 volt MOV boards.

250 volt DC Power System

The plant dc power system is protected by its physical location and circuit design such that essential circuits for emergency shutdown are available irrespective of the main control room condition. The battery and board rooms are dispersed along the length of the Control Bay at elevation 593.0 level which is below the Cable Spreading Rooms. Penetrations into the Cable Spreading Rooms are designed to prevent fire propagation across them. The circuits necessary for shutdown do not traverse the Cable Spreading Rooms but cross the wall into the reactor building via conduits. Such circuits are provided for backup systems and equipment and are obtained from the 250 volt DC reactor MOV boards which have direct feeds from the unit battery boards.

Emergency Equipment Cooling Water System (EECW)

The emergency equipment cooling water system needed for cooling the diesels, RHR pump seal, and RHR room coolers and ventilation/air-conditioning have pump and valve control switches at the backup control panels as backup for the normal manual or automatic initiation from the control room. Pump control switches are required as part of the RHRSW system. Transfer switches for the EECW valves are located on the appropriate 480 volt AC boards or 250 volt DC boards. Spurious closure of the EECW sectionalizing valves is prevented by maintaining the valve breakers open during normal power operation.

Reactor Core Injection Cooling (RCIC)

The valve, pump and turbine controls necessary to operate the RCIC system and the appropriate instrumentation for monitoring its operation are provided on a backup control panel (s) or the appropriate 250 volt DC or 480 volt AC boards. Spurious operation of the RCIC system is not a concern based on the flow rate (600 GPM). Plant procedures and training allow adequate time for manual actions to prevent water intrusion into the main steam lines due to the spurious initiation of RCIC.

High Pressure Coolant Injection (HPCI)

The control of the steam supply valve for the HPCI system is provided on the appropriate 250 volt DC reactor MOV board to ensure that uncontrolled filling of the reactor vessel is not caused if HPCI is brought on by circuit malfunction or reactor low level. Analysis of the spurious operation of the HPCI system shows that the operator can terminate HPCI flow within 10 minutes to prevent water intrusion into the main steam lines.

Residual Heat Removal (RHR)

Valve, pump and motor controls and the appropriate instrumentation are provided for monitoring the operation of one RHR loop per unit. The modes of RHR operation provided from the backup control panel (and/or the appropriate boards) include:

a. Suppression Pool Cooling
b. Low Pressure Coolant Injection (LPCI)
c. Shutdown Cooling

Transfer switches and control switches for all the RHR pumps and valves for one loop per unit are located on the appropriate 4160 volt AC or 480 volt AC or 250 volt DC boards.

Core Spray (CS)

A control circuit is provided at the 4KV shutdown boards to trip and lock-out all core spray pumps independent of the condition of the control room or spreading room circuits (to prevent potential overload on the 4KV busses and associated diesels).

Diesel Generator System

Diesel Generator manual controls for diesel startup are located on the respective 4160 volt shutdown boards and locally at the diesel generator(s) as backup for the automatic or manual initiation from the diesel information panel for Unit 1/2 and from the 4KV shutdown boards for Unit 3. Operation of the loads on the diesels is performed at the 4KV shutdown boards. Undesired loads (which might occur from circuit malfunctions and thus cause diesel/4KV overload conditions) are prevented by using control circuits which are independent of the control room and/or cable spreading rooms.

Control Rod Drive (CRD)

The backup control (transfer and control switches) for CRD Hydraulic Pumps 1B and 3B (and the required valves) are provided on the appropriate 480 volt AC reactor MOV board and 4160 volt AC board for supporting the reactor water level associated with the operation of the RHR (LPCI) and RCIC systems. The scram discharge volume test pilot solenoid valve is provided with a transfer switch and a control switch on the backup control panel. Spurious operation of the CRD system is not a concern based on the flow rate for CRD (200 GPM). Plant procedures and training allow adequate time for manual actions to prevent water intrusion into the main steam lines due to the spurious operation of the CRD system.

Analyses were performed to determine the effects of spurious operations on the shutdown capability of the minimum Safe Shutdown Systems (SSDS). This analysis was performed for four categories of plant equipment at BFN:

a. Minimum SSDS (RHR, RHRSW, EECW, etc.)
b. MSRVs
c. High-low Pressure Interface
d. Other Plant Equipment (Core Spray, HPCI, RCIC, etc.)

The process of identifying the significant spurious operation for a fire within the nuclear steam supply system and balance-of-plant system was performed by locating the following:

a. All high-low pressure interfaces
b. All potential paths for coolant inventory loss
c. All potential paths for flow diversion
d. All potential flow blockages

Each of these potential adverse spurious operations was evaluated for its potential consequence in accordance with the assumptions described below:

a. Spurious operation occurs simultaneously with other fire effects.
b. Spurious operation for any equipment is considered plausible unless the equipment is protected in the fire area.
c. The number of spurious operations considered in this analysis is limited by the design requirements for associated circuits which is:
   1. For non-high-low pressure interface components circuit failures/spurious operations are analyzed one at a time.
   2. For high-low pressure interface components two or more circuit failures/spurious operations are assumed to occur at the same time.
d. Spurious operation which could defeat the RPS or MSIVs is not considered to be plausible (The RPS and MSIVs are redundant and fail-safe on loss of power. This redundancy provides for a system which is single-failure proof such that a failure will fail the system in the safe direction).
e. Spurious operation of three-phase electrically powered equipment due to hot shorts of the power cables is considered to be incredible (with the exception of high-low-pressure interfaces).

As described above, all significant plant damage states; i.e. all high-low pressure interface spurious actuations, all potential paths for coolant inventory loss, all potential paths for flow diversion, all potential flow blockages; were taken into consideration. Note that spurious actuations are considered one at a time unless at high low pressure interfaces, where multiple spurious are assumed in any single line. Therefore, spurious operation analysis was performed for the minimum SSDS for the time frame before the manual transfer occurs. This evaluation shows that the system design capability ensures the availability of the minimum SSDS in spite of their own spurious operation.

Cables and components are considered to be incapacitated (unavailable) when subjected to a fire environment; spurious actuations and circuit failures due to fires are not specifically modeled as described in response to Question 1. As stated in the response; "currently circuit faults cannot be adequately modeled due to lack of accrued experience and availability of quantitative PRA methods".

FIRE QUESTION 7 - CONSIDERATION OF TRANSIENT COMBUSTIBLES

*In general, the fire risk associated with a given compartment is composed of contributions from fixed and transient ignition sources. Neglect of either contribution can load to an underestimate of the compartment's risk and, in some cases, to improper screening of fire scenarios. If such compartments contain the cables for all redundant trains of important plant safety systems, a major vulnerability may be overlooked, without sufficient analysis of potential accident sequences and needed recovery actions.*

*In the Browns Ferry submittals, transient combustibles appear to have been considered only in the reactor buildings. No basis for excluding other fire zones was given. Also, in calculating the area ratio (the u-term in FIVE) for fires from transient combustibles leading to damage by radiant exposure, the appropriate floor area to be used is defined by a perimeter drawn around the target a damage distance away. As such, the u-factor varies from room to room depending* *on the number and dimensions of targets. (As an example, for a trash bag with a 5-foot damage radius, and a target with a square footprint 4 feet on a side, the damage footprint would have an area of about 158 square feet, i.e., all of the floor area within 5 feet of the target.) it is not clear that such considerations were used to determine the 1500 square feet area used in Section 6.1.1 of the submittals.*

*In compartments where all fixed ignitions sources have been screened out, has the possibility of transient combustible fires been considered? For each compartment where transient fires have not been considered, please provide the justification for this conclusion and provide a discussion on compartment inventory in terms of system trains and associated components (i.e, cables and other equipment). Please explain whether or not the conditional core damage probabilities, given damage to all cables and equipment in these compartments, are significant (i.e., cables from redundant trains are present). If the conditional core damage probability for a compartment is considered significant, please provide justification for assigning a very low likelihood of occurrence to transient fuel fires for the compartment. Finally, please confirm or correct the estimated contribution from transient combustible fires in the reactor buildings to the plants' fire risks.*

Response to Question 7

The initial screening phase of the analysis (Section 5 of submittal) considers engulfing fire in all compartments and components located within the compartment are assumed to be damaged. Therefore, fixed or transient combustible analysis is not necessary at this stage. The compartments which were not screened out initially were then evaluated as part of detailed screening process (Section 6). The detailed phase of the analysis considers specific fire scenarios involving fixed and transient combustibles. Fixed and transient ignition sources were specifically addressed for the Unit 2 and Unit 3 Reactor Buildings. Other fire areas/compartments (e.g. 4,5,8,9,16-1,16-2,16-3,18,25-1,25-2 and 25-3 in Unit 2) are mostly electrical/switchgear rooms with the exception of turbine building and some areas in the control building. In the electrical rooms, the source and targets will generally be electrical cabinets and cables associated with the same cabinet. Therefore, a source/target evaluation involving fixed or transient combustibles is not practical. These areas were evaluated based on an "event tree" approach. In the use of an event tree approach to the analysis of fires, the fire frequency for the areas is segmented into a range of cases. These cases are selected to cover the range between "high frequency/low consequence" such as fires that result in a turbine trip only, to "low frequency/high consequence" events, such as control room evacuation. Note that the total ignition frequency used in the event tree analysis includes contribution of transient combustibles.

The target damage foot print area calculations for radiant exposure (from transient combustibles) were not necessarily based on all of the floor area within 5 feet of the target. For example, if the 5 feet distance from the target included the walkways, access areas, space behind electrical cabinets, etc. then those spaces were not considered in the area calculations. However, due to the uncertainties involved in the area calculations, a sensitivity analysis has been performed to assess the impact on CDF estimates.

The following spreadsheet reproduces the current transient combustible analysis for Unit 2 reactor building. The surface area of targets facing floor (for radiant exposure) was changed to 2000, 3000 and 5000 square feet. The change in the CDF values were then computed. It can be seen that the transient combustible scenarios still remain screened with sufficient margin.

| PROBABILITY OF TRANSIENT COMBUSTIBLE FIRE EXPOSURE | | | |
|---|---|---|---|
| | PLUME REGION | | RADIANT EXPOSURE |
| PROBABILITY OF COMBUSTIBLES BEING EXPOSED (p) | 0.1 | | 0.1 |
| SURFACE AREA OF TARGETS FACING FLOOR ($FT^2$) | 1000 | | 1500 |
| RADIANT EXPOSURE SURFACE AREA ($FT^2$) | 0 | | 100 |
| NET FLOOR AREA ($FT^2$) | 56000 | | 56000 |
| PROBABILITY OF TRANSIENT COMBUSTIBLES BEING LOCATED IN RANGE OF TARGET (u) | 0.018 | | 0.029 |
| FREQUENCY OF CRITICAL COMBUSTIBLE LOADING ($F_{CCL}$) | 1 | | 1 |
| FREQUENCY OF INSPECTION ($F_W$) | 52 | | 52 |
| $x = F_{CCL}/F_W$ | 0.019 | | 0.019 |
| FREQUENCY OF CRITICAL AMOUNT OF TRANSIENTS BEING PRESENT (w) | 0.038 | | 0.038 |
| PROBABILITY OF TARGET EXPOSURE = ( $P_{fst}$ ) x (u) x (p) x (w) | 6.78E-05 | | 1.09E-04 |
| TRANSIENT COMBUSTIBLE IGNITION FREQUENCY | 2.26E-02 | | 2.26E-02 |
| PROBABILITY OF TARGET DAMAGE = ( Pfst ) x (u) x (p) x (w) x IGNITION FREQ. | 1.53E-06 | | 2.45E-06 |
| **TOTAL PROBABILITY OF TARGET DAMAGE** | | 3.99E-06 | |
| HIGHEST FIXED COMBUSTIBLE CCDF (for 240V Lighting transformer TL2A) | | 1.43E-03 | |
| **CORE DAMAGE FREQUENCY DUE TO TRANSIENT COMBUSTIBLES** | | 5.7E-09 | |
| CDF (radiant exposure surface area = 1000 $ft^2$) | | 7.70E-09 | |
| CDF (radiant exposure surface area = 2000 $ft^2$) | | 9.90E-09 | |
| CDF (radiant exposure surface area = 5000 $ft^2$) | | 1.60E-08 | |

## FIRE QUESTION 8 - NFPA COMPLIANCE OF AUTOMATIC SUPPRESSION SYSTEMS

*The failure probability for automatic suppression assumes values from the FIVE methodology. This data is acceptable for systems that have been designed, installed, and maintained in accordance with appropriate industry standards. such as those published by National Fire Protection Association (NFPA).*

*Please verify that automatic fire suppression systems at Browns Ferry meet NFPA standards. If not NFPA compliant, please revise the CDF estimates to reflect the actual reliabilities of the installed systems.*

### Response to Question 8

The BFN analysis takes credit for automatic suppression only for the Cable Spreading Room (CSR) (compartment16-2) fire scenario. Automatically actuated pre-action systems are provided in the CSR A and B. The systems are designed in accordance with NFPA-13-1991 and per guidelines provided in EPRI NP-2660 & NP-7332. The EPRI documents provide documentation of fire suppression tests conducted for grouped cable tray configurations. Use of quick response sprinkler heads spaced at a maximum of 10 ft. centers; design density of 0.3 $gpm/ft^2$ ; sprinkler heads located between racks of cable trays; sprinkler temperature rating of 160/165 $^0F$, etc. provide adequate suppression capability commensurate with the hazards in the area.

Units 2 and 3 reactor building have also been provided with NFPA code complying automatic sprinkler systems. However, for fire scenarios in the reactor buildings, no credit is taken for the automatic operation of the sprinkler systems. Smoke detector response and/or sprinkler activation response calculations were performed for information purposes only.

## FIRE Question 9 - FIRE SEVERITY FACTORS

*Fire severity factors were used in the analysis of many fire compartments in the fire assessment. No source is cited, and values were not typically specified for a given scenario. The severity factors were used in scenarios where fire suppression was credited. Since the potential for a large fire Is dependent upon fire suppression, there appears to be a significant possibility that the use of a fire severity factor, when fire suppression is explicitly modeled, takes double credit for suppression efforts.*

*For the scenarios where manual and/or automatic fire suppression and severity factors were credited, please explain why crediting both does not constitute redundant credit for suppression. Also, provide the bases for all the fire severity factors used in the study.*

### Response to Question 9

Fire severity factors have been used in the analysis of compartments where the "event tree" approach is used as described in response to question number 7. The factors have been used to define probabilities of:

a. minor and severe fires
b. success and failure of automatic suppression
c. success and failure of manual suppression

Minor and severe fires: A fire in any compartment usually starts by ignition of a single material or component. The frequency of this occurrence is addressed as the ignition frequency for that specific compartment. The fire can remain as a "minor" fire which does not require any manual or automatic means of suppression, or the fire can develop into a "severe" fire which does require manual or automatic means of suppression. Section 6.2.1 of the submittals describe the development of the fire severity factors. The purpose of the severity factors was to segment the ignition frequencies into "minor" and "severe" cases. In the development of fire severity factors, the adaptation of information from the EPRI fire events database (FEDB) specifically considered that any fire that was suppressed with hose streams or automatic suppression systems be addressed as a severe fire. In other words, the evaluations did not "double count" for those fires in the FEDB where manual suppression was provided by the fire brigade or actuation of the installed systems.

Success and failure of automatic suppression: As described above, only severe fires are likely to become fully developed fires. There is a chain of ignitions which could lead to fully developed conditions, and depending upon the fire resistance of the compartment boundaries, the fire could spread beyond the compartment. There is however, a chance (probability) that this chain could break at some stage due to automatic suppression or manual fire fighting before involving the entire compartment. The automatic suppression, if available in the compartment has a reliability of 95% or a non-suppression probability of 0.05 (References: EPRI TR-100370, Reference Table 3 for preaction systems; NSAC-179L ). Note that automatic suppression systems, where taken credit for, are installed to meet NFPA codes and industry standards. The systems are regularly tested for operability and performance at pre-defined intervals.

Success and failure of manual suppression: BFN has a dedicated on-site fire brigade. The fire brigade response time is within five to ten minutes of smoke/fire detection (based on observed fire drill response time) . A central fire alarm panel and color graphics monitor is located at the permanently manned fire brigade station. Therefore, there is no time delay due to notification from the control room. The prompt response time of the fire brigade ensures that electrical cabinet fires remain confined to the cabinet (15 minutes - EPRI TR-105928); cable tray fires remain confined to the initial tray (12 minutes - NUREG /CR5384); and exposure fires are extinguished before damaging the targets in most cases. Based on demonstrated manual response time and effectiveness, the probability of manual suppression not controlling the fire is conservatively assigned a value of 0.1 (EPRI TR-100370, Section 6.3.6.2).

Factors for non-suppression in the control room are discussed in response to question 2.

FIRE QUESTION 10 - FIRE PROAGATION SCENARIO IN CONTROL BUILDING EL 593 (FIRE COMPARTMENT 16-1)

*In the treatment of fires in fire compartment 16-1, the effect of CO2 fire suppression systems on the fire scenario frequency did not take into account the competition between the time required for suppression and the time required for damage or the time required for control room evacuation (see Section 6.2.6 in the Unit 2 submittal and Section 6.2.4 in the Unit 3 submittal). Delays in suppression may be significant and important to determining the scenario outcome.*

*Please re-examine the fire propagation scenarios in compartment 16-1. Include time-to-damage and time-to-suppress estimates in the evaluation of the CDF contribution from this compartment.*

Response to Question 10

Manually actuated $CO_2$ systems are installed in each of the three Auxiliary Instrument Rooms and the two Computer Rooms in fire compartment 16-1 (control building EL 593). These areas primarily house low voltage electrical cabinets. Automatic addressable smoke detectors (photo-electric) are installed in these rooms and meet the location and placement requirements of NFPA 72. These rooms have a relatively low ceiling height (12'); ceiling is beamed construction type (will trap smoke and heat); and detectors are located within beam pockets. All these features help early fire detection. Fire events experience with low voltage (250V or less) electrical fires indicates that these fires are slowly developing. Electrical cabinets are separated from each other by double walls and have some air gap. Fire is not expected to spread to an adjacent cabinet for at least 15 minutes (EPRI TR-105928, Appendix H). See Attachment 3 for smoke detector response time for the Auxiliary Instrument Room. Computer room response time will be similar. Electrical cabinet peak heat release rate is assumed to be 190 Btu/sec (as suggested in Q-4). However, calculations were also done at lower HRR to conservatively determine the smoke detector response time and also make sure that there will be no smoke stratification.

The following table depicts the results of the calculation in Attachment 3. Note that in most cases the fire brigade will be at the location well before fire spread to an adjacent cabinet (based on review of fire drills).

| Heat Release Rate Btu/sec | Smoke Detector Activation Time Sec | Fire Spread to Adjacent Cabinet Min | Fire Brigade Manual Response Min |
|---|---|---|---|
| 50 | 24 | 15 | 5-10 |
| 100 | 8 | 15 | 5-10 |
| 190 | 3 | 15 | 5-10 |

The above analysis shows that the time to detection and the time taken for manual response will limit the fire damage to the cabinet of origin. Therefore, the non-suppression probability of 0.1 in the analysis is justified. Control room evacuation is conservatively assumed for all severe fires that are not suppressed by either the manual actuation of the installed $CO_2$ system or by the fire brigade. This evaluation results in no change in the CDF contribution from this compartment.

FIRE QUESTION 11 - BASIS FOR SINGLE STUCK OPEN SRV IN CONTROL ROOM FIRE SCENARIO

*In the control room fire scenario, two cases were evaluated, each involving a single stuck-open safety/relief valve (SRV). Please provide the basis for selecting the number of stuck-open SRVs in fire scenarios.*

Response To Question 11

[Later]

FIRE QUESTION 12 - FIRE PROPAGATION FROM CABLE SPREADING ROOMS TO CONTROL ROOMS

*In the control building, fires were considered individually in each of three zones. Also, propagation into the middle zone (16-2) was considered, but not out of the middle zone to the overlying and underlying zones. Of particular interest is the scenario involving a fire which originates in the middle zone, containing the cable spreading room, and propagates to the overlying control room (16-3).*

*Please evaluate the contribution to the fire CDF from this scenario.*

Response to Question 12

Fire compartment 16-2, Cable Spreading Room (CSR) is located in the control building. It interfaces with the control rooms (16-3) above and below with series of rooms including auxiliary instrument rooms, computer rooms, etc. (16-1) and fire areas 17, 18 and 19. CSR is not separated from control rooms by fire rated barriers. However, as described in the submittal, the CSR ceiling construction provides substantial protection against spread of fire and smoke. Note that appropriate pressure seals are provided to maintain control room habitability. Cable spreading room presents a deep seated fire hazard scenario and therefore, a quick response and high density sprinkler system was designed for the area (refer to details in response to question 8). The CSR ceiling is of obstructed construction, i.e. construction where beams, trusses, or other members impede heat flow or water distribution in a manner that materially affects the ability of sprinklers to control or suppress a fire. Beams are approximately 30" deep and spaced approximately 8 ft. apart and therefore treated as separate spaces. Cross members provide additional obstruction forming deep pockets. The detection and suppression design considered all of these aspects. Smoke detectors and sprinkler are placed within the beam pockets to provide prompt detection capability and adequate spray pattern. Additionally, intermediate level sprinklers are installed in the flue space between stacks of cable trays (similar to protection of rack storage occupancies). Due to congestion of cable trays, two smoke detectors are placed within each beam pocket (37' x 8'). Sprinkler are spaced approximately 10' apart. Sprinkler and smoke detectors design meets the NFPA Code requirements.

Based on the above described ceiling construction and detector/sprinkler placement; smoke detector response and sprinkler activation time is calculated in Attachment 5. The HRR is assumed to be a slow growth fire.

The evaluation shows that for slow growing fires, time to reach 300 Btu/sec fire size (design objective to limit the fire to one or two trays) is 219 seconds, whereas time to detect and activate sprinklers is no more that 50 seconds. Therefore, it can be concluded that fires in the CSR can be detected and suppressed well before critical conditions are reached. Even for medium and fast developing fires the time to reach 300 Btu/sec is 164 seconds and 82 seconds respectively and the sprinkler system is expected to control such fires and prevent fires from propagating to the control rooms located above.

<u>FIRE QUESTION 13 - CONSIDERATION OF FIRES AFFECTING BOTH UNITS</u>

*Fires that could affect both Units 2 and 3 were not considered. The submittal indicates that some fire areas contain elements of both units. For multi-unit sites, there are three issues of potential interest. Hence, please answer the following:*

a. *A fire in a shared area might cause a simultaneous trip demand for more than one unit. This may considerably complicate the response of operators to the fire event, and may create conflicting demands on plant systems which are shared between units. Please provide the following information regarding this issue: (1) identify all fire areas that are shared between units and the potentially risk important systems/components for each unit that are housed in each such area, (2) for each area identified in (1) above, provide an assessment of the associated multi-unit fire risk, (3) for the special case of control rooms, assess the likelihood of a fire or smoke-induced evacuation with subsequent shutdown of both units from remote shutdown panels, and (4) provide an assessment of the CDF contribution of any such multi-unit scenario.*

b. *At some sites, the safe shutdown path for a given unit may call fbr cross-connects to a sister unit in the event of certain fires. Hence, the fire analysis should include the unavailability of the cross-connected equipment due to outages at the sister unit (e.g., routine in-service maintenance outages and/or the potential that normally available equipment may be unavailable during extended or refueling outages at the sister unit). Please provide the following relevant information regarding this issue: (1) indicate whether any fire response safe shutdown procedures call for unit cross-connects, and (2) if any such cross-connects are required, determine the impact on the fire CDF if the total unavailability of the sister unit equipment is included in the assessment.*

c. *Propagation of fire, smoke, and suppressants between fire zones containing equipment for one unit to fire zones containing equipment for the other unit also can result in multi-unit scenarios, Hence, the fire assessment for each unit should include analyses of scenarios addressing propagation of smoke, fire and suppressants to and from fire zones containing equipment for the other unit. From the information in the submittal, it is not clear if these types of scenarios are possible. Please provide an assessment of the contribution to the core damage frequency of any such multi-unit scenarios.*

Response to Question 13

[Later]

FIRE QUESTION 14 - MISCELLANEOUS ISSUES RELATED TO FIRE AREAS 12 & 13

*On page 76 of both submittals, fire areas 12 and 13 (shutdown board rooms F and E) were described as containing Division 1 and 2 essential switchgear separated by a three to four-foot wide walkway. The Unit 2 submittal describes these as 4 kV shutdown board rooms. Neither essential switchgear nor any 4 kV equipment were noted in the discussion of these areas in Sections 5 and 6 of the submittals. In the Unit 2 submittal, these areas were screened based on fire frequency alone.*

*In the Unit 3 submittal, screening of area 12 assumed an all-engulfing fire to determine a P2-value of 3.07x $10^{-3}$ (Table 5-5). The detailed analysis of this same area in Section 6 also assumed an all-engulfing fire scenario. However, the P2-value noted was 2.86 x $10^{-4}$ (Table 6-6). No reason for this difference was given.*

*Question 4 above (electrical cabinet heat release rate assumption) questions the assumptions that heat release rates will be small and that cabinets will prevent propagation of the fire and damage to surrounding equipment. Crediting electrical cabinets with the ability to contain damage can also be an optimistic assumption for high-voltage cabinets (480V and higher) since an explosive breakdown of the electrical conductors may breach the cabinet and allow fire and damage to spread. For example, switchgear fires at Yankee-Rowe in 1984 and Oconee Unit 1 in 1969 both resulted in fire damage outside the cubicles. In fire areas 12 and 13, the adequacy of separation of Divisions 1 and 2 essential switchgear by a three to four-foot wide walkway is also questioned.*

a. *For fire areas 12 and 13 of both units, please review the equipment inventory assumed in the fire study for equipment of the types discussed above. Please describe any corrections to the equipment list and fire frequency for these areas, (i.e., updates of the appropriate discussions in Section 5 of the submittals).*

b. *For any fire areas 12 or 13 left unscreened, please describe and develop any new scenarios (through to the contribution to the CDF) and update any scenarios already described in the submittals that result from Section 5 updates.*

c. *For any fire areas 12 or 13 left unscreened and containing multiple divisions of essential switchgear, please demonstrate the importance of the assumed confinement by the cabinet of fire and damage by dropping the assumption and estimating the effects of propagating fire and/or damage on the CDF estimates.*

Response to Question 14:

No reference could be found in the Unit 2 submittal indicating fire areas 12 and 13 to be 4kV shutdown board rooms. As shown in the equipment listing for Fire Area 12 on Page 5-14 of the Unit 2 submittal and Page 5-28 of the Unit 3 submittal, shutdown board rooms E and F contain 250VDC and 480VAC switchgear, but do not contain 4kV switchgear. As noted in the discussion, however, the 250VDC panel in this room supplies control power for 4kV shutdown boards 3EA and 3EC. These switchgears supply loads that are primarily dedicated to Unit 3 loads, such that the impact on Unit 2 operation is less significant than a fire related impact on one of the Unit 2 boards, which are located in shutdown board rooms A, B, C and D, respectively.

In Unit 3 submittal for fire area 12, the difference in P2 value of 3.07E-03 (Table 5-5) and P2 value of 2.86E-04 (Table 6-6) is due to the treatment of 120VAC I&C Bus 3B failure rate. The initial screening failed 120VAC I&C Bus 3B (Top Event DO), whereas, the detailed review considered this as a degraded failure (i.e. used Split Fraction DO3). The Unit 3 submittal (Page 6-49, above Table 6-6) states that "This case is similar to the initial screening evaluation, except that I&C bus 3B is not assumed to fail, only to lose power from sources that are located in this area." Further discussion of the basis for this change is provided under item (3) on Page 6-47 of the Unit 3 submittal. Note that 120VAC I&C Bus 3B is not located in this area, only one of its power sources.

For the Unit 2 submittal, these fire areas were screened at the initial level of quantification. This assumes that all equipment in the area is damaged by any fire in the area, which is similar to the "explosive breakdown of the electrical conductors" resulting in damage outside the cubicles case discussed above. In other words, the "assumed confinement" for this type of fire was not used.

In the case of the Unit 3 evaluation, since the equipment in these rooms are primarily devoted to Unit 3 operation, neither of these areas were screened at the initial level of quantification. The detailed evaluation of each of these areas is then described in Section 6.2.2 (Fire Area 12) and 6.2.3 (Fire Area 13). Several cases were developed in each of these sections. The intent was that the worst case would be similar to that shown in Section 5 (i.e. an "engulfing" fire, similar to the "explosive breakdown" case described by the reviewer).

The fraction of fires assigned to this case was 7.3% (i.e. 0.073) of the total fire ignition frequency for the affected area. The derivation of this factor is described in Section 6.2.1 of the Unit 3 report, which identified 18 of 245 fires for this type of area that were suppressed with hose streams or installed systems (i.e. a non-minor fire).

It should be noted that this evaluation only considers the fire severity factor for this type of area and does not address suppression. If all fires are considered as engulfing, the evaluation of fire areas 12 and 13 for Unit 3 would simplify to:

Fire Area 12: 6.97E-3 x 2.86E-4 = 1.99E-6
Fire Area 13: 6.87E-3 x 2.12E-4 = 1.46E-6

Though neither of these values is below the screening cutoff of 1E-6, both are within a factor of two of the cutoff and neither yet addresses suppression or fire severity. This treatment is judged to be overly conservative.

## FIRE QUESTION UNIQUE TO THE UNIT 3 SUBMITTAL

*In computing the extent of fire propagation and equipment damage for a given scenario, it is important that experimental results not be used out of context, Inappropriate use of experimental results (e.g. employing propagation times or assuming a fire spread geometry specific to a particular cable tray separation to fires involving cable trays with different separation) can lead to improper assessments of scenario importance. The Browns Ferry Unit 3 submittal assumes a fixed fire spread geometry (35") for at least one cable tray fire scenario, based on a single test. The submittal does not provide a basis for expecting the single experimental observation to be reproduced In the plant fire scenario.*

*For each fire scenario in which experimental data were used to estimate the rate and extent of fire propagation, please: (a) indicate if FIVE (or similar) calculations were performed for the scenario and provide the results (equipment damaged) of these calculations; (b) indicate which experimental results were used and how they were utilized in the analysis; and, (c) justify the applicability of these experimental results to the scenario being analyzed. The discussion of results applicability should compare the geometries, ignition sources, fuel type and loadings, ventilation characteristics, and compartment characteristics of the experimental setup(s) with those of the scenario of interest.*

### Response To The Fire Question Unique To Unit 3

This scenario will be re-examined neglecting the time delay in fire propagation and limited use of experimental information.

This fire scenario involves a dry type transformer as a fire source, and stack of cable trays as target located approximately 14" above the transformer. As noted in the submittal, plastic associated with the transformer windings is the only combustible source. There is no oil in the transformer. However, it is conservatively assumed that the cable trays will get involved in the transformer fire. The extent of vertical and horizontal fire propagation in cable tray is then determined to calculate the heat release rates. The FIVE methodology generally assumes that the width of the fire plume is the foot print of the fire source. Any component within the zone of the fire plume is considered damaged, or in this case ignited. Due to the uncertainty in the timing of fire propagation, it is conservatively assumed that the trays are involved almost immediately and therefore, no timing study is necessary. It is observed by review of some tests (NUREG/CR 5384) that the area of horizontal propagation spreads outwards at an angle of $35^0$. This observation was considered in determining the extent of the damage rather than just the foot print of the fire source. Therefore, the only experimental information used in this scenario is to determine the extent of outward spread of fire. This is conservative based on limited fire potential of the transformer and instantaneous involvement of all four cable trays.

The heat release rate (HRR) calculation remains unchanged. As shown in the submittal, the HRR calculation is based on guidance provided in the SFPE Handbook. A simple "zone" fire model (Fastlite 1.1.2 by NIST) was used to run this case. Fastlite uses a two-zone method to calculate fire growth. Each zone is assumed to have uniform properties such as temperature, heat flux, gas concentration, etc. See Attachment 4 for the results of this calculation. A much smaller floor area was considered in the analysis; the fire was considered unconstrained and the peak HRR of 475 Btu/sec was assumed to occur within 100 seconds. Note that FIVE methodology cannot be used to predict fire propagation and COMPBRN does not adequately model fire propagation in cable trays.

The results of the calculation show that the upper layer (hot gas) temperatures of 320 $^0$F are well below the damage threshold of the cables.

## HIGH WINDS, FLOODS, AND OTHER EXTERNAL EVENTS QUESTIONS ON UNITS 1, 2, AND 3

[Later]

# ATTACHMENTS

**Compartment Fires ( Pre-flashover Temperatures )**
Pre-flashover temperatures in compartments can be calculated using the method of MQH for naturally ventilated fires: (SFPE Handbook 2nd Edition, page 3-139, Equation 12)

$$\Delta T_g = 6.85\left(\frac{Q^2}{A_0\sqrt{H_0}\,h_k\,A_T}\right)^{1/3}$$

Where:

- Q = heat release rate, kW
- Ao = area of opening, sq. m
- Ho = opening height, m
- $h_k$ = effective heat transfer coefficient, kW/m.K
- $A_T$ = total area of interior compartment surfaces, sq. m
- $\Delta T_g$ = upper gas layer temperature rise above ambient, K

**Effective Heat Transfer:**

$$h_k = \frac{k}{\delta} for(t > t_p)$$

$$h_k = \left(\frac{k\rho c}{t}\right)^{1/2} for(t \le t_p)$$

**Thermal Penetration Time:**

$$t_p = \left(\frac{\rho c}{\kappa}\right)\left(\frac{\delta}{2}\right)^2$$

Where:

$$\rho = density(kg / m^{3)}$$

$$c = SpecificHeat(kW / m * K)$$

$$\delta = Thickness(m)$$

$$t = ExposureTime(s)$$

$$k = ThermalConductivity(kW / m * c)$$

Browns Ferry Nuclear Plant - IPEEE
Alternate Method to Calculate Compartment Temperatures



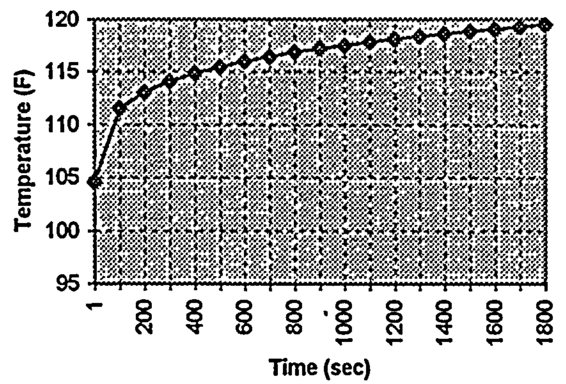
| | Thickness (m) | t (sec) | k | $\rho$ | c | $t_p$ | $h_k\ for(t > t_p)$ | $h_k\ for(t \le t_p)$ |
|---|---|---|---|---|---|---|---|---|
| Concrete(12") | 0.305 | 1800 | 1.40E-03 | 2000 | 0.88 | 29236 | 0.005 | 0.037 |

| Time (sec) | Concrete $h_k$ | Compt. Temp (K) | Compt. Temp (F) |
|---|---|---|---|
| 1 | 1.570 | 313 | 105 |
| 100 | 0.157 | 317 | 111 |
| 200 | 0.111 | 318 | 113 |
| 300 | 0.091 | 319 | 114 |
| 400 | 0.078 | 319 | 115 |
| 500 | 0.070 | 319 | 115 |
| 600 | 0.064 | 320 | 116 |
| 700 | 0.059 | 320 | 116 |
| 800 | 0.055 | 320 | 117 |
| 900 | 0.052 | 320 | 117 |
| 1000 | 0.050 | 320 | 117 |
| 1100 | 0.047 | 321 | 118 |
| 1200 | 0.045 | 321 | 118 |
| 1300 | 0.044 | 321 | 118 |
| 1400 | 0.042 | 321 | 119 |
| 1500 | 0.041 | 321 | 119 |
| 1600 | 0.039 | 321 | 119 |
| 1700 | 0.038 | 321 | 119 |
| 1800 | 0.037 | 322 | 119 |

**DATA:**

| | |
|---|---|
| Heat Release Rate (Q), kW | 200 |
| Area of Opening (Ao), $m^2$ = | 25 |
| Opening Height (Ho), m = | 5 |
| *Total area of surfaces, ( $A_T$) $m^2$ = | 4000 |

**Compartment temperature**




*Note: Total area of surfaces includes the floor area. If floor area is ignored, the compartment temperature will be 123 $^0$F.

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 565 | | |
| Equipment | 480V RMOV Board 2C | | |
| Floor Area | $ft^2$ | 16500 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 22 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 190 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 307 | $T_c$-$T_a$-$T_{hgl-Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **8.7** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 76.0 | $Q_{eff}$-Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.5** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 372000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 111600 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 363000 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.31 | |
| HGL Temperature Increase ($T_{hgl-Incr}$) | F | 18 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **118** | Ta+HGL Temp Incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 565 | | |
| Equipment | 480V RB Vent Board 2B | | |
| Floor Area | $ft^2$ | 16500 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0F$) | 100 | <-User Input |
| Critical Radial Flux to Target | $Btu/s/ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0F$) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 22 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 190 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0F$) | 305 | $T_c$-$T_a$-$T_{hgl-Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **8.7** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 76.0 | $Q_{eff}$*Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.5** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 408000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 122400 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 363000 | |
| Calculated Qnet/V | $Btu/ft^3$ | 0.34 | |
| HGL Temperature Increase ($T_{hgl-Incr}$) | F | 20 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **120** | Ta+HGL Temp Incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 565 | | |
| Equipment | 250V RMOV Board 2C | | |
| Floor Area | $ft^2$ | 16500 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 22 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 190 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 298 | $T_c$-$T_a$-$T_{hgl\text{-}Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **8.8** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 76.0 | $Q_{eff}$·Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.5** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 544000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 163200 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 363000 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.45 | |
| HGL Temperature Increase ($T_{hgl\text{-}Incr}$) | F | 27 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **127** | Ta+HGL Temp incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 565 | | |
| Equipment | Drywell Torus Compressor | | |
| Floor Area | $ft^2$ | 16500 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 22 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 450 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 450 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 318 | $T_c$-$T_a$-$T_{hgl\text{-}Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **12.0** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 180.0 | $Q_{eff}$*Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **5.4** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 145000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 43500 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 363000 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.12 | |
| HGL Temperature Increase ($T_{hgl\text{-}Incr}$) | F | 7 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **107** | Ta+HGL Temp Incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 593 | | |
| Equipment | 480V RMOV Board 2D | | |
| Floor Area | $ft^2$ | 12800 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 22 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 190 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 295 | $T_c$-$T_a$-$T_{hgl\text{-}Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **8.9** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 76.0 | $Q_{eff}$·Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.5** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 462000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 138600 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 281600 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.49 | |
| HGL Temperature Increase ($T_{hgl\text{-}Incr}$) | F | 30 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **130** | Ta+HGL Temp incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 593 | | |
| Equipment | Unit 2 Preferred AC Transformer | | |
| Floor Area | $ft^2$ | 12800 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0F$) | 100 | <-User Input |
| Critical Radial Flux to Target | $Btu/s/ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0F$) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 22 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 224 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 224 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0F$) | 307 | $T_c$-$T_a$-$T_{hgl\text{-}Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **9.2** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 89.6 | $Q_{eff}$·Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.8** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 280000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 84000 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 281600 | |
| Calculated Qnet/V | $Btu/ft^3$ | 0.30 | |
| HGL Temperature Increase ($T_{hgl\text{-}incr}$) | F | 18 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **118** | Ta+HGL Temp Incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 593 | | |
| Equipment | RBCCW Pump 2A/2B | | |
| Floor Area | $ft^2$ | 12800 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 22 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 30 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 30 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 320 | $T_c$-$T_a$-$T_{hgl\text{-}Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **4.0** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 12.0 | $Q_{eff}$*Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **1.4** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 75000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 22500 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 281600 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.08 | |
| HGL Temperature Increase ($T_{hgl\text{-}Incr}$) | F | 5 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **105** | Ta+HGL Temp Incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 621 | | |
| Equipment | 480V RMOV Board 2E | | |
| Floor Area | $ft^2$ | 9640 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 13 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 4 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 760 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 302 | $T_c$-$T_a$-$T_{hgl\text{-}Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **15.2** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 304.0 | $Q_{eff}$-Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **7.0** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 163000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 48900 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 125320 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.39 | |
| HGL Temperature Increase ($T_{hgl\text{-}Incr}$) | F | 23 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **123** | Ta+HGL Temp Incr. |

The above fire source will create a ceiling jet sublayer extending ________ from the source.

(damage threshold elevation exceeds the ceiling height)

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 621 | | |
| Equipment | MG Sets 2DN and 2EA | | |
| Floor Area | $ft^2$ | 9640 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 13 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 112 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 112 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 284 | $T_c$-$T_a$-$T_{hgl-Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **7.3** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 44.8 | $Q_{eff}$·Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **2.7** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 280000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 84000 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 125320 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.67 | |
| HGL Temperature Increase ($T_{hgl-Incr}$) | F | 41 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **141** | Ta+HGL Temp Incr. |

| Location: | Reactor Building, Unit 2, EL 621 | | |
|---|---|---|---|
| Equipment | 4KV-480V Transformer | | |
| Floor Area | $ft^2$ | 9640 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0F$) | 100 | <-User Input |
| Critical Radial Flux to Target | $Btu/s/ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0F$) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 13 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 112 | <-User Input |
| Location factor (LF) | | 2 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 224 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0F$) | 284 | $T_c$-$T_a$-$T_{hgl\text{-}Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **9.7** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 89.6 | $Q_{eff}$·Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.8** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 280000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 84000 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 125320 | |
| Calculated Qnet/V | $Btu/ft^3$ | 0.67 | |
| HGL Temperature Increase ($T_{hgl\text{-}Incr}$) | F | 41 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **141** | Ta+HGL Temp incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 621 | | |
| Equipment | 2-LPNL-025-0031 | | |
| Floor Area | $ft^2$ | 9640 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 13 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 190 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 225 | $T_c$-$T_a$-$T_{hgl-Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **10.4** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 76.0 | $Q_{eff}$·Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.5** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 653000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 195900 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 125320 | |
| Calculated Qnet/V | Btu/$ft^3$ | 1.56 | |
| HGL Temperature Increase ($T_{hgl-Incr}$) | F | 100 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **200** | Ta+HGL Temp Incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 621 | | |
| Equipment | 4KV RPT Boards 2-1 / 2-2 | | |
| Floor Area | $ft^2$ | 9640 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 13 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 190 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 284 | $T_c$-$T_a$-$T_{hgl-Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **9.1** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 76.0 | $Q_{eff}$·Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.5** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 280000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 84000 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 125320 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.67 | |
| HGL Temperature Increase ($T_{hgl-Incr}$) | F | 41 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **141** | Ta+HGL Temp incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 639 | | |
| Equipment | MG Sets 2DA and 2EN | | |
| Floor Area | $ft^2$ | 8600 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0F$) | 100 | <-User Input |
| Critical Radial Flux to Target | $Btu/s/ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0F$) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 18 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 112 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 112 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0F$) | 292 | $T_c$-$T_a$-$T_{hgl-Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **7.2** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 44.8 | $Q_{eff}$*Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **2.7** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 280000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 84000 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 154800 | |
| Calculated Qnet/V | $Btu/ft^3$ | 0.54 | |
| HGL Temperature Increase ($T_{hgl-Incr}$) | F | 33 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **133** | Ta+HGL Temp incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 639 | | |
| Equipment | LPNL-25-23 and 24 | | |
| Floor Area | $ft^2$ | 8600 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0F$) | 100 | <-User Input |
| Critical Radial Flux to Target | $Btu/s/ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0F$) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 18 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 190 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0F$) | 249 | $T_c$-$T_a$-$T_{hgl-Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **9.8** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 76.0 | $Q_{eff}$·Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.5** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 630000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 189000 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 154800 | |
| Calculated Qnet/V | $Btu/ft^3$ | 1.22 | |
| HGL Temperature Increase ($T_{hgl-Incr}$) | F | 76 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **176** | Ta+HGL Temp Incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 639 | | |
| Equipment | 240V Lighting Board 2B | | |
| Floor Area | $ft^2$ | 8600 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 18 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 190 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 190 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 312 | $T_c$-$T_a$-$T_{hgl\text{-}Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **8.6** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 76.0 | $Q_{eff}$*Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **3.5** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 112000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 33600 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 154800 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.22 | |
| HGL Temperature Increase ($T_{hgl\text{-}Incr}$) | F | 13 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **113** | Ta+HGL Temp Incr. |

| | | | |
|---|---|---|---|
| Location: | Reactor Building, Unit 2, EL 639 | | |
| Equipment | SLC Pumps A and B (oil) | | |
| Floor Area | $ft^2$ | 8600 | <-User Input |
| Maximum Ambient Temperature (Ta) | ($^0$F) | 100 | <-User Input |
| Critical Radial Flux to Target | Btu/s/$ft^2$ | 0.5 | <-User Input |
| Radiant Fraction of Heat Release | | 0.4 | <-User Input |
| Critical Damage Temperature (Tc) | ($^0$F) | 425 | <-User Input |
| Height from Fire Source to Ceiling, H | ft | 18 | <-User Input |
| Fire heat release rate (Q) | Btu/sec | 450 | <-User Input |
| Location factor (LF) | | 1 | <-User Input |
| Effective heat release rate ($Q_{eff}$) | Btu/sec | 450 | Q*LF |
| Critical temperature rise $(\Delta T)_{crit}$ | ($^0$F) | 292 | $T_c$-$T_a$-$T_{hgl-Incr}$ |
| **Damage Threshold Elevation ($Z_{crit}$)** | **ft** | **12.6** | Equation 1 & 2 |
| Radiant Heat Release rate | Btu/s | 180.0 | $Q_{eff}$*Radiant Frac. |
| **Critical Radial Flux to Distance** | **ft** | **5.4** | (Equation 5) |
| Total Heat (Qtot to HGL) | Btu | 280000 | <-User Input |
| Estimated Heat Loss Fraction (HLF) | | 0.70 | <-User Input |
| Calculated Qnet | Btu | 84000 | $Q_{tot}$ (1-HLF) |
| Calculated Enclosure Volume, V | $ft^3$ | 154800 | |
| Calculated Qnet/V | Btu/$ft^3$ | 0.54 | |
| HGL Temperature Increase ($T_{hgl-Incr}$) | F | 33 | Equation 3 and 4 |
| **Hot Gas Layer Temp. ($T_{hgl}$)** | **F** | **133** | Ta+HGL Temp Incr. |

## REFERENCED EQUATIONS

$$\Delta T(^{0}F) = 340 \frac{Q_{eff}^{2/3}(btu/\sec)}{H_{target}^{5/3}(ft)} \qquad \text{............(1)}$$

$$Zcrit = 33 \frac{Q_{eff}^{2/5}}{\Delta T_{crit}^{3/5}} \qquad \text{...........(2)}$$

$$\Delta T = T_0 \left[ e^{(Q_{net}/V \rho_0 C_p T_0)} - 1 \right] \qquad \text{.............(3)}$$

$$Q_0 = \rho_0 T_0 C_p V = 0.071 * 0.24 * 560 * V = 9.54V \qquad \text{...................(4)}$$

$$R_{crit} = \sqrt{\frac{Q_{rad}}{4\Pi q_{crit}}} \qquad \text{.................(5)}$$

## SMOKE DETECTOR ACTIVATION AND SMOKE STRATIFICATION

The upward movement of the smoke in the plume is dependent on the smoke being buoyant relative to the surroundings. Given the physical configuration (fire sources and detector location), following correlations can be used to determine the time to detector actuation and smoke stratification possibility.

References:

1. NFPA 72, Fire Alarm and Detection System.
2. NFPA 92 B, Smoke Management Systems.
3. Fire technology, Aug 1990, Smoke management of Covered Malls and Atria.
4. Fire technology, May 1991, Letters to editor

<u>Ceiling Mounted Smoke Detector Response</u>

For radius-to-ceiling height ratios less than approximately 0.6, the temperature rise of the smoke can be estimated as function of time based on theoretical generalizations of the limited amount of experimental data. For X < 100:

$$X = 4.6*10^{-4}Y^2 + 2.7*10^{-15}Y^6$$

where:

$$X = tQ^{1/3} / H^{4/3}$$

$$Y = DT*H^{5/3} / Q^{2/3}$$

and where:

t = time from ignition (sec)
Q = heat release rate (steady fire) (Btu/sec)
H = ceiling height above fire surface (ft)
DT = Temperature rise of gasses within ceiling jet ($^0$F)

<u>Stratification of Smoke</u>

Assuming the ambient temperature increases linearly with increasing elevation, the maximum rise of of the plume is dependent on the convective portion of the heat release rate of the fire and temperature change from floor to ceiling.

$$H_{max} = 74Q_c^{2/5}DT_0^{-3/5}$$

where:

$Q_c$ = Convective portion of the heat release rate (Btu/sec) (approximately 70% of total heat release rate)
$DT_0$ = difference between ambient temp. at ceiling and ambient temp. at the level of fire surface ($^0$F)

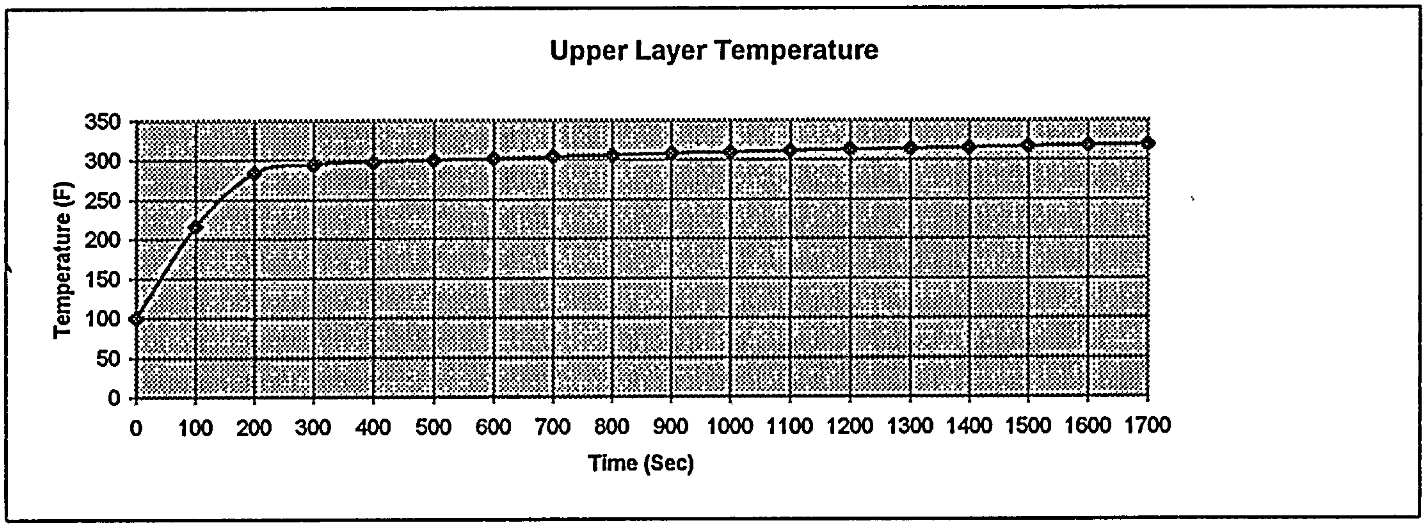
| **Description:** | **Data** |
|---|---|
| Height (H): | 12 |
| Temperature rise within ceiling jet (DT) (Temp. rise required for smoke detector activation): | 18 |
| Heat release rate (Q): | 50 |
| Difference between ambient temp. at ceiling and ambient temp. at the level of fire surface ($DT_0$): | 30 |
| Convective heat release rate ($Q_c$) (Q*0.7): | 35 |

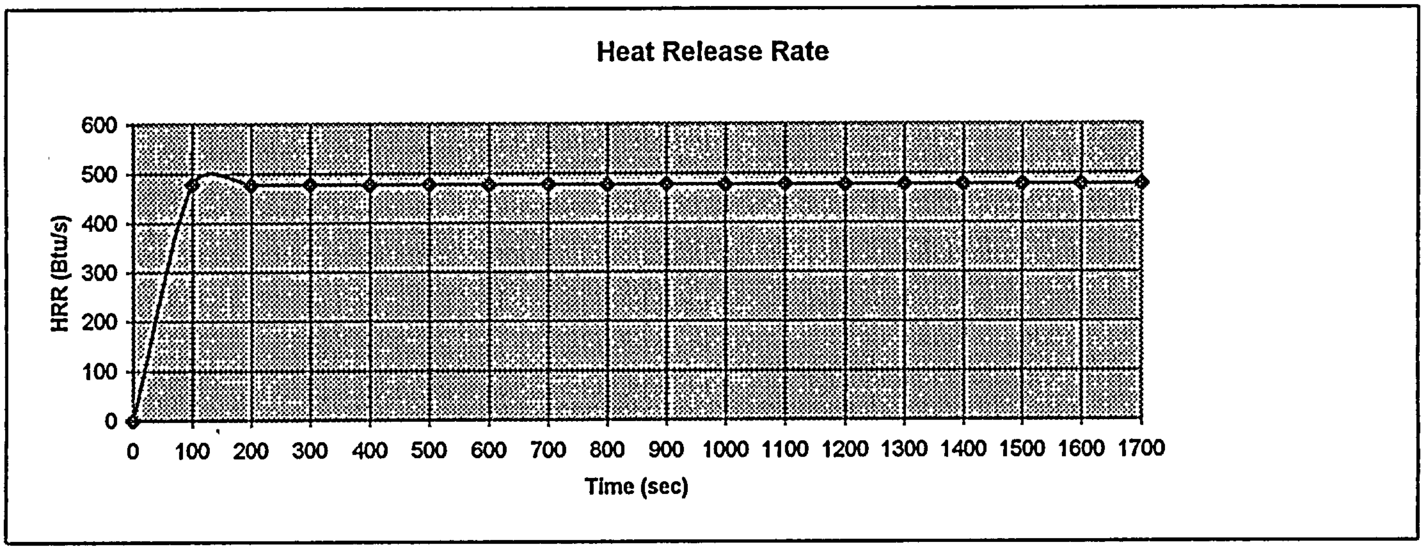
Y = 83.42
X = 3.20
**Activation time for smoke detector (t) = 24 Seconds**

**Maximum Smoke Height ($H_{max}$) = 40 Feet**
(Activation time @Q=100 Btu/s is 8 sec; @190 Btu/s is 3 sec)
**Fire Brigade manual Response = 5 to 10 Minutes** (Based on Fire Drills)
**Fire Damage to Adjacent Cabinet = 15 Minutes** (Based on Industry Tests)

***Reactor Building, Unit 3, El 621***
**4KV-480V Transformer 0-FXA-266-OTHB**

| INPUT DATA: | | RESULTS | | |
|---|---|---|---|---|
| | | TIME | HRR | Upper Layer Temp |
| Floor Area | 625 $ft^2$ | sec | BTU/s | F |
| Height | 15 ft | 0 | 0 | 100 |
| Horiz. Openings | 5' W x5' H | 100 | 475 | 216 |
| Vert. Openings | None | 200 | 475 | 285 |
| Peak HRR | 475 Btu/s | 300 | 475 | 294 |
| Heat of Combustion | 20000 Btu/lb | 400 | 475 | 298 |
| | | 500 | 475 | 300 |
| Unconstrained Fire | | 600 | 475 | 302 |
| | | 700 | 475 | 304 |
| | | 800 | 475 | 306 |
| | | 900 | 475 | 308 |
| | | 1000 | 475 | 310 |
| | | 1700 | 475 | 320 |



# CABLE SPREADING ROOM FIRE PROPAGATION ANALYSIS

A fire in the CSR is expected to be *slow* growing at least initially, and if not controlled may become *medium* or *fast* growing fire. It is intended to detect and suppress the fire while still in the slow growth phase. A slow growth fire is defined as a fire which takes 400 or more seconds from the time established burning takes place until the fire reaches a HRR of 1000 Btu/sec. If the fire has to be limited to a maximum of 300 Btu/s (design objective); i.e the fire may have caused limited damage to one or two cable trays, the time to detection and suppression can be evaluated. The following calculation evaluates if the design objective is met by the installed fire suppression and detection systems:

Input Parameters (metric units)

| | | | |
|---|---|---|---|
| Ceiling Height (m): | | 3.1 | 10.0 ft |
| Ambient Temp. (C) | | 20 | |
| Growth Time (s) | | 400 | (slow fire) |
| HRR (KW) | | 1055 | (1000 Btu/sec reached in 400 sec) |
| Power Law "p" | | 2 | |
| HRR (KW) | | 315 | (Design objective to limit fire size to 300 Btu/sec) |
| Radial distance to Detector (r) m | | 3.4 | 11.0 ft |
| Radial distance to Sprinkler (r) m | | 1.54 | 5.0 ft |
| Height of Ceiling Above Fire (H) m | | 2.47 | 8.0 ft |

Slow Fire Intensity Coefficient

$$\dot{Q}(kW) = \alpha(kW/s^2)t^p(s)........Equation 1$$

$\alpha$ = 0.0066 kW/s$^2$

Time to Reach 315 kW (300 Btu/sec)

$$t(\text{sec}) = \sqrt{\frac{Q}{\alpha}}..............Equation 2$$

t (sec) = 219 Sec

Lag Time Associated with Fire Detection

The total lag time ($Lag_{plume} + Lag_{ceiling\ Jet}$) can be calculated as follows:
(Mowrer, F.W.,"Lag times associated with suppression and detection", Fire Technology, Vol 26, No 3, 1990)

$$t = \frac{(1.4r + 0.2H)}{(0.028\alpha H)^{1/5}}...........Equation 3$$

t (sec) = 24 Sec

Time to Detection (English Units)
(See Attachment 4 for References and associated information)

| Description: | Data |
|---|---|
| Height (H): | 10 |
| Temperature rise within ceiling jet (DT) (Temp. rise required for smoke detector activation): | 18 |
| Heat release rate (Q): | 300 |
| Convective heat release rate ($Q_c$) (Q*0.7): | 210 |

Y = 18.64
X = 0.16
**Activation time for smoke detector (t) = 1 Seconds**

Time for Sprinkler Activation

| | Data |
|---|---|
| Length (radial distance) of sprinkler from fire source centerline (L) ft. | 5 |
| Width (Distance between beams) (W) ft. | 8 |
| Distance from fire source to ceiling (H) ft | 8 |
| Detector (sprinkler) actuation temperature (Td) ($^0$F) | 165 |
| Time Constant (TC) seconds (Ref: Table A-6E, EPRI FIVE Document for Quick Response) | 30 |
| Heat release rate (Q) Btu/sec (design Objective) | 300 |
| Plume temperature rise ($^0$F) (Equation 2) | 476 |
| Ceiling Jet temperature rise factor at sprinkler (Ref: Table 6A/6B EPRI FIVE Document) | 0.4 |
| Ambient Temperature ($^0$F) | 100 |
| Temperature rise at target ($^0$F) | 190 |
| Temperature at target ($^0$F) | 290 |

$$\frac{t_d}{\tau} = -\ln\left[1 - \frac{(Td - Ta)}{(Tg - Ta)}\right] \ldots\ldots\ldots\ldots\ldots Equation 1$$

$$\Delta T(^0F) = 340 \frac{Q_{eff}^{2/3}(btu/\sec)}{Z_{ceil}^{5/3}(ft)} \ldots\ldots\ldots\ldots Equation 2$$

$t_d / \tau$ = (dimensionless actuation time, Equation 1) 0.42

**Estimated time for sprinkler actuation ($t_d$) (seconds) 13**

Conclusion
The above evaluation shows that for slow growing fires, time to reach 300 Btu/sec fire size is 219 seconds, whereas time to detect and activate sprinklers is no more that 50 seconds. Therefore, it can be concluded that fires in the CSR can be detected and suppressed well before critical conditions are reached. Even for medium (300 sec) and fast (150 sec) developing fires the time to reach 300 Btu/sec is 164 seconds and 82 seconds. The sprinkler system is expected to control such fires.