19M Fire Protection Probabilistic Risk Assessment

19M.1 Introduction

As part of the Advanced Boiling Water Reactor (ABWR) design certification process, the USNRC requested that General Electric expand upon earlier considerations of the subject of fire risk. Through discussions with the NRC it was mutually agreed that a fire screening analysis approach was appropriate. It was further agreed that the Fire Vulnerability Evaluation (FIVE) Methodology Plant Screening Guide (Reference 19M-1) being developed by the Electric Power Research Institute (EPRI) provided an appropriate vehicle for performing this analysis.

The FIVE methodology provides procedures for identifying fire compartments for evaluation purposes, defining fire ignition frequencies, and performing quantitative screening analyses of fire risk. The criterion for screening acceptability is that the risk of core damage from any postulated fire be less than an acceptably small criterion. Any fire scenarios not meeting this criterion require more detailed consideration.

Five bounding fire scenarios and corresponding ignition frequencies were developed on the basis of the FIVE methodology. The first three of these consider the impact of fires which incapacitate each of the three divisions of emergency power, and thus the ECCS equipment which is dependent on each for successful performance. The fourth scenario considers the impact of a fire in the control room with the assumption that the only ECCS functions available are those that can be controlled and operated from the remote shutdown panel, and the RCIC, which can be manually operated outside of the control room. The fifth and final scenario examines the consequences of a fire in the turbine building based upon the assumption that resulting loss of off-site power bounds the possible outcomes of this initiator.

19M.2 Basis of the Analysis

This analysis is prepared with Figures 5.1 and 6.0 and related text sections from the FIVE Methodology Draft Report as the basis. In performing this analysis the ABWR was broken into three major groupings as follows:

(1) A safety-related building grouping consisting of the reactor building except primary containment, control building except the control room complex, and the intake structure. This grouping contains all of the equipment required for safe shutdown except that within primary containment and the control room complex. The buildings are subdivided by three hour rated fire barriers into fire areas corresponding to the safety divisions. Each division is considered as a unit, although each division encompasses several fire areas in three buildings. For these groupings, it is conservatively assumed that a fire at any location in a divisional fire area results in the immediate loss of function of the division. This precludes having to calculate the rate of spread and possible magnitude of a fire within a fire area. The requirement

that the fire contain- ment system be capable of confining any fire within the fire area of origin is documented in Subsection 9.5.1.

(2) Control room complex—The control room complex contains safety-related equipment from all four divisions in a single fire area and therefore must be uniquely analyzed. The redundant system to the control room is the remote shutdown panel. For the purposes of this analysis, remote manual operation of the RCIC system is also included as a method of mitigation.

(3) Turbine building—As documented in Subsection 9A.5.5.1, fire induced failure of the small amount of safety-related sensors located in this building cannot prevent safe shutdown of the plant. The turbine building is included in the analysis because a turbine building fire could result in a plant shutdown concurrent with a loss of off site power.

19M.3 Summary of Results

All three major groupings were determined to be “Significant Fire Areas” by the screening procedures outlined in FIVE Methodology Figure 5.1, which is included as Figure 19M-1. They were then screened out by the Step 2 path of the procedures outlined in FIVE Figure 6.0, which is included as Figure 19M-2, on the basis that:

(1) The product of the Fire Ignition Frequency and the probability that the redundant or alternate systems would not be available was less than the acceptance criteria.

(2) The redundant or alternate systems for which credit was taken are in fire areas other than the one experiencing the fire and therefore the fire cannot affect the redundant or alternate systems. Fire areas are separated by three hour fire rated barriers.

Results of the analysis are that the core damage frequencies per year are less than the acceptance criteria for all cases. Originally, the remote shutdown panel included controls for just three safety-relief valves. For this configuration, the core damage frequency for a fire in the control room was greater than the acceptance criteria, even though credit was taken for local manual operation of the RCIC (See Subsection 19.9.12 for COL license information). A control switch for a fourth SRV was added to the remote shutdown panel. This dropped the probability of core damage for a control room fire to less than the acceptance criteria. This is considered a very conservative estimate because of the conservative assumptions that a fire in one area disables all potentially affected equipment. Taking credit for the distance between fire sources and targets would reduce the core damage probability to a fraction of the calculated low probability. For this reason, it was judged not appropriate to add these results to other core damage frequencies estimated elsewhere in Chapter 19.

The analyses required to calculate the fire ignition frequencies and combine them with the PRA models are included in Subsections 19M.4 through 19M.6.

19M.4 Phase I Scenario and Phase II Fire Frequency Analysis

This analysis is prepared with Figures 5.1 and 6.0 from the FIVE Methodology Draft Report as the basis. Subsections of the analysis bear the titles of the applicable FIVE Methodology sections or the applicable blocks from the FIVE Methodology figures, flagged with "(FIVE)" for identification. The subsections detail the method of compliance or source of information requested by the block.

19M.4.1 Phase I Qualitative Analysis (FIVE)

19M.4.1.1 Identify Plant Fire Areas (FIVE, Use Table 1 Matrix)

For the purpose of this analysis the ABWR has been broken into three major groupings as follows:

(1) A safety-related building grouping consisting of the reactor building except primary containment, control building except the control room complex, and the intake structure. This grouping contains all of the equipment required for safe shutdown except that within primary containment and the control room complex. The buildings are subdivided by rated fire barriers into fire areas corresponding to the safety divisions. Each division is considered as a unit, although each division encompasses several fire areas in three buildings. For these groupings, it is assumed that a fire at any location in a divisional fire area results in the immediate loss of function of the division.

The assumption of the immediate loss of function for the division is a conservative adaptation of the FIVE methodology and makes it unnecessary to calculate the rate of fire growth and spread within a fire area, provided the results of the analysis confirm that the probability of the redundant/alternate systems being unavailable is less than the acceptance criteria.

(2) Turbine building—As documented in Subsection 9A.5.5.1, fire induced failure of the small amount of safety-related sensors located in this building cannot prevent safe shutdown of the plant. The turbine building is included in the analysis because a turbine building fire could result in a loss of off site power and/or a plant shutdown.

(3) Control room complex—The control room complex contains safety-related equipment from all four divisions in a single fire area and therefore must be uniquely analyzed. The redundant system to the control room is the remote shutdown panel. For the purposes of this analysis, remote manual operation of the RCIC system is also included as a method of mitigation.

Primary containment was determined to not be a significant fire area because:

(1) It is inerted during plant operation.

(2) A fire in containment cannot prevent safe shut- down of the plant. (Subsection 9.5.1.0.2.)

(3) The containment spray system could serve as a fire suppression system if the need did arise.

(4) The FIVE Analysis excluded the containment.

The equipment in primary containment was included in the probabilistic failure models as required to support safe shutdown, however.

Fire in non safety-related buildings other than those listed above was not considered as the buildings are separated from the equipment required for safe shutdown by three hour rated fire barriers. Therefore, fire in the non safety-related buildings cannot prevent safe shutdown.

A table of fire areas for the safety related buildings (reactor and control) is provided as Table 9A.6-1. The fire areas listed on the table are as shown on the fire area separation drawings, Figures 9A-1 through 9A-18. Except as described above for the control complex and primary containment, fire areas are assigned to specific safety divisions.

As stated above, screening of the fire areas is on a grouped basis. A fire in any one of the grouped fire areas is assumed to result in the immediate loss of function for the equipment of the division of the grouped area, and screening is on that basis. For example, all of the Division 1 fire areas are screened as a group because it is possible for a fire to occur at any location in the Division 1 fire area and the fire is assumed to result in immediate failure of Division 1 for purposes of evaluating the effects on safe shutdown.

The relative location of the fire areas has been specified such that there should be no reason for the detail designer to route piping or cable trays of non-conforming divisions though divisional fire areas. It is an interface requirement (Subsection 9.5.13.12) that the utility confirm that the routing of piping and cable trays during the detailed design phase conforms with the fire area divisional assignment documented in the fire hazard analysis.

19M.4.1.2 List Safe Shutdown Systems (FIVE, Use Table 1 Matrix)

In this conservative analysis, credit is taken for only safety-related systems for accomplishing safe shutdown. Not all safety-related systems are safe shutdown systems. A differentiation is not made, however, as a fire involving a safety-related system not required for safe shutdown could result in the loss of a divisional power supply common to the safety-related system required for safe shutdown. Rather than analyzing all possible interactions between systems within a division, the worst case is assumed. Therefore, damage to any safety-related system is considered to have the possibility of affecting a system required for safe shutdown during a fire situation. Safety-related equipment is identified by a 1, 2, 3, or 4 in the “Electrical Division” column of Table 9A.6-1. The system identification is included in the master parts list number shown on the table.

The acceptability of possible spurious operation (e.g. motors randomly starting or stopping, valves randomly opening and closing, etc.) was also addressed and found acceptable as a result of the analysis for uncontrolled acts by an inside saboteur. The results of the study is provided in Appendix 19C.

19M.4.1.3 Identify Safe Shutdown Systems in Each Fire Area (FIVE, Use Table 1 Matrix)

The devices are sorted by system for each room on Table 9A.6-2. The safety division and room number are also shown on the table. This allows cross comparison of the table and the fire separation drawings to determine what systems are in each fire area. A column listing the fire area for each device will be added to the table so that cross reference to the fire protection drawings is not required to determine the fire area for each piece of equipment.

19M.4.1.4 Shutdown Equipment In Fire Area (FIVE)

If there is safety-related equipment in any fire area, it is assumed that either the equipment is required for safe shutdown or its loss by fire could affect equipment required for safe shutdown. The answer for this block is assumed to be “yes” if there is safety-related equipment in the area.

19M.4.1.5 Fire Causes Demand For Safe Shutdown Equipment (FIVE)

It is assumed that accomplishment of safe shutdown must be possible with a fire at any location in the plant. This block is always “yes”.

19M.4.1.6 Significant Fire Areas (FIVE)

The above screens confirm that the reactor building except primary containment, the control building except the control room complex, the intake structure, the turbine building and the control room complex should be termed to be “significant fire areas”. They must be subjected to the screening depicted by Figure 6.0 of the FIVE Methodology.

19M.4.2 Phase II Quantitative Analysis (FIVE)

19M.4.2.1 Identify Fire Compartments For Evaluation Purposes (FIVE)

The fire areas established in the ABWR design meet the requirements for fire areas as defined in section 2.2 of the FIVE Methodology Draft Report. The ABWR fire protection design is on the basis of separation being on a fire area basis. Conservatively, credit is not taken for the lesser separation allowed by the fire compartment definition of section 2.4 of the FIVE Methodology Draft Document. Most ABWR fire areas encompass more than one room. The separation between rooms within a fire area is similar to that required for fire compartments in the FIVE methodology. Separation within a fire area by room does tend to limit the consequences of a fire within a fire area, but no credit is taken for this in the ABWR analysis.

To summarize, screening of the fire areas is by a grouping of the intake structure, reactor building and control building except primary containment and the control room complex; the turbine building; and the control room complex. The fire areas of each safety division external to the control room complex and primary containment are considered as a group. A fire in any one of these grouped areas is assumed to result in immediate loss of function for the equipment in the grouped area and screening is on that basis.

19M.4.2.2 Evaluate Fire Vulnerability Frequency (FI) For Fire Compartment (FIVE)

This evaluation is done by the FIVE methodology on the basis of grouped fire areas and not fire compartments.

19M.4.2.3 Determine Fire Ignition Frequency (FI) (FIVE) [Figure 6.3.1.2]

Figure 6.3.1.2 of the FIVE report is used and the results are entered in the appropriate locations on Table 1. See Subsection 19M.5.2 for the calculations for the fire ignition frequency. There are no significant fire areas with a fire ignition frequency less than 1E-6 per year.

19M.4.2.4 Choose (FIVE)

The choice is always for Step 2. The ability of the plant to accommodate the complete burnout of any fire area without recovery is a design requirement and is always assumed. Step 3, separation of redundant safety-related systems by less than a rated fire barrier, is not available for a new plant design.

19M.4.2.5 Probability For Redundant/Alternate System Unavailable (FIVE)

The Level 1 PRA models are used to determine the probability of failure of the redundant systems external to the grouped fire area. The PRA models were combined with the fire ignition frequency for the calculation.

All significant fire areas have a fire induced core damage frequencies of less than the acceptance criteria.

19M.4.2.6 Can Fire Affect Redundant/Alternate Path (FIVE)

It is concluded that a fire cannot affect the redundant/alternate paths in other divisional fire areas since only physical separation by rated fire barriers (as described in Subsection 9.5.1 and confirmed in the fire hazard analysis, Appendix 9A) is relied upon. All fire areas screen out.

19M.5 Calculation of the Fire Ignition Frequency

19M.5.1 General Comments On Completion Of FIVE Table 3

- Fire Compartment Boundaries: (FIVE)

  All boundaries are three hour rated structures such as walls, ceilings, floors and doors. All penetrations are closed by penetrations with a fire rating equal to the rating of the structure penetrated.

- Inside Fire Area: (FIVE)

  No general comments.

Fire Ignition Frequency

- Step 1.1 (FIVE)

  – Selected Fire Location (FIVE, Table 1.1)

  No general comments.

- Step 1.2 (FIVE)

  – Location Weighting Factor (WF_L) (FIVE, Table 1.2)

  The location weighting factors for the ABWR are summarized on Table 19M-2. The first two columns of the table were copied from Table 1.1 of the FIVE methodology. The third and fourth columns apply specifically to the ABWR. The rationale for determining each factor is stated on the table.

  Division 4 is not included in the table because a very small fraction of the plant fire areas are Division 4 areas. Division 4 only provides additional instrumentation and control logic in support of the other three divisions which contain all of the safety-related depressurization, core cooling and containment heat removal capacity. Loss of Division 4 can therefore only have an impact which is a fraction of the loss of any one of the other 3 safety-related divisions.

  Some equipment which was in the reactor building in operating plants is located in the lower portion of the control building for the ABWR. Separation from the control room complex by three hour rated fire barriers is provided for this equipment and it is considered in conjunction with the reactor building for purposes of the analysis. A fire in a single divisional area in either building is assumed to cause loss of that division without recovery. Considering the two locations as one provides an ABWR basis similar to the basis for the fire frequency data for the FIVE methodology.

- Step 1.3 (FIVE)

  – Ignition Source Weighting Factor (FIVE)

  Potential Fixed Ignition Sources—It appears that the list of potential ignition sources in Table 1.2 of the FIVE methodology report represents all types of significant ignition sources that have resulted in fires in the existing plants and are therefore all inclusive. Potential ignition sources which are in existing plants but which have not ignited a fire may experience a fire in the future. Since they have not yet served as an ignition source, the frequency would be less than any data given on the FIVE tables. Any new potential fire sources unique to the ABWR have been considered. The new potential sources are the fine motion control rod drive (FMCRD) power supplies and the reactor internal pump (RIP) adjustable speed drives. These two new sources are included in the reactor building analysis.

In the FIVE methodology, the ignition source weighting factors are fractional numbers calculated on the basis of the number of ignition sources in the fire compartment (fire area) being considered divided by the total number of similar ignition sources for the plant. For example, if there are 30 electrical cabinets in the reactor building and 10 of them are in a fire compartment (fire area) being analyzed, the ignition source weighting factor would be 10/30 or 0.33 for the fire compartment. Counted quantities are used to calculate fractions.

The specific rationale for derivation of the weighting factor for each potential ignition source is given below for each Ignition Source Data Sheet (ISDS), Table 3 (FIVE).

19M.5.2 Completed Ignition Source Data Sheets and Notes

The fire compartment fire frequency was determined for the applicable building areas by completing Ignition Source Data Sheets. These fire compartment fire frequency values were used as input to the probability risk assessment models.

19M.5.3 Not Used

19M.6 Calculation of Core Damage Frequencies

19M.6.1 Methodology

The calculations were based upon original ABWR functional fault trees for the reactor water injection and heat removal functions, which included a gas turbine generator as a diverse source of emergency power. The fault trees and input data are described in detail in Chapter 19. Fault tree analyses were performed using the CAFTA computer program.

Functional fault trees were developed to reflect the reduced injection and heat removal capabilities defined by each of the five bounding fire scenarios. Estimates of expected core damage frequency were developed for each scenario by applying results of these functional fault tree analyses to accident sequence event tree structures developed for the ABWR internal events PRA, and described in Chapter 19. The isolation/loss of feedwater event tree, Figure 19D.4-3, was selected for evaluation as a conservative representation of the sequence of events for fires which lead to divisional power loss and for control room fires.

The consequences of a turbine building fire were determined to be bounded by a loss of off-site power event, and therefore the loss of off-site power event trees, Figures 19D.4-4 through 19D.4-10, were used as the basis for its assessment.

Conservative estimates of fire initiating event frequencies and assumed consequences were developed in a preceding task using the EPRI FIVE methodology.

19M.6.2 Results

Only event sequences categorized as accident Class I are found to contribute significantly to core damage frequency.

The main contributor to core damage frequency for each initiator leading to a divisional power loss is that sequence in which both high and low pressure injection systems fail, following successful scram and SRV performance and loss of feedwater. In the case of the control room fire event, assumed inability to recover feedwater or inject condensate at low pressure increases the values of both high and low pressure Class I sequences. The probability of failure to manually depressurize also has greater impact in this latter event, since only four SRVs can be controlled from the remote control location in the modified scenario, and opening of three is required for success. For the divisional fire sequences, failure to depressurize is essentially determined by human error. Turbine building fire core damage frequency is dominated by station blackout event sequences.

The core damage frequency initially calculated for control room fires (initiating event CR) was greater than that predicted for a divisional electrical fire, and did not pass the FIVE Methodology screen. This was due to the provision of capability at the remote shutdown location to control a single loop for high pressure injection (HPCF) as well as only three safety relief valves for depressurization. With respect to the latter, successful operation of all three valves would be necessary to prevent core damage in the event of a need to depressurize. Therefore, a more detailed analysis was required for this initiator, as well as consideration of possible system control capability modifications to the remote shutdown control system.

Potential courses of action to reduce control room fire risk which were identified and evaluated included the following:

- Providing control capability for a fourth SRV at the remote shutdown control panel, and
- Taking credit for operating the RCIC system from outside the control room if determined to be practical, i. e., from the motor control center and locally at the RCIC.

Examination of the latter possibility led to the conclusion that successful operation of the RCIC system from outside the control room would be practical, and it is an interface requirement that the applicant provide an emergency operating procedure for manual operation of the RCIC.

Neither of the above actions by itself satisfies the screening criterion. In combination, however, the criterion is met, and with incorporation of the above two actions no further analyses are required to demonstrate acceptably low fire risk for the ABWR.

19M.6.3 FIVE Review

The ABWR FIVE analysis was reviewed to assess changes to the ABWR design since the issuance of the original design certification. The following summarizes the risk impact for deviations potentially affecting the FIVE results:

- Changes to the RCIC pump reduce the overall fire risk. The new RCIC pump design is expected to increase RCIC reliability and reduce overall risk. This reduction also occurs in the fire risk results, due to the importance of the RCIC pump operation following a control room fire.
- The Reactor Internal Pump (RIP) motor generator (MG) sets (2) and their switchgear relocation from the Control Building to the Control Building Annex lowers the ignition frequencies for fire compartments in the Control Building due to the relocation of the MG sets. Since there are fewer cables affecting Safe Shutdown Systems in the Annex, the impact of the change is an overall reduction in the Fire Risk.
- Turbine building modifications do not affect the generic fire frequencies used to perform the FIVE analyses described in the various Tier 2 Chapter 19 sections. Potential changes to turbine building design do not affect the loss of offsite power event models used to quantify the effects of fire in the turbine building. Because the generic initiating event frequencies are unaffected, and the event models are unaffected, the results of the FIVE analyses for the turbine building fire scenarios are unaffected.

Overall, the ABWR FIVE results for the original design certification for ABWR are bounding for these changes.

19M.7 Not Used

19M.8 References

19M-1 "Fire Vulnerability Evaluation Methodology, FIVE, Plant Screening Guide", Electric Power Research Institute, Preliminary Draft.

Table 19M-1 Not Used

Table 19M-2 Weighting Factors for Adjusting Generic Location Fire Frequencies for Application to Plant-Specific Locations (References FIVE Table1.1)

Plant Location (Table 1.1 Of Five)	Weighting Factors[1] (Wfl) (Table 1.1 Of Five)	Weighting Factor (Wfl) ABWR Analysis	WFL Value
Auxiliary Building (PWR)	The number of units per site and divide by the number of buildings.	Not Applicable.	N/A
Reactor Building (BWR)[2]	The number of units per site and divide by the number of buildings.	One unit divided by three divisionally grouped fire areas. In effect, the reactor building is divided into three separate buildings by the three hour rated fire barriers for the divisional fire areas.	0.33
Diesel Generator Room	The number of diesels and divide by the number of rooms per site.	Three diesels per site divided by three rooms per site.	1
Switchgear Room	The number of units per site and divide by the number of rooms per site.	One reactor per site divided by nine switchgear rooms (2-TB, 3-RB and 4-CB) per site.	0.11
Battery Room	The number of units per site and divide by the number of rooms per site.	One reactor per site divided by five battery rooms (Divisions 1, 2, 3 and 4 and non divisional in CB) per site.	0.20
Control Room	The number of units per site and divide by the number of rooms per site.	One reactor per site divided by one control room complex per site.	1
Cable Spreading Room	The number of units per site and divide by the number of rooms per site.	Not applicable, due to the data communication functions there are no cable spreading rooms in the ABWR. This is a significant difference between the plants characterized in FIVE and the ABWR.	N/A
Intake Structure	The number of units per site and divide by the number of rooms per site.	One unit divided by three single division fire areas. This is equivalent to three separate intake structures per site.	0.33
Turbine Building	The number of units per site and divide by the number of rooms per site.	One reactor per site divided by one turbine building per site.	1

Table 19M-2 Weighting Factors for Adjusting Generic Location Fire Frequencies for Application to Plant-Specific Locations (References FIVE Table1.1) (Continued)

Plant Location (Table 1.1 Of Five)	Weighting Factors[1] (Wfl) (Table 1.1 Of Five)	Weighting Factor (Wfl) ABWR Analysis	WFL Value
Radwaste Area	The number of units per site and divide by the number of radwaste areas.	One reactor divided by one radwaste building per site. (Since the radwaste building is a grouping of fire areas separate from any area containing safety-related equipment, a fire in the radwaste building cannot affect safe shut- down of the plant.)	1
Transformer Yard	The number of units per site and divide by the number of switch-yards.	One reactor divided by one switchyard.	1
Plant-Wide Components (cables, transformers, elevator motors, hydrogen analyzer).	The number of units per site.	One reactor per site.	1

Notes:

1. The analyst must identify the number of like locations when determining the number of building, e.g., a 480 volt load center is “like” a switchgear room.
2 Reactor building does not include containment.

The following tables are not used in the DCD:

Tables 19M-3 through 19M-14

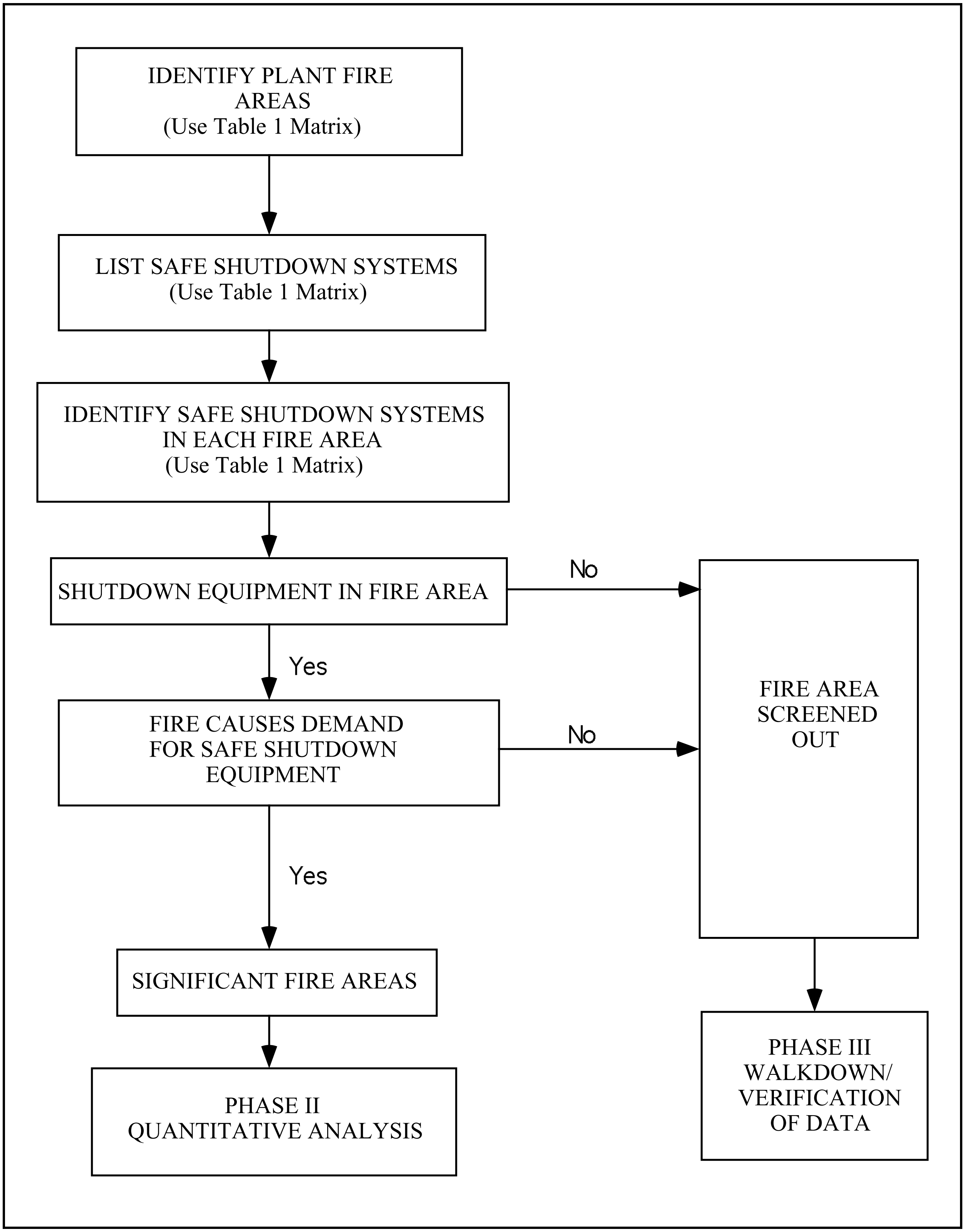

Figure 19M-1 Phase I Qualitative Analysis Flow Chart

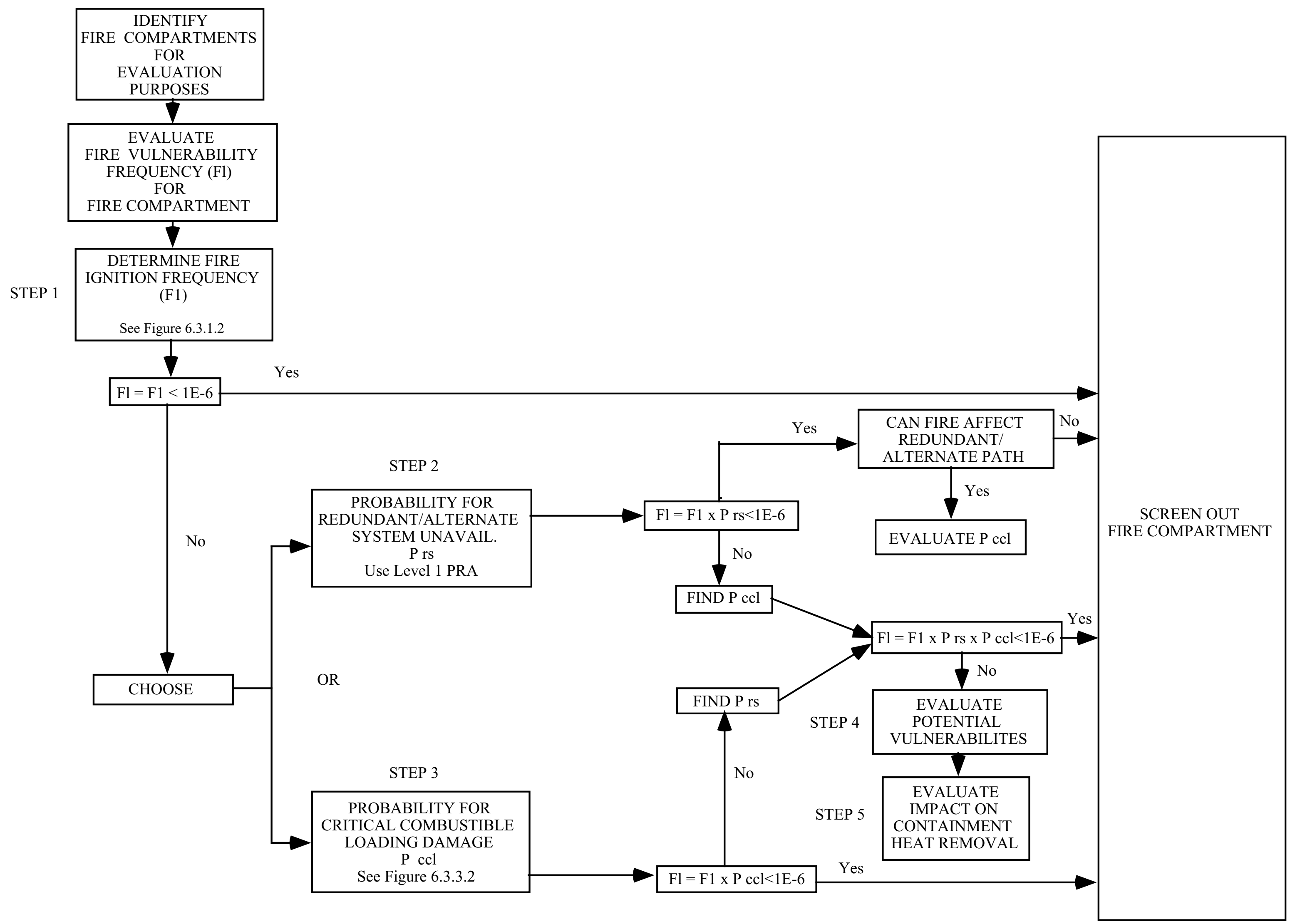

Figure 19M-2 Phase II Qualitative Analysis Flow Chart

The following figures are not used in the DCD:

Figures 19M-3 through 19M-13