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AUTH.NAME AUTHOR AFFILIATION
BOHLKE,W.H. Florida Power & Light Co.
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SUBJECT: Forwards documentation of util approach for resolving Thermo-Lag fire barrier issues at facilities.

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L-94-104
10 CFR 50 APP.R

April 29, 1994

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D. C. 20555

Subject: St. Lucie Units 1 & 2 and Turkey Point Units 3 & 4
Docket Nos. 50-335, 50-389, 50-250, and 50-251
Performance-based Approach for Resolving Thermo-Lag Fire Barrier Issues

In the March 10, 1994 meeting, Florida Power & Light (FPL) presented to the NRC a performance-based approach for resolving Thermo-Lag fire barrier issues at the Turkey Point and St. Lucie facilities. On April 14, 1994, FPL and NRC staff reviewers met to discuss some of the specifics of the FPL fire methodology. The purpose of this submittal is to provide documentation of the FPL approach for resolving Thermo-Lag fire barrier issues at both plant facilities. Please find attached:

Attachment A: A summary of the FPL Thermo-Lag resolution methodology including performance-based acceptance criteria;

Attachment B: A description of the fire barrier evaluation methodology used for evaluating Thermo-Lag fire barriers, and

Attachment C: A description of the Probabilistic Safety Assessment (PSA) techniques used by FPL as an independent method for examining fire risk in areas that have Thermo-Lag fire barriers.

The methodology described in Attachments A, B, and C meets the objectives of Appendix R by integrating performance-based acceptance methodology for fire barrier evaluations and PSA verification techniques. This methodology includes conservative criteria and safety factors, conservative fire barrier evaluation methodologies, and PSA verification techniques.

Further, as discussed at the March 10 and April 14 meetings, FPL has used the Thermo-Lag product for outdoor fire barriers at the Turkey Point Nuclear facility. These fire barrier configurations are unique to the Turkey Point site, and to our knowledge, there has been little or no outdoor use by other utilities within the industry. These are low combustible areas which are not subject to fire damage from stratified gases or ceiling jet layers that can occur from a fire in an indoor area.

A029

[illegible]

Attachment D to this document provides the description and bases for meeting the objectives of Appendix R for Turkey Point outdoor areas. This would allow the use of 30-minute Thermo-Lag fire barriers for shutdown functions that are located 50 or more feet away from major in-situ combustibles. This use of fire barriers outdoors provides equivalent or better protection as compared to that of radiant energy shields in large indoor areas, such as the reactor containment.

In order to maintain FPL's current Thermo-Lag resolution schedule as described in FPL's letters L-94-24 dated February 7, 1994 and L-94-33 dated February 11, 1994, we ask that you review these submittals at your earliest opportunity and communicate your estimated schedule for informing us of your findings and comments. We will contact the NRC project managers periodically for a status on this request. Please let us know if we can be of any help during the review process.

Very truly yours,

W. H. Bohlke
Vice President
Nuclear Engineering and Licensing

WHB:abk

Attachments 4

cc: Stewart D. Ebneter, Regional Administrator, Region II, USNRC (2 copies)
Senior Resident Inspector, USNRC, Turkey Point Plant
Senior Resident Inspector, USNRC, St. Lucie Plant

St. Lucie Units 1 & 2

Turkey Point Units 3 & 4

Docket Nos: 50-335, 50-389, 50-250, 50-251

Attachment A

SUMMARY OF FPL APPROACH FOR RESOLVING THERMO-LAG FIRE BARRIER ISSUES

FLORIDA POWER & LIGHT

FPL

SUMMARY OF FPL APPROACH FOR RESOLVING

THERMO-LAG FIRE BARRIER ISSUES

Introduction

As in the case with other licensees, Florida Power & Light (FPL) has used the Thermo-Lag product for fire barriers that protect safe shutdown functions at its nuclear facilities. Now that the industry testing programs are nearing completion, it is clear that the ASTM E119 ratings for this fire barrier product are less than the original design and installation specifications. While investigating methods for resolving Thermo-Lag fire barrier issues, FPL has implemented interim compensatory measures at its nuclear facilities to assure continued compliance with Appendix R and other fire protection requirements, as appropriate.

Appendix R criteria for fire barrier rating selection are extremely conservative and as the industry and NRC have learned, are very difficult and expensive to implement. The selection of one and three hour fire barriers in Appendix R has provided the designer with a method for meeting the defense in depth objectives of Appendix R. These defense in depth objectives are required in order to assure protection of safe shutdown functions during postulated fires. This method of achieving Appendix R compliance does not require the evaluation of actual fire area combustible loading or combustible configurations. However, when actual combustible loadings are determined and compared to one and three hour fire barriers, it is clear that many fire areas inside nuclear facilities have levels of safety far beyond those needed to assure protection of safe shutdown functions. Hence, in many fire areas a reduction in fire barrier rating, as determined during recent industry testing, may have no impact on the defense in depth objectives of Appendix R.

FPL has developed a methodology that integrates fire methodologies and Probabilistic Safety Assessment techniques with performance-based criteria and safety factors. This approach allows FPL fire protection experts to evaluate the fire areas and determine if the defense in depth objectives of Appendix R are still met with reduced credit for Thermo-Lag fire barriers.

The following discussion of FPL's approach is also provided in the logic flow chart format at the end of this summary. It is noted that since the use of Thermo-Lag in outdoor areas is applicable only to the Turkey Point site and not of generic industry concern, FPL's resolution approach for outdoor areas is provided as Attachment D in this submittal.

Fire Methodologies

Fire Hazards Screening

A fire hazards screening evaluation is conducted using methods from the National Fire Protection Association's (NFPA) "Fire Protection Handbook." The screening method is a traditional fire hazards evaluation which is used to determine if a more detailed analytical approach should be employed. The intent of the fire hazards screening is to filter out areas which contain combustible loadings that are clearly incapable of threatening the fire barriers.

The combustible loading is calculated based on a review of in-situ combustibles in the fire area. This review includes drawings and a walkdown of the fire area. The uniformity or the non-uniformity of the fire load is assessed during the walkdown. The combustible loading is converted to an equivalent fire duration as described in the NFPA's Fire Protection Handbook. The resulting fire duration is compared to the installed fire barriers, employing appropriate fire barrier ratings as determined through the use of industry tests and the NEI (NUMARC) Application Guide.

The results of the fire hazards **screening analysis** are considered acceptable when:

(a) for areas that have detection but are <u>without automatic suppression</u>, the as-installed fire barrier ratings must be a factor of two or more greater than the actual *fire loading*; or

(b) for areas that have detection and <u>automatic suppression</u> for the fire barrier, an as-installed fire barrier rating is credited with a three fold improvement, and the resulting enhanced barrier rating must be a factor of two or more greater than the actual *fire loading*.

When the results of the screening analysis are found to be acceptable, no further fire evaluations are necessary and it is concluded that the fire area meets the objectives of Appendix R.

<u>Fire Modeling</u>

A fire analysis is performed in accordance with a fire model based on the Electric Power Research Institute (EPRI) report, "Fire Induced Vulnerability Evaluation" (FIVE) methodology. The fire model method will be used for barriers that do not meet the screening method or for areas that are not appropriate for the screening method.

The flammable transients for a given fire area are assumed to ignite and burn until totally consumed. The fire modeling technique conservatively assumes that the worst case fire barrier in the fire area is directly over or adjacent to the fire plume. The barrier is evaluated against this worst case impingement fire. Additionally, the model evaluates the worst case ceiling jet outside the plume and determines the potential impact on the worst case fire barrier.

The results of the **fire modeling analysis** are considered acceptable when:

(a) the fire burn time is less than one-half the as-installed fire barrier ratings.

This fire model method provides assurance that worst case fires would burn out in less than one-half the time of the protection provided by the installed fire barriers.

Probabilistic Safety Assessment (PSA) Techniques

PSA techniques will be used to evaluate fire risk for areas containing Thermo-Lag fire barriers after the areas have passed the fire hazard screening or modeling analysis described above. The

PSA fire model uses the EPRI "FIVE" methodology to screen or estimate core damage frequency in the fire areas.

PSA Analysis

The fire ignition frequencies are combined with the failure probability of alternative success paths for placing the plant in a safe shutdown condition. It is first assumed that the plant's unprotected cable functions and in-situ equipment located in the fire compartment fail and there is no credit for detection, suppression, or plant fire brigade response. If the resulting core damage failure frequency is less than 1.0 x 10^{-6} per reactor year (or 1 x 10^{-5} per reactor year for compartments with automatic detection and suppression), the fire compartment is screened and no further PSA evaluation is needed. If the fire compartment does not pass the initial screening process, additional analysis that considers suppression systems, additional operator fire-related recovery actions, fire geometry considerations, etc. may be performed. If at anytime during this analysis the core damage frequency is calculated at less than approximately 1.0 x 10^{-6} per reactor year for a fire compartment, the compartment is considered to have acceptably low risk and no further PSA work is conducted.

The PSA model includes an estimate of the failure probability of cables protected by Thermo-Lag. This unique feature in the PSA model allows FPL to determine if the core damage frequency of a fire compartment is driven by or is sensitive to Thermo-Lag fire barrier failure. If it is determined that Thermo-Lag fire barriers are the cause of a realistic fire vulnerability, appropriate plant modifications and procedure changes will be made.

Conclusions

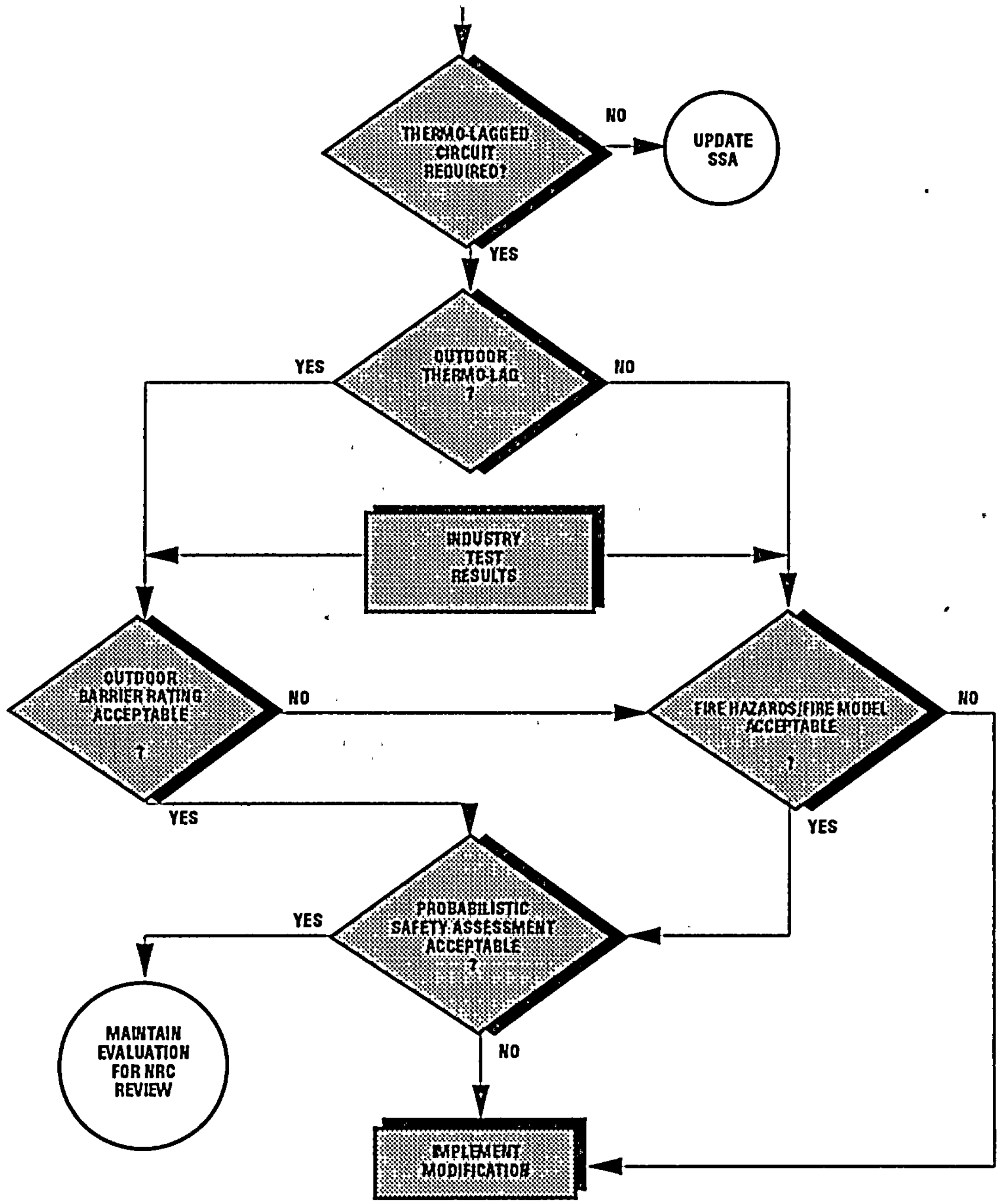
FPL believes that this comprehensive performance-based approach will determine:

(1) if nuclear plant indoor fire areas are able to meet the defense in depth objectives of Appendix R with Thermo-Lag fire barriers as currently configured, or

(2) if plant modifications are required.

FPL PERFORMANCE-BASED APPROACH TO THERMO-LAG ISSUE RESOLUTION

ST. LUCIE UNITS 1 & 2 and TURKEY POINT UNITS 3 & 4



FPL

St. Lucie Units 1 & 2

Turkey Point Units 3 & 4

Docket Nos: 50-335, 50-389, 50-250, 50-251

Attachment B

PERFORMANCE-BASED APPROACH TO FIRE BARRIER EVALUATION:

DESCRIPTION AND METHODOLOGY

FLORIDA POWER & LIGHT

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Table of Contents

I. Introduction

Historically, compliance with 10CFR50 Appendix R fire barrier requirements has been a relatively simple matter of applying a nominal criteria of "3 hour" fire barriers (or "1 hour" fire barriers with suppression and detection) for separation of redundant trains of safe shutdown equipment/components/cables. These general criteria are based on conservative assumptions which allow the criteria to easily bound most actual plant situations; however, since they give no consideration to actual combustible loadings and other location specific characteristics, they are overly conservative in many situations. Advances in fire modeling techniques have made this conservatism evident.

As a result of recent Thermo-Lag fire barrier adequacy issues, Florida Power and Light (FPL) has re-examined the fire barrier criteria used in the past. As an alternative, a performance-based approach to fire barrier evaluation can be used to meet the objectives of 10CFR50 Appendix R. The performance-based approach involves a quantitative determination of fire barrier adequacy for specific plant areas through an evaluation of combustible loadings and other location specific characteristics. The result is a postulated fire hazards analysis, which is based on a technically sound methodology. This methodology addresses location specific fire barrier adequacy, while maintaining conservative factors of safety.

II. General Description

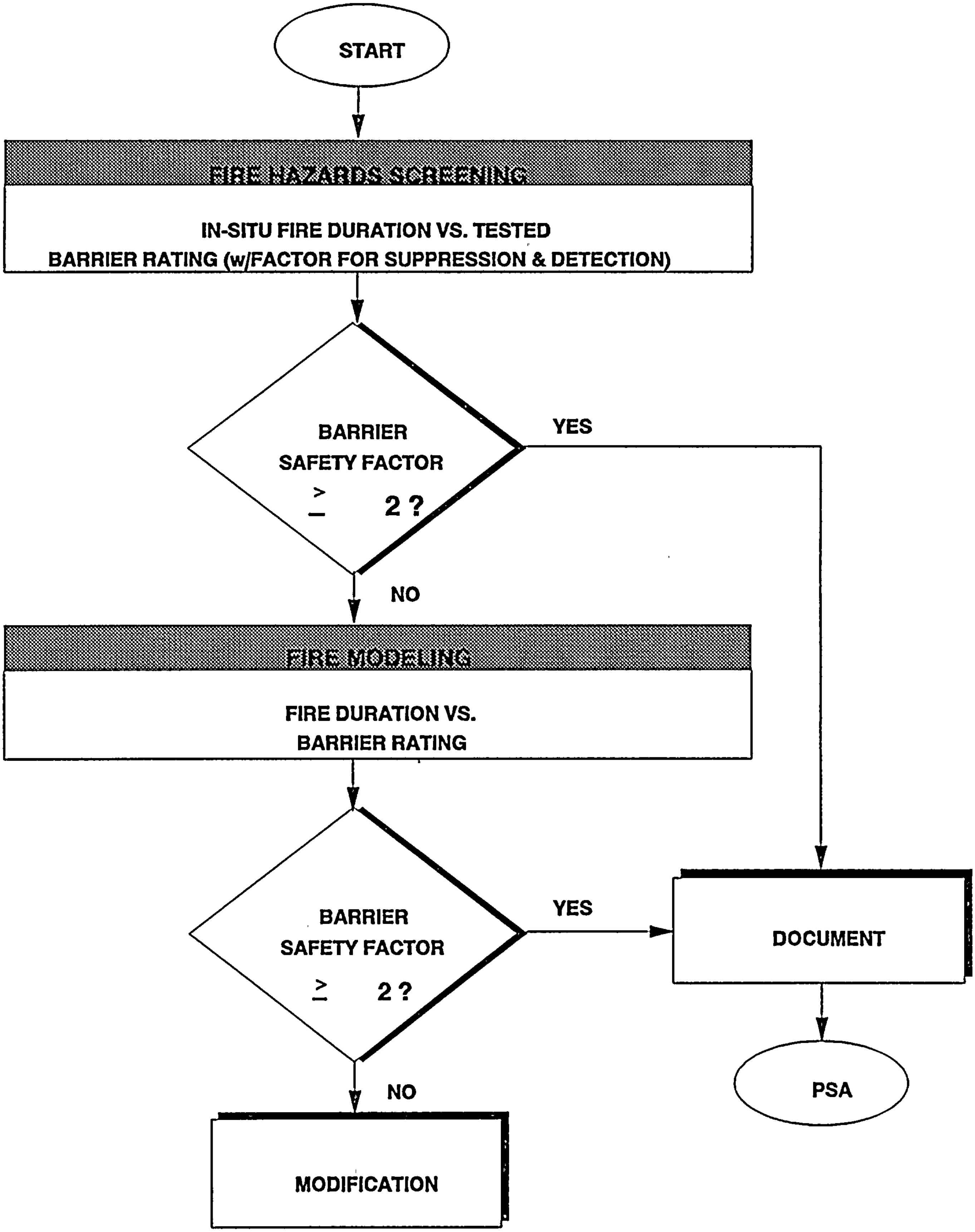
FPL's performance-based approach to fire barrier evaluations is comprised of a two-step process which determines case-by-case fire barrier acceptability.

The first step involves a conservative fire hazards screening which is based on traditional National Fire Protection Association (NFPA) methodology. A combustible loading derived fire duration is calculated for each compartment or fire area and compared to the industry test derived fire barrier rating using a conservative safety factor.

The second step involves conducting a detailed fire model of areas which do not pass the initial screening. The fire model is based, in part, on the EPRI "FIVE" (Fire Induced Vulnerability Evaluation) methodology, and includes consideration of flammable transients and transient combustibles, which could potentially ignite bulk in-situ combustibles. Key characteristics (such as relative position of ignition sources) are evaluated to determine if the ignition source could challenge the fire barrier or create conditions which could ignite the bulk in-situ combustibles.

The performance-based approach demonstrates that 1) redundant safe shutdown trains remain free from fire damage, or 2) modifications (including possible fire barrier upgrades) will be pursued to achieve safe shutdown objectives. A detailed description of the fire hazard screening methodology and fire modeling methodology is provided in the following sections. Figure 1 provides a flowchart for the general process.

Figure 1 - Fire Barrier Evaluation Process Flowchart



III. Fire Hazards Screening Methodology

The intent of the fire hazards screening is to filter out areas which contain combustible loadings that are clearly incapable of threatening the existing fire barriers.

The screening is conducted by comparing the fire duration resulting from all in-situ combustibles to the as-tested fire barrier rating, with all calculations performed on a specific case-by-case basis. A safety factor of 2 is used in making the comparison to ensure that the resulting fire duration is actually less than one-half of the fire barrier rating[1].

The specific screening steps are:

A) The fire barriers (Thermo-Lag as a wall or Thermo-Lag as a raceway fire barrier) in the area are fire rated using applicable industry testing. In the case of Thermo-Lag used for raceway protection, this rating will be assigned using testing as well as the NEI (NUMARC) Application Guide.

B) The total in-situ combustible loading in Btu/ft^2 is determined for each area . This value includes all cable except cable which is totally enclosed in a steel raceway.

C) The total combustible loading is divided by 80,000 Btu/ft^2-hr. This yields an equivalent fire duration in hours for the area (Ref. VI.A).

---

[1]A safety factor of two is required to pass the screening process. However, this process uses a simple acceptance criteria (fire barrier rating > twice the in-situ combustibles necessary to challenge the fire barrier rating). The factor of safety of two is used to account for unforeseen circumstances such as potential transient combustibles in the area, potentially elevated temperatures at a particular component due to unusual fire geometry, or the possibility of an in-situ combustible which is not captured in the Fire Hazards Analysis (FHA) report. See Glossary under "fire load", for the basis of the screening methodology and III.F for the guidelines for determining the applicable room geometry and combustible loading for this screening process.

D) The assigned fire barrier rating is divided by the calculated fire duration, to obtain a safety factor (for the fire barrier):

$$\frac{FireBarrierRating(Minutes)}{RoomFireLoading(Minutes)}=SafetyFactor$$

For fire barriers in fire areas with installed suppression and detection, the barrier rating is increased by a factor of 3 prior to calculating the safety factor[2]:

$$\frac{FireBarrierRating(Minutes)\times 3}{RoomFireLoading(Minutes)}=SafetyFactor$$

E) If a safety factor of 2 or greater is obtained, the fire barrier is considered acceptable for the hazard in that area; no further evaluation is required. If the area does not pass the screening, the fire modeling technique described below in Section IV is applied.

F) The applicability of the screening method depends on the type of combustible present in the rooms and the distribution of the combustibles within the room. The types of combustibles are consistent with this methodology. The most prevalent combustible is cable. The distribution of the combustibles is evaluated as follows: 1) if the overall combustible load is small i.e., $\approx$ 20,000 Btu/ft^2, (a few cable trays running in the area) then the method is valid, 2) if the barrier(s) being analyzed are not near a concentration of combustibles in the area then the method is valid, 3) if the concentrated loading is less than twice the average loading (this is appropriate due to less than a 50% combustion efficiency for the most prevalent combustible cable) then the method is valid. The uniformity or the non-uniformity of the fire load is assessed during a fire area walkdown.

Figure 2 provides typical results from the fire hazard screening methodology.

---

2 Credit is given for providing suppression and detection for a particular fire barrier. Temperatures necessary to challenge a fire barrier will also activate fire suppression and detection systems. These systems will provide early warning of a fire and will mitigate the effects of the fire in the room.

Figure 2 - Typical Fire Hazards Screening Results

Example 1

Charging Pump Room with traditional "3 hour" fire barrier with no suppression or detection

Assigned Barrier Rating

65 minutes (from testing)

Fire Duration for Location

[27,300 Btu/ft^2 (combustible loading)/80,000 Btu/ft^2-hr] x 60 minutes = 21 minutes

Barrier Safety Factor

65 minutes (barrier rating)/21 minutes (fire duration) = 3

Conclusion

Barrier Safety Factor = 3 which is > 2, therefore PASS

Example 2

Charging Pump Room with traditional "1 hour" fire barrier with suppression and detection

Assigned Barrier Rating

28 minutes (from testing) X 3 (for suppression/detection) = 84 minutes

Fire Duration for Location

[27,300 Btu/ft^2(combustible loading)/80,000 Btu/ft^2-hr] x 60 minutes = 21 minutes

Barrier Safety Factor

84 minutes (barrier rating)/21 minutes (fire duration) = 4

Conclusion

Barrier Safety Factor = 4 which is > 2, therefore PASS

Figure 2 (Cont'd) - Typical Fire Hazards Screening Results

Example 3

Cable Loft with "1- hour" fire barrier with detection

Assigned Barrier Rating

60 minutes (from testing) = 60 minutes

Fire Duration for Location

[259,500 Btu/ft^2(combustible loading)/80,000 Btu-ft^2-hr] x 60 minutes = 192 minutes

Barrier Safety Factor

60 minutes (barrier rating)/192 minutes (fire duration) = .31

Conclusion

- Barrier Safety Factor = .31 which is < 2, therefore **FAILS SCREENING.**
- Requires Fire Modeling in accordance with Section IV (below).

IV. Fire Modeling Methodology

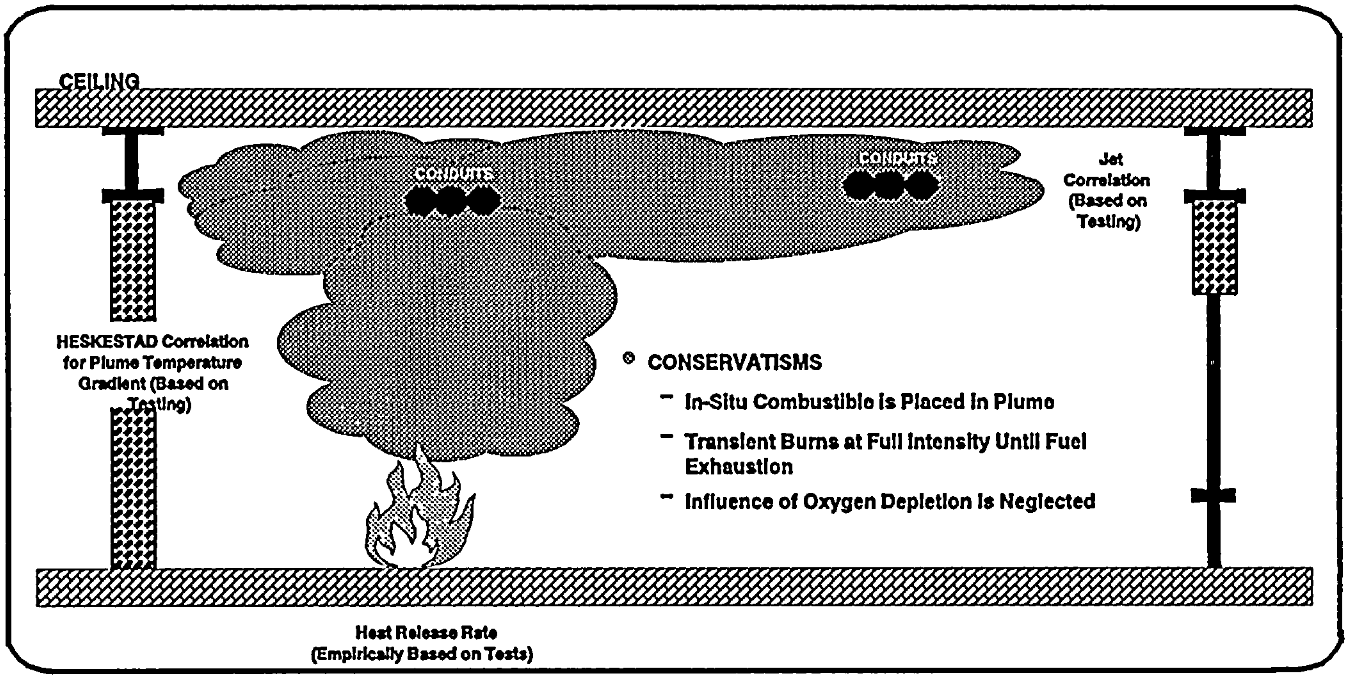
The intent of the fire model is to permit the detailed evaluation of locations with respect to potential fire hazards. Based on in-situ combustibles, transient combustibles and flammable transients assumed to be present, the model determines a fire duration (burn time) assuming that the flammable transients will be the initiator in the fire scenario. The fire duration is compared to the fire barrier rating assigned from testing. The duration must be no more than one-half the assigned fire barrier rating.

This model (Fig. 3) also provides a conservative estimate of the room air temperatures that could evolve at a target as a result of the exposure fire scenario. The air temperature must be below the ignition temperature for the bulk in-situ combustibles in the room. The fire model input includes credible flammable transients, transient combustibles, in-situ combustible targets in actual locations, and room geometry. Four separate target scenarios are evaluated:

- Targets in the plume
- Targets in the ceiling jet outside the plume
- Targets in the hot gas layer outside the plume
- Radiant targets outside the plume

More than one scenario can be evaluated for each room. Combustible targets may be located in any of the locations listed above. The model and this description are based on EPRI formulations and methodologies (Ref. VI.B and Ref. VI.C).

Figure 3 - Fire Model Conceptual Arrangement



IV. Fire Modeling Methodology (cont'd)

An effective peak fire intensity is calculated when the target is located in the fire plume and a mean effective peak fire intensity is calculated when the target is located in the ceiling jet region. The maximum plume and ceiling jet temperature at the location of the target is evaluated based on this intensity. If the plume or ceiling jet temperature exceeds the ignition temperature of the in-situ combustible target placed in that location, then the in-situ combustible will burn and release heat. For the purpose of modeling ignition temperatures, grouped electrical cables could be considered as semi-infinite solids. The semi-infinite solid is representative of targets with non-negligible internal resistance to heat flow and sufficient thickness to prevent heat loss from the back face of the solid. Thermal gradients occur within the material, with the surface temperature rising more quickly than internal temperatures under imposed heat flux conditions due to the internal resistance to heat transfer. However, for this conservative model, the transient thermal response of the target is neglected. The target is assumed to instantly equilibrate to the environmental conditions.

Since this model provides a comprehensive tally of room temperatures, it could be used to activate suppression systems. Although the information is available for additional analysis, it is not used to activate any suppression systems, even though they would aid in extinguishing the fire or cooling the effects of a fire.

A radiant target may be evaluated; however, if it is not ignited it is not considered to contribute to the fire loading in the room. The parameters provided for the radiant target are the heat flux at the target and the equivalent surrounding air temperature throughout the scenario. If it is determined that a radiant target will burn in a room then it must be placed in the plume or ceiling jet to properly emulate heat release. Typical fire model results are shown in Fig. 4.

Figure 4 - Typical Fire Model Results

Example

Switchgear Room with traditional "3 hour" fire barrier with no suppression or detection

Assigned Barrier Rating

70 minutes (from testing)

Fire Load Inputs

All In-Situ combustibles, 10 gallons flammable transient

Resulting Fire Duration

Fire duration = 11 minutes

Conclusion

Fire duration < 1/2 Barrier Rating; therefore **PASS**

VI. Fire Model Detailed Description

A. Design Basis Fire

Since the in-situ and potential transient combustibles vary widely in different areas of the plant (Ref. VI.D), the establishment of a specific "design basis fire" for individual areas is a prerequisite to performance of a valid fire hazards analysis (Ref. VI.E).

Accordingly, each fire area is evaluated for all in-situ combustibles and potential transient combustibles and flammable transients. This includes a review of plant procedures and an area walkdown to assess the transport and use of combustible materials in each fire area. A flammable transient (flash point < 100°F) such as paint, paint thinner, alcohol, etc, is determined for each fire area. The model sequence initiates the ignition of the flammable transient, independent of the presence of an ignition source. The location of the flammable transient is selected conservatively such that the impact on in-situ combustibles is maximized.

For Turkey Point the combustible controls program requires all flammable transient liquids to be attended at all times, and requires a permit for quantities in excess of an administrative limit. The design basis flammable transient is assumed to be equal to the administrative limit, and the type of flammable transient is determined on an area-by-area basis.

For St. Lucie the combustible controls program manages transient combustibles to an administrative limit, and requires safety cans (not exceeding one-half the administrative limit in capacity) for flammable transient liquids in buildings. The design basis flammable transient is assumed to be equal to the administrative limit, and the type of flammable transient is determined on an area-by-area basis.

An inventory of the in-situ and transient combustibles is available. This inventory includes a) BTU content, b) burn rate, c) quantity, d) ignition temperature, and e) location in the fire area (height, distance from walls, etc). This conservative combination of transient and in-situ combustibles comprises the design basis fire.

B. Identification of Fire Scenarios

This model determines the temperature of the room in the locations indicated in Section IV (above). These temperatures are tabulated for each time interval until the termination of the calculation. A representative ignition temperature is provided for each combustible target (e.g., IEEE-383 cable is 700°F). The room is examined to determine the worst location for a floor based flammable transient fire with regard to in-situ combustibles.

C. Exposure Fire Source Characterization

Peak Fire Intensity

Combustible target exposure scenarios require evaluation of the exposure peak fire intensity. It is possible to conservatively estimate peak heat release rates for representative exposure fire fuels. A conservative assessment of fire source intensities is made by calculating the peak heat release rate as:

$$Q_{peak}(\frac{Btu}{\sec})=q(\frac{Btu}{\sec \cdot ft^2})\cdot A_s(ft^2)$$

Where: **q** - the appropriate unit heat release rate associated with fully involved conditions

A_s - the total exposed surface area of the fuel.

This method of assessing the peak fire intensities assumes the entire exposed surface area of the fuel spill will be actively burning. It neglects the periods of fire development and fuel burnout that can diminish the actual fire intensity from this peak burning rate. This method also uses unit heat release rates associated with fully-involved burning. With these conservative approximations, this approach can be applied directly for fuels with well defined planar surfaces, such as liquid pools.

Transient Combustible

A flammable liquid spill is postulated as the transient fuel exposure fire which initiates the fire scenario. One of the tasks is to estimate the surface area of the liquid spill. This is a function of the quantity, viscosity and surface tension of the spilled liquid and the cohesion, contour and absorption rate of the floor finish. On a smooth floor the area is simply equal to the volume of the liquid spilled divided by the thickness of the spill once it stops spreading. Floors in power plants, however, are not smooth, level or without obstructions. A spill would migrate to the low points and reduce the surface area calculated for a smooth surface.

In addition, the postulated spill will be an artificially large quantity, which would appear to spread over a large smooth floor area. This would cause the fire to burn intensely for a very short period of time. This would not occur in an actual spill; thus, the model spill area will be kept small (i.e., $\approx$ 8 ft^2 for 10 gallons) to better simulate actual spill and fire conditions while maximizing the burn time which is the acceptance criterion.

D.) **Target in Plume**

Heat which is present in the plume, the ceiling jet or the hot gas layer is transmitted via convective and radiant heat transfer. These methods are described below:

Convection

Heat is transfered from the flame to the body (e.g., wall) via standard convective and radiant heat transfer. For convective heat transfer the typical formula below is used:

$$q''=h_c(T_f-T_s)\frac{Btu}{hr{\cdot}ft^2}$$

Where: h_c - the convective surface heat transfer coefficient (See Section VI.F below), T_f the flame temperature T_s- the surface temperature of the body.

Radiation

According to the Stefan-Boltzmann equation, the total energy emitted by a body is proportional to T^4 (See Ref. VI.F), where T is in absolute degrees. The total emissive power is:

$$E=\epsilon\sigma T^4(W/m^2)(Btu/hr{\cdot}ft^2)$$

Where: σ - Stefan-Boltzmann constant (5.67×10^{-8} W/m^2K^4) (1.713×10^{-9} Btu/ft^2 hr $°R^4$)

ϵ - emissivity (dimensionless), is a measure of the efficiency of the surface as a radiator

The intensity of radiant energy (q") falling on a surface remote from the emitter can be found by using the appropriate configuration factor (ϕ), generally assumed to be unity, which takes into account the geometrical relationship between the emitter and the receiver.

$$q''=\phi\epsilon\sigma T^4(W/m^2)(Btu/hrft^2)$$

Fire Location Factor

Fires located along walls or in corners formed by walls can result in higher plume and ceiling jet temperatures than fires located in the center of compartments. These higher temperatures result from reduced entrainment of ambient air, which is blocked by the solid boundaries adjacent to the fire. The concept of reflection has been applied to calculate the effects of fire location in plume and ceiling jet temperatures. This concept concludes that a fire burning along a wall is equivalent to a fire with twice the heat release rate with respect to temperature rise at any location, while a fire in a corner is equivalent to a fire with quadrupled heat release rate. Once the peak fire intensity is estimated, an effective fire intensity (Q_{eff}) can be calculated from the product of the peak intensity and the appropriate fire location factor (FLF).

FLF = 4, fires located in corners
FLF = 2, fires against walls
FLF = 1, fires located in the open

Generally, a fire must be located within a few inches of a wall or corner for these location factors to apply.

Virtual Origins

The fire plume correlations are founded on the theory developed for a weak point source of heat release. Real fires are strongly buoyant and have area sources. To account for the effects of these differences, methods to calculate virtual origins have been developed. A virtual origin is an elevation offset above or below the actual fuel surface that yields conditions, based on the point source theory, equivalent to those produced by the actual fire.

Virtual Origin calculations are feasible only for pool type fires and other fires without substantial in-depth combustion. For pool fires Heskestad (Ref. VI-G, page 1-112) suggests virtual origin elevation can be calculated as:

Z_o - Virtual Origin (m) = $-1.02D + 0.083\ Q^{2/5}$

Where: D - Effective Fire Diameter (m)
Q - Total Heat Release Rate (kw)

Plume Temperature Rise

The plume temperature rise is calculated using:

$$\Delta T(^{o}F)=340\frac{Q_{eff}^{\frac{2}{3}}(\frac{Btu}{sec})}{(z-z_{o})^{\frac{5}{3}}(ft)}$$

Where: z - Target Height off the floor (ft)

This formula is found in Ref. VI.B. The differential temperature is recalculated for each time interval, and is added to the hot gas room temperature calculated for that time interval to obtain the resultant plume temperature at the specified elevation (z) above the floor.

E.) Target in the Ceiling Jet

The target is considered to be in the ceiling jet if it is in the upper 20 percent of the room height. Ceiling jet targets are evaluated at a mean distance from the fire centerline to the nearest wall. For a fire in a corner or against a wall this distance is one-third the width (shortest room dimension) of the room. For a fire in the open, this distance is one-sixth the width of the room.

Unconfined Ceiling Jet

The formula (Ref. VI.B) for determining the unconfined differential ceiling jet temperature (ΔT_{cj}) is as follows:

$$\Delta T_{cj}=\frac{0.3\times\Delta T_{pl,ceil}}{(\frac{L}{H})^{\frac{2}{3}}}$$

Where:

$\Delta T_{pl,ceil}$	-	differential temp in the plume at the ceiling
L	-	length of the room (ft)
H	-	height of the room (ft)
W	-	width of the room (ft)

This formula is used when the ratio of the room length to the room width is less than 0.5 and when the ratio of the room height to the room width is greater than 2.5.

Confined Ceiling Jet

The formula (Ref. VI.B) for determining the confined differential ceiling jet temperature (ΔT_{cj}) is as follows:

$$\Delta T_{cj}=0.37\times\Delta T_{pl,ceil}\times(\frac{H}{W})^{\frac{1}{3}}\times\exp[-0.16\times(\frac{L}{H})\times(\frac{W}{H})^{\frac{1}{3}}]$$

This formula is utilized when the ratio of the room length to the room width is greater than 0.5 and when the ratio of the room height to the room width is less than 2.5.

F.) Target in the Hot Gas Layer

The hot gas layer is considered to be the bulk room temperature outside the plume and the ceiling jet regions. A transient heat balance is performed on the room as follows to obtain the transient bulk room temperature:

Heat transfer from the room is evaluated as follows:

- A one-dimensional finite difference method is employed for heat transfer through the walls, floors, ceilings, (Including Thermo-Lag walls which have activated the char layer due to the fire).
- Conductive heat transfer is utilized for fire doors, hatches and Thermo-Lag walls which have not activated from the fire.
- Normal ventilation systems are in operation and will be deenergized for associated circuits in the fire room or fire dampers in the ductwork.
- Heat transferred to structural steel in the room (cabinets, cable tray supports, conduits, etc.) is evaluated.

Heat transferred into the fire room is evaluated as follows:

- The heat from the flammable transient released to the room at the peak burn rate until the transient is consumed. As a conservatism, oxygen depletion is not considered.
- The in-situ combustibles which are exposed to a room temperature in excess of their ignition temperature in the plume, ceiling jet or hot gas layer are burned at their peak burn rate until the combustible is consumed. Again, oxygen depletion is not considered.
- Heat from the energized equipment in the room is released to the room.

G.) **Radiant Target**

Thermal radiation can be the significant mode of heat transfer for situations where a target is located laterally from the exposure fire source. This would be the case for a floor-based fire located adjacent to an electrical cabinet, a vertical cable tray or a conduit containing safe shutdown equipment and/or cables. Evaluation of the thermal radiation requires the evaluation of the incident heat fluxes at a target. A point source estimate of radiant flux is used in this calculation. The incident radiant heat flux at a target located at a radius (r) from the point source is then given as:

$$Q_R = \chi_R Q_f / 4\pi r^2$$

Where: χ_R - (0.4 - Radiant fraction)
Q_f - Peak Heat Release Rate (kw)

For conservatism, 0.9 will be used for the absorptivity and emittance of the target. This yields a net 81% of the incident radiation which will be retained by the target. This is incorporated into the total incident radiant heat flux formula. The radiant heat flux at various distances from the edge of the plume and at the designated radiant target are tabulated for the user of the program. Critical fluxes for some targets are available in Ref. VI.B and VI.C.

H.) **Validation**

This fire modeling technique uses empirical formulas which were derived from testing. These formulas were derived from pool fire tests on hydrocarbon fires. Thus, the formulas are based on actual fires and actual fire tests. The fire model computer program has been verified to ensure that it follows the empirical formulas from which it is comprised. The conclusion is that the fire model is valid to tested field configurations for hydrocarbon pool fires.

VII. References

A. NFPA Handbook, Fifteenth Edition.
B. EPRI Report TR-100370, "Fire Induced Vulnerability Evaluation Methodology", Revision 1, dated April 1992.
C. EPRI Report TR-100443, "Methods of Quantitative Fire Hazards Analysis", May 1992.
D. Generic Letter 86-10, Section 3.8.2
E. Appendix R, Section II.B(1) and BTP CMEB 9.5-1, Sections C.b(1) and (2).
F. Fire Dynamics, D. Drysdale, John Wiley and Sons, 1987.
G. SFPE Handbook of Fire Protection Engineering, First Edition, dated September, 1988.

VIII. List of Figures

IX. Glossary

Ceiling Jet: A thin layer of hot gases from the fire plume which are located in the upper 20% of the room height.

Fire Location Factor: The fire location factor accounts for the reduced entrainment rate associated with fires located adjacent to walls and in corners and the consequent increase in the plume temperature. The fire location factors are:

4	for fires located in corners
2	for fires located against walls
1	for fires located in the open

Fire Load: Ref. VI.A Section 5/Chapter 9.B, "Fire Load", states the following:

> Analysis of tests by the National Bureau of Standards developed an approximate relationship between fire loading and an exposure to a fire severity equivalent to the standard time-temperature curve. The weight per square foot of ordinary combustibles (wood, paper and similar materials with a heat of combustion of 7,000-8,000 Btu per lb) was related to hourly fire severity as described in Table 5-9B. (Table 5-9B relates multiples of 80,000 Btu per square foot to multiples of an equivalent fire severity of one hour.
>
> The fire load-fire severity relationship was the first method developed to predict the severity of a fire that would be anticipated in various occupancies. It could be used to determine resistance required of fire barriers as well as structural components. Although the technique has its limitations, it does provide a **conservative estimate** of the maximum expected fire in most residential, business, institutional and many commercial occupancies. It is simple and easy to use, although it is often not considered in some code requirements. A principal caution that must be exercised is in application of this technique to

combustibles having a very high heat release rate. Such fires may expose the barriers to higher temperatures than those at which they are tested.

Fire load is a measure of the maximum heat that would be released if all the combustibles in a given fire area burned. Maximum heat release is the sum of the product of the weight of each combustible times its heat of combustion. In a normal building, the fire load includes combustible contents, interior finish, floor finish, and structural elements. Fire load is commonly expressed in terms of the average fire load, which is the equivalent combustible weight divided by the fire area in square feet.

Equivalent combustible weight is defined as the weight of ordinary combustibles, having a heat of combustion of 8,000 Btu per lb, that would release the same total heat as the combustibles in the space could. For example, the equivalent weight of 10 lbs per sq ft of a plastic with a heat of combustion af 12,000 Btu per lb would be:

$$10 \cdot lbs \cdot per \cdot sqft \times 12{,}000 \cdot Btu \cdot per \cdot lb = 120{,}000 \cdot Btu \cdot per \cdot sqft$$

$$\frac{120{,}000 \cdot Btu \cdot per \cdot sqft}{8{,}000 \cdot Btu \cdot lb \cdot ordinary \cdot combustibles} = 15 \cdot lbs \cdot per \cdot sqft$$

On the conservative side, using the gross fire load for the combustibles does not account for the combustion efficiency of the combustible. For cable the combustion efficiency is 45%. Additionally, any oxygen depletion is not accounted for in this screening.

The applicability of this method is discussed in III.F.

Fire Room: A space bounded by non-combustible barriers where heat and products of combustion from a fire within the enclosure will be substantially confined.

Flammable Transient: A transient combustible with a flash point < 100°F (paint, paint thinner, alcohol, etc).

Hot Gas Layer: The hot gas layer is assumed to extend to the floor for this technique, thus the bulk room temperature is the same as the hot gas layer.

In-Situ Combustible: Combustible material which is permanently located in an area and material which is located in an area for long periods of time.

Plume: The location directly above a fire source which contains the products of combustion from the fire and associated high temperatures (flame).

Transient Combustible: Combustible material passing through a place with only a brief stay usually associated (but not limited to) maintenance or modifications involving combustible and flammable liquids, wood and plastic products, waste, scrap, rags, or other combustibles resulting from the work activity.

Virtual Origin: This is the source point of the fire when using a point source formulation to model a fire plume.

St. Lucie Units 1 & 2

Turkey Point Units 3 & 4

Docket No's: 50-335, 50-389, 50-250, 50-251

Attachment C

PERFORMANCE-BASED APPROACH TO FIRE BARRIER ADEQUACY:

PROBABILISTIC SAFETY ASSESSMENT DESCRIPTION AND METHODOLOGY

FLORIDA POWER & LIGHT

FPL

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I. Introduction

Probabilistic Safety Assessment (PSA) technology will be used to estimate the level of safety, or fire hazards risk, for fire compartments that contain cables with Thermo-Lag application. The PSA analysis will provide an additional and diverse review of the plant's capability to cope with postulated fires. The PSA review or screen will be applied to those plant fire compartments that have successfully passed the deterministic or traditional fire barrier evaluation in the FPL performance-based approach to fire barrier adequacy.

II. The FPL PSA Fire Model Methodology

A) Overview

The PSA fire model utilizes the EPRI "FIVE" (Fire Induced Vulnerability Evaluation) methodology to screen or estimate the core damage frequency (CDF) for each fire compartment containing cables with Thermo-Lag. The PSA methodology used in this study to calculate a CDF for each fire compartment can be summarized as follows:

$$CDF = \prod_{i=1}^{5} P_i$$

P_1 = The fire ignition frequency in the fire compartment being examined.

P_2 = The failure probability of alternate success paths to put the plant in a safe shutdown condition.

P_3 = Probability of critical combustible loading causing damage to the target components and cables.

P_4 = Failure probability of fire suppression systems.

P_5 = Failure probability of fire-related recovery actions.

B) Fire Ignition Frequencies

Fire ignition frequencies (P_1) for each fire compartment are developed using fire database information contained in the EPRI "FIVE" Report (Ref. V.A). This information is applied to the FPL site specific configurations by calculating fire ignition frequencies based on actual ignition sources present in the fire compartments.

C) **Alternate Success Paths**

The PSA fire model is used to calculate the conditional CDF (P_2) or the failure probability of alternate success paths to put the plant in a safe shutdown condition. The initiating fire events are propagated through the appropriate PSA event and fault tree models in the PSA computer model by failing unprotected cables and equipment in the postulated fire compartment.

Figure 1 provides an example for a postulated fire in the safety related auxiliary feedwater area at the Turkey Point Plant. The PSA model would estimate the failure probability to maintain the plant in a safe condition using "defense in depth" or redundant success paths such as the standby feedwater pumps to remove decay heat.

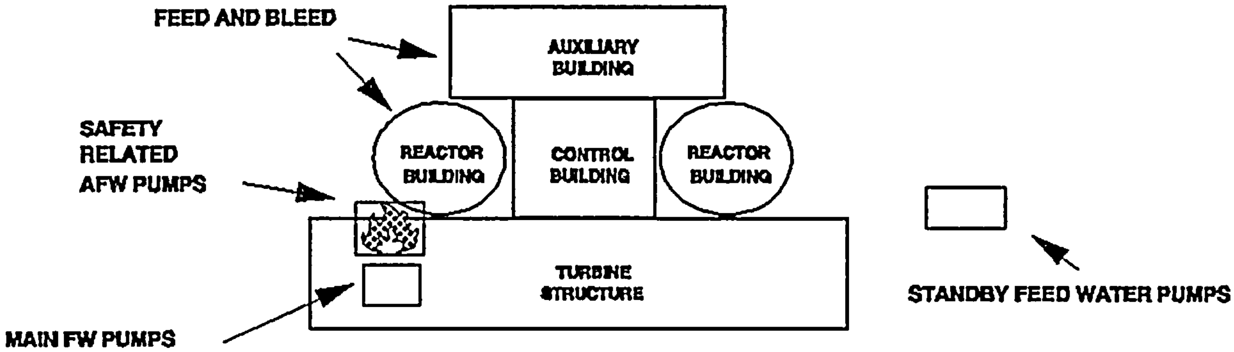

Figure 1 Example of Alternate Success Paths

If the resulting CDF, calculated as ($P_1 \times P_2$), is less than 1.0×10^{-6} per reactor year, the fire compartment is screened out from further analysis. A screening value of 1.0×10^{-5} per reactor year will be used for fire compartments with automatic detection and suppression. For those fire compartments that did not pass this initial quantitative screening, a more detailed analysis is performed which includes the P_3, P_4 and P_5 terms given above.

The quantitative screening, at this step is very conservative. This is because the PSA model at this point assumes:

- All PSA equipment in the fire compartment fails.
- All unprotected cables in the fire compartment fail.
- No credit is given for detection, suppression systems or fire brigades.

D) **Additional Fire Compartment Specific Modeling**

Additional detailed modeling is performed for the fire compartments that do not pass the initial quantitative screening ($P_1 \times P_2$). The additional analysis may include the probability of critical combustible loading damage to target components and cables(P_3), the failure probability of fire suppression systems (P_4), the failure probability of manual suppression and additional recovery

actions in the PSA model that are in plant procedures (P_5).

E) **Comparison of the FPL Model to the EPRI "FIVE" Methodology.**

The FPL PSA assessment of fire barriers uses the EPRI "FIVE" methodology as described in Ref. V.A with differences as identified below. A cross reference in the terms used above and in FIVE are:

P_1 = The fire ignition frequency in the fire compartment being examined is the same as F_1 in FIVE (p. 6-9 in Ref. V.A).

P_2 = The failure probability of alternate success paths to put the plant in a safe shutdown condition is the same as P_2 in FIVE (p. 6-12 in Ref. V.A).

$P_3 \times P_4 \times P_5$ = The probability of critical combustible loading damage is the same as P_3 in FIVE (p. 6-36 in Ref. V.A).

The calculation of the probability of critical combustible loading damage will either use the FIVE tables for fire-target analysis or the FPL plant specific fire hazards model.

The FPL PSA analyses will estimate the failure probability of protected cables in the PSA fault trees(P_2). See Section III for additional detail.

The scope of the FPL analysis includes only those fire compartments with Thermo-Lag.

The recovery actions in the P_5 term refers to manual fire suppression and additional fire related proceduralized actions.

III. The Modeling of Thermo-Lag Barriers

A key feature of this analysis is the modeling of protected cables or Thermo-Lag in the PSA model. For the initial quantitative screening described in Section II.C, failure of all PSA components(i.e., valves, pumps, etc.) located in the fire compartment is assumed. In addition, PSA components in areas outside the fire compartment are also failed if they have unprotected cables in the postulated fire compartment. The Thermo-Lag protected cables, or the associated equipment in the PSA model, are assigned a failure probability based on the Thermo-Lag fire barrier rating determined by industry testing and the anticipated fire duration in the fire compartment. Finally, the probability of Thermo-Lag failure is assumed to be negligible for fire compartments that pass the initial fire hazards analysis screen since there is high confidence that cables will be protected due to the low amount of in-situ combustibles in these fire compartments.

Figure 2 is a simplified representation of the modeling of components in the postulated fire compartment for the initial PSA quantitative screen(P_1 x P_2).

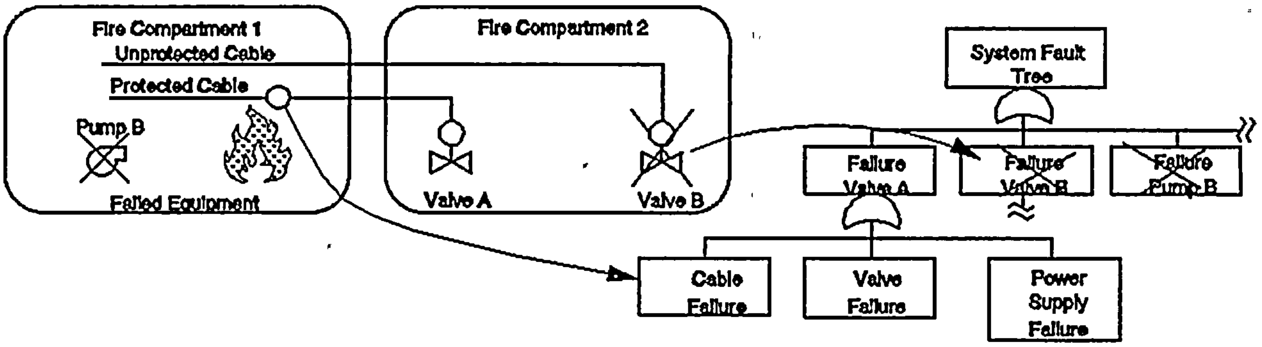

Figure 2 PSA Modeling of Equipment and Cables

The probability of failure of the Thermo-Lag fire barriers for cables is primarily a function of its recent industry tested fire endurance rating and of the duration of the specific fire hazard to which it is exposed. A probability distribution function is estimated based on industry testing of the Thermo-Lag fire endurance rating. Similarly, a probability distribution function is estimated for fire durations based on the FPL fire hazards analysis, plant procedures, and discussions with knowledgeable plant personnel concerning expected flammable transients in the plant. A stress-strength interference model is used to estimate the failure probability of the Thermo-Lag based on the probability distribution of the Thermo-Lag failure time derived from industry testing (i.e., "strength") and that of the estimated fire duration (i.e., "stress"). The estimated Thermo-Lag failure probability for the worst case as-tested conduit size(3/4 inch and one inch) will be used for all currently classified one-hour and three-hour protected cable barriers in the fire compartment for the initial screening effort. The distribution curves will be submitted with the final reports.

If a fire compartment does not screen out due to the initial conservative Thermo-Lag failure probability, a more realistic assessment of the probability of failure of the Thermo-Lag may be performed. This additional analysis corresponds to the P_3 , P_4, and P_5 above. The detailed assessment may consider factors specific to each fire compartment such as the types and quantities of the combustible and the location of the electrical conduits protected by Thermo-Lag. The conservative screening assumption of using test data for the worst case conduit size for all conduits in a fire compartment is reexamined at this point. The fire duration used in the stress-strength interference model is generally an upper bound compared to that which a fire barrier will experience due to the fact that the combustibles and the plume are not always located directly under the Thermo-Lag in an actual fire. If the Thermo-Lag protected cable is not in the fire plume in outdoor fire compartments, the Thermo-Lag failure probability is assumed to be negligible due to the absence of a ceiling affect to trap hot gases.

IV. Review of PSA Model Results

The PSA analysis estimates a level of plant safety or risk for each fire compartment through the PSA computer model of the probability that a fire will start combined with the ability of the plant equipment and plant operators to cope with the fire. The fire compartment will be screened out from any further evaluation during the PSA analysis if the CDF for a fire compartment is determined to be less than 1.0×10^{-6} per reactor year. A level of safety of 1.0×10^{-6} per reactor year for a fire compartment has been accepted in the industry consistent with the FIVE methodology. A fire compartment will also be screened from further evaluation at 1.0×10^{-5} per reactor year if $P_1 \times P_2$ alone is less than 1.0×10^{-5} per reactor year and the fire compartment has automatic detection and suppression.

The results of the analysis will provide a relative comparison of the level of safety for the various fire compartments that contain cables with the Thermo-Lag application. Procedural or physical modifications for fire compartments would be recommended if PSA sensitivity analyses demonstrate that Thermo-Lag protected cables with reduced fire endurance ratings are the cause of a realistic fire vulnerability.

V. References

A. EPRI Report TR-100370, "Fire Induced Vulnerability Evaluation Methodology", Revision 1, dated April 1992.

VI. List of Figures

Turkey Point Units 3 & 4

Docket Nos: 50-250, 50-251

Attachment D

TURKEY POINT OUTDOOR FIRE BARRIERS:

DESCRIPTION AND METHODOLOGY

FLORIDA POWER & LIGHT

FPL

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TURKEY POINT OUTDOOR FIRE BARRIERS

I. Introduction

Florida Power & Light (FPL) has used the Thermo-Lag product for outdoor fire barriers at the Turkey Point Nuclear facility. These fire barrier configurations are unique to the Turkey Point site and, to our knowledge, there has been little or no outdoor use by other utilities within the industry. FPL believes that equivalent protection to subsections III.G.2.a and c to Appendix R can be provided for outdoor areas using Thermo-Lag as a fire barrier material where the following conditions are met:

(1) As-installed fire barriers have a minimum rating of 30 minutes, based on test results and the NEI (NUMARC) Application Guide; and

(2) The fire barriers are not within 50 feet of a major in-situ combustible.

Outdoor areas present special characteristics that mitigate the effects of fires. Fire damage from stratified hot gases or ceiling jet layers is not a concern in outdoor areas or other large enclosures such as the reactor containment. The fire energy is not localized by physical boundaries and dissipates quickly with the large outdoor heat sink. Major in-situ combustibles in outdoor areas such as transformers, oil reservoirs, etc, are contained and have suppression systems. A 50-foot separation provides additional assurance that a fire from one of these sources would not challenge a 30-minute fire barrier.

II. Turbine Lube Oil System

The major combustibles in the Turbine Lube Oil (TLO) system are the TLO reserviors, filters, and the hydrogen seal oil units. No 30-minute Thermo-Lag fire barriers will be allowed within 50 feet of these major sources.

The balance of the TLO system consists of a turbine control oil system, turbine auto stop oil system, and associated piping. Both are supplied by the shaft driven main turbine lube oil pump. This pump operates at about 380 psig. Oil is supplied to the shaft bearings at about 15 psig. The TLO system has annunciators that will alert operators to a high pressure lube oil pipe break, or other pressure loss related problems. These annunciators include:

	Set Point	
Turbine Bearing lube oil press. (E 2/1)	8	psig
Emergency Bearing oil pump running (E 2/3)	7	psig
Turbine Aux oil pump running (E 4/1)	10	psig
Guarded oil actuation (E 5/6)	2	psig
Turbine bearing oil low pressure trip (E 6/2)	5.5	psig

There are no valves (potentially leak locations) in the TLO piping under the turbine deck. The high pressure supply piping is encased in a low pressure (atmospheric) guard pipe which drains to the TLO sump.

In the event of a leak in a high pressure TLO line, the leakage will be diverted to the TLO sump via the guard piping. A leak in the high pressure portion of the TLO system will cause turbine trip and/or turbine valve closures and/or control room annunciation.

Only a low pressure (atmospheric) TLO leak could occur in the turbine building. This would not be a large release of oil, and would be discovered by operators before any significant accumulation would occur.

A wet pipe suppression system is provided for the TLO piping in the turbine building under the turbine deck.

A leak in the low pressure lube oil piping could result in:

- impingement on a hot steam pipe or other ignition source which would ignite the oil. This would be under the suppression system and would be quickly detected by operators.

- no impingement on any ignition sources and end up in a storm drain or sump system. This would not likely be of any significant quantity and would be discovered by plant personnel.

This low leakage TLO piping design will assure that the fire hazard is low in the TLO piping areas.

III. Combustible Control Programs

The Turkey Point Combustible Control Program does not allow storage of combustibles in outdoor areas that contain safe shutdown equipment or cables. Procedures require that liquid flammable combustibles must be attended at all times and a special permit is required for quantities greater than 5 gallons. Hence, transient combustible controls assure that a worst case transient fire caused by a spill would be far below a hazard level that could challenge a 30-minute fire barrier. As an example, a fire from a 20 gallon flammable transient spill (over ≈ 20 ft^2 area) would generate a fire with a duration less than 15 minutes. Initiation of a fire of this size would require multiple breakdowns of the plant transient combustible control processes. However, were these breakdowns to occur, there is still at least a factor of safety of two when compared to a 30-minute fire barrier located directly in the fire plume. Additionally, the actual fire brigade response time for outdoor fires is well below a 30 minute fire barrier fire endurance rating.

IV. 30-Minute Outdoor Fire Barriers

Subsection III.G.2.f of Appendix R allows for the protection of safe shutdown equipment and cables in containment using radiant energy shields. This protective feature is appropriate given the fact that the containment is a large open area and extreme temperature build-up around a postulated fire is not possible. For outdoor open areas, this approach provides equivalent protection for safe shutdown equipment and cables as compared to that allowed by subsection III.G.2.f of Appendix R for the reactor containment. It is also noted that the detection and fire brigade response to a fire in an outdoor area is better than for inside reactor containment. Additionally, 30-minute Thermo-Lag fire barriers can perform the functions of radiant energy shields. The NRC has provided concurrence with this use of fire barriers in Generic Letter 86-10.

Given the identified fire hazards, this method for outdoor areas provides equivalent protection to that of subsections III.G.2.a and c of Appendix R, and is comparable to the provisions of subsection III.G.2.f of Appendix R for protecting safe shutdown equipment and cables.

This method will be used initially to evaluate the Turkey Point outdoor open fire areas/zones described in the Final Safety Analysis Report.

[illegible]