FIRE PROTECTION EVALUATION REPORT COVER SHEET

REPORT NUMBER: PTN-FPER-97-013 REV. 1

TITLE: EVALUATION OF TURBINE LUBE OIL FIRE

LEAD DISCIPLINE: FIRE PROTECTION

ENGINEERING ORGANIZATION: PTN PLANT ENGINEERING

REVIEW/APPROVAL:

GROUP	INTERFACE TYPE			PREPARED	REVIEWED	APPROVED	FPL APPROVED
	INPUT	REVIEW	N/A				
MECH		X				[signature] 6/27/97	
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I & C			X				
CIVIL			X				
NUC**		X				[signature]	
ESI			X				
NUC FUEL			X				
FIRE PROT.	X			[signature] 6/23/97	[signature] 6/23/97	[signature] 6/23/97	[signature] 6/27/97

* For Contractor Evals As Determined By Projects ** Review Interface As A Min On All 10CFR50.59 Evals and PLAs

SPECIAL PROGRAMS APPROVAL: See Fire Prot. appvl. above DATE: ________

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ATTACHMENTS

1.0 PURPOSE/SCOPE

The purpose of this evaluation is to review the existing and proposed, active and passive, fire protection features to determine if the protection is adequate to protect those Thermo-Lag raceways in the Turbine Building from a fire which results from a release of turbine lube oil from failed generator and/or low pressure turbine bearing seals. This evaluation will show that the effects of a postulated Turbine Building lube oil fire on Thermo-Lag protected raceways in the transition area of the OUTDOOR Fire Area (Fire Area OD) will not challenge the raceway protection to the point of failure. The existing and proposed fire protection features will be reviewed for their mitigating effects on the fire and resulting protection of the Thermo-Lag protected raceways. In addition, the anticipated temperatures will be shown to be below the furnace temperatures at 25 minutes during ASTM E-119 fire tests. The scope will include those raceways in the transition area of the Turbine Building located between the D and J_e column lines along the entire length of the east side of the Turbine Building.

This evaluation does not justify a change to the configuration or operation of any equipment described in the FSAR (Ref. 7), and does not alter any plant design basis related to fire protection. Proposed changes to the plant for fire protection will be evaluated using the plant change process.

Revision 1 is issued to document a refinement of the fire scenario, to include additional supporting documentation for the evaluation, and address additional areas of concern. The conclusions of Revision 0 remain valid and are supplemented by conclusions resulting from evaluating other areas of concern. Due to the extensive nature of Revision 1, revision bars are not included within the text.

2.0 BACKGROUND

Thermo-Lag conduit and cable tray wrap material was installed (circa 1985) in the Turkey Point Plant on various conduits and terminal/pull boxes. The wrap was installed to provide a 1-hour and 3-hour level of protection in various areas of the facility to meet the requirements of 10CFR50 Appendix R, Section III.G.2.

In 1991, the NRC alerted licensees to problems associated with certain Thermo-Lag barrier configurations (NRC IN 91-47). These problems were related to the material's inability to successfully pass a fire test for a specific configuration. Further testing at various independent laboratories showed several deficiencies with the material when installed per the manufacturers directions. These deficiencies included lower than specified fire endurance, inability to withstand hose streams and the material was found to be combustible.

The Thermo-Lag in the outdoor areas was installed to meet a 1-hour fire rated configuration. Further testing has shown that the material when tested in it's as-built configuration on 3/4" diameter conduits in accordance with ASTM E-119 withstands a standard time-temperature curve fire for approximately 25 minutes (Ref. 12).

The construction of the Turbine Building is such that there are no fixed walls forming a perimeter around the building and no roof above the operating deck. This allows for the release of smoke and hot gases to the atmosphere in the event of a fire within the Turbine Building. The D to J_e sector runs north-south along the length of the east side of the Turbine Building which faces the Containment, Control and Auxiliary Buildings. The area between the D to J_e column lines contains varying ceiling heights and degree of openness to the atmosphere.

3.0 REFERENCES:

1. National Fire Protection Association, *Fire Protection Handbook*, Seventeenth Edition.
2. Society of Fire Protection Engineers and the National Fire Protection Association, *SFPE Handbook of Fire Protection Engineering*, Second Edition.
3. National Fire Protection Association, NFPA 92-1937, *Suggested Good Practice for Waterproofing of Floors, Drainage, Installation of Scuppers*
4. NFPA 325M-1991, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*

5. Drysdale, D., *An Introduction to Fire Dynamics*, copyright 1985, John Wiley and Sons publishers
6. Baumeister,et.al., *Marks' Standard Handbook for Mechanical Engineers*, Eighth Edition
7. Turkey Point Safety Analysis Report, Revision 13, dated October, 1996
8. Alpert, R.L., *Calculation of Response Time of Ceiling Mounted Fire Detectors*, Fire Technology, 1972.
9. Florida Power and Light, Evaluation PTN-FPER-97-015, Rev. 0, *Technical Evaluation for Turbine Building Fire Protection*
10. American Society for Testing and Materials, *Standard Methods of Fire Tests of Building Construction and Materials* (ASTM E-119)
11. Florida Power and Light, Calculation PTN-BFJM-91-052, Rev. 0, *Fire Protection System Pipe Flow Analysis.*
12. Omega Point Laboratories, *Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope Test 2-2*, April 11, 1994
13. Electric Power Research Institute, Fire-Induced Vulnerability Evaluation (FIVE), EPRI TR-100370, April 1992.
14. National Fire Protection Association, *Standard for the Installation of Sprinkler Systems*, NFPA-13 (1996).
15. Evans, D.D. and Stroup, D.W., *Methods to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings*, Fire Technology, 1986
16. Mower, F.W., *Lag Times Associated With Fire Detection and Suppression*, Fire Technology, August 1990.
17. Florida Power and Light Calculation M08-203-06, Rev. 0, *Hydraulic Calculation for Unit Auxiliary Transformer Deluge Water Spray System, Units 3 & 4.*
18. Florida Power and Light Specification 5610-M-29A, Rev. 1, *Specifications for Hydraulically Designed Sprinkler Systems*
19. Florida Power and Light drawings -
    a. 5610-M-75, Rev. 14 — Turbine Area - Area & Equipment Drainage, Radwaste Area - Roof Drainage Ground Floor Plan
    b. 5610-C-13, Rev. 18 — Utility Piping, Main Plant Area
    c. 5610-A-61, Sht 2, Rev. 6 — Floor Plan at El. 18'-0" Showing Detection, Suppression and Lighting
20. Babrauskas, V., *Temperatures in Flames and Fires*, May, 1997.
21. Factory Mutual Research Corporation, *Fire Tests of Automatic Sprinkler Protection for Oil Spill Fires*, Sept. 9, 1957.

4.0 METHODOLOGY

1. Determine which bearing failures would result in a worse case fire exposure for the Thermo-Lag protected raceways.
2. Review the existing and proposed fire protection features to determine if the features will provide adequate protection of the Thermo-Lag raceways in the Turbine Building.
3. Power plant accidents which resulted in turbine lube oil fires will be reviewed under a separate evaluation. The conditions which led to those accidents will be compared to the Turkey Point facility to determine if similar conditions could occur at Turkey Point. (Ref. 9)
4. Determine the type and location of features in Fire Area OD which act as mitigating features.
5. Determine the environmental conditions to be utilized in the evaluation.
6. Utilizing documented fire and heat transfer formulas and general fire protection theory, determine the anticipated temperatures based on the postulated fuel loading.
7. Document the overall conclusions of the cumulative effects of the worst case anticipated factors with respect to the effects of fire on the Thermo-Lag protected raceways in the transition area of Fire Area OD.
8. Provide recommendations, if necessary, to enhance the protection of the Thermo-Lag protected raceways in Fire Area OD.

5.0 KNOWNS/ASSUMPTIONS

5.1 Known Data

1. The 18'0" elevation is sloped toward the floor drains such that the openings to the floor drains are 2" (0.167') below the floor grade. (Ref. 19)
2. Floor drains are 4" diameter. Waste oil drains are 3" diameter. (Ref. 19)
3. Based on measurements taken during walkdowns the total width of openings which would allow flow to escape from the 18'0" elevation to the Condenser and Condensate Pump Pits is 26'5" and to the outside (west) of the Turbine Building are two flood gate openings which are 36" wide each.
4. Four drains are in the area between column lines A-D and 23.1-25.1 (and 30.1-32.1), three - four inch diameter heavy cast iron pipes which drain to a catch basin and one drain not identified on drawings. (Ref. 19)
5. Oil pressure at the bearings is 10 - 15 psi based on field observation.
6. Plant records indicate that the turbine lube oil is Texaco 00700 Regal R&O 32. Composition of the turbine lube oil is contained in Attachment A.
7. Turbine vibration significant enough to cause the failure of three bearing seals (generator and/or low pressure turbine) will trip the turbine. The turbine coastdown time may be as long as 45 minutes (Ref. 9)
8. Walkdown measurements indicate that 37.65% (1,139.14 ft^2) of the area bounded by column lines A-D and 23.1-25.1 is occupied by fixed equipment or structural components (electrical cabinets, curbed dikes and Turbine pedestals).
9. Walkdown measurements indicate that drain covers throughout the Turbine Building are slotted or perforated. The slotted drain covers provide an effective opening to the drains which is equivalent to an actual diameter of 3.3 inches each while the perforated drain covers provide from 1.24 inches to 1.7 inches in equivalent diameter opening.
10. Wet pipe sprinklers installed in the Turbine Building are intermediate temperature sprinklers rated at a temperature of 212°F (100°C).

5.2 Assumptions:

1. Based on PTN Evaluation PTN-FPER-97-015 bearing vibration within the generator and/or low pressure turbine as a result of an overspeed event causes three bearing seals to fail. The evaluation further concludes that a maximum of 150 gpm flow of lube oil from each failed seal would occur under a worse case scenario. (Ref. 9)
2. All drain covers are assumed to be slotted to allow for the maximum equivalent diameter for the drain covers to be utilized throughout the evaluation. (See Recommendations)

6.0 EVALUATION

The assessment of the postulated lube oil fire in the Turbine Building will start with an evaluation of the existing and proposed fire protection features both active and passive. An analysis utilizing fire protection engineering calculations will be used to quantify the effectiveness of the features described in the evaluation. The analysis will proceed through a determination of the basic values which will be used throughout the remainder of the evaluation. Area features such as the drain flow rates, amount of fluid which can be retained over the drains prior to overflow, the characteristics of the lube oil, rate of discharge for the lube oil will be discussed/evaluated prior to the evaluation of the heat and temperatures generated by the fire, and the postulated sprinkler responses. These features form the basic building blocks from which the evaluation of the conditions resulting from the fire will be based.

Evaluation PTN-FPER-97-015 (Ref. 9) determined that the credible failures of bearing seals would be a total quantity of three (3) in the generator and/or low pressure turbine which would release 150 gpm of lube oil from each bearing for a total of 450 gpm. The location of the bearings which present the worst case fire scenario are the generator and # 6 low pressure turbine bearing. These bearings are located such that two are directly over the area bounded by the proposed curb 6.5' west of the C column line and D column line and 23.1-25.1 (Unit 3) and the

proposed curb 6.5' west of the C column line and D column line and 30.1-32.1 (Unit 4) at the 18'0" elevation, a second is located directly over the condensers and the third is located over the condenser and the 18'0" elevation. Therefore, it is reasonable to postulate only half of the 450 gpm flow of lube oil to the Condenser/Condensate Pump Pits and half to the area between the Switchgear Room and the Condenser (for this evaluation, the area bounded by the proposed curb 6.5' west of the C column line and D column line and 23.1-25.1). The areas bounded by the proposed curb 6.5' west of the C column line and D column line and 23.1 -25.1, and the proposed curb 6.5' west of the C column line and D column line and 30.1-32.1 column lines are the areas where an accumulation of lube oil released due to failed generator and/or low pressure turbine bearing seals would occur in the event of the postulated bearing failure. These areas will herein be referred to as the "curbed area" for the remainder of the evaluation.

6.1 Fire Protection Features

The existing and proposed fire protection features are both active and passive in nature. (See Attachment B) The proposed and existing features in the Turbine Building support the conclusion that the Thermo-Lag raceways in the Turbine Building (column lines E-J) and the transition area to the out-of-doors area ($J-J_c$) do not require any further upgrade to their existing fire resistive properties. This is supported by the augmentation of the sprinklers in the areas where lube oil will pool (the "curbed area" (See Section 6.0 for description)) and at the location of the Thermo-Lag raceways within column lines A-J, as well as, the addition of retention curbs to prevent migration of lube oil from the spill area to the $D-J_c$ column lines.

The provision of full coverage of sprinklers over the areas where the lube oil will pool (the "curbed area" (See Section 6.0 for description)) is the predominant factor in support of the conclusions reached regarding the integrity of the Thermo-Lag protected raceways in the event of a postulated generator and/or low pressure turbine bearing seal failure. Full coverage sprinklers have been shown to be effective in extinguishing fires involving combustible liquids with flash points of 200°F (93.3°C) and higher. The lube oil utilized at Turkey Point has a flash point of 395°F (202°C) which is well in excess of the above stated value. The essential contributor to extinguishing high flash point fires is considered to be the cooling of the liquid surface by the water discharged from the sprinklers to a point where it can no longer generate enough volatile vapors to support combustion. The cooling is through the absorption of approximately 8,440 kJ (8000 Btu) of heat for each gallon of water converted to steam.

Predominant in-situ combustible loading throughout the Turbine Building is limited to the materials which are presently protected by fixed water spray systems with other minor amounts of combustibles protected by the existing sprinkler coverage.

6.1.1 Existing Wet Pipe Sprinklers

Partial coverage of the Turbine Building is provided by wet pipe sprinklers.

Hazard: The wet pipe sprinklers were installed to protect against the hazard of lubricating oil. The sprinkler installation is such that it follows the routing of the guarded oil pipe and also provides coverage of areas where localized pooling of lube oil may occur. The localized pooling of turbine lube oil would occur at the 18'0" elevation between the Switchgear Rooms and the Condenser Pit and within the Condensate Pump Pit. The lube oil with a flash point of 395°F (202°C) is considered to be a Class IIIB combustible liquid. (Ref. 1, p. 3-44).
Hydrogen in the generator is not a contributor to the fire hazards within the Turbine Building other than serving as an ignition source for the lube oil in the event of bearing seal failure on the generator and low pressure turbine. The hydrogen supply to the generator is in a closed piping network whose supply valve is normally closed.

Density: The original design density for the system was to provide 0.3 gpm/ft²/3000 ft². (Ref. 18) In accordance with NFPA 13 (Ref. 14), lube oil hazards in piping, such as those considered in the original design, are classified as an Extra Hazard Group 1 occupancy. The required density for a

similar design area in such an occupancy is 0.28 gpm/ft²/3000 ft². Therefore, the design density used at Turkey Point exceeds the NFPA 13 required density for this hazard type.

Spacing: Sprinkler spacing along the majority of the existing wet pipe sprinkler system is conservative in that it is below the maximum spacing allowed by NFPA 13 which allows a maximum of 100 ft²/head for an extra hazard occupancy.

Coverage: Sprinklers provide full coverage in the Condensate Pump Pit, partial coverage in the Condenser Pit, and partial coverage is provided throughout the remainder of the Turbine Building primarily located to protect areas where guarded oil pipe is routed throughout the Turbine Building. Any fire postulated to be occurring in the Condensate Pump Pit simultaneously to that on the 18'0" elevation is assumed to be suppressed by the existing closed head sprinkler system in the pit. Based on original design documents the sprinkler system for the entire turbine building was designed to provide the area with 0.3 gpm/ft²/3000 ft². The head spacing in the lowest area of the Condensate Pump Pit was observed to be conservatively installed at approximately 50% of the maximum 100 ft²/head spacing. In addition, the configuration of the Condensate Pump Pit lends itself to consideration as an enclosure due to the massive equipment obstructions, and the presence of multiple coverings over various elevations. Therefore, the production of steam in this area will result in aiding in extinguishment via smothering.

6.1.2 Existing High Hazard Areas

Hazards: Lube Oil Reservoir, Lube Oil Transfer Pump Skid, Main Transformer, Auxiliary Transformer, Hydrogen Seal Oil Unit, Start-Up Transformer

Density: Design criteria for the fixed water spray systems installed to protect these hazards indicates that the minimum design density for the systems is 0.25 gpm/ft² over the protected surface. The actual design density has been shown by calculation to be higher for the as-installed system protecting the Auxiliary Transformer. (Ref. 17)

Spacing: The heads are spaced in accordance with the requirements of NFPA 15 (1977 and 1979) and the manufacturer's test documentation for the spray nozzles installed (Automatic Sprinkler 668 and 668WA) so that complete coverage of protected surface area is provided.

Passive: Each of the above named high hazard areas is provided with a diked area for containment of fluid leaks from equipment thus preventing combustible fluids from migrating to other areas.

Coverage: Each system is equipped with heat actuated detectors (rate-of-rise) which are activated when a change of 5°F/minute is detected. This type of detection will sense both a fire involving the equipment being protected as well as a fire adjacent to it. In the event of a fire involving equipment in one of these areas, protection is provided. In the event of a fire adjacent to these areas, such as the postulated turbine lube oil fire, exposure protection will be provided by the spray system to prevent damage to the equipment.

6.1.3 Proposed Augmentation of the Wet Pipe Sprinkler System

Areas of the Turbine Building will be augmented by additional wet pipe sprinklers as a result of a postulated turbine lube oil release and resulting fire. These sprinklers will be provided to complete coverage in areas where pooling of lube oil will occur, and beneath areas of Thermo-Lag protected raceways between the D and J column lines. Sprinkler modifications in the Condensate Pump Pits will be performed as outlined in Recommendation 4 to replace sidewall sprinklers with standard upright sprinklers.

The addition of sprinklers under the Thermo-Lag protected raceways results in the complete coverage of all Thermo-Lag protected raceways throughout the Turbine Building between the A-J column lines. Further, the area of coverage for sprinklers installed within the Turbine Building will be based on a 5000 ft² area and density will be based on a potential lube oil hazard.

Hazard: The additional wet pipe sprinklers will enhance protection in two areas.
Sprinklers will be added to the existing wet pipe system in the area where lube oil will pool on the 18'0" elevation. This area where pooling is a concern is the "curbed area" (See Section 6.0 for

description). The addition of sprinklers to the existing system will provide complete coverage in this area.

Sprinklers will also be installed within, adjacent to, or over locations where Thermo-Lag protected raceways are installed along the length of the Turbine Building between the D-J column lines. The sprinklers for this particular area will be installed where appropriate to protect both the 18'0" elevation and the 30'0" elevation. The additional suppression will provide both cooling of smoke/hot gases from a lube oil fire in an adjacent area as well as protect against the effects of a transient fire beneath the raceways.

Density: The original design density for the existing system was to provide 0.3 gpm/ft^2/3000 ft^2. Due to the nature of the postulated lube oil fire, the area of coverage will be increased to 5000 ft^2 and the design density will consider the lube oil hazard. The increase in area is based on the facts that the areas at the 18'0" elevation and within the pit area where lube oil will pool is approximately 3000 ft^2 and that the intensity of a combustible liquid fire presents the possibility that elevated temperatures adjacent to the area of the fire may be such that the sprinklers therein will also activate. As such this density will be equivalent to or in excess of the NFPA 13 recommended density of 0.2 gpm/ft^2/5000 ft^2.

Spacing: Sprinkler spacing will be in accordance with NFPA 13 which allows a maximum of 100 ft^2/head for an Extra Hazard Group 1 occupancy.

Coverage: Coverage throughout the Turbine Building will remain partial after the installation of the additional sprinklers. However, the areas where lube oil is postulated to pool after a generator and/or low pressure turbine bearing seal failure will be protected by full sprinkler coverage.

6.1.3.1 Effectiveness of Automatic Sprinklers on Lube Oil Fires

NFPA 13, *Standard for the Installation of Sprinkler Systems*, specifies design densities for hazards such as the lube oil hazard which the Turbine Building sprinklers will be designed to suppress. The design densities in NFPA 13 are considered to reflect historical experience with the concept of fire control/containment. Sprinkler head spacing in the Turbine Building in the area of the postulated fire is more conservative than that required to meet the minimum requirements of NFPA 13 and design densities will meet or exceed those required by NFPA 13.

Factory Mutual Research Corporation (FMRC) performed sprinkler discharge testing over lubricating oil fires for the Atomic Energy Commission (AEC) (Ref. 21). The oil utilized was more volatile (ignition temperature approximately 360°F) than the lube oil used at Turkey Point. The oil and floor were preheated to approximately 165°F and 130°F respectively. In all cases the oil was difficult to ignite and required the use of accelerants (gasoline soaked products). The ceiling height in the test facility was 33 feet with vented openings at the ceiling and around the perimeter. Standard 212°F, 1/2" orifice sprinklers were installed on a 10'x10' spacing. Sprinkler operation began to occur at 17 seconds after the pool fire had grown to 5 feet in diameter. The ceiling temperatures in Test #2 never exceeded 600°F (316°C). The maximum pool radius was 6 ft. which was at 18 seconds after the first sprinkler operated. However, it was noted that the fire had been knocked down to a lingering flame at the pool surface within one minute of the first sprinkler operating with an application rate of 0.13 gpm/sq.ft. Another test was performed to establish the effectiveness of sprinklers over a large pool fire. Gasoline/kerosene mixtures were spilled over the lube oil pool and ignited. Water was manually controlled to the sprinklers and not allowed to discharge until the pool fire had grown in size to approximately 1400 sq.ft. Fire control was achieved between 2-1/3 and 4 minutes. Although ceiling temperatures reached 1200°F and flames extended up to 10 feet beyond the vent openings in the structure, the fire was brought under control quickly and without damaging effects to the building. Steel temperatures with automatic sprinkler protection in the area indicated that temperatures which would result in failure would not be reached.

The FMRC testing shows that effective control of temperatures and fire can be achieved for lube oil pool fires with a minimum of discharge density. This supports the conclusion that the sprinkler head type, temperature rating, and discharge density as utilized in the Turbine Building will effectively control the fire and prevent structural steel failure.

6.1.4 Thermo-Lag Protected Raceways

The Thermo-Lag protected raceways located within the area bounded by the A-D and 23.1 -25.1, and A-D and 30.1-32.1 and located within and over the Condensate Pump Pits will be upgraded to meet a 1-hour fire resistance. Other Thermo-Lag raceways between column lines E-J_e throughout the length of the Turbine Building will remain in their present configuration will be assumed to provide approximately 25 minutes of fire resistance.

Temperature Profile

The NFPA Handbook (Ref. 1, p. 6-77 and 6-78) provides descriptions of various occupancies surveyed to develop the characteristic time-temperature curves based on occupancy and fire loading. High hazard occupancies are depicted by the "E" curves in the time-temperature figure. The maximum fire loading which could occur on the 18'0" elevation prior to runoff to other areas would be 483.7 gallons which equates to a combustible loading of approximately 3.1 lb./ft^2. This fire loading when compared to the NFPA fire severity time-temperature "E" curve produces a fire of approximately 15 minutes in duration and maximum temperatures of approximately 760°C (1400°F). This approximated temperature is nonconservative when compared to those temperatures presented in Section 6.7.1, and does not account for cooling which would result from sprinkler discharge in the area. In addition, it is not conservative to utilize the time temperature profiles provided in the NFPA Handbook as a result of changing combustible loading on the various elevations of the Turbine Building as a result of the postulated spill time for the Lube Oil Reservoir to drain as well as the drainage from the elevations via drains, runoff and sump pump operation.

Babrauskas (Ref. 20) indicates that the peak value for fire temperatures is governed by the ventilation and fuel supply characteristics. The maximum value documented is approximately 1200°C (2192°F). Alpert's experiments of large scale fires (668kW - 105 MW) without sprinkler protection indicated a maximum temperature for a large scale fire at a 15' ceiling height was 927°C (1700°F), and temperatures at higher elevations were lower during the same fire. Temperatures of laminar or turbulent diffusion flames as summarized by Babrauskas (Ref. 20) show that an upper temperature limit of 1250°C (2282°F) was observed for natural gas. Other fuels yielded lower upper limit temperatures as well as lower temperatures for the intermittent and continuous flaming regions. Average continuous flame region temperatures of 900°C (1652°F) and intermittent flame temperatures of 320°C (608°F) have been documented for a variety of fuels. Discussion regarding the adiabatic flame temperature (i.e. no loss of heat occurring) for methane and propane indicate temperatures of 1949°C (3540°F) and 1977°C (3591°F) respectively. However, adiabatic temperatures are not realistic in an actual fire scenario due to the continuous loss of heat to surroundings through various means (i.e. radiative, convective, etc.). In addition, the ASTM E-119 time-temperature curve has a maximum temperature of 1260°C (2300°F) which is reached at 8 hours.

The FMRC testing described above in Section 6.1.3.1 indicates that ceiling temperatures at 33' over the base of the fire never exceeded 600°F (316°C) with automatic sprinkler protection and control was established within minutes of the operation of the first sprinkler.

The fire duration is postulated to occur over the time frame in which the entire contents of the lube oil storage tank are assumed to be discharged as a flaming stream. This was postulated in order to present a very conservative analysis. However, due to the complete coverage with sprinklers of the area where pooling will occur at the 18'0" elevation and the manual fire fighting efforts which will be involved, suppression is likely to occur at an earlier time within the postulated scenario.

Therefore, based on the above discussion, the temperatures that are predicted throughout the duration of the fire as shown in Section 6.7.1 are significantly conservative in view of the documented maximum temperatures for gas layers, and flame temperatures. As such, the areas east of the "E" column line will not be recommended for Thermo-Lag upgrade, since temperatures at the "E" column line are conservatively calculated to be below the temperatures in the ASTM E-119 furnace at 25 minutes.

Tubular Steel Survivability

Conduits and pipes, which are located above Thermo-Lag protected raceways, in the vicinity of the fire scenario are supported by tubular steel (unistrut). Failure of the supports for these unprotected conduits or pipes could affect the integrity of the Thermo-Lag protected raceways located beneath them. Therefore, a review of the potential for steel failure is included in this evaluation.

Steel failure is known to occur when the steel temperature reaches approximately 649°C (1200°F). However, steel will not fail at the same time that a room or ceiling jet temperature of 649°C (1200°F) is reached. Heat transfer within the steel itself must occur for a period of time before the member will reach its critical temperature. Discussion in *Temperature Profile* (above) regarding the temperatures in the fire scenario has concluded that the temperatures predicted for the ceiling jet and in the intermittent and continuous flaming regions will be lower than those postulated in Section 6.7.1. As such the only areas of concern based on the temperatures documented in the referenced section will be within the area bounded by the B-D column lines where temperatures are postulated to be in excess of the temperatures at which steel failure can occur. Additional protection of supports in the area of the fire are not recommended or considered necessary based on the following points of consideration:

- Sprinkler discharge will provide water impingement on the supports of raceways/pipes within the boundaries of the flaming fire. This discharge will provide direct cooling to the support steel for the raceways. This is supported by the FMRC testing discussed in Section 6.1.3.1.
- Temperatures which are postulated are very conservative based on the discussion in *Temperature Profile*. Actual temperatures are postulated to be much lower, thereby reducing the threat to the soundness of the steel supports. This is supported by the FMRC testing which indicated that the ceiling temperatures over the pool fire never exceeded 600°F (316°C).

6.1.5 Retention of Lube Oil - 18'0" elevation

The areas bounded by the "curbed area" (See Section 6.0 for description) where an accumulation of lube oil released due to failed generator and/or low pressure turbine bearing seals will occur. Due to the open areas associated with normal ingress/egress from these areas to other areas of the Turbine Building, the potential exists for the migration of turbine lube oil beyond the area to the exterior of the Turbine Building and to the J column line. Retention curbs are proposed to prevent the migration of released lube oil and sprinkler discharge beyond the D column line and 6.5' west of the C column line. (Refer to Section 6.3 and Attachment B)

6.1.6 Physical Arrangement

Mitigating physical arrangements within the 18'0" elevation of the Turbine Building exist which could shield or otherwise inhibit the flow of smoke and hot gases from an oil release and fire to the areas where Thermo-Lag protected raceways are located. This is due to the presence of the structures or equipment in the area with respect to generator and/or low pressure turbine bearing locations and postulated pooling areas. The area to be bounded is the "curbed area" (See Section 6.0 for description) and was determined to present the worst case scenario for transmission of heat to the Thermo-Lag protected raceways due to the location of Thermo-Lag protected raceways with respect to the postulated pooling area. In addition, the location of the generator and/or low pressure turbine bearings postulated to leak are such that one is directly over the area mentioned, a second is directly over the condensers and the third is over both areas. Therefore, it is reasonable to postulate only half of the 450 gpm flow of lube oil to the Condenser/Condensate Pump Pits and half to the area between the Switchgear Room and the Condenser (for this evaluation the "curbed area" (See Section 6.0 for description)). Sloped curbing will be introduced to confine the lube oil spill between approximately 6.5 feet

west of the C column line and the D column lines thus providing a limited pool size which will be channeled to runoff to the Condenser and Condensate Pump Pits.

6.2 Drain Flows

No credit is taken for drain flow from the 18'0" elevation through the waste oil floor drains due to the low capacity of the waste oil separator. The waste oil separator is located at the Turkey Point Fossil Facility.

Based on a 2" (0.167') depth of oil over the drain opening and utilizing Bernoulli's equation (Ref. 6), where the slotted drain covers provide an effective diameter opening of 3.3 inches each, the effective flow into any one of the 4" diameter drains is approximately:

$$\frac{P_1}{\rho_1}+\frac{v_1^2}{2g}+z_1=\frac{P_2}{\rho_2}+\frac{v_2^2}{2g}+z_2$$

where:

$$\frac{P_1}{\rho_1}=\frac{P_2}{\rho_2}$$

$\frac{v_1^2}{2g}$ is considered negligible

$z_2 = 0$

therefore,

$$z_1=\frac{v_2^2}{2g}\Rightarrow v_2=\sqrt{2gz_1}=\sqrt{2(32.2ft/s^2)(0.167ft)}=3.28ft/s$$

Based on an approximate 3.3 inch diameter opening:

$$v_2=3.28ft/s\Rightarrow Q_2=v_2A=v_2\pi r^2=(3.28ft/s)\pi(0.1375ft)^2=0.195ft^3/s$$

Converting to gpm:

$$Q_2=(0.195ft^3/s)(7.481gal/ft^3)(60s/\min)=87.53gpm$$

Therefore the flow resulting from the 2 available drains is:

$$Q_{MD}=2\bullet Q_2=2\bullet(87.53gpm)=175.06gpm$$

Full flow of oil/water output at the catch basin through the 4" drains is not anticipated due to the lower flow rate calculated through the drain covers (175 gpm). However, a flow rate of 66 gpm will be used in the evaluation as the maximum rate that the turbine lube oil or other fluid will drain from the 18'0" elevation.

Therefore, based on a 4" diameter main drain, converting to velocity we obtain:

$$V_{MD}=(66gpm)(1\min/60\sec)(1ft^3/7.481gal)/\pi(0.16775ft)^2=1.66ft/s$$

Assuming entrance, fitting and exit losses within the drainage piping are considered negligible, their associated valves will not be considered in the evaluation of the drain flows. Using Bernoulli's equation we find that for the drain flow resulting from a combination of flows from 2 drains to the catch basin:

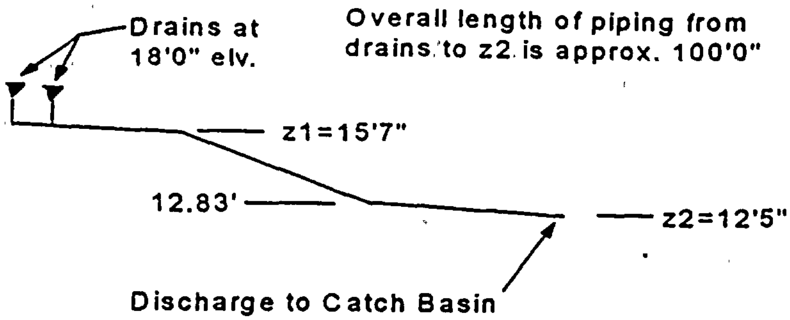

Figure 1
General Elevations in Drain Piping from 18'0" Elevation

$$\frac{p1}{\rho 1}+\frac{v1^2}{2g}+z1-h_{loss}=\frac{p2}{\rho 2}+\frac{v2^2}{2g}+z2$$

where:

$\frac{p1}{\rho 1}=\frac{p2}{\rho 2}$

$v_1 = v_{MD} = 6.62 ft/s$

$z_1 = 15.6'$

$z_2 = 12.4'$

and

h_{loss} = friction loss in the approx. 100' of pipe between the drains and the catch basin

$= fLv^2 / D2g$

where:

$f =$ friction factor based on the Moody diagram

$L =$ length of the pipe in feet $= 100 ft.$

$v =$ velocity of the fluid in feet / s $= 1.66 ft/s$

$D =$ internal diameter of the pipe in feet $= 0.3355 f$

$g =$ acceleration due to gravity $= 32.2 ft/s^2$

The values for viscosity and density of the turbine lube oil shall be used in the calculation of the friction factor. The friction factor (f) is based on the Reynold's number (N_{RE}) and the relative roughness (ε / D).

$N_{RE} = vD / \upsilon$

υ = kinematic viscosity $= 31.5 cSt = 31.5 * 10^{-6} \frac{m^2}{s} = (31.5 * 10^{-6} \frac{m^2}{s}) * (10.76 \frac{ft^2}{m^2})$

$\upsilon = 3.389 * 10^{-4} ft^2 / s$

$N_{RE} = (1.66 ft/s)(0.3355 ft) / 3.389 * 10^{-4} \frac{ft^2}{s} = 1.643 * 10^3$

$\varepsilon / D = (0.00085 ft) / (0.3355 ft) = 2.55 * 10^{-3}$

In applying these values to the Moody diagram, one observes that the Reynolds number above is representative of laminar flow which follows a friction loss formula of $64/N_{RE}$. The friction loss factor of 4" pipe is therefore = $64/1.643*10^3 =$ 0.0389 ft

The friction loss $(h_{loss}) = (0.0389)(100ft)(1.66ft/s)^2/(0.3355ft)(2)(32.2ft/s^2) = 0.5ft$

Substituting these values into Bernoulli's Equation yields:

$$v_2 = \sqrt{v_1^2 + 2g(z_1 - z_2 - h_{loss})} = \sqrt{(6.62ft/s)^2 + 2(32.2ft/s^2)(15.6' - 12.4' - 0.5')} = 14.75ft/s$$

Converting to gpm:

$$v_2 = 14.75ft/s \Rightarrow Q_2 = v_2 A = (14.75ft/s)((0.3355ft/2)^2 \pi)(60s/\min)(7.481gal/ft^3) = 585.3gpm$$

Therefore, based on the above calculations, the reduced flow into drains which is postulated at 66 GPM is valid.

6.3 Fluid Retention Around Drains

The presence of drains with top-of-drain-elevations (TODE) below the grade elevation of 18'0" coupled with slope indications toward those drains are indications that configuration similar to inverted pyramids exist over the drains.

Although the drain areas are not mirror images of one another (Ref. 19a), it is assumed that dividing the non-occupied area equally amongst the four drain areas would present a reasonable representation of the volume of fluid which could be retained over the drains as a whole.

a. Gross floor area (A_g) between column lines A-D and 23.1-25.1: $A_g = 62.85' * 48.125' \approx 3026.sq.ft.$

b. Each drain opening is 2" (0.167) below grade which will be used as the height..

c. Floor area not occupied by structural components or equipment (A_f): $A_f \approx 1887 sq.ft.$

d. Divided into four quadrants, the area per quadrant (A_q): $A_q = 0.25 * A_f = 472 sq.ft.$

e. Gross area bounded by curbing (A_p): $A_p = (33.875' * 48.125) = 1630.23$ ft² (151.4 m²)

f. A_p area occupied by equipment (A_{pe}): $A_{pe} =$ 457 ft² (42.45 m²)

g. Area of floor unoccupied where lube oil can pool (A_{pf}): $A_{pf} =$ 1173.23 ft² (109 m²)

h. Calculating the volume of a quadrant as a pyramid:

$$V_q = (1/3)(base)(height) = (0.33)(472ft^2.)(0.167ft) = 26ft^3$$

$$V_q = (26ft^3)(7.481gal/ft^3) = 194.6gallons$$

i. Total potential retention over the drains prior to runoff occurring:

$$V_t = (1173.23ft^2/472ft^2) * 194.6gallons = 483.7gallons$$

6.4 Critical values associated with the Turbine Lube Oil

A comparison of characteristics of the Turbine Lube Oil used at Turkey Point was performed against similar parameters of other combustible liquids.

Table 1
Material and Burn Characteristics of Various Petroleum Based Hydrocarbons

	Flash Point °F (°C)	Ignition Temp. °F (°C)	Spec. Gravity	Boiling Point °F (°C)	NFPA Fire Hazard Rating[4]	ΔH_c^u MJ/kg	Mass Loss Rate kg/m²s
Mineral Oil	380°F (193C)		0.8-0.9	680°F (360C)	1	45.8-46.0	
Lubricating Oil, Mineral	300°F-450°F (149°C-232°C)	500°F-700°F (260°C-371°C)	<1	680°F (360°C)	1		
Turbine Oil	400°F (204°C)	700°F (371°C)	<1		1		
Regal Oil [1]	395°F (202°C)		0.8681		1	45.37 [6]	
Fuel Oil No. 1	100°F-162°F (38°C-72°C)	410°F (210°C)	0.825 [5] <1	482°F (250°C) 305°F-574°F (152°C-301°C)	2	43.1 [5] 46.5 [2]	
Fuel Oil No. 2	126°F-204°F (52°C-96°C)	494°F (257°C)	<1		2		
Fuel Oil No. 4	142°F-240°F (61°C-116°C)	505°F (263°C)	<1		2		
Light Fuel Oil No. 5	156°F-336°F (69°C-169°C)		<1		2		
Heavy Fuel Oil No 5	160°F-250°F (71°C-121°C)		0.94-1 [3] <1		2	39.7 [3]	0.035 [2]
Fuel Oil No. 6	150°F-270°F (66°C-132°C)	765°F (407°C)	1+/-		2	42.5 [2]	

Notes:

1 All values except heat of combustion are from the Texaco Material Safety Data Sheet for 00700 Regal R&O Oil. (Att. A)
2 Fire Protection Handbook, 17th edition, Table A-3 (Ref. 1)
3 Handbook of Fire Protection Engineering, 2nd Edition, Table 3-1.2 (Ref. 2)
4 Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids, NFPA 325M-1991 (Ref. 4)
5 Handbook of Fire Protection Engineering, 2nd Edition, Table C-1 (Ref. 2)
6 Fire Protection Handbook, 17th edition, Page A-7: $\Delta H_c^u (MJ/kg) = 52.12 - 8.79d^2 - 0.14d$
where d=specific gravity (Ref. 1)

In comparing the known values for flash point, ignition temperature, specific gravity, boiling point, and fire hazard rating we see a distinct similarity in values associated with the lubricating oils, and the Texaco Regal Oil . In reviewing the characteristics of the fuel oils one can see that fuel oil is more volatile than the lubricating oils with flash points and ignition temperatures lower in almost all cases.

The comparison of heats of combustion (Δh_c) shows a small deviation in values for all fuel chosen including the approximated value for the Texaco Regal Oil. Although the heat of combustion may be determined from empirical rules characterizing petroleum products due to it being a material property, the mass loss rate ($\dot{m}''$) is typically found experimentally (Ref. 1, p. 10-100 and Ref. 2, p. 3-3). Due to the limited information available on mass loss rate values, the mass loss rate value associated with heavy fuel oil will be used throughout the remainder of this evaluation where necessary as that of the Texaco Regal Oil. This assumption is felt to be valid based on the comparison and similarity of the material properties of several petroleum based hydrocarbons.

The Turbine Lube Oil used at Turkey Point is Texaco 00700 Regal R&O 32 a lubricating oil consisting of 95-99% solvent dewaxed heavy paraffinic hydrocarbon distillates* (mineral oil) with the remainder being composed of butyl phenol, and [redacted] and methaacrylic acid as additives (Att. A). The burning characteristics of the lube oil will be slightly different from 100% mineral oil since the lighter fractions will ignite earlier and are likely to burn faster. However due to the small amount of additives in the total volume it is not likely to have a significant impact on the mass loss rate to be used.

6.5 Lube Oil Pool Depth

Based upon assumptions related to the flow rate and dispersion of the turbine lube oil, 225 gpm is postulated to flow to the 18'0" elevation. The pool depth at any point in time will be affected by the following factors:

- Drain capacity
- Mass loss due to burning of the fuel
- Runoff to the Condenser and Condensate Pump Pits or through flood gates

a. The postulated flow of lube oil to the 18'0" elevation is 225 gpm. Bearing seal failures at three bearings (generator bearing and bearings 7 and 8 of the low pressure turbine) are postulated. The bearing locations are such that one is directly over the "curbed area" (See Section 6.0 for description), the second is over the column line separating the condenser from the 18'0" elevation and the third is over the condensers. Therefore, it is postulated that 50% of the lube oil released due to the postulated bearing seal failures will discharge to the 18'0" elevation and the remaining 50% will be discharged over the condensers and will collect in the Condensate Pump Pit (See section 5.2.1).

b. The calculated drain capacity at the 18'0" elevation calculated in Section 6.1 was determined to be 175 gpm. As a matter of conservatism this value will be reduced by approximately 62% to 66 gpm for calculation of the effects of a lube oil fire with or without sprinkler interaction.

c. The capacity over the drains before spill over to the Condenser Pit, down the stairs to the Condensate Pump Pit is calculated to be approximately 483.2 gallons based on calculations performed above in Section 6.3.

d. The total width of openings from the area of concern at the 18'0" elevation to the Condenser and Condensate Pump Pits is 11'2" per unit. Suggested Good Practice for Waterproofing of Floors, Drainage, Installation of Scuppers (Ref. 3) which is no longer in effect but the majority of whose content is contained in the Fire Protection Handbook (Ref. 1, 6-28), provides information on the tested discharge values through standard 4" scuppers. The approximate discharge for the total width present in the area of concern will be used later in this evaluation. The discharge rate will be applied such that the flow

* PROPRIETARY
6/29/98

[redacted]

associated with the fluid height calculated will be extrapolated based on the values shown in Table 2 below.

Table 2
Flow Rates for Standard Scuppers and Other Openings

Depth of water inches (meters)	Discharge from a 4" scupper (NFPA 92-1937)	Average Discharge Per Square Inch (Opening Width x Fluid Depth)	Approximate discharge through 11'2" (134 inches)of openings to the Condenser and Condensate Pump Pits
1 (0.0254)	33 gpm	8.25 gpm	1105.5 gpm
2 (0.051)	71 gpm	8.875 gpm	2379 gpm
3 (0.0762)	132 gpm	11 gpm	4422 gpm
4 (0.1016)	188 gpm	11.75 gpm	6298 gpm
4.4 (0.1118)	210 gpm	11.93 gpm	7033.9 gpm
5 (0.127)	218 gpm	10.9 gpm	7303 gpm
6 (0.1524)	245 gpm	10.2 gpm	8200.8 gpm

e. Based on no sprinkler activation; the above discharge rates of oil (225 gpm) and drain flow rates (66 gpm), fuel accumulation over time will be seen on the 18'0" elevation.

f. Confinement of the burning lube oil will be primarily contained within the curbed area, minor splashing is expected to occur but will be limited due to the position of the curbs. Addition of water due to sprinkler activation will increase the effective pool area and pool diameter due to spreading of the fuel across the area bounded by the curbing on the 18'0" elevation. The effects of the addition of water will be calculated on a one minute time step basis in order determine the effective curb height, the mass loss and heat release due to burning. For the purposes of calculating the heat release from the fire an effective pool diameter will be calculated based on a circular pool with an area approximately equal to the unoccupied area bounded by the proposed curbing.

g. Based on potential lube oil flow patterns and assumed drainage rates from the 18'0" elevation, the heat release and resulting ceiling jet temperatures prior to sprinkler activation will be based on streaming burning combustible liquid which is estimated to cover the entire unoccupied portion of the curbed area which is equivalent to 109 m^2 (1173.23 ft^2).

h. The activation of the spray systems which protect the Hydrogen Seal Oil Unit and the Auxiliary Transformer discharge approximately 105 gpm and 390 gpm respectively. The diked areas surrounding each of these hazards will contain the system discharge for approximately 5.23 minutes and 11.11 minutes respectively. After these discharge times overflow will occur onto the 18'0" elevation in the area being evaluated. It is postulated that at approximately 2 minutes into the fire scenario the temperature rise in the vicinity of these spray systems will activate the respective detection systems which are set to respond to a temperature rise of 5°F/minute. Therefore, at the above mentioned times at which overflow will occur, the discharge of these systems will be added to the amount of fluid on the 18'0" elevation outside of the curbed area.

i. Prior to runoff occurring down to the Condenser and Condensate Pump Pits the maximum pool depth of 2" is postulated (~ 483.7 gallons of lube oil on the 18'0" is postulated to exist).

6.6 POSTULATED FIRE - PRE-SPRINKLER ACTIVATION

Hydrogen release as a result of the failed hydrogen oil seals will ignite and cause the subsequent ignition of the lube oil.

As stated above, 225 gpm of turbine lube oil is calculated to be flowing across the 18'0" elevation during the initial phase of the postulated fire. There will be no runoff to the Condenser and Condensate Pump Pits during the early stages of the postulated fire based on floor slopes in the areas of concern. Flow of oil beyond the D column line is not postulated due to the addition of a retention curb. It is postulated that the initial release of lube oil will generate a pool with an area of approximately half the total unoccupied floor space in the curbed area.

Sprinkler response times are affected by the radial distance of the sprinklers with respect to the fuel package, fire plume temperatures, ceiling jet temperatures and ceiling jet velocities. The sprinkler response times in the areas of concern will also be affected by the inconsistent ceiling heights in the area. Since sprinklers are located at various heights in these areas the response times in both will be calculated using ceiling heights of 3.66 m (12'0") and 7.315 m (24'0").

6.6.1 Heat Release

The heat release in the area due to the postulated fire will not include any other in-situ or transient combustibles other than the postulated release of turbine lube oil. This is based on combustibles documented in the FSAR (Ref. 7) for those fire zones where the fire is postulated to occur and those fire zones adjacent to the fire. The combustibles documented are either negligible or consist of combustible liquids contained within equipment which is bermed and protected with automatic water spray systems.

The following assumptions pertain to the determination of the heat release in the area of the fire as shown in Table 4:

- Transient effects such as unsteady burning during the initial stage of the fire as a result of gradual heating of the ground underneath and surrounding boundaries will be ignored. This effect cannot be quantified particularly for a nonenclosed structure. This is a conservative measure resulting in greater heat release in the early stage of the fire.
- Wind effects will not be considered. Prevailing winds in the area as documented in the FSAR (Ref. 7) were reviewed and found to be from the easterly direction. As such the affects of the prevailing winds in the area would actually benefit this analysis. The configuration of the Turbine Building is such that partial shielding from the effects of the wind will result due to other structures and equipment. Further, it has been observed that the effects of wind are dampened to a point of insignificance upon entry into the area where the fire is postulated to occur. Therefore, in an effort to provide conservative results the effects of wind will not be considered.

The heat release generated by the pool fire size postulated is found by using the formula (Ref. 2, p. 3-4):

$$Q = \dot{m}'' * \Delta h_c * A$$

where: Q = heat release in kilowatts

$\dot{m}''$ = mass loss rate in kg/m^{2}s

Δh_c = heat of combustion in kJ/kg

A = pool area in m^2

A semitheoretical analysis together with a study of available experimental data showed that the following formula can be used to represent the mass loss rate of a pool fire burning in the open. (Ref. 2, p. 3-3).

$$\dot{m}'' = \dot{m}_{\infty}''(1 - e^{-k\beta D})$$

where:

$\dot{m}_{\infty}''$ = mass loss rate for an infinite diameter pool = 0.035kg./$m^2 s$ (for heavy fuel oil)

k = the extinction - absorption coefficient of the flame

β = the mean - beam - length corrector

$k\beta$ = 1.7 m^{-1} (for heavy fuel oil)

D = pool diameter in meters

Calculating the effects of the fire based on a circular unrestricted pool entirely involved will provide conservative results because by doing so we will be postulating more complete combustion, unrestricted air flow and entrainment, an unrestricted flame structure and that turbine lube oil will be present across the surface of the pool. However, a 20% reduction in the mass loss rate is typically used for pool sizes greater than 10 meters which is based on test results which show incomplete combustion for pool diameters of this size (Ref. 2, p. 3-5). Additional tests (Ref. 5, p. 172) conducted to evaluate the fraction of total heat release which resulted from the combustion of various fuels showed heptane releasing as low as 69% of the total potential heat release during its combustion phase. Therefore, since actual heat release rates will be significantly lower than the theoretical heat release rates, a reduction of 20% of the total heat release will be used for all estimates of actual heat release.

6.6.2 Ceiling Jet and Plume Centerline Temperatures

The area of concern has an ceiling configuration of varying heights such that the ceiling at the center of the area (A-D, 23.1-25.1) is at a higher elevation than the remainder, thus forming a pocket (See Figure 2). Although some heat will pocket in the center of the area due to the higher ceiling elevation, the remainder of the ceiling area which is lower will transport heat from the plume laterally to the exterior of the structure and to the east of the D column line. The ceiling height east of the D column line is higher than west of the D line and as such the higher ceiling elevation will be used to postulate temperatures anticipated at Thermo-Lag protected raceways in this area.

Alpert (Ref. 8) reported on the behavior of fire plume and fire induced flow near ceilings. The tests used to justify the equations derived were of a variety of flammable liquids and combustible materials. The fire sizes varied as well as ceiling heights and room sizes. Room sizes in many cases were up to 100 m in width. Therefore, the use of these formulas for the postulated case is sound. The following formulas show that the maximum temperature of the plume is dependent upon the ceiling height and radial position from the center of the plume (Ref. 5, p. 137 and Ref. 2, p. 2-33). These formulas will be utilized in the development of values shown in Tables 3, 5, 6, 8, and 9.

for r > 0.18H

$$T_{max} - T_{\infty} = \frac{5.38\left(\frac{\dot{Q}}{r}\right)^{2/3}}{H}$$

for r ≤ 0.18H (i.e. within the area where the plume impinges on the ceiling)

$$T_{max} - T_{\infty} = \frac{16.9\dot{Q}^{2/3}}{H^{5/3}}$$

Where:

$\dot{Q}$ = heat release (kW)
r = radius from the centerline of the fuel package (m)
H = height above the fuel package (m)
T_∞ = ambient temperature in the area (°C) assumed to be 29.4°C (85°F)

6.6.3 Velocity of Ceiling Jet Flow

Similar to the ceiling temperatures there are correlations for the ceiling jet velocities which are dependent on both the ceiling height and the radial distance from the center of the fuel package (Ref. 2, p. 2-33). This formula is used in Table 3.

For $r > 0.15H$:

$$U_m = 0.195\left(\frac{\dot{Q}^{1/3}}{r^{5/6}} h^{1/2}\right)$$

and for $r \leq 0.15H$:

$$U_m = 0.96\left(\frac{\dot{Q}}{h}\right)^{1/3}$$

Where:

$\dot{Q}$ = rate of heat release (kW)
r = radius from the centerline of the fuel package (m)
h = height above the fuel package (m)
U_m = gas velocity (m/s)

6.6.4 Sprinkler Response Times

Sprinkler response times are dependent upon the characteristics stated above as well as a value known as the Response Time Index (RTI) value. The RTI is a value which results from the sprinkler or heat detector time constant (obtained from controlled testing) multiplied by the square root of the velocity.

The formula shown below for determination of the sprinkler response time (Ref. 1, p.10-106 and Ref. 2, p.4-5) will be used to determine the time at which sprinklers at various distances from the center of the fuel package are anticipated to operate. This will be a rough correlation since the factor of varying ceiling heights will affect the responsiveness of the sprinklers in the area. In addition, this formula is based on instantaneous transport and detection of heat, i.e. not incorporating a factor for the transport lag time. Therefore, due to this and the open nature of the Turbine Building sprinkler response times are assumed to be delayed beyond those times indicated below due to heat transport and dissipation. (Ref. 8, 15, and 16)

$$t_{operation} = \frac{RTI}{\sqrt{U_m}} \log_e\left(\frac{T_m - T_\infty}{T_m - T_{operation}}\right)$$

where:

$t_{operation}$ = time to operation (seconds)
RTI = Response Time Index value (110.415 $m^{1/2}/s^{1/2}$ (200 $ft^{1/2}/s^{1/2}$))
U_m = maximum gas velocity (m/s)
T_M = plume or ceiling temperature (°C) (dependent on distance from center of pool)
T_∞ = ambient temperature (°C)
$T_{operation}$ = operating temperature of the sprinkler head (100°C (212°F))

The columns shown in Table 3 are based upon a 225 gallon spill of turbine lube oil on the 18'0" with an approximate pool diameter equal to that occupied by a one inch depth of fluid (~1/3 the available unoccupied area on the floor bounded by the "curbed area" (See Section 6.0 for description)). The table shows the time required to operate sprinklers at various radial distances from the center of the fuel package.

It is also noted that this formula will not be used later in this evaluation to determine the sprinkler operation in the remainder of the area after the first sprinklers in the area operate over the fire plume. This is due to the cooling effects that the operated sprinklers will have on the fire below thereby resulting in lower ceiling jet temperatures, thus effecting whether additional sprinklers will or will not operate.

Table 3
Characteristic Temperatures and Velocities and Sprinkler Response Times
Associated with Turbine Lube Oil Fire on the 18'0" elevation
Pre-Sprinkler Activation

Pool Area 38.18 m^2 (411 ft^2)								
Effective Pool Dia. 6.97 m (22.88 ft)								
	Radial Distance From the Center of the Fuel Package							
					D Column		E Column	J Column
	0.01 m	1 m	2 m	4 m	6.97 m	8 m	10.66 m	17.37 m
Heat Release (kW)	48,501.61	48,501.61	48,501.61	48,501.61	48,501.61	48,501.61	48,501.61	48,501.61
Plume Centerline Temperature (°C)								
@ 3.68 m (12 ft.)	2,614.96							
@ 7.31 m (24 ft.)	845.47							
Ceiling Jet Temperature (°C)							811.67	
@ 3.68 m (12 ft.)		1,985.07	1,281.36	805.47	565.33	518.28	433.13	320.95
@ 7.31 m (24 ft.)		845.47	645.80	417.70	297.55	274.01	231.40	175.28
Velocity of Ceiling Jet (m/s)								
@ 3.68 m (12 ft.)	22.71	13.60	7.63	5.45	2.70	2.41	1.89	1.26
@ 7.31 m (24 ft.)	18.03	18.03	10.79	7.70	3.81	3.40	2.68	1.78
Sprinkler Response Times (sec)								
@ 3.68 m (12 ft.)	0.64	1.10	2.36	4.51	9.49	11.10	15.42	27.26
@ 7.31 m (24 ft.)	2.35	2.35	4.09	7.99	17.28	20.39	29.02	54.72

6.7 - EFFECTS OF SPRINKLERS ON THE ENERGY AND TEMPERATURE OUTPUTS OF THE FIRE

General

The rough correlation of sprinkler response times calculated in Section 6.6.4 was based on a smooth, unobstructed ceiling in a large enclosure. The varying ceiling heights in the Turbine Building will affect the responsiveness of the sprinklers in the area. In addition, factors associated with the cooling effects of discharge from the first sprinklers to operate as well as the characteristics of the fire being three dimensional must be considered. Sprinklers which activate during the early stages of the fire will provide cooling of the ceiling temperatures and make it impossible to predict (by current methods) the actuation times for all sprinklers. However, due to the postulated fluid being on fire as it is running down from the operating deck, the ceiling temperatures may be elevated resulting in the activation of the sprinklers outside the plume at the shown. Therefore, the sprinkler response times are assumed to be delayed beyond those times indicated below due to less uniform ceiling jet flows and the cooling effects of the initial sprinkler response. Sprinkler activation is assumed to occur within 1 to 2 minutes over half of the "curbed area" (See Section 6.0 for description).

Cooling Effects and Production of Steam

The design density stipulated during the original design of the existing wet-pipe systems in the Turbine Building was 0.3 gpm/ft²/3000 ft² This design density is in excess of the requirements of NFPA-13 (1996) (Ref. 14) for a Extra Hazard Group 1 hazard. NFPA 13 design densities are considered to reflect historical experience with the concept of fire control/containment. This presents an area where additional cooling and steam production effects are anticipated due to increased water application.

The fire postulated herein is a three dimensional one. The lube oil coming from the failed bearing seals is presumed to be flowing down from the 42'0" elevation to the elevations below. Upon activation the sprinklers will be wetting and cooling the burning fuel near the elevation at which they are installed, i.e cooling the burning fuel before it reaches the floor elevation.

Production of water droplets will lead to significant cooling of surrounding equipment and structures, thereby reducing the radiative feedback to a fire which is necessary to sustain the combustion process.

Evaporation of water droplets create steam with a volume more than 1700 times that of water and will aid in smothering the fire since it reduces the ability of the fire to obtain needed oxygen (Ref. 1, p. 5-156). Steam production over the fire will be removing heat from the fire which results in lower radiative feedback to the pool. It is not necessary for the sprinkler discharge to remove the heat as fast as it is being released since the fire is transferring heat to the surroundings as well. In some cases only a small additional loss of heat will be sufficient to upset the balance of the chain reaction of the combustion process resulting in extinguishment. Further, manual fire fighting efforts are likely to be implemented within 5 minutes of the fire which will provide hose stream flow directed into the base of the fire. The 5 minutes for initiation of manual fire fighting is based on average response times by fire brigade members during training and actual fire events. The cooling provided by the hose streams will provide additional removal of heat from the fire. Droplets from the sprinkler discharge which contain sufficient momentum to penetrate the plume will provide cooling of the fuel pool. Steam rising from the suppression of the fire in the Condensate Pump Pit will rise up directly adjacent to the edge of the fuel pool on the 18'0" elevation. This steam will be entrained into the fire plume at the base of the fire (combustion zone) which will aid in smothering the fire. All of these effects will reduce the overall heat release and plume temperatures in the area and thus the temperatures resulting within the areas where the Thermo-Lag protected raceways are installed.

Basic parameters for the wet pipe sprinkler discharge in the area

For the purposes of calculating a curb height the original design criteria for the closed head sprinkler system (0.3 gpm/ft^2/3000 ft^2) shall be applied to the area of concern which has a gross floor area at the 18'0" elevation of 3026 ft^2. Based on flows stipulated by previous system calculations (Ref. 11) for the wet pipe systems in the Turbine Building the demand for the 18'0" elevation over the lube oil fire will be postulated to be 1000 gpm based on the gross area of coverage with all sprinklers operated (i.e. column lines A-D and 23.1-25.1). Discharge over the curbed and non-curbed areas will be determined based on their size when proportionally compared to the size of the overall gross floor area. Therefore, the flow of sprinklers over the curbed area where lube oil will be present will be approximately equal to (1630.23 ft^2/3026 ft^2)*1000 gpm or 539 gpm and the flow over the remainder of the area outside of the curbs will be approximately 461 gpm.

The effects of the sprinkler discharge on the pool size are postulated to be that the pool size will cover the entire area bounded by the curbs and result in overflow to the Condenser and Condensate Pump Pits. Sprinkler discharge over the area not bounded by the curbs but located between the A-D and 23.1 - 25.1 column lines will overflow to the Condenser Pit and discharge through the flood gates located on the west side of the area.

The time step sequence for the addition of water due to sprinkler operation will conservatively assume that 1/2 of the sprinklers over the area of concern operate at 2 minutes into the fire and the remainder operate at 5 minutes into the fire. The addition of water due to hose streams from manual fire fighting efforts will be assumed to occur at 5 minutes into the fire.

Addition of water from fixed spray systems

The imminent activation of the deluge systems within the area will also be considered. The Auxiliary Transformer and Hydrogen Seal Oil Unit spray systems are located within the area under evaluation. The flow rates to each of the aforementioned spray systems is approximated from the total demand of all three systems (1498 gpm), the known demand for the auxiliary transformer spray system (389 gpm) and then approximated for the remaining spray systems based on the total number of nozzles protecting the commodity. As such the flow rates are as follows: Main Transformer ~1009 gpm, Auxiliary Transformer ~389 gpm and the Hydrogen Seal Oil Unit ~100 gpm.

The volume of the diked areas were determined to be ~523 gallons for the Hydrogen Seal Oil Unit, and ~4,321 gallons for the Auxiliary Transformer. The drains in each of these diked areas are routed to the oil-water separator which will allow flow through without separation in the event of a high flow situation. Under normal conditions the oil-water separator can accommodate an approximate flow of 100 gpm and still continue to perform it's function. In the event of higher flow rates the separator will allow flow to be directly routed to discharge. Therefore, back up of this system is not anticipated. From a conservative standpoint and based upon the discharge rates of the two aforementioned spray systems, overflow will be considered to occur. This will present a worst case runoff scenario for the 18'0" area under review. This will be conservative as flow is anticipated to be drained to the oil-water separator. Therefore, the Auxiliary Transformer pit will be postulated to overflow its dike at 11.11 minutes after activation, and the Hydrogen Seal Oil Unit will be postulated to overflow its dike at 5.23 minutes after activation. Activation will be postulated to occur at 1 minute into the scenario. The effects of the overflow of these systems are shown below based on the available floor area outside of the diked area where the lube oil will be contained. Calculations below will be used to assure that a curb height sufficient to prevent overflow from/to either side of the curb will not occur. The maximum width of openings from this area is 255 inches. The unoccupied floor space and amount of fluid that can be retained prior to runoff are approximately 713.8 ft^2 and 295 gallons respectively. The total postulated flow rate to this area from sprinklers and spray system overflow is approximately 950 gpm which is less than calculated for the area where lube oil will be contained. Therefore, based on the greater width of openings in the area beyond the lube oil containment area and all other factors being nearly equal, the area where the lube oil will be discharged presents the greater challenge for containment and calculations for runoff from the area beyond the lube oil containment will not be performed.

Pool width and depth

Based on the calculations in Section 6.2, which show that as much as 483.7 gallons of fluid can be retained over the drains, the maximum pool width will be assumed to occur at 5 minutes into the scenario due to the activation of the sprinklers. The maximum pool area would be equivalent to the floor area not occupied by structural components or equipment. As determined by walkdowns the unoccupied gross floor area is 1,887 ft^2 between the A-D and 23.1-25.1 column lines and the unoccupied area to be bounded by the "curbed area" (See Section 6.0 for description) will be 1173.23 ft^2 (109 m^2) (See Section 6.3).

For the purposes of this evaluation the curbed area will be used to determine water/fuel pool depth and flow through available openings. Revised heat release rates and ceiling jet temperatures will be based on the smaller area bounded by the curbing being the location of the fire. The effective pool diameter which corresponds to the unoccupied floor area bounded by the curbs is approximately 38.65' (11.78 m).

The pool diameter will be based on a circular pool area and the pool edge will be postulated to be at the D column line which is conservative. The actual pool will be essentially made up of smaller interconnected pools due to the intervening equipment in the area. Calculating the effects based on a large unrestricted pool will result in larger heat release values and temperatures. A 20% reduction in the mass loss rate will be used due to the pool sizes being greater than 10 m. (32.81 ft) in diameter which is based on test results which show incomplete combustion for pool diameters of this size.

From the 2 minute time step and to final release of Turbine lube oil a maximum pool area will be assumed. The lube oil reservoir has a nominal capacity of 10,000 gallons (Ref. 7). Based on the postulated 450 gpm total flow rate from failed bearing seals an approximate release time of 23 minutes will result. As such, the total scenario time will be postulated to be equivalent to the release time plus five minutes to stop all manual and automatic fire suppression activities and the time to drain the fluid retention over the drains at the 18'0" elevation. Therefore, based on the drain flow of 66 gpm via the drains (Section 6.2) and the fluid retention over the drains of 483.7 gallons (Section 6.3), a scenario time of 35 minutes will be postulated throughout the remainder of the evaluation.

Parameters for the determination of heat release

In calculating the heat release from this fire a reduction of 50% is taken in both the mass loss and heat release values during the time step sequence from time = 2 minutes to time = 4 minutes and a 75% of the total heat release and mass loss will be credited from time = 5 minutes to time = 28 minutes due to the following mitigating factors, many of which have been discussed elsewhere in this evaluation:

- Full coverage of sprinklers over the postulated lube oil pool.
- Cooling of the burning fuel prior to reaching the floor.
- Transient effects of heating the surroundings are not credited.
- Cooling of other facility surfaces which reduces radiative feedback to support combustion.
- Design densities which meet or exceed NFPA 13 (1996) requirements for Extra Hazard Group 1 occup.
- Sprinkler spacing over the pool fire is conservative at approximately 60% of the maximum allowed by NFPA 13 which will aid in droplet penetration.
- Large area of ceiling is open to the atmosphere which should aid in promoting a larger loss of heat away from the Thermo-Lag raceways.
- Proposed sprinkler additions between the D-J column lines will provide additional cooling of the ceiling jet temperatures.
- NRC approved FIVE methodology allows for a 30% reduction in heat release due to absorption by boundaries in enclosures (Ref. 13).
- Large pool fires are known to exhibit incomplete combustion.
- Steam generated as a result of sprinkler discharge over burning fuel in the Condensate Pump Pit will be entrained into the fire on the 18'0" elevation which will aid in smothering and cooling.

Based on the amount of turbine lube oil calculated to be present during the time steps shown in Table 4 below, it can be seen that the available capacity of ~483.7 gallons over the drains will be exceeded during the first minute of sprinkler operation. This will result in runoff to the Condenser and Condensate Pump Pits.

Table 4
Heat Release for the Postulated Turbine Building Lube Oil Fire

Column A	Column B	Column C	Column D	Column E	Column F	Column G	Column H	Column I	Column J	Column K	Column L	
									Potential	Actual		
Time	Fluid	Spill	Pool area	Pool area	Eff. Dia. of	Eff. Dia. of	Mass loss	Depth over	Overflow	Overflow	Heat Release	Heat Release
minutes	gallons	cu.ft.	sq. ft.	sq. m.	Pool (ft)	Pool (m)	gpm	floor	to pit	to pit	kW	MW
1	225.00	30.08	411.00	38.18	22.88	6.97	19.58	—	—	—	48,501.61	48.50
2	633.92	84.74	1,173.23	108.99	38.65	11.78	27.95	0.17	184.81	150.22	69,225.73	69.23
3	884.25	118.20	1,173.23	108.99	38.65	11.78	27.95	0.51	563.18	400.55	69,225.73	69.23
4	884.25	118.20	1,173.23	108.99	38.65	11.78	27.95	0.51	563.18	400.55	69,225.73	69.23
5	1,653.75	221.06	1,173.23	108.99	38.65	11.78	13.97	1.58	1,824.23	1,170.05	34,612.86	34.61
6 - 23	1,667.73	222.93	1,173.23	108.99	38.65	11.78	13.97	1.60	1,848.84	1,184.03	34,612.86	34.61
23-28	1,442.73	192.85	1,173.23	108.99	38.65	11.78	13.97	1.29	1,460.02	959.03	34,612.86	34.61
29	403.73	53.97	979.25	90.97	35.31	10.76	—	—	—	—	—	—
30	337.73	45.14	819.17	76.10	32.30	9.84	—	—	—	—	—	—
31	271.73	36.32	659.08	61.22	28.97	8.83	—	—	—	—	—	—
32	205.73	27.50	499.00	46.35	25.21	7.68	—	—	—	—	—	—
33	139.73	18.68	338.91	31.48	20.77	6.33	—	—	—	—	—	—
34	73.73	9.86	178.83	16.61	15.09	4.60	—	—	—	—	—	—
35	7.73	1.03	18.74	1.74	4.89	1.49	—	—	—	—	—	—
							—	—	—	—	—	—

Note: For description of time step sequence for the fire scenario, refer to discussion above "*Pool Width and Depth*"

6.7.1 Ceiling Jet Temperatures with Sprinkler Flow and Reduced Heat Release

Using the formulas shown in Section 6.6.2 the ceiling jet temperatures will be calculated using the heat release data from Table 4 above. The formulas utilized are dependent on heat release, radial distance from the centerline of the pool and ceiling height. Therefore, where the heat release as shown above in Table 4 remains constant, one calculation will be performed to show the temperatures for the associated time frame. The temperatures shown within Tables 5 and 6 for the ceiling jet are conservative in nature. Actual fire temperatures will be significantly lower than those shown in the following tables. (Refer to the discussion titled "Temperature Profile" in Section 6.1.4). Therefore, it is important to note that maximum temperatures of the ASTM E-119 time-temperature curve are as follows: 25 min, 821°C (1510°F); 1-hour, 927°C (1700°F); 2-hour, 1010°C (1850°F); and 3-hour, 1052°C (1925°F).

Table 5
Temperatures of the Ceiling Jet at 3.66m (12'0")
Above the Pool Fire at the 18'0" elevation

			Temperature (°C) of the ceiling jet at the following distance from the centerline of the fuel package						
						D Column Line		E Column Line	J column line
Time	Eff. Dia. of	Heat Release	1 meter	2 meters	4 meters	6.97 meters	8 meters	10.66 meters	17.37 meters
minutes	Pool (m)	kW	(3.281 ft)	(6.562 ft)	(13.124 ft)	(22.868 ft)	(26.248 ft)	(34.975 ft)	(57 ft)
1	6.97	48,501.61	1,985.07	1,261.36	805.47	565.33	518.28	433.13	320.95
2 to 4	11.78	69,225.73	2,508.58	1,591.15	1,013.22	708.80	649.15	541.20	399.00
5 to 28	11.78	34,612.84	1,591.15	1,013.22	649.15	457.38	419.81	351.81	262.23

Table 6
Temperatures of the Ceiling Jet at 7.31m (24'0")
Above the Pool Fire at the 18'0" elevation

			Temperature (C) of the ceiling jet at the following distance from the centerline of the fuel package						
						D Column Line		E Column Line	J column line
Time	Eff. Dia. of	Heat Release	1 meter	2 meters	4 meters	6.97 meters	8 meters	10.66 meters	17.37 meters
minutes	Pool (m)	kW	(3.281 ft)	(6.562 ft)	(13.124 ft)	(22.868 ft)	(26.248 ft)	(34.975 ft)	(57 ft)
1	6.97	48,501.61	1,008.57	646.22	417.97	297.73	274.18	231.54	175.38
2 to 4	11.78	69,225.73	1,270.68	811.34	521.98	369.56	339.70	285.65	214.45
5 to 28	11.78	34,612.84	811.34	521.98	339.70	243.68	224.87	190.82	145.97

6.8 FLAME HEIGHT

Heskestad in 1983 correlated data from diffusion flames including pool fires using the equation:

$$\frac{l}{D} = 15.6N^{1/5} - 1.02$$

where:

l = flame height above the fuel surface in meters

D = diameter of the fuel bed in meters

N is a dimensionless number derived from a modified Froude number (Heskestad, 1981) and is given by the formula:

$$N = \left(\frac{c_p T_\infty}{g \rho_\infty^2 \left(\frac{\Delta H_c}{r} \right)^3} \right) \frac{\dot{Q}_c}{D^5}$$

where:

c_p = specific heat of air

T_∞ = temperature of ambient air

ΔH_c = heat of combustion

$\dot{Q}_c$ = rate of heat release (kW)

ρ_∞ = density of ambient air

g = acceleration due to gravity

r = stoichiometric ratio of air to volatiles

D = diameter of the pool in meters

However, based on standard values ($T_\infty = 293K, g = 9.81m/s^2$, etc.)
and that $\frac{\Delta H_c}{r} \approx 3000 - 3100 \frac{kJ}{kg}$, then the equation for flame height can be reduced to

$$l = 0.23\dot{Q}_c^{2/5} - 1.02D$$

which has been shown to be a satisfactory correlation for values within the range:

$$7kW^{2/5}/m < \frac{\dot{Q}_c^{2/5}}{D} < 700kW^{2/5}/m$$

The values of $\dot{Q}_c^{2/5}/D$ for the all postulated heat releases and pool diameters but one fall within the acceptable values for which this formula can be utilized. The lowest heat release is outside the lower bounds of the acceptable range. Therefore, although the flame heights are shown below in Table 7 for all heat release values and are presented for consideration, caution must be applied in utilizing the flame height value for the lowest heat release value.

Table 7
Flame Heights for Varying Heat Release

Heat Release (kW)	Effective Diameter (m)	$\dot{Q}^{2/5}/D$	Approx. Flame Height (m)	Approx. Flame Height (ft)
48,501.61	6.97	10.74	10.11	33.17
69225.73	11.78	7.33	7.84	25.72
34612.84	11.78	5.55	3.03	9.94

Further, Zukowski, et. al., as discussed in Drysdale's *Fire Dynamics* (Ref. 5, p.134), commented that for $\frac{l}{D} < 1$ the flame breaks up into a number of smaller flamelets that are apparently independent. Although the value of $\frac{l}{D} > 1$ based on the results shown in the above table, it must be noted that the above values are based upon a circular unrestricted pool. The area in which the postulated spill will occur is occupied by numerous obstructions including structural components and equipment. Due to the nature of the postulated spill and the intervening equipment and structural components, the phenomenon of smaller flame heights associated with smaller pool diameters may be observed under actual conditions. However, it is not possible to definitively say this will occur due to a lack of documented tests conducted of pool fires involving configurations where intervening equipment/structural components such as those existing in the Turbine Building are present.

In addition, where a fire source is close to the wall or in a corner formed by the intersection of two walls, the resulting restriction on free air entrainment will have a significant effect on the flame length. Flame extension will occur along the wall to allow for air entrainment as needed for combustion of the volatiles. It is further discussed that where the vertical extent of the flame is confined by the ceiling, the hot gasses will be deflected as a horizontal ceiling jet (Ref. 5, p. 135).

Flame extension for a configuration similar to that postulated here as related to interferences, ceiling and boundary conditions that exist in the area under evaluation have not been studied. Therefore, no attempt to correlate the potential flame extension which may be experienced during this scenario will be performed.

6.9 EFFECTS OF NOT SPRINKLERING VARIOUS AREAS OF THE TURBINE BUILDING

- *Column Lines A-D, at Column lines 27 to 29 and 34-36, 18'0" elevation* - The areas bounded by the column lines noted have similar layouts and represent Unit 3 and 4 respectively. The respective units' lube oil transfer pump and the Steam Generator Feed Pump Room are found in this area. Those sections of each of these areas which contain fire related hazards are currently protected by fixed protection systems. These include the Steam Generator Feed Pump Room (partial wet pipe sprinklers), lube oil transfer pump (fixed water spray system) and the pit south of the condensers (wet pipe sprinklers at two elevations). The lube oil reservoir is adjacent to each of these areas to the west of the Turbine Building and is diked to contain a spill and is protected by an automatic spray system. Essential raceways are not located within these areas. Turbine bearings located over this area are high pressure turbine bearings. High pressure turbine related accidents resulting the release of turbine lube oil in this area are not postulated (Ref. 9).

The evaluation of a postulated turbine lube oil release shown above presents worst case for proximity of burning oil to Thermo-Lag protected raceways. Therefore, the scenario is a bounding case for resulting temperatures from lube oil related fires in the Turbine Building. As a result, the fire related incidents in this area, being adequately protected and contained, do not present a hazard to safe shutdown raceways located in other areas of the Turbine Building and further augmentation of the suppression systems in these areas are not recommended.

6.10 EFFECT OF TURBINE BUILDING CEILING CONFIGURATION AND OBSTRUCTIONS ON ANTICIPATED TEMPERATURES

Tables 8 and 9 illustrate the conservatively postulated temperatures that are calculated for various distances from the centerline of the fire under the postulated fire condition.

A percentage split of heat release is used to determine the approximate temperatures. The division of heat release to the mezzanine (ceiling El. 42'0") is likely to be significantly larger than the flow of heat that will

contribute to the temperatures seen at the 18'0" elevation (ceiling height 30'0"). This is the result of the sudden change in ceiling elevation at the D column line.

The configuration of the ceiling over the area which includes the "curbed area" on the 18'0" elevation is similar to that shown below in Figure 2.

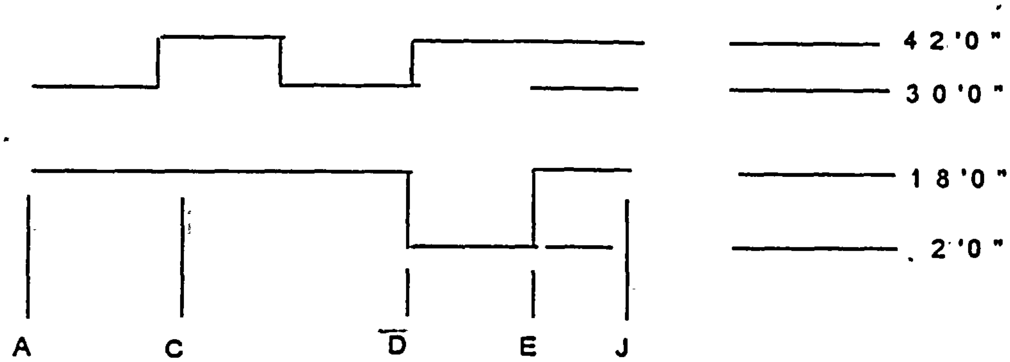

Figure 2
Cross section of floor/ceiling elevations in the Turbine Building
at column line 24 (or 31)

The areas beyond the A and J column lines to the east and west, respectively are open to the atmosphere. There is existing, between the E to J column lines, dense congestion of equipment and cable trays which will significantly inhibit the flow of smoke and hot gasses beyond the D column line at the 18'0". In addition, the calculations used to determine the maximum temperatures in Tables 5,6,7 are based on a flat unobstructed ceiling. Therefore, the existing analysis for the temperatures at the various elevations, as shown in Tables 5, 6 and 7 are conservative in nature for determination of the Thermo-Lag functional integrity.

The temperatures which are likely to be seen beyond the "curbed area" will be significantly less. It is postulated that 35% of the total heat release will contribute to the temperatures on the 18'0" elevation and 65% to those on the Mezzanine level. This is supported by the following:

- FMRC Tests (Ref. 21) indicated that the ceiling temperatures at 33' over the lube oil pool fire did not exceed 600°F (316°C) during the test where automatic sprinkler protection was provided.
- Ceiling configuration is irregular rather than flat (varying heights throughout).
- Ceiling elevation at the D column line is 42'0".
- The D-E column lines are open to the Mezzanine level and provide a means of transport of smoke and hot gasses away from the 18'0" elevation.
- Severe congestion exists directly across from the "curbed area" between column lines E-J and 23.1-25.1 (and 30.1 to 32.1)
- Heat loss to surrounding equipment in the area of transport will reduce temperatures.
- Effects of radiant energy on the heat release will be negligible due to loss of a direct line of sight with the majority of the area.
- Heated gasses rise.

Table 8
Anticipated Temperatures of the Ceiling Jet at 3.66m (12'0")
Above the Pool Fire at the 18'0" elevation

			Temperature (°C) of the ceiling jet at the following distance from the centerline of the fuel package							
						D Column Line		E Column Line	J column line
Time	Eff. Dia. of	Heat Release	1 meter	2 meters	4 meters	5.16 meters	7 meters	8.86 meters	15.56 meters
minutes	Pool (m)	kW	(3.281 ft)	(6.562 ft)	(13.124 ft)	(16.9375 ft)	(22.967 ft)	(29.063 ft)	(51.063 ft)
1	6.77	15,992.55	962.77	617.37	399.79	285.18	262.73	222.08	168.55
2 to 4	11.78	24,224.25	1,260.46	804.90	517.93	366.76	337.14	283.54	212.93
5 to 28	11.78	12,112.13	804.90	517.93	337.14	241.92	223.26	189.50	145.01

Table 9
Anticipated Temperatures of the Ceiling Jet at 7.31m (24'0")
Above the Pool Fire at the 18'0" elevation

			Temperature (C) of the ceiling jet at the following distance from the centerline of the fuel package						
						D Column Line		E Column Line	J column line
Time	Eff. Dia. of	Heat Release	1 meter	2 meters	4 meters	5.16 meters	7 meters	8.86 meters	15.56 meters
minutes	Pool (m)	kW	(3.281 ft)	(6.562 ft)	(13.124 ft)	(16.9375 ft)	(22.967 ft)	(29.063 ft)	(51.063 ft)
1	6.77	29,700.45	735.48	474.19	309.60	222.90	205.91	175.16	134.66
2 to 4	11.78	44,987.90	960.69	616.06	398.96	284.61	262.21	221.66	168.24
5 to 28	11.78	22,493.95	616.06	398.96	262.21	190.17	176.06	150.51	116.86

The temperatures at the ceiling level of the mezzanine show acceptable temperatures at the J line with respect to IEEE 634 (325°F (164°C)). Therefore, consideration of the linear distance from the centerline of the fire (16.875' west of the D line, 24' south of the 23.1 and 30.1 column lines) to the J column line (51 feet from the centerline of the fire) at both elevations will be acceptable with respect to survivability of unprotected cable (cable in trays). The length of time which cable in conduit would survive would be greater than unprotected cable. Internal temperatures of conduits will be less than the maximum predicted in Tables 8 and 9 at the various distances for longer periods of time due to a time lag related to the heat transfer through the steel conduit.

7.0 CONCLUSIONS

The existing and proposed additions to the active and passive fire protection for the Turbine Building provide adequate protection of those raceways in the Turbine Building (column lines A-J_c and 22-36) such that further upgrades to the Thermo-Lag protected raceways beyond the E column line throughout the Turbine Building are unnecessary to assure the protection of the raceways.

The fire analysis presented within this report supports the review of the existing and proposed features. ASTM Test Standard E-119 (Ref. 10) utilizes the standard time-temperature curve to establish furnace temperatures during testing of fire barriers. The standard time-temperature curve temperature of 821°C (1509°F) corresponds to the furnace temperature at 25 minutes into the fire test. This is the temperature at which the 3/4" diameter conduits protected with baseline Thermo-Lag failed the test criteria. The temperatures presented in this evaluation for the ceiling jet temperatures are very conservative with respect to documented fire tests and do not indicate that this temperature will be exceeded based on the distance at which the protected raceways are located between the D and J-J_c column line during a postulated Turbine Building lube oil fire. These temperatures are based on cooling effects due to sprinkler discharge at the 18'0" elevation and fuel pool location within the "curbed area" (See Section 6.0 for description). Structural steel supports will retain their structural integrity during the postulated fire due to a limited rise in temperatures as a result of sprinkler discharge.

The configuration of diamond plate over the length of the Condensate Pump Pit presents only two areas where surface flaming in the pit has the potential for communicating with the 18'0" elevation. These areas are at the stairway leading to the pit from the 18'0" elevation and directly over the Condensate Pumps. The overall size of the openings and the complete coverage of sprinklers in these areas within the pit does not lend itself to becoming

a significant contributor of heat or flame height which would further threaten the protected raceways which are located beyond the E column line during a postulated Turbine Building lube oil fire.

8.0 RECOMMENDATIONS

1. All drain covers in the Turbine Building between column lines A-D will be replaced by slotted covers which provide an equivalent opening of approximately 3.3 inches in effective diameter opening.
2. Install curbing to a peak height of nominal 2 inches within the vicinity of the D and 6.5 feet west of the C column lines to prevent the flow of potentially burning combustible liquid from spreading beyond the area evaluated. Suggested location for curbing is shown in Attachment B.
3. Modify the existing water supply to extend the design area of the sprinkler system to provide coverage over an area of 5000 ft^2 plus 500 gpm for manual hose streams for the wet pipe system and the maximum flow anticipated for the fixed water spray systems in the area.
4. Modify the existing wet pipe system in the Condensate Pump Pit (south section) to replace the sidewall sprinklers with standard upright sprinklers (intermediate temperature) spaced in accordance with the requirements of NFPA 13 for an Extra Hazard occupancy.
5. Install additional sprinklers as Shown on Attachment B.
6. Maintain conservative sprinkler head spacing for all sprinklers to be added to the areas where Turbine Lube Oil is postulated to occur.
7. Modify the existing grating (other than the stairs) in the Condenser/Condensate Pump Pits to solid diamond plate.

3/30/

ATTACHMENT A

Letter, Texaco to Florida Power and Light (R. Conrad), dated March 12, 1997

(11 PAGES)

March 12, 1997

Ms. Roseann Conrad
Turkey Point Nuclear Power Plant
FPL Company
P.O. Box 4332
Princeton, Florida 33032

Dear Ms. Conrad:

Enclosed please find a compositional disclosure for Texaco product code 00700 Regal R&O 32.

Please note that this information is considered confidential and is provided solely for use by your environmental, health and safety professionals.

Also attached is the Texaco Material Safety Data Sheet (MSDS) for this product. We consider the Texaco MSDS to be our primary means of hazard communication for all our products. As products are reformulated or product information changes, any new information will be reflected in the current Texaco MSDS.

We trust this information will satisfy your needs. If we can be of further assistance, please do not hesitate to contact Paula Beach at (914) 838-7530.

Thank you for using Texaco products.

PMB:jms

Enclosure (1)

cc: ECB

00700 REGAL R&O 32

NAME	CAS NUMBER	RANGE %
Solvent-dewaxed heavy paraffinic petroleum distillates	64742650	95.00 - 99.99
2,6-di-tert-butyl phenol	128392	0.1 - 0.99
[redacted]	CBI*	[redacted]
[redacted]	CBI*	[redacted]
Methacrylic acid, copolymer	56631891	0.1 - 0.99

CONFIDENTIAL

* Supplier Confidential Business Information

Date Issued: 1996-12-19
Supersedes: 1996-10-01
845/20

PTN-FPER-97-013, Rev. 0
Attachment A

TEXACO
MATERIAL SAFETY DATA SHEET

NOTE: Read and understand Material Safety Data Sheet before handling or disposing of product.

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

MATERIAL IDENTITY
Product Code and Name:
00700 REGAL R&O 32
Chemical Name and/or Family or Description:
Turbine Oils

Manufacturer's Name and Address:
TEXACO LUBRICANTS COMPANY
A DIVISION OF TEXACO REFINING AND MARKETING INC.
P.O. Box 4427
Houston, TX 77210-4427

Telephone Numbers:

Transportation Emergency	-Company	(914) 831-3400
	CHEMTREC (USA)	(800) 424-9300
	In Canada	(800) 567-7455
Health Emergency	-Company	(914) 831-3400
General MSDS Assistance		(914) 838-7204
Texaco FaxBack System		(713) 432-3383
Technical Information	-Fuels	(914) 838-7336
	-Chemical	(512) 459-6543
	-Lubricant/ Antifreezes/Fuel Additives	(800) 782-7852(Option 4)
	-Solvents	(800) 876-3738

2. COMPOSITION/INFORMATION ON INGREDIENTS

THE CRITERIA FOR LISTING COMPONENTS IN THE COMPOSITION SECTION IS AS FOLLOWS: CARCINOGENS ARE LISTED WHEN PRESENT AT 0.1 % OR GREATER: COMPONENTS WHICH ARE OTHERWISE HAZARDOUS ACCORDING TO OSHA ARE LISTED WHEN PRESENT AT 1.0 % OR GREATER: NON-HAZARDOUS COMPONENTS ARE LISTED AT 3.0 % OR GREATER. THIS IS NOT INTENDED TO BE A COMPLETE COMPOSITIONAL DISCLOSURE. REFER TO SECTION 14 FOR APPLICABLE STATES' RIGHT TO KNOW AND OTHER REGULATORY INFORMATION.

Product and/or Component(s) Carcinogenic According to:

OSHA	IARC	NTP	OTHER	NONE
-	-	-	-	X

Composition: (Sequence Number and Chemical Name)

Seq.	Chemical Name	CAS Number	Range in %
01 #	Solvent-dewaxed heavy paraffinic petroleum distillates	64742-65-0	95.00-99.99

PRODUCT IS NON-HAZARDOUS ACCORDING TO OSHA (1910.1200).
COMPONENT, BY DEFINITION, IS CONSIDERED HAZARDOUS ACCORDING TO OSHA BECAUSE IT CARRIES THE PERMISSIBLE EXPOSURE LIMIT (PEL) FOR MINERAL OIL MIST.

Exposure Limits referenced by Sequence Number in the Composition Section

Seq.	Limit	
01	5	mg/m3 TWA-OSHA (MINERAL OIL MIST)
01	5	mg/m3 TWA-ACGIH (MINERAL OIL MIST)
01	10	mg/m3 STEL ACGIH (MINERAL OIL MIST)

3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW
Appearance:
Light pale liquid
Odor:
Mild odor

WARNING STATEMENT
NONE CONSIDERED NECESSARY

N.D. - NOT DETERMINED N.A. - NOT APPLICABLE N.T. - NOT TESTED
< - LESS THAN > - GREATER THAN

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Attachment A
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3. HAZARD IDENTIFICATION (CONT)

HMIS				NFPA			
Health:	1	Reactivity:	0	Health:	1	Reactivity:	0
Flammability:	1	Special	: -	Flammability:	1	Special	: -

POTENTIAL HEALTH EFFECTS

	EYE	SKIN	INHALATION	INGESTION
Primary Route of Exposure:	X	X	X	-

EFFECTS OF OVEREXPOSURE

Acute:

Eyes:

May cause minimal irritation, experienced as temporary discomfort.

Skin:

Brief contact may cause slight irritation. Prolonged contact, as with clothing wetted with material, may cause more severe irritation and discomfort, seen as local redness and swelling.

Other than the potential skin irritation effects noted above, acute (short term) adverse effects are not expected from brief skin contact; see other effects, below, and Section 11 for information regarding potential long term effects.

Inhalation:

Vapors or mist, in excess of permissible concentrations, or in unusually high concentrations generated from spraying, heating the material or as from exposure in poorly ventilated areas or confined spaces, may cause irritation of the nose and throat, headache, nausea, and drowsiness.

Ingestion:

If more than several mouthfuls are swallowed, abdominal discomfort, nausea, and diarrhea may occur.

Sensitization Properties:

Unknown.

Chronic:

No adverse effects have been documented in humans as a result of chronic exposure. Section 11 may contain applicable animal data.

Medical Conditions Aggravated by Exposure:

Because of its irritating properties, repeated skin contact may aggravate an existing dermatitis (skin condition).

Other Remarks:

Material from high pressure equipment, pinhole leaks, or high pressure line failure can penetrate the skin and, if not properly treated, can cause severe injury, including disfigurement, loss of function, or even require amputation of the affected area. To prevent such serious injury, immediate medical attention should be sought even if the injection injury appears to be minor.

4. FIRST AID MEASURES

Eyes:

Flush eyes with plenty of water for several minutes. Get medical attention if eye irritation persists.

Skin:

Wash skin with plenty of soap and water for several minutes. Get medical attention if skin irritation develops or persists.

Ingestion:

If more than several mouthfuls of this material are swallowed, give two glasses of water (16 oz.). Get medical attention.

Inhalation:

If irritation, headache, nausea, or drowsiness occurs, remove to fresh air. Get medical attention if breathing becomes difficult or respiratory irritation persists.

N.D. - NOT DETERMINED   N.A. - NOT APPLICABLE   N.T. - NOT TESTED
< - LESS THAN   > - GREATER THAN

4. FIRST AID MEASURES (CONT)

Other Instructions:
Remove and dry-clean or launder clothing soaked or soiled with this material before reuse. Dry cleaning of contaminated clothing may be more effective than normal laundering. Inform individuals responsible for cleaning of potential hazards associated with handling contaminated clothing.

High pressure injection of material can cause severe injury. Failure to debride the wound of all residual material can result in disfigurement, loss of function, or may require amputation of the affected area.

5. FIRE-FIGHTING MEASURES

Ignition Temperature - AIT (degrees F):
Not determined.
Flash Point (degrees F):
395 (COC)
Flammable Limits (%):
Lower: Not determined.
Upper: Not determined.

Recommended Fire Extinguishing Agents And Special Procedures:
Use water spray, dry chemical, foam, or carbon dioxide to extinguish flames. Use water spray to cool fire-exposed containers. Water or foam may cause frothing.

Unusual or Explosive Hazards:
None

Special Protective Equipment for Firefighters:
Wear full protective clothing and positive pressure breathing apparatus.

6. ACCIDENTAL RELEASE MEASURES (Transportation Spills: CHEMTREC (800)424-9300)

Procedures in Case of Accidental Release, Breakage or Leakage:
Ventilate area. Avoid breathing vapor. Wear appropriate personal protective equipment, including appropriate respiratory protection. Contain spill if possible. Wipe up or absorb on suitable material and shovel up. Prevent entry into sewers and waterways. Avoid contact with skin, eyes or clothing.

7. HANDLING AND STORAGE

Precautions to be Taken in
Handling:
Minimum feasible handling temperatures should be maintained.

Storage:
Periods of exposure to high temperatures should be minimized. Water contamination should be avoided.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Protective Equipment (Type)
Eye/Face Protection:
Safety glasses, chemical type goggles, or face shield recommended to prevent eye contact.

Skin Protection:
Workers should wash exposed skin several times daily with soap and water. Soiled work clothing should be laundered or dry-cleaned.

N.D. - NOT DETERMINED   N.A. - NOT APPLICABLE   N.T. - NOT TESTED
< - LESS THAN   > - GREATER THAN

8. EXPOSURE CONTROLS/PERSONAL PROTECTION (CONT)

Respiratory Protection:
Airborne concentrations should be kept to lowest levels possible. If vapor, mist or dust is generated and the occupational exposure limit of the product, or any component of the product, is exceeded, use appropriate NIOSH or MSHA approved air purifying or air supplied respirator after determining the airborne concentration of the contaminant. Air supplied respirators should always be worn when airborne concentration of the contaminant or oxygen content is unknown.

Ventilation:
Adequate to meet component occupational exposure limits (see Section 2).

Exposure Limit for Total Product:
None established for product; refer to Section 2 for component exposure limits.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance:
Light pale liquid
Odor:
Mild odor

Boiling Point (degrees F):
Not determined.

Melting/Freezing point (degrees F):
Not applicable.

Specific Gravity (water=1):
.8665

pH of undiluted product:
Not applicable.

Vapor Pressure:
Not determined.

Viscosity:
31.5 cSt at 40.0 C

VOC Content:
Not determined.

Vapor Density (air=1):
Not determined.

Solubility in Water (%):
Not determined.

Other: None

10. STABILITY AND REACTIVITY

This Material Reacts Violently With:
(If Others is checked below, see comments for details)

Air	Water	Heat	Strong Oxidizers	Others	None of These
_	_	_	X	_	_

Comments:
None

Products Evolved When Subjected to Heat or Combustion:
Toxic levels of carbon monoxide, carbon dioxide, irritating aldehydes and ketones.

Hazardous Polymerizations: DO NOT OCCUR

N.D. - NOT DETERMINED
N.A. - NOT APPLICABLE
N.T. - NOT TESTED
< - LESS THAN
> - GREATER THAN

11. TOXICOLOGICAL INFORMATION

TOXICOLOGICAL INFORMATION(ANIMAL TOXICITY DATA)

Median Lethal Dose

Oral:
LD50 Believed to be > 5.00 g/kg (rat) practically non-toxic

Inhalation:
Not determined.

Dermal:
LD50 Believed to be > 2.00 g/kg (rabbit) practically non-toxic

Irritation Index, Estimation of Irritation (Species)

Skin:
(Draize) Believed to be > .50 - 3.00 /8.0 (rabbit) slightly irritating

Eyes:
(Draize) Believed to be < 15.00 /110 (rabbit) no appreciable effect

Sensitization:
Not determined.

Other:
None

12. DISPOSAL CONSIDERATIONS

Waste Disposal Methods

This product has been evaluated for RCRA characteristics and does not meet the criteria of a hazardous waste if discarded in its purchased form. Under RCRA, it is the responsibility of the user of the product to determine at the time of disposal, whether the product meets RCRA criteria for hazardous waste. This is because product uses, transformations, mixtures, processes, etc. may render the resulting materials hazardous.

Remarks

None

13. TRANSPORT INFORMATION

Transportation

DOT:
Proper Shipping Name:
Not regulated

IMDG:
Proper Shipping Name:
Not regulated

ICAO:
Proper Shipping Name:
Not regulated

TDG:
Proper Shipping Name:
Not regulated

14. REGULATORY INFORMATION

Federal Regulations:

SARA Title III:

Section 302/304 Extremely Hazardous Substances

Seq.	Chemical Name	CAS Number	Range in %
None			

Section 302/304 Extremely Hazardous Substances (CONT)

Seq.	TPQ	RQ
None		

Section 311 Hazardous Categorization:

Acute	Chronic	Fire	Pressure	Reactive	N/A
-	-	-	-	-	X

Section 313 Toxic Chemical

Chemical Name	CAS Number	Concentration
None		

N.D. - NOT DETERMINED N.A. - NOT APPLICABLE N.T. - NOT TESTED
< - LESS THAN > - GREATER THAN

16. OTHER INFORMATION (CONT)

TO DETERMINE APPLICABILITY OR EFFECT OF ANY LAW OR REGULATION WITH RESPECT TO THE PRODUCT, USER SHOULD CONSULT HIS LEGAL ADVISOR OR THE APPROPRIATE GOVERNMENT AGENCY. TEXACO DOES NOT UNDERTAKE TO FURNISH ADVICE ON SUCH MATTERS.

Date: 1996-12-19 _ New X Revised, Supersedes: 1996-10-01
Date printed: 1997-01-06

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Inquiries regarding MSDS should be directed to:
Texaco Inc.
Manager, Product Safety
P.O. Box 509
Beacon, N.Y. 12508

PLEASE SEE NEXT PAGE FOR PRODUCT LABEL

N.D. - NOT DETERMINED N.A. - NOT APPLICABLE N.T. - NOT TESTED
< - LESS THAN > - GREATER THAN

14. REGULATORY INFORMATION (CONT)

CERCLA 102(a)/DOT Hazardous Substances: (+ indicates DOT Hazardous Substance)

Seq.	Chemical Name	CAS Number	Range in %
None			

CERCLA/DOT Hazardous Substances (Sequence Numbers and RQ's):

Seq.	RQ
None	

TSCA Inventory Status:
This product, or its components, are listed on or are exempt from the Toxic Substance Control Act (TSCA) Chemical Substance Inventory.

Other:
None.

State Regulations:
California Proposition 65:
The following detectable components of this product are substances, or belong to classes of substances, known to the State of California to cause cancer and/or reproductive toxicity.

Chemical Name	CAS Number
None	

International Regulations:

WHMIS Classification:
Not regulated

Canada Inventory Status:
This product, or its components, are listed on or are exempt from the Canadian Domestic Substance List (DSL).

EINECS Inventory Status:
Not determined.

Australia Inventory Status:
Not determined.

Japan Inventory Status:
Not determined.

15. ENVIRONMENTAL INFORMATION

Aquatic Toxicity:
Not determined.

Mobility:
Not determined.

Persistence and Biodegradability:
Not determined.

Potential to Bioaccumulate:
Not determined.

Remarks:
None

16. OTHER INFORMATION

None

THE INFORMATION CONTAINED HEREIN IS BELIEVED TO BE ACCURATE. IT IS PROVIDED INDEPENDENTLY OF ANY SALE OF THE PRODUCT FOR PURPOSE OF HAZARD COMMUNICATION AS PART OF TEXACO'S PRODUCT SAFETY PROGRAM. IT IS NOT INTENDED TO CONSTITUTE PERFORMANCE INFORMATION CONCERNING THE PRODUCT. NO EXPRESS WARRANTY, OR IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE IS MADE WITH RESPECT TO THE PRODUCT OR THE INFORMATION CONTAINED HEREIN. DATA SHEETS ARE AVAILABLE FOR ALL TEXACO PRODUCTS. YOU ARE URGED TO OBTAIN DATA SHEETS FOR ALL TEXACO PRODUCTS YOU BUY, PROCESS, USE OR DISTRIBUTE AND YOU ARE ENCOURAGED AND REQUESTED TO ADVISE THOSE WHO MAY COME IN CONTACT WITH SUCH PRODUCTS OF THE INFORMATION CONTAINED HEREIN.

N.D. - NOT DETERMINED　N.A. - NOT APPLICABLE　N.T. - NOT TESTED
< - LESS THAN　> - GREATER THAN

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17. PRODUCT LABEL

Label Date: 1996-10-01

READ AND UNDERSTAND MATERIAL SAFETY DATA SHEET BEFORE HANDLING OR DISPOSING OF PRODUCT. THIS LABEL COMPLIES WITH THE REQUIREMENTS OF THE OSHA HAZARD COMMUNICATION STANDARD (29 CFR 1910.1200) FOR USE IN THE WORKPLACE. THIS LABEL IS NOT INTENDED TO BE USED WITH PACKAGING INTENDED FOR SALE TO CONSUMERS AND MAY NOT CONFORM WITH THE REQUIREMENTS OF THE CONSUMER PRODUCT SAFETY ACT OR OTHER RELATED REGULATORY REQUIREMENTS.

00700 REGAL R&O 32

WARNING STATEMENT

NONE CONSIDERED NECESSARY

PRECAUTIONARY MEASURES

-Avoid prolonged breathing of vapor, mist, or gas.
-Workers should wash exposed skin several times daily with soap and water.

FIRST AID

Eye Contact:
Flush eyes with plenty of water for several minutes. Get medical attention if eye irritation persists.

Skin Contact:
Wash skin with plenty of soap and water for several minutes. Get medical attention if skin irritation develops or persists.

Ingestion:
If more than several mouthfuls of this material are swallowed, give two glasses of water (16 oz.). Get medical attention.

Inhalation:
If irritation, headache, nausea, or drowsiness occurs, remove to fresh air. Get medical attention if breathing becomes difficult or respiratory irritation persists.

Note to Physician:
High pressure injection of material can cause severe injury. Failure to debride the wound of all residual material can result in disfigurement, loss of function, or may require amputation of the affected area.

FIRE

In case of fire, use water spray, dry chemical, foam or carbon dioxide. Water may cause frothing. Use water spray to cool fire-exposed containers.

	Chemical Name	CAS Number	Range in %
#	Solvent-dewaxed heavy paraffinic petroleum distillates	64742-65-0	95.00-99.99

PRODUCT IS NON-HAZARDOUS ACCORDING TO OSHA (1910.1200).
COMPONENT, BY DEFINITION, IS CONSIDERED HAZARDOUS ACCORDING TO OSHA BECAUSE IT CARRIES THE PERMISSIBLE EXPOSURE LIMIT (PEL) FOR MINERAL OIL MIST.

Pennsylvania Special Hazardous Substance(s)	CAS Number	Range in %
None		

HMIS				NFPA			
Health:	1	Reactivity:	0	Health:	1	Reactivity:	0
Flammability:	1	Special	: -	Flammability:	1	Special	: -

Transportation
DOT:
Proper Shipping Name:
Not regulated

CAUTION: Misuse of empty containers can be hazardous. Empty containers can be hazardous if used to store toxic, flammable, or reactive materials. Cutting or welding of empty containers might cause fire, explosion or toxic fumes from residues. Do not pressurize or expose to open flame or heat. Keep container closed and drum bungs in place.

N.D. - NOT DETERMINED N.A. - NOT APPLICABLE N.T. - NOT TESTED
< - LESS THAN > - GREATER THAN

17. PRODUCT LABEL (CONT) Label Date: 1988-10-01

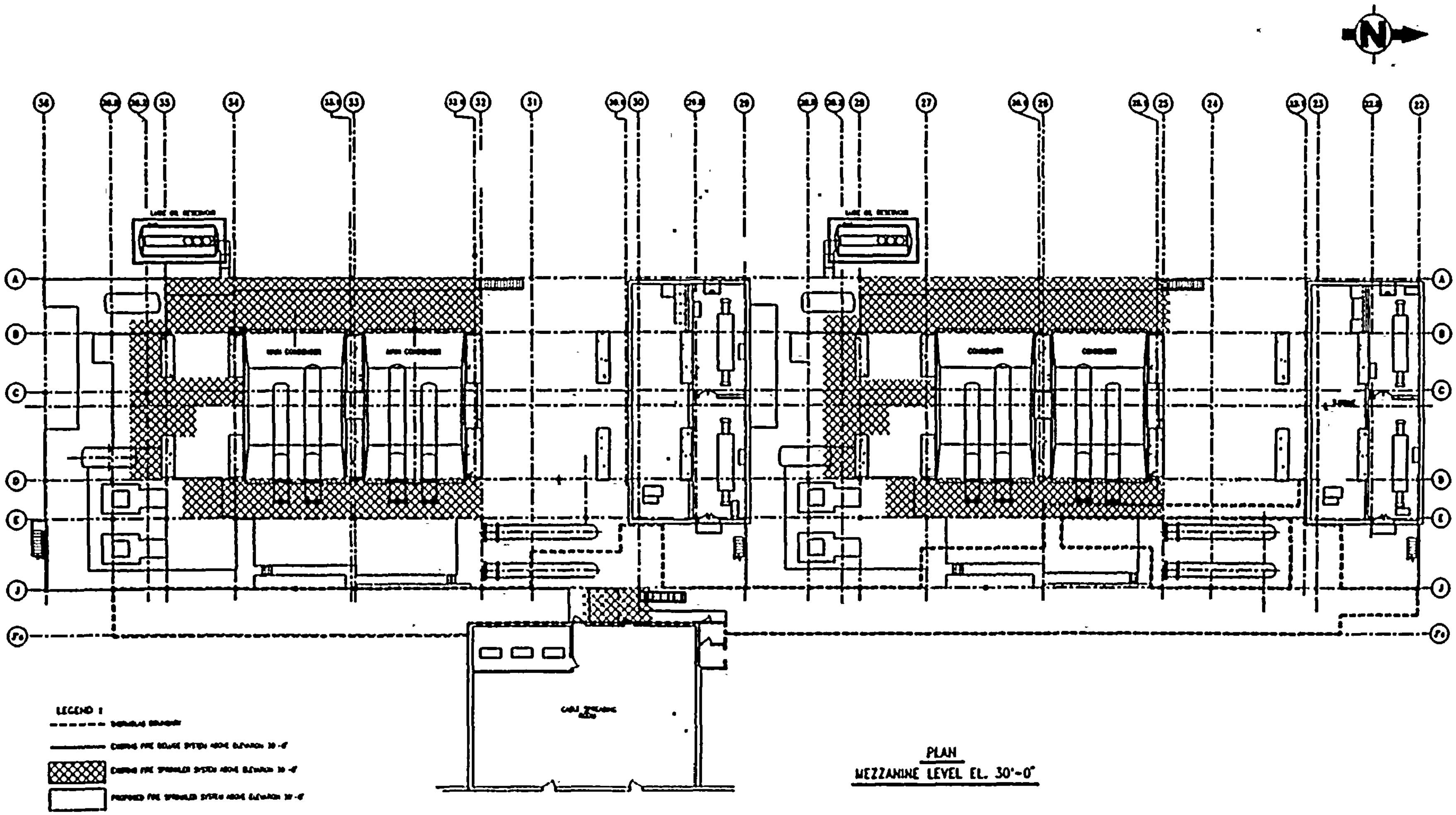
Manufacturer's Name and Address:
TEXACO LUBRICANTS COMPANY
A DIVISION OF TEXACO REFINING AND MARKETING INC.
P.O. Box 4427
Houston, TX 77210-4427

TRANSPORTATION EMERGENCY	Company:	(914) 831-3400
	CHEMTREC:	(800) 424-9300
HEALTH EMERGENCY	Company:	(914) 831-3400

ATTACHMENT B

Suggested Locations for Addition of Sprinklers and Curbs to be Installed in the Turbine Building

(2 PAGES)



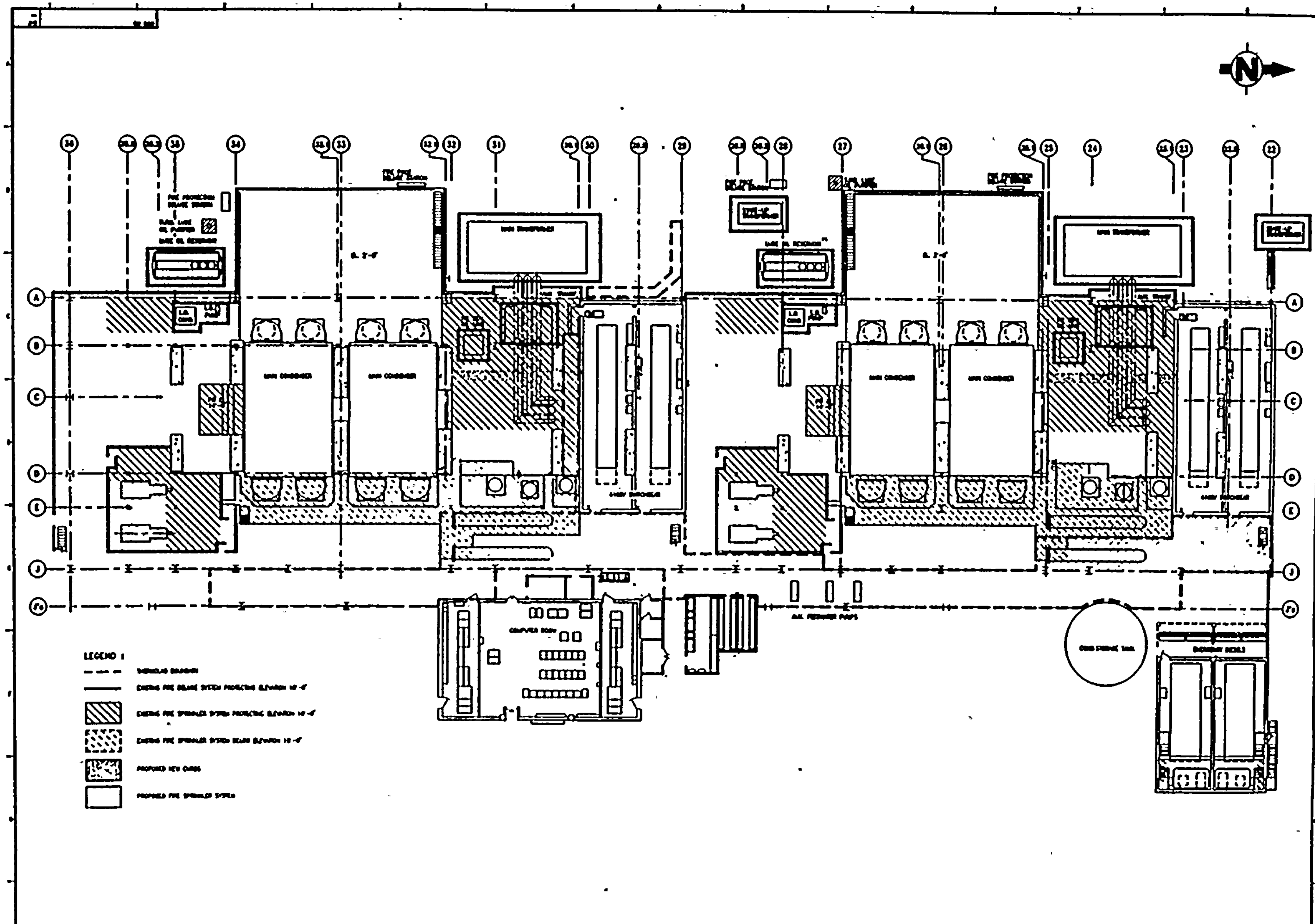
PLAN
MEZZANINE LEVEL EL. 30'-0"

TURKEY POINT NUCLEAR UNITS 3 & 4

FIRE PROTECTION
MEZZANINE LEVEL
ELEVATION 30'-0"

FLORIDA POWER & LIGHT

PTN FPER 97-013
ATTACHMENT 8



TURKEY POINT NUCLEAR UNITS 3 & 4

FIRE PROTECTION
GROUND FLOOR PLAN
EL. 18'-0" & BELOW

FLORIDA POWER & LIGHT

FPL

PTN FPER 87-013
ATTACHMENT B

Temperatures in flames and fires

by

Dr. Vytenis Babrauskas, Fire Science and Technology Inc.

Introduction

It is unfortunately not too rare to find that fire investigators estimate flame temperatures by looking up a handbook value, which turns out to the *adiabatic flame temperature*. Statements are then made about whether some materials could have melted, softened, lost strength, etc., based on comparing such a flame temperature against the material's melting point, etc. The purpose of this short paper is to point out the fallacies of doing this, and to present some more appropriate information for a more realistic assessment.

First, we must point out that measuring of flame temperatures to a high degree of precision is quite difficult, and many combustion research scientists have devoted decades to studying the task. The difficulties come from two sources: (1) intrusiveness of instrumentation; and (2) interpretation difficulties due to the time-varying nature of the measurement. Non-intrusive (e.g., optical laser techniques) methods are available, but these are difficult and expensive to make and are generally not applied to the study of building fires. In most cases, thermocouples are used for temperature measurement. These have a multitude of potential errors, including surface reactions, radiation, stem loss, etc. A whole textbook is available on the subject of instrumentation for studying flames [1]. As we see below, the flames of most interest for unwanted fires are turbulent. This time fluctuation presents tremendous difficulties in making measurements and in interpreting them meaningfully. Such flames move about in little "packets." Thus, a measurement at a single location returns a complicated average value of reacting and unreacting packets flowing by. Some of these issues are elucidated in [2].

Even careful laboratory reconstructions of fires cannot bring in the kind of painstaking temperature measuring technologies which are used by combustion scientists doing fundamental research studies. Thus, it must be kept in mind that fire temperatures, when applied to the context of measurement of building fires, may be quite imprecise, and their errors not well characterized.

Flame types

Before we discuss details of flame temperatures, it is important to distinguish between some of the major flame types. Flames can be divided into 4 categories:

- laminar, premixed
  laminar, diffusion

- laminar, diffusion
- turbulent, premixed
- turbulent, diffusion

An example of a laminar premixed flame is a Bunsen burner flame. Laminar means that the flow streamlines are smooth and do not bounce around significantly. Two photos taken a few seconds apart will show nearly identical images. Premixed means that the fuel and the oxidizer are mixed before the combustion zone occurs.

A laminar diffusion flame is a candle. The fuel comes from the wax vapor, while the oxidizer is air; they do not mix before being introduced (by *diffusion*) into the flame zone. A peak temperature of around 1400°C is found in a candle flame [3].

Most turbulent premixed flames are from engineered combustion systems: boilers, furnaces, etc. In such systems, the air and the fuel are premixed in some burner device. Since the flames are turbulent, two sequential photos would show a greatly different flame shape and location.

Most unwanted fires fall into the category of turbulent diffusion flames. Since no burner or other mechanical device exists for mixing fuel and air, the flames are diffusion type.

Adiabatic flame temperature

When one consults combustion textbooks for the topic of 'flame temperature,' what one normally finds are tabulations of the *adiabatic flame temperature*. 'Adiabatic' means without losing heat. Thus, these temperatures would be achieved in a (fictional) combustion system where there were no losses. Even though real-world combustion systems are not adiabatic, the reason why such tabulations are convenient is because these temperatures can be computed from fundamental thermochemical considerations: a fire experiment is not necessary. For methane burning in air, the adiabatic flame temperature is 1949°C, while for propane it is 1977°C, for example. The value for wood is nearly identical to that for propane. The adiabatic flame temperatures for most common organic substances burned in air are, in fact, nearly indistinguishable. These temperatures are vastly higher than what any thermocouple inserted into a building fire will register!

Flames temperatures of open flames

For convenience, we can subdivide the turbulent diffusion flames from unwanted fires into two types: flames in the open, and room fires. First we will consider open flames.

The starting point for discussing this topic can be the work of the late Dr. McCaffrey, who made extensive measurements [4] of temperatures in turbulent diffusion flames. He used gas burners in a "pool fire" mode (i.e., non-premixed) and studied various characteristics

of such fire plumes. He described three different regimes in such a fire plume:

1. Slightly above the base of the fire begins the *continuous flame* region. Here the temperatures are constant and are slightly below 900°C.
2. Above the solid flame region is the *intermittent flame* region. Here the temperatures are continuously dropping as one moves up the plume. The visible flame tips correspond to a temperature of about 320°C.
3. Finally, beyond the flame tips is the thermal plume region, where no more flames are visible and temperature continually drop with height.

French researchers at the University of Poitiers recently made the same types of measurements and reported numerical values [5] indistinguishable from McCaffrey's. Cox and Chitty [6] measured similar plumes and obtained very similar results: a temperature of 900°C in the continuous flame region, and a temperature of around 340°C at the flame tips. The latter value does not appear to be a universal constant. Cox and Chitty later measured slightly higher heat release rate fires, and found a flame tip temperature of around 550°C. In a later paper [7], researchers from the same laboratory examined turbulent diffusion flames under slightly different conditions, and found peak values of 1150-1250°C for natural gas flames, which is rather higher than 900°C. The above results were from fires of circular or square fuel shape. Yuan and Cox [8] measured line-source type fires. They found a temperature of 898°C in the continuous flame region, and a flame tip temperature of around 340°C. This suggests that such results are not dependent on the shape of the fuel source.

In studying fires in a warehouse storage rack geometry, Ingason [9] found an average solid-flame temperature of 870°C. At the visible flame tips, the average temperature was 450°C, but the range was large, covering 300~600°C. In a related study, Ingason and de Ris [10] found typical flame tip temperatures of 400°C for burner flames of propane, propylene, and carbon monoxide fuels.

In the SFPE Handbook, Heskestad [11] recommends using a value of 650°C for the temperature rise at the flame tip, i.e., an actual temperature of about 670°C. This seems notably high compared to the experimental data cited above, and Heskestad does not provide any explanation where his value comes from. Also in the Handbook, Mudan and Croce [12] summarize some continuous-flame region measurements for various liquid pools. With the exception of a few data points, most values lie between 827°C to 1127°C. The variations appear to be more attributable to experimental technique than to type of liquid being burned. Most of the values are for quite large (many meters in diameter) pools. Fundamental radiation considerations would suggest that smaller pools might show somewhat lower temperatures, but data to demonstrate this point seem sparse. Curiously, in a later study [13], Heskestad adopts a criterion of 500°C for the flame tip temperature.

Taking all of the above information in account, it appears that flame tip temperatures for

turbulent diffusion flames should be estimated as being around 320~400°C. For small flames (less than about 1 m base diameter), continuous flame region temperatures of around 900°C should be expected. For large pools, the latter value can rise to 1100~1200°C.

Flame temperatures in room fires

There is fairly broad agreement in the fire science community that flashover is reached when the average upper gas temperature in the room exceeds about 600°C. Prior to that point, no generalizations should be made: There will be zones of 900°C flame temperatures, but wide spatial variations will be seen. Of interest, however, is the peak fire temperature normally associated with room fires. The peak value is governed by ventilation and fuel supply characteristics [14] and so such values will form a wide frequency distribution. Of interest is the maximum value which is fairly regularly found. This value turns out to be around 1200°C, although a typical post-flashover room fire will more commonly be 900~1000°C. The time-temperature curve for the standard fire endurance test, ASTM E 119 [15] goes up to 1260°C, but this is reached only in 8 hr. In actual fact, no jurisdiction demands fire endurance periods for over 4 hr, at which point the curve only reaches 1093°C.

The peak expected temperatures in room fires, then, are slightly greater than those found in free-burning fire plumes. This is to be expected. The amount that the fire plume's temperature drops below the adiabatic flame temperature is determined by the heat losses from the flame. When a flame is far away from any walls and does not heat up the enclosure, it radiates to surroundings which are essentially at 20°C. If the flame is big enough (or the room small enough) for the room walls to heat up substantially, then the flame exchanges radiation with a body that is several hundred °C; the consequence is smaller heat losses, and, therefore, a higher flame temperature.

Temperatures of objects

It is common to find that investigators assume that an object next to a flame of a certain temperature will also be of that same temperature. This is, of course, untrue. If a flame is exchanging heat with a object which was initially at room temperature, it will take a finite amount of time for that object to rise to a temperature which is 'close' to that of the flame. Exactly how long it will take for it to rise to a certain value is the subject for the study of *heat transfer*. Heat transfer is usually presented to engineering students over several semesters of university classes, so it should be clear that simple rules-of-thumb would not be expected. Here, we will merely point out that the rate at which target objects heat up is largely governed by their thermal conductivity, density, and size. Small, low-density, low-conductivity objects will heat up much faster than massive, heavy-weight ones.

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Another factor that needs to be evaluated is the effect of particle size on the nitrogen gas requirements. From these investigations we observed that particle size does have some effect on the gas velocity required to avoid surging, i.e., the larger particles require a higher velocity. Hence, there should be some effect on the gas flow rates required to expell a given dry chemical flow rate. We hope to evaluate these effects during future research work in the area of dry chemical flow and pressure losses.

Calculation of Response Time of Ceiling-Mounted Fire Detectors

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Factory Mutual Research Corporation

An understanding of the behavior of the fire plume and fire-induced flow near the ceiling of a room is necessary if one is to optimize detector response time and placement.

ONE of the most important problems in fire protection is the rapid detection of fire in a room while the fire is sufficiently small to be easily controlled. Such small, controllable fires generally exist for more than half a minute after ignition when flames are confined by inert barriers or air gaps to a distinct portion of the total available fuel. Subsequent to this initial period of relatively constant fire intensity, there is usually a period of rapid fire spread to surrounding combustible materials. The resulting fully developed fire may also be of nearly constant intensity but large enough to endanger the building structure in the absence of a sprinkler system. It is thus desirable to detect a fire as quickly as possible.

Ceiling-mounted devices that do not interfere with normal room arrangement are generally preferred for fire detection. Finding optimum values of spacing, placement below the ceiling, and sensitivity for such devices in all possible room geometries is a rather complicated problem. The problem can be simplified, however, by assuming that the ceiling is essentially smooth, horizontal, and large in unobstructed area.

There are two main types of fire detection devices. One type is actuated by radiation, a significant portion of the total thermal energy release in a fire. The most common devices, however, depend on a movement of hot products of combustion directly to a sensor. These combustion products contain the remainder of the thermal energy release in addition to suspensions of fine particles and droplets (smoke). Thermally actuated detectors and smoke actuated detectors constitute the second class of detection devices. The object of the subsequent discussion is to fully describe the fire-induced environment in which thermally actuated and

NOTE: This paper was presented at the 76th Annual Meeting of the National Fire Protection Association on May 18, 1972 in Philadelphia, Pa.

smoke [illegible]ated detectors must operate, so that in certain cases, the response time of these devices can be calculated.

FIRE-INDUCED CONVECTION

Buoyancy causes the hot products generated in a fire to rise to the ceiling while mixing with room air to form a fire plume. Impingement of the fire plume on a ceiling, as shown in Figure 1, results in a gas flow near the ceiling even at a considerable distance from the fire axis. It is this flow that is responsible for transferring hot gases or smoke particles to the thermally actuated and smoke-actuated group of detection devices. Since a knowledge of the fire-induced flow is particularly valuable if the response time of such detectors is to be optimized, a detailed scientific study of the fire plume and the near-ceiling flow resulting from the plume has been undertaken at Factory Mutual Research. Only smooth, horizontal ceilings are considered in the study, although it should not be difficult, using the methods described herein, to extend the results to most types of ceiling.

Two parameters of considerable importance in any discussion of fire-induced convection near a ceiling are the rate of heat released by the burning fuel and the ceiling height above this fuel. Experimental data indicate that these two parameters, properly defined, generally determine the major characteristics of the fire-induced flow. The ceiling height, H*, henceforth refers to the distance between the uppermost burning fuel surface and the ceiling, while the rate of heat release, Q, is consistently the product of the rate of the fuel weight loss and the maximum theoretical heating value per unit mass of fuel. In reality, only a portion of the maximum combustion energy is transferred directly to the flow, but this portion may be about the same for most ordinary combustible materials.

The period of rapid fire spread a short time after ignition usually results in a rapid increase in the magnitude of the heat release rate. If, during such periods, the magnitude of Q doubles in less than about one minute, the near-ceiling flow will be somewhat different in character from that due to a constant rate of heat release. Although the study described herein is only applicable to the latter case of constant or slowly varying Q, many real fires will, in the initial or final stages (after flame spread), have such a slowly varying heat release rate.

Basic research on fire-induced convection at Factory Mutual has led to development of a theoretical analysis[1] for predicting gas velocity, temperature, and dimensions of the near-ceiling flow induced by constant intensity, "small" (flame zone maximum dimension much less than ceiling height) fires. This analysis, which extends work previously done by Morton *et al*[2] on fire plumes, is in excellent agreement with measurements obtained during "small" fires beneath flat ceilings 4 ft to 30 ft in height. However, the air flow induced by such small fires is easily affected by room

*See list of nomenclature on page 194.

ventilation and often will not trigger ceiling-mounted detectors. Larger fires, on the other hand, are of greater interest for practical detection devices. An experimental and theoretical program[3] has, therefore, been undertaken to study convection associated with large fires for which flames are often comparable in height to the ceiling.

Experiments during the most recent convection study are performed at the Factory Mutual West Glocester Test Center and involve the use of several different combustible materials. As shown in Table 1, heat release rates for these experiments range from 38,000 to nearly 6,000,000 Btu min⁻¹ while ceiling heights from 15 to 51 ft are used. Figure 2 is an example of the heptane spray fire produced by 8 nozzles located on a 12-ft diameter circle. The plume can be seen impinging on a ceiling 26 ft above the nozzles and spreading out radially in a thin layer near the ceiling. For all the large-scale tests shown in Table 1, the radially-spreading ceiling flow is obstructed by walls only at distances 100 ft or more from the fire axis. In addition, the test building is either ventilated at ceiling level or data is obtained only when the accumulated layer of hot gas and smoke is far from the floor.

Temperature Measurements

Extensive measurements of gas temperature have been made during the test fires in order to determine how gas temperature, T, varies with

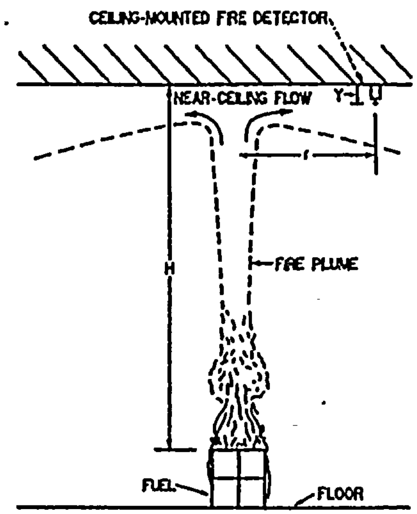

Figure 1 (Above). Schematic diagram of the gas flow induced by a fire.

Figure 2 (Right). Photograph of the heptane spray fire. Ceiling hight above spray nozzles is 26 ft, and heptane flow rate is 12 gpm.

TABLE 1. *Summary of Fire Tests*

Fuel	*Fuel array size (ft)*	*Fire intensity (Btu min⁻¹)*	*Ceiling height (ft)*
Heptane spray	12-ft diameter	4×10^5 to 1.3×10^6	15, 26
Heptane pan in 90° corner	2 by 2	5.8×10^4	25
Ethanol pan	3.2 by 3.2	3.8×10^4	28
Wood pallets in 90° corner	4 by 4 by 5 high	2.8×10^5	20
Cardboard boxes	8 by 8 by 15 high	2.2×10^5	45
Polystyrene in cardboard boxes	8 by 8 by 15 high	5.6×10^4	45
Polyvinylchloride in cardboard boxes	8 by 8 by 15 high	2×10^5	44
Polyethylene pallets	4 by 4 by 9 high	2.4×10^5 to 6.5×10^5	51

distance, Y, below the ceiling at several radial distances, r, from the fire axis (see Figure 1). It has been found in each case that, outside the fire plume, the maximum gas temperature, T_{max}, occurs a few inches from the ceiling and that temperatures decrease to near the "room temperature" value, T_{rm}, a few feet below the ceiling (see diagram in Figure 3). The exact locations below the ceiling where $T = T_{max}$ and where T approaches T_{rm} are a function primarily of ceiling height, radial position, and thermal characteristics of the ceiling material (transfer of heat through the ceiling causes a small decrease in gas temperature). All available experimental data show that, when the hot gases are vented some distance from the fire or when there is only negligible accumulation of stagnant hot gases, T_{max} occurs a distance below the ceiling of no more than 1 percent of total ceiling height while T approaches T_{rm} a distance below the ceiling of 5.5 percent to 12.5 percent of total ceiling height.

Within the fire plume, experiments show that gas temperature increases with vertical distance, Y, below the ceiling. However, for distances below the ceiling to 5.5 percent or even 12.5 percent of total ceiling height, there is a negligibly small increase in gas temperature from the value at the ceiling.

From the measurements of gas temperature described here, it has been found that all data on T_{max}, the maximum gas temperature at a given radial position near the ceiling, can be correlated by the equations:

$$T_{max} - T_{rm} = \frac{4.74\,(Q/r)^{2/3}}{H} \qquad (1)$$

for r greater than $0.18H$ and:

$$T_{max} - T_{rm} = \frac{14.9\,Q^{2/3}}{H^{5/3}} \qquad (2)$$

for r less than or equal to $0.18H$; where temperature, T, is in °F, heat

release rate, Q, is in Btu min⁻¹, and ceiling height and radial position (H and r) are in ft. These empirically determined relations for gas temperature and similar types of relations for gas velocity are in good agreement with the previous theoretical analysis[1] for a "small" fire.

Typical values of T_{max} near the ceiling are shown in Figure 3 for a one-million Btu min⁻¹ fire beneath ceilings of various heights, H. Gas temperatures would increase from room temperature to the values shown a short time after the attainment of the one-million Btu min⁻¹ fire intensity. At later times, gas temperatures would not change significantly if the hot gases were vented or not allowed to accumulate. Insufficient venting of the hot gases would result in a gradual increase in all gas temperatures at a rate that depends on the room size.

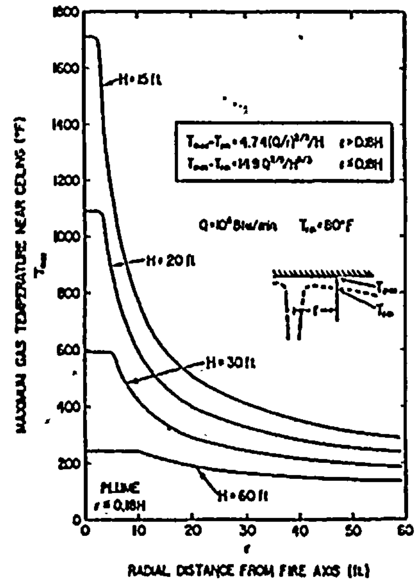

Figure 3. Gas temperature close to the ceiling for a typical large-scale fire. Ceiling is a height, H, above fuel burning with heat release, Q.

It can be seen from Figure 3 that T_{max} is nearly constant for a radial distance from the fire axis of about 18 percent of the ceiling height. Beyond this point, which actually corresponds to the outer boundary of the fire plume at the ceiling, there is a rather sharp drop in gas temperature with radius, r, until the ambient or room temperature value is approached. As expected, gas temperature at all radial positions, but especially near the fire plume, decreases as the ceiling height increases.

All of the temperature measurements used to derive Equations 1 and 2 were made with the burning fuel either a minimum of 300 percent of total ceiling height from the nearest wall obstruction or practically in contact with wall obstructions. Gas temperatures obtained from Equations 1 and 2 should, in fact, be valid for a wide range of floor areas as long as the fire axis is *either* immediately adjacent to walls *or* at least 10 fire plume

radii, a 80 percent of total ceiling height, from the nearest wall. In the former case, the minimum wall to wall distance should be about 180 percent of total ceiling height, and a modified value of fire heat release rate, Q, must be used. If, for instance, the burning fuel is adjacent to the 90° corner formed by two walls, the appropriate value of Q is four times the usual value while, for a fire adjacent to a single flat wall, Q is twice the usual value. The preceding rules have been verified by fire tests in a simulated room corner (see Table 1).

Velocity Measurements

Measurements of gas velocity, as well as temperature, have been made during fire tests similar to those discussed above. These experiments mainly yield the maximum gas velocity, V_{max} at each radial position, r, outside the fire plume and the gas velocity near the ceiling within the fire plume. The gas velocity data can be correlated quite well by the following equations:

$$V_{max} = \frac{0.25\, Q^{1/3} H^{1/2}}{r^{5/6}} \qquad (3)$$

for r greater than 0.15 H and

$$V_{max} = 1.2 \left(\frac{Q}{H}\right)^{1/3} \qquad (4)$$

for r less than or equal to $0.15H$, where V_{max} is in ft sec.$^{-1}$

Calculations of gas velocity from Equations 3 and 4 are shown in Figure 4 for a one-million Btu min^{-1} fire intensity. In much the same manner as the gas temperature, the velocity is nearly constant in the fire plume but decreases sharply with radial distance beyond the fire plume. A rather unexpected result shown in Figure 4 is the increase in gas velocity with increasing ceiling height at radial positions *outside* the fire plume. This effect is due to the increase in the mass of hot air rising to the near-ceiling flow as the ceiling height increases.

As noted before, the gas velocity in Equations 3 and 4 refers to the

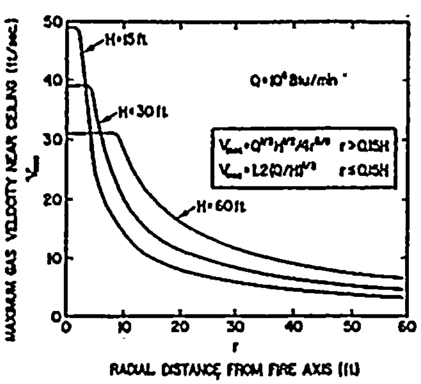

Figure 4. Gas velocity close to the ceiling for a typical large-scale fire. Ceiling is a height, H, above fuel burning with heat release, Q.

maximum value at a given radial position. This maximum val generally found quite close to the ceiling. Although gas velocity is nearly independent of distance below the ceiling within the fire plume, a velocity considerably less than V_{max} would be measured outside the plume if the distance, Y, below the ceiling is sufficiently large. Evidence available from small-scale "model" fires[3] (ceiling height 2–4 ft) indicates that, outside the plume, the gas velocity in fact approaches zero at approximately the same distance below the ceiling where the gas temperature approaches room temperature. For both temperature and velocity, therefore, the value of Y at the lower edge of the near-ceiling flow outside the plume is from 5.5 percent to 12.5 percent of total ceiling height. It is expected, as a result, that beams or structures at the ceiling protruding downward a distance less than 1 percent of ceiling height will not "disturb" the flow. Such ceilings could still be considered "smooth".

ULTIMATE SENSITIVITY OF FIXED-TEMPERATURE RATING FIRE DETECTORS

The preceding description of the near-ceiling flow induced by "real" fires forms the basis for an analysis of heat transfer rates to objects, including the ceiling itself, immersed in this flow. Specifically, it is now possible to compute the rate at which heat is transferred to the sensing elements of thermally actuated detectors by utilizing the equations for fire-induced gas velocity and temperature.

No amount of heat transfer to a detector will cause it to actuate, however, if the detector is of the fixed temperature thermostat type and the gas temperature is below the fixed temperature rating of the device. It is, therefore, possible to determine the ultimate sensitivity of such detectors since the gas temperature as a function of ceiling height, radial position, and fire intensity is known from Equations 1 and 2. If the detector is assumed to operate only when the maximum near-ceiling gas temperature, T_{max}, is greater than the fixed temperature rating, T_L, then from Equation 1, the smallest detectable fire intensity, Q_{min}, is:

$$Q_{min} = r\,[(T_L - T_{rm})\, H/4.74]^{3/2} \qquad (5)$$

as long as the radial distance, r, from the fire axis to the detector is greater than 18 percent of total ceiling height. When r is less than 18 percent of H, the detector is effectively within the boundaries of the fire plume, thus requiring the use of Equation 2, which yields:

$$Q_{min} = [(T_L - T_{rm})/14.9]^{3/2} H^{5/2} \qquad (6)$$

To be conservative, it is assumed that the fire axis is as far as possible from any individual detector. The radial distance to the nearest detector in a square array of spacing, S, then becomes:

$$r = \frac{S}{2^{1/2}} \qquad (7)$$

Using Equations 5 through 7 allows the smallest detectable fire intensity, Q_{min}, to be plotted in Figure 5 as a function of ceiling height and the fixed temperature rating, T_L, of thermostats on a 20-ft by 20-ft spacing. It is seen that, even for a 135° F temperature rating (assuming T_{rm} = 80° F), a ceiling mounted detector 35 ft above the burning fuel will only respond to a fire intensity greater than 100,000 Btu min^{-1}, which is equivalent to the combustion of 1 gpm of heptane. The response time for this combination of fire intensity, ceiling height, and temperature rating would probably be unacceptably long, since the thermal inertia of detectors only allows rapid actuation when the gas temperature is far above the actual temperature rating of the device. Thermal inertia can be simulated, however, by assuming a 135° F rated detector will respond in a reasonable time when gas temperature is greater than 300° F, which means assuming $T_L - T_{rm}$ is 220° F for this detector. Figure 5 shows that such a detector mounted at a ceiling height of 35 ft will only be actuated by a fire intensity greater than one-million Btu min^{-1} (equivalent to a 9 gpm heptane fire).

OPTIMUM LOCATION OF FIRE DETECTORS

Ceiling-mounted fire detectors should be located so that transfer of heat (thermally actuated) or mass (smoke actuated) to the detector is maximized in order to minimize the response time. It is thus necessary to calculate heat and mass transfer rates induced by a fire.

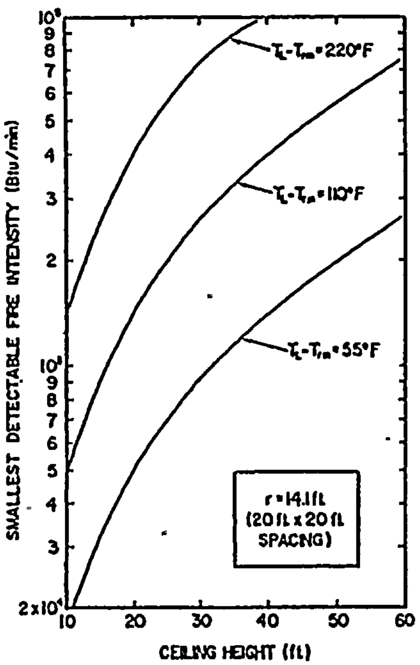

Figure 5. Smallest fire intensity, Q_{min}, that can be detected by a thermostat with a fixed temperature rating, T_L.

HEAT TRANSFER RATE

The rate of heat transfer to an object in a flow of high temperature gas is usually expressed as the product of a heat transfer coefficient and the temperature difference between the gas and the object. Detector sensing elements are generally so small (compared to either the fire plume diameter or the total thickness of the near-ceiling flow outside the plume) that the heat transfer coefficient to a given sensing element will be nearly proportional to the square root of gas velocity, V, and independent of temperature[4]. Furthermore, the temperature difference between the gas and sensing element is simply the quantity $T - T_{rm}$ as long as the sensing element is nearly at its initial state of room temperature. Of course, the sensing element is gradually "warmed up" (above room temperature) by the fire-induced flow.

The heat transfer rate, q, to the sensing element of a detector is, therefore, given by the following proportionality:

$$q = C_1 (T - T_{rm}) V^{1/2} \qquad (8)$$

where C_1 is contant for any one detector.

Proportionality 8 is valid at any location in the fire-induced flow before the temperature of a sensing element changes significantly. Within the fire plume, the near-ceiling heat transfer rate, q_p, is obtained by substitution of T_{max} and V_{max} from Equations 2 and 4, respectively, for T and V in the proportionality. This substitution is possible because gas temperature and velocity in the portion of the fire plume near the ceiling do not change significantly with vertical distance below the ceiling (for Y as much as 12.5 percent H). Outside the fire plume, the near-ceiling heat transfer rate, q, is obtained by replacing V with the equivalent expression, $(V/V_{max}) V_{max}$ and by substituting for V_{max} from Equation 3 and by similarly replacing $(T - T_{rm})$ and substituting from Equation 1. Both Equations 3 and 1, it should be noted, are indeed applicable outside the plume.

The near-ceiling heat transfer rate outside the fire plume relative to that within the fire plume is then simply the ratio, q/q_p, which is given by:

$$q/q_p = 0.15 (V/V_{max})^{1/2} (\Delta T/\Delta T_{max})/(r/H)^{1.1} \qquad (9)$$

if r/H is greater than 0.18, where $\Delta T = T - T_{rm}$.
By definition:

$$q/q_p = 1 \qquad (10)$$

within the fire plume, where r/H is less than 0.18.

Although q_p does not change significantly as long as the vertical distance, Y, below the ceiling is much less than ceiling height, both V/V_{max} and T/T_{max}, and hence q, are strongly dependent on Y. Both V and ΔT, in fact, approach zero when Y is from 5.5 percent to 12.5 percent of ceiling height while $V = V_{max}$ and $T = T_{max}$ when Y is about 1 percent of H.

Mass Transfer Rate

The transfer of combustion products, such as smoke, to suitable detectors in the near-ceiling flow is a mass transfer process similar in many respects to the transfer of heat. For example, the rate at which mass is transferred to an object is generally expressed as the product of a mass transfer coefficient and the difference between the mass concentration (lbm ft^{-3}) in the flow and that close to the object. A theoretical analysis does, in fact, show that the mass concentration of a given constituent (such as smoke) in the near-ceiling combustion products should always be proportional to the excess of gas temperature over room temperature, $T - T_{rm}$. The difference between the mass concentration in the near-ceiling flow and that close to or within a smoke detector will also be proportional to $T - T_{rm}$ as long as no significant quantity of smoke accumulates in the detector. Furthermore, it is easily shown that the mass transfer coefficient in flows similar to the fire-induced flow should be proportional to the heat transfer coefficient.[4] Mass transfer rates should thus be proportional to heat transfer rates to a given detector or the quantity q/q_p is identical to the ratio of near-ceiling mass (smoke) transfer rate outside the plume to that within the plume. Equations 9 and 10, as a result, probably describe how the transfer of smoke to detectors is affected by detector position and ceiling height.

Optimum Heat Transfer Rate

Calculations of q/q_p obtained both from Equations 9 and 10 and from data on $\Delta T/\Delta T_{max}$ and V/V_{max} as functions of Y are shown in Figure 6. It is seen that the rate of heat (or smoke) transfer to detectors is always close to the maximum value for a ratio of radial position to ceiling height, r/H, less than about 0.18. However, there is a sharp decrease in q to about half the maximum value at $r/H = 0.30$ if the vertical position, Y, is less than 3 percent of ceiling height. There is also a sharp decrease in q just outside the plume if the vertical distance Y below the ceiling increases to 6 percent of ceiling height. In fact, the heat transfer rate outside the plume is never more than 10 percent to 20 percent of the maximum value, as

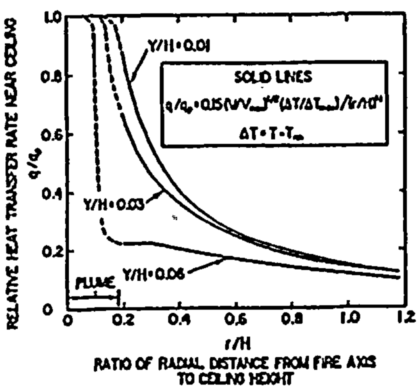

Figure 6. Heat transfer rate to room temperature objects near the ceiling relative to that in the fire plume or over the fire.

shown by the trend of the curves in Figure 6, if a detector is mounted more than $0.06H$ below the ceiling. The latter result should not be surprising because the total thickness of the hot gas layer outside the plume can be as small as 5.5 percent of ceiling height.

It is clear from the preceding that the maximum heat or mass transfer rates (and hence minimum response times) will be attained for detectors located a radial distance from the fire axis less than about 18 percent of total ceiling height and a vertical distance below the ceiling of from 1 percent to 3 percent of total ceiling height. Values for r and Y should not be much less than $0.18H$ and $0.01H$, respectively, since there is no significant improvement in heat transfer rate above the maximum value for r less than $0.18H$ and there is actually a slight decrease in heat transfer rate for Y less than $0.01H$ due to ceiling friction and heat loss. With r equal to $0.18H$, Equation 7, therefore, shows that the spacing of detectors in a square array should never be less than about ¼ of ceiling height. Such a minimum spacing for optimum response time would not ordinarily be practical with ceiling heights less than 40 ft, although detector spacings in use are often less than the minimum ¼ of ceiling height for ceiling heights of 50 ft or more.

Detector sensing elements, as a result, should be a vertical distance from the ceiling of 1 percent to 6 percent of ceiling height and should be spaced at intervals no less than 25 percent of ceiling height. In order to find the *maximum* possible detector spacing, specific details of the ceiling-mounted detector and the intensity of the fire must be known in addition to the preceding heat transfer information. The maximum possible spacing can be determined quite easily, however, if the detector is thermally actuated with a fixed temperature rating. In this case, Equation 5 yields the maximum possible radial distance, r, between the fire axis and the detector, since, for the following value of r, gas temperature just equals T_L:

$$r = Q_{min} \, [4.74/H \, (T_L - T_{rm})]^{3/2} \tag{11}$$

where Q_{min} is the smallest heat release rate which must actuate a detector. If the value of r from Equation 11 is less than $0.18H$, then the desired value of detectable fire intensity, Q_{min}, must be increased. Once r is determined from Equation 11, the maximum possible spacing can be calculated, for instance, by use of Equation 7.

CALCULATION OF DETECTOR RESPONSE TIME FOR FIXED TEMPERATURE RATING

In the earlier discussion of convection, characteristics of the fire-induced flow near the ceiling are related to the fire intensity or heat release rate, the ceiling height, and the location of a detector. The response time of all thermally actuated detectors can, in principle, be derived from these relations if sufficient information about the sensing element of the detector is available. With such information, even the response time of

detectors actuated by the rate of rise of gas temperature can be calculated as long as the fire heat release rate both is known at all times and does not double in less than about one minute.

It is simplest, for the present discussion, to consider only a constant fire intensity that must be detected by a ceiling-mounted device with a fixed temperature rating. Both the heat release rate during the growth of the fire to this constant intensity and the time necessary to establish the steady fire-induced flow are ignored. These effects, however, probably have an equal and opposite influence on the detector response time.

For a fire-induced gas temperature, T, that does not change with time (due to the assumed constant fire intensity), the time, t, it takes the thermostat detector to reach the rated temperature, T_L, from an initial room temperature, T_{rm}, is given by the well-known relation[4]:

$$t = C h^{-1} \log[(T - T_{rm})/(T - T_L)], \tag{12}$$

where C is a constant dependent only on the thermal inertia of the detector sensing element and h is the coefficient of heat transfer at the detector. Calculation of C from known characteristics of the sensing element is, of course, possible. However, it is quite difficult to determine the absolute magnitude of the heat transfer coefficient, h. Not only is this quantity proportional to the square root of near-ceiling gas velocity, as noted before, but also the proportionality constant is dependent on flow details caused by the shape of a specific detector and sensing element.

A more convenient procedure than the direct use of Equation 12 is the calculation of response time, t, during a fire relative to the response time, t_s, measured during a standard fire test. Such a test might well be similar to that described in the Factory Mutual Approval Standard for thermostat fire detectors. The time for a detector to be actuated by a fire is then found from the product of a measured value of t_s and the computed ratio t/t_s. It is easily shown with the use of Equation 12 that this ratio is given by:

$$t/t_s = (V_s/V)^{1/2} \log[1 - \Delta T_L/\Delta T]/\log[1 - \Delta T_L/\Delta T_s] \tag{13}$$

$$\Delta T_L = T_L - T_{rm},\ \Delta T = T - T_{rm},\ \text{etc.}$$

where V_s and T_s are the near-ceiling velocity and temperature, respectively, during the standard test and $(V_s/V)^{1/2}$ is a ratio of heat transfer coefficients.

If it is assumed the detector is positioned sufficiently close to the ceiling (from 1 percent to 3 percent of ceiling height) for V and T to approximately equal V_{max} and T_{max}, respectively, Equations 1 through 4 can be used together with Equation 13 to give the result:

r greater than $0.18H$

$$t/t_s = \frac{(Q_s/Q)^{1/6}(H_s/H)^{1/4}(r/r_s)^{5/12}\log[1 - \Delta T_L (r/Q)^{2/3} H/4.7]}{\log[1 - \Delta T_L (r_s/Q_s)^{2/3} H_s/4.7]} \tag{14}$$

r less than or equal to $0.18H$

$$t/t_s = \frac{(Q_s H/Q H_s)^{1/6}\log[1 - \Delta T_L H^{5/3}/14.7 Q^{2/3}]}{\log[1 - \Delta T_L H_s^{5/3}/14.7 Q_s^{2/3}]} \tag{15}$$

where Q_s, r_s, and H_s refer to standard test conditions, Q is the heat release rate of the fire to be detected, r is the maximum radial distance between detector and fire axis, and H is the ceiling height above the burning fuel.

A plot of t/t_s from Equations 14 and 15 appears in Figure 7 for the following standard test conditions: ceiling height of 15 ft, detector spacing of 20 ft by 20 ft (r_s = 14.1 ft if an equally spaced, square array is used), and heat release rate (presumably from a pan or liquid spray fire) of 150,000 Btu min.$^{-1}$ The fixed temperature rating is taken to be about 135° F and the magnitude of Q identical to Q_s in this figure. As a result, Figure 7 yields detector response time during a 150,000 Btu min^{-1} fire relative to that during the standard test and thus a t/t_s of unity for H = 15 ft, r = 14.1 ft.

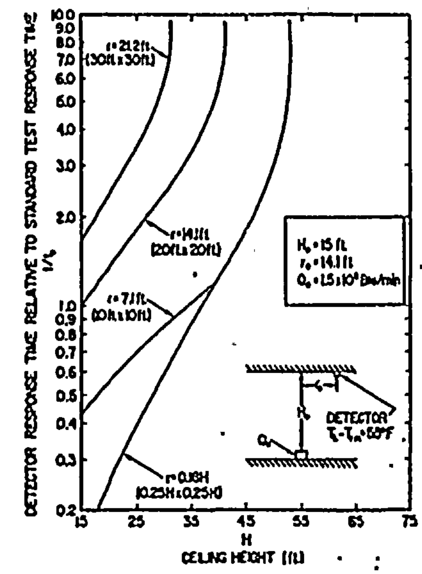

Figure 7. Response time of a fixed temperature thermostat during a typical large-scale fire relative to response time during a standard test.

The sharp increase in response time with either ceiling height or detector spacing is clearly shown. It is also seen that, for each spacing, the fire can be detected in a reasonable time only if the ceiling height is less than some maximum or limiting value. In accordance with the previously described concept of a minimum detectable fire intensity, the magnitude of this limiting ceiling height for each spacing can be obtained directly from Equation 5 or 6 with $Q_{min} = Q$.

If the heat release rate of the fire to be detected is not that assumed for Figure 7, the proper value of Q could be substituted into Equation

14 or 1[illegible] order to determine t/t_o. The "proper" value of Q would have to be estimated from the known composition and arrangement of the combustible materials, a difficult task indeed. The calculation of response time either from the equations or from Figure 7 will be most conservative if the magnitude of the ceiling height is taken to be the total distance from floor to ceiling rather than from the top surface of the burning fuel. If, then, a fire actually occurs at a position in the fuel array well above the floor, the actual detector response time would be much less than the value calculated. Shorter than calculated detector response times would also result if the fire actually is located in a corner or adjacent to a wall, but the value of Q is not modified to take this into account.

CONCLUSIONS

1. Fire detectors should be located a vertical distance below the ceiling of no more than 6 percent of the ceiling height.
2. For optimum response time, fire detectors should be spaced at intervals of ¼ of the ceiling height. Spacings smaller than this value will yield no significant improvement in detector response time.
3. It is possible to calculate from the results of a standard test the response time of thermally actuated fire detectors under known conditions of ceiling height, detector spacing, and fire intensity (total heat release rate).
4. These conclusions are subject to the following restrictions:

- Detectors are ceiling-mounted.
- Ceilings are smooth (vertical length of obstructions less than 1 percent of ceiling height) and horizontal.
- Minimum wall to wall distance is 2 to 4 ceiling heights.
- Fire intensity does not double in less than one minute.
- Drafts induced by room ventilation and stable temperature stratification due to a sun-baked roof are not present. This restriction is approximately satisfied whenever the fire intensity is sufficiently large, although the conclusions are otherwise applicable for fire intensities from several hundred to several million Btu min.$^{-1}$ However, ventilation drafts and stable stratification could prevent the plume induced by a low intensity fire from reaching the ceiling whenever gas velocity and temperature over the fire (see Equations 4 and 2, with T_{rm} measured at floor-level) are not much greater than draft velocity and roof-level room temperature, respectively.

NOMENCLATURE

H = Ceiling height above burning fuel (ft)
h = Heat transfer coefficient (Btu ft^{-2} min^{-1} ° F^{-1})
Q = Heat release rate (intensity) of fire (Btu min^{-1})
Q_{min} = Smallest detectable heat release rate (Btu min^{-1})

q = Heat transfer rate to detectors (Btu min^{-1})
r = Radial distance from fire axis to detector (ft)
S = Detector spacing (ft)
T = Gas temperature (° F)
T_L = Fixed temperature rating (° F)
t = Response time of detector
V = Gas velocity (ft sec^{-1})
Y = Vertical distance from ceiling to sensing element of detector (ft)

SUBSCRIPTS

$_{max}$ = Maximum value at any one radial position
$_o$ = Standard test condition
$_p$ = Fire plume
$_{rm}$ = Ambient condition

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Methods to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings

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Recently developed methods to calculate the time required for ceiling mounted heat and smoke detectors to respond to growing fires are reviewed. A computer program that calculates activation times for both fixed temperature and rate of rise heat detectors in response to fires that increase in heat release rate proportionally with the square of time from ignition is given. This program produces nearly equivalent results to the tables published in Appendix C, Guide for Automatic Fire Detector Spacing (NFPA 72E, 1984). A separate method and corresponding program are provided to calculate response time for fires having arbitrary heat release rate histories. This method is based on quasi-steady ceiling layer gas flow assumptions. Assuming a constant proportionality between smoke and heat released from burning materials, a method is described to calculate smoke detector response time, modeling the smoke detector as a low temperature heat detector in either of the two response time models.

INTRODUCTION

STUDIES OF THE RESPONSE of heat detectors to fire driven flows under unconfined ceilings have been conducted since the early 1970s.[1,2,3,4] Results of these largely experimental studies have been used to develop correlations of data that are useful under a broad range of fire conditions and building geometries. These correlations have been used to con-

Reference: David D. Evans and David W. Stroup, "Methods to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings," *Fire Technology*, Vol. 22, No. 1, February 1985, p. 54.

Key Words: Heat detectors, smoke detectors, response time, t²-fires, gas flow, computer routines.

struct engineering methods to determine heat detector spacing, sprinkler response time, and smoke detector alarm times for industrial buildings where large undivided ceilings over storage and manufacturing facilities are common. The method for calculation of heat detector spacing has been adopted by the National Fire Protection Association (NFPA) as an alternate design method published in the standard NFPA 72E, 1984.[5]

Although the NFPA heat detector spacing calculation is a well documented method, it is not in a convenient form for use by the Nuclear Regulatory Commission (NRC) in evaluating the response characteristics of existing systems for two reasons: (1) Currently, the only available form of the information is the tabular form published in the NFPA 72E standard. An analytic form or computer subroutine that produced equivalent answers would be more flexible and of greater use to NRC, and (2) the published tables are organized to look up spacing requirements for a given response time. In the evaluation of existing systems, the opposite problem is of interest — for a given spacing and detector, determine the response time.

As part of this study, the basis for the calculation method published in Appendix C of NFPA 72E was determined. Alternative correlations of the same experimental data that are the basis for the tables in Appendix C of NFPA 72E were used to construct a FORTRAN program (DETACT-T2 Code) to evaluate the response time of existing heat detector systems. Using the program, calculated values for response time agree to within 5 percent of those published in the tables contained in Appendix C of NFPA 72E. Although this calculation method is the most firmly based of those to be discussed in this report, it is restricted to applications in which the fire to be detected increases in energy release rate proportionally with the square of time from the ignition.

A separate program (DETACT-QS Code), written in PC BASIC, is capable of evaluating detector response for a fire with an arbitrary energy release rate history. The only restriction is that the energy release rate must be represented as a series of connected straight lines, the end points of which are entered as user input data. Inaccuracies may be introduced in the analysis of rapidly varying fires because this code uses a quasi-steady approximation for the fire driven gas flow. This means that changes at the fire source immediately affect the gas flows at all distances from the fire. In reality, time is required for the gases to travel from the fire to remote locations. Generally, fire driven flows have a velocity the order of one meter per second. Thus a quasi-steady analysis for locations close to the fire will only be in error by a few seconds, while remote locations can be delayed by tens of seconds. Keeping this approximation in mind, this program represents the most flexible of available methods but has not been tested against experimental data.

Both of the codes discussed above analyze detector response at installation sites under large unconfined ceilings. For smaller compartments, in which confining walls will cause a layer of fire products to accumulate under the ceiling, hence submerging the ceiling jet flow before the heat detector

can respond, different calculations are necessary. The problem of analyzing the response of heat detectors or sprinklers in a two layer environment (warm fire products over cool air) has been studied,[6] but no single code has been produced to facilitate analysis. This class of problem will not be discussed in this report.

Analysis of smoke detector response is currently performed by approximating the smoke detector as a low temperature zero lag time heat detector. Selection of the response temperature corresponding to a given detector sensitivity also depends on the relative proportion of "smoke" and energy released by the burning fuel. Test data of gas temperature rise at the time of smoke detector alarm is presented in this report. An alternative approximate method is given to determine this same temperature rise by using fuel smoke and energy release rate measurements obtained in a laboratory scale apparatus developed by Tewarson.[7]

DETECTOR RESPONSE TO t^2-FIRES

Appendix C of NFPA 72E[5] contains methods to determine the required heat detector spacing that will provide alarms to growing fires before the fire has grown to a user specified energy release rate. Tables provide information to evaluate different fire growth rates, ceiling heights, ambient temperatures, detector alarm conditions (fixed temperature or rate of rise), and detector thermal time constant. The tables reflect the extensive experimental studies and mathematical fire modeling performed by Heskestad and Delichatsios at Factory Mutual Research Corporation.[3,4]

Beyler[8] uses a different correlation of Heskestad and Delichatsios' data than was used to produce the tables in NFPA 72E Appendix C, to obtain an analytical expression for the gas flow temperature and velocity produced under ceilings that can be used to evaluate heat detector response. Beyler's solutions are limited to evaluation of fires that increase in energy release rate proportionally with the square of time from ignition. This class of fire is commonly referred to as a "t-squared-fire." Briefly, the problem of the heat detector response is solved using analytic solutions for the time dependent temperature of the detector sensing element up to the point when it is heated to the specific alarm conditions. The model for the detector sensing element temperature is based on a convective heat transfer process. Characterization of the thermal response of heat detector and sprinkler thermal sensing elements is discussed by Heskestad and Smith,[9] and Evans.[10] The first order differential equation that describes the rate of temperature increase of the sensing element is:[6]

$$\frac{dT_e}{dt} = \frac{U^{1/2}}{RTI}(T - T_e) \tag{1}$$

The notation for all equations is given in the nomenclature section. The value of RTI (Response Time Index), a measure of the thermal time con-

stant of the detector, is determined by testing.[9] Values of the time-dependent gas temperature and velocity are obtained from the following correlations.[8]

$$
\begin{aligned}
\Delta T_2^* &= 0 \text{ for } t_2^* < (t_2^*)_f \\
\Delta T_2^* &= [(t_2^* - 0.954(1 + r/H))/(0.188 + 0.313\, r/H)]^{4/3} \text{ for } t_2^* > (t_2^*)_f \\
(t_2^*)_f &= 0.954\,[1 + r/H] \\
U_2^* &= 0.59\,[r/H]^{-0.63}\,[\Delta T_2^*]^{1/2}
\end{aligned} \tag{2}
$$

where

$$
\begin{aligned}
U_2^* &= U/[A\,\alpha\,H]^{1/5} \\
\Delta T_2^* &= \Delta T/[A^{2/5}(T_\infty/g)\,\alpha^{2/5}\,H^{-3/5}] \\
t_2^* &= t/[A^{-1/5}\,\alpha^{-1/5}\,H^{4/5}] \\
A &= g/(c_p T_\infty \rho_\infty) \\
\Delta T &= T - T_\infty \\
\alpha &= t^2/Q
\end{aligned}
$$

The solutions to Equation 1 for detector sensing element temperature, T_e, and rate of temperature rise, dT_e/dt, in response to the t^2-fire with growth rate specified by the value of α are from Beyler[8] as follows:

$$\Delta T_e = (\Delta T/\Delta T_2^*)\,\Delta T_2^*\,[1 - (1 - e^{-Y})/Y] \tag{3}$$

$$\frac{dT_e}{dt} = \frac{(4/3)(\Delta T/\Delta T_2^*)(\Delta T_2^*)^{1/4}}{(t/t_2^*)(0.188 + 0.313\, r/H)}(1 - e^{-Y}) \tag{4}$$

where

$$Y = \frac{3}{4}\left(\frac{U}{U_2^*}\right)^{1/2}\left(\frac{U_2^*}{\Delta T_2^*}\right)^{1/2}\left(\frac{\Delta T_2^*}{RTI}\right)\frac{t}{t_2^*}\,(0.188 + 0.313\, r/H)$$

assuming that $\Delta T_e = 0$ initially. T and U in Equation 1 are obtained from the correlations in Equation set 2 for ΔT_2^* and U_2^* respectively. Equations 3 and 4 were programmed into a user interactive FORTRAN code called the DETACT-T2 Code. This code solves for the time required to reach a specified positive value of ΔT_e or dT_e/dt representing detector alarm. (Details

of DETACT-T2 Code use, and worked example are shown in Appendix A.) Briefly for a fixed temperature detector, the user enters values for:

Ambient air temperature.
Detector response temperature or rate of temperature rise.
Detector RTI.
Fuel to ceiling distance.
Radial distance of detector from the fire plume axis.
Fire growth rate constant α (for t^2-fires).

Outputs of the code are the time to detector response and fire energy release rate at that time.

In Appendix A use of the DETACT-T2 Code to calculate the response time of a fixed temperature detector is demonstrated in an example using the following program inputs:

Ambient air temperature	21.1°C (70°F).
Detector response temperature	54.44°C (130°F).
Detector RTI	370.34 $m^{1/2} s^{1/2}$ (670.8 $ft^{1/2} s^{1/2}$).
Fuel to ceiling distance	3.66 m (12 ft).
Radial distance of detector from axis of fire	2.16 m (7.07 ft).
Fire growth rate constant	11.71 J/s^3 (0.0111 Btu/s^3).

The calculated response time using the DETACT-T2 Code is 298 sec and corresponding fire energy release rate is 1.04 MW (986 Btu/s). This same fire and detector combination can be seen in the Table C-3-2.1.1(e) in Appendix C of NFPA 72E,[3] (in the table notation, threshold fire size 1000 Btu/s, fire growth rate, medium; DET TC = 300 Δ s, ΔT = 60°F, ceiling height = 12 Δft, installed spacing in the body of the table 10 ft). All values in the table[4] are for detector response times of 300 sec. This is in agreement with the 298 sec calculated with the DETACT-T2 Code in Appendix A.

Eleven other randomly selected combinations of fires and detectors were calculated using the DETACT-T2 Code and results compared to table values in Appendix C of NFPA 72E. Of these cases the greatest deviation was 7.5 percent and least was 0.17 percent.

Use of the DETACT-T2 Code has two main advantages over the tables in Appendix C of NFPA 72E. One is that the code is specifically designed to evaluate existing facilities. The other is that any t^2-fire growth rate can be analyzed. The tables in Appendix C of NFPA 72E contain only three different fires. At present, an NBS special publication is being prepared containing tabular results with the same information as those in the NFPA 72E, Appendix C, but recast into a form useful for evaluation of existing facilities. This publication "Evaluating Thermal Fire Detection Systems," by Stroup, Evans, and Martin should become available in 1986.

DETECTOR RESPONSE TO ARBITRARY FIRES

The DETACT-T2 Code is useful for evaluating the response of specified detectors to t^2-fire growth rates. In some cases a fire of interest does not follow an energy release rate that is proportional to the square of time from ignition. For these cases use of the DETACT-T2 Code to evaluate the responses of detector systems is inappropriate.

To evaluate detector response to an arbitrary energy release rate history, an assumption of quasi-steady gas flow temperatures and velocities is made. With this assumption, correlation for ceiling jet temperatures and velocities obtained from experiments using steady fire energy release rate sources can be used to evaluate growing fires. The growing fire is represented in the calculation as a series of steady fires with energy release rates changing in time to correspond to the fire of interest.

Correlations of ceiling jet temperatures and velocities from experiments using steady fire sources have been published by Alpert.[1] Recast into metric form they are:

$$\Delta T = 16.9\, Q^{2/3}/H^{5/3} \qquad \text{for } r/H < 0.18$$
$$U = 0.95\, (Q/H)^{1/3} \qquad \text{for } r/H < 0.15$$
$$\Delta T = 5.38 (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18 \qquad (5)$$
$$U = 0.2\, Q^{1/3} H^{1/2}/r^{5/6} \qquad \text{for } r/H > 0.15$$

where the metric units are T[°C], U[m/s], Q[kW], r[m], H[m].

A computer code to perform the integration of Equation 1, the differential equation for detector sensor temperature, using the quasi-steady fire driven flow approximation and Alpert's correlations. From equations in 5, called the DETACT-QS Code, is written in PC BASIC. The code requires user input similar to the DETACT-T2 Code with the one exception that the fire energy release rate is specified as a series of time, energy release rate data pairs.

The same fire and detector case used as an example of execution for the DETACT-T2 Code was evaluated using the DETACT-QS Code. The fire was input as time, energy release rate pairs at intervals of 5 sec to match the t^2-fire with $\alpha = 11.7105$ W/s^2. Other parameters were maintained the same. The resulting predicted detection time using the DETACT-QS Code was 313 sec with the corresponding fire energy release rate at detection of 1147 kW. Remember that with the DETACT-T2 Code the calculated time of detection was 298 sec with fire energy release rate at detection of 1040 kW. This example was chosen to demonstrate specifically that there will be dif-

ferences between the two methods even in the evaluation of the same fire. The quasi-steady fire analysis on which the DETACT-QS Code is based has the advantage that arbitrary fire energy release rates can be input as a data set.

SMOKE DETECTOR RESPONSE

Both of the heat detector response models discussed are based on predictions of the temperature and velocity of the fire driven gas flow under the ceiling and models of the heat detector response. The same calculations could be used to predict smoke detector response given a relationship between smoke concentration and temperature rise in the fire driven gas flow and the response characteristics of the smoke detector.

The response characteristics of smoke detectors are not as well understood as thermal detectors. Smoke detector alarm conditions depend on more than smoke concentration. Smoke particle sizes and optical or particle scattering properties can affect the value of smoke concentration necessary to reach alarm conditions. For thermal detectors, measured values of RTI characterize the lag time between gas temperature and sensing element temperature. For smoke detectors there is no analogous method to characterize the lag time between gas flow smoke concentration and the smoke concentration within the sensing chamber. In the absence of understanding of the many processes affecting smoke detector response, a smoke detector will be considered to be a low temperature heat detector with no thermal lag, i.e. RTI = 0. The analogy between smoke obscuration in the gas flow and temperature rise will be developed in order to determine the corresponding temperature rise to use as a model for a smoke detector known to alarm at a given smoke obscuration.

Similarity between temperature rise and smoke concentration will be maintained everywhere within a fire driven flow if the energy and smoke continuity equations are similar. For the case of constant c_p, k, and D these equations are:

$$\varrho c_p \frac{d\Delta T}{dt} - k\nabla^2 \Delta T = \dot{Q}''' \tag{6}$$

$$\varrho \frac{dY_s}{dt} - \varrho D \nabla^2 Y_s = \dot{m}''' \tag{7}$$

If the Lewis number $k/\varrho c_p D = 1$, then the ratio of temperature rise to smoke concentration can remain constant throughout the fire driven flow, if the ratio $\dot{Q}'''/(c_p\ \dot{m}_s''')$ is maintained constant in all regions where energy is exchanged with the flow. Reactions in the flame over the burning fuel will determine the ratio of temperature rise to smoke concentration throughout the flow. Other energy exchanges in normal fire flows, convection to cool room boundaries, and radiation from smoky gases decrease the ratio of temperature rise to smoke concentration because energy is extracted from the flow without a proportional decrease in smoke concentration. Mixing of hot combustion products with cool smoky gases that may accumulate in an enclosure also decreases the ratio of temperature rise to smoke concentration because smoke mass is added to the flow without a proportional increase in energy. For fire driven flows in which the effects that alter the ratio of temperature rise to smoke concentration are not significant, the response of a smoke detector may be calculated as if it were a fixed temperature heat detector. The temperature rise necessary for alarm of this substitute heat detector is calculated from the product of smoke concentration needed to alarm the smoke detector and the ratio of temperature rise to smoke concentration produced by the burning material.

Generally the sensitivity of smoke alarms is given in terms of the amount of obscuration by the smoky flow that is necessary to produce an alarm and not directly in smoke concentration. The more sensitive the smoke detector the smaller the amount of obscuration needed to alarm.

The obscuring ability of a smoke laden gas flow is measured by the attenuation of a light beam. The measure of the attenuation is the optical density per unit beam length, OD,[3]

$$OD = (\log_{10} \frac{I_o}{I})/L \tag{8}$$

By testing, Seader and Einhorn[11] found that the attenuating abilities of smokes produced from many different materials undergoing flaming combustion were similar. For flaming combustion they found that the optical density per unit length was proportional to the mass concentration of "smoke" in a gas flow as:

$$OD = 3330\, C_s \tag{9}$$

where OD is optical density per meter and C_s is smoke mass concentration in kilograms per cubic meter.

The ratio of temperature rise in a fire driven flow to smoke concentration may be recast in terms of optical density using Equation 9 as:

$$\frac{\Delta T}{Y_s} = \frac{\varrho \Delta T}{C_s} = \frac{3330 \varrho \Delta T}{OD} \tag{10}$$

Under the assumption discussed at the beginning of this section, this ratio will be equal to the ratio $\dot{Q}'''/(c_p\ \dot{m}_s''')$. The last ratio may be approximated by a volume average over the combustion region so that

$$\frac{3330 \varrho \Delta T}{OD} = \frac{\dot{Q}}{c_p\ \dot{m}_s}$$

or (11)

$$\frac{OD}{\Delta T} = \frac{3330 \varrho c_p \dot{m}_s}{\dot{Q}}$$

As an example, literature values for oak wood may be used to obtain a representative value. For oak:

$\dot{Q}$ = 7600 kJ/kg fuel consumed per unit time[12]

$\dot{m}_s$ = 0.017 kg smoke/kg fuel consumed per unit time[12]

air c_p = 1 kJ/kg °C

air ϱ = 1.165 kg/m³ at 30°C

From Equation 11 $\frac{OD}{\Delta T} = 8.68 \times 10^{-3}$ (m °C)$^{-1}$.

Heskestad and Delichatsios[3] have reported representative optical density per meter for smoke detector alarm and corresponding temperature rise in the gas flow. For wood crib (unknown type) fires, the ratio of these values was OD/ΔT = 1.2×10^{-3} (m°C)$^{-1}$. This is the same order of magnitude as the number calculated in the analysis given above and may be representative of the expected accuracy given no knowledge of wood type. Heskestad and Delichatsios report that an ionization detector will alarm in response to a wood fire at OD = 0.016 1/m.

Using the OD/ΔT value for wood of 1.2×10^{-3} (m°C)$^{-1}$ the corresponding change in gas temperature would be 13°C ($0.016/1.2 \times 10^{-3}$). For the purpose of response time calculation using the heat detector models, this ionization smoke detector would be represented as a low temperature heat detector alarming at 13°C above ambient for a wood fire.

Other measurements of the ratio OD/ΔT are obtained for burning materials in a laboratory scale apparatus developed by Tewarson.[7] Values for a large number of plastics and wood under many environmental conditions are given by Tewarson and Pion.[11]

SUMMARY

Two methods have been presented to calculate the response of heat detectors installed under large unobstructed ceilings in response to growing fires. Smoke detector response is calculated using the same thermal calculations by approximating the smoke detector as a low temperature, zero lag time thermal detector.

NOTE: NBSIR 85-3167 *Methods to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings*, contains the complete DETACT-T2 Code and DETACT-QS Code in Appendix A and Appendix B.

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NOMENCLATURE

A	$g/(c_p T_\infty \varrho_\infty)$
c_p	specific heat capacity of ambient air
C_s	smoke mass concentration
D	effective binary diffusion coefficient
g	acceleration of gravity
H	vertical distance from fuel to ceiling
I	light intensity
I_o	initial light intensity
L	light beam length
$\dot{m}_s'''$	smoke gas mass production rate per unit volume
OD	optical density per unit length (see Equation 8)
$\dot{Q}$	fire energy release rate
$\dot{Q}'''$	energy release rate per unit volume
r	radial distance from fire axis to the detector
RTI	response time index, the product of the detector thermal time constant and the square root of the gas speed used in the test to measure the time constant.[9]
t	time
t_2^*	dimensionless time $t/[A^{-1/3} \alpha^{-1/3} H^{4/3}]$
$(t_2^*)_f$	dimensionless time for time delay for gas front travel
T_∞	ambient temperature
T^{**}	gas temperature at detector location
T_s	temperature of detector sensing elements
ΔT	$T - T_\infty$
ΔT_2^*	dimensionless temperature differences $\Delta T/[A^{2/3}(T_\infty/g) \alpha^{2/3} H^{-5/3}]$
U	gas speed at the detector location
U_2^*	dimensionless gas speed $U/[A \alpha H]^{1/3}$
Y_s	local ratio of smoke mass to total mass in flow
α	proportionality constant for t^2-fire growth $= Q/t^2$
ϱ_∞	ambient air density

APPENDIX A. DETACT-T2 CODE

A FORTRAN Program to Calculate Detector Response to t^2-Fires

This appendix describes the theory and use of a computer program which determines the response of fixed temperature and rate of rise heat detectors to fires with energy release rates described by the expression $Q = \alpha t^2$. The program is designed for use in evaluating detectors installed at known spacings.

The activation time of a given detector is a function of fire growth rate, ceiling height, detector spacing, detector activation temperature, ambient temperature, and detector response time index (RTI). The program prompts the user to provide this information. These input data are converted to a dimensionless form for use in the calculations. Equations for the activation time of a fixed temperature detector and a rate of rise detector are set up. The two equations are then solved using a Newton-Raphson technique. Once the activation times are known, the fire energy release rates at those times are calculated. Finally, the results for each detector type are printed as well as some appropriate input data.

In the following example, input prompts from the computer program are printed in all capital letters while user responses are printed in lower case (where possible) and preceded by the character ">".

EXAMPLE

Calculate the activation times for fixed temperature and rate of rise heat detectors installed, using a 3.05 meter spacing, in an area with a ceiling height of 3.66 meters. The detectors have an RTI of 370.3 $(m\text{-}sec)^{1/2}$. The detector activation temperature is 54.4°C, and the activation rate of rise is 8.33°C/min. Ambient temperature is 21°C.

```
ENTER 1 FOR ENGLISH UNIT INPUT
      2 FOR METRIC UNIT INPUT

>2
ENTER THE AMBIENT TEMPERATURE IN DEGREES C.
>21
ENTER THE DETECTOR RESPONSE TIME INDEX (RTI) IN
(M-SEC)**½.
>370.3
ENTER THE DETECTOR ACTIVATION TEMPERATURE IN
DEGREES C.
>54.4
ENTER A DETECTOR RATE OF RISE IN DEGREES C/MIN.
>8.33
```



```
ENTER THE CEILING HEIGHT IN METERS.
>3.66
ENTER THE DETECTOR SPACING IN METERS.
>3.05
ENTER: S FOR SLOW FIRE GROWTH RATE
       M FOR MEDIUM FIRE GROWTH RATE
       F FOR FAST FIRE GROWTH RATE OR
       O FOR OTHER
>m

RESULTS:

CEILING HEIGHT = 3.66 METERS (12.0 FEET).
DETECTOR SPACING = 3.05 METERS (10.0 FEET).
DETECTOR RTI = 370.3 (M-SEC)**½ (670.8 (FT-SEC)**½).
FIRE GROWTH CONSTANT =(.1171+002 WATTS/SEC**2).
        (.1111-001 BTU/SEC**3).
FOR TEMPERATURE ACTUATED DETECTOR:
   ACTIVATION TEMPERATURE = 54.4 DEGREES C (129.9
   DEGREES F).
   TIME OF ACTIVATION = 297.88 SECS.
   HEAT RELEASE RATE = .1038+007 WATTS (.9840+003
   BTU/SEC).

FOR RATE OF RISE ACTUATED DETECTOR:
   ACTIVATION RATE OF RISE = 8.33 DEGREES C/MIN
                             (14.99 DEGREES F/MIN).
   TIME OF ACTIVATION = 182.75 SECS.

   HEAT RELEASE RATE = .3908+006 WATTS (.3704+003
   BTU/SEC).
```

The results show that the heat detector would activate approximately 298 seconds after the fire reaches a flaming state. The heat release rate at this time would be 1038 kilowatts. A rate of rise detector would activate at about 183 seconds with a corresponding heat release rate of 391 kilowatts.

If English units had been selected, the input requests would have called for data in English units instead of metric units.

The program is written in ANSI 77 FORTRAN. A PC BASIC version has been coded. Each is in a form which makes it easy to incorporate it into existing computer fire models as a subroutine.

Lag Times Associated With Fire Detection and Suppression

Frederick W. Mowrer*

Abstract

The effectiveness of fire detection systems and fire mitigation strategies can be related to three distinct time lags associated with building fires: a transport time lag, a detection time lag, and a suppression time lag. The impacts of these lag periods on fire detection and suppression are developed. Transport lag periods are considered in terms of available correlations of fire plume and ceiling jet data, detection lag periods in terms of available heat detector response models that use these data correlations. Suppression lags are developed in terms of expected response times for automatic and manual suppression. Example calculations are presented.

Introduction

Calculation of the response of fire detectors, sprinklers, and other heat-sensitive objects located at ceiling level requires a knowledge of the fire environment to which these elements are exposed. Currently, such information is available for large spaces with flat, unobstructed ceilings in terms of temperature and velocity correlations for fire plumes and ceiling jets. Correlations currently utilized to describe the fire environment at detectors are reviewed, and the relationship between the available t-squared and quasi-steady correlations is developed.

The response of fire detection devices and fire suppression systems can be evaluated in terms of three distinct lag periods: a transport time lag, a detection time lag, and a suppression time lag. Transport lags are considered here within the context of the available data correlations, while detection lags are developed in terms of available detector response models that use these data correlations. Suppression lags are

Key words: Fire plumes; ceiling jets; detection; suppression; response time.

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considered in terms of expected response times for automatic and manual suppression systems. The overall impact of these lag periods on the response of fire detectors and on the formulation of fire mitigation strategies is developed. Example calculations are presented to illustrate these influences.

Review of Fire Plume/Ceiling Jet Data Correlations

Available fire plume and ceiling jet data correlations are of two types: quasi-steady and power law. Quasi-steady correlations are based on fire experiments with heat release rates that do not vary appreciably with time; power law correlations are based on fires characterized with heat release rates that grow as a power of the time from ignition. The primary focus here is on the relationship between these two types of correlations and on the use of these correlations for fire detection analysis. Data correlations of Alpert,[1] Heskestad and Delichatsios (H&D),[2] and Alpert and Ward (A&W)[3] are used for this discussion. Beyler[4] has compiled a comprehensive review of available fire plume and ceiling jet data correlations.

Alpert developed the original of these correlations based on large-scale quasi-steady fire experiments, while Heskestad and Delichatsios have developed correlations for both quasi-steady fires as well as power law fires. More recently, Alpert and Ward have suggested new coefficients for the original Alpert correlation. These new coefficients produce results closer to the quasi-steady correlation of Heskestad and Delichatsios.

Quasi-steady Fires

Plume theory[5] suggests that the maximum temperature rise above ambient of a plume of hot gases rising from a point source of heat can be expressed with an equation of the form:

$$dT = k_T \dot{Q}^{2/3} / H^{5/3} \qquad (1)$$

where:

dT = Temperature rise above ambient (K)
k_T = Temperature coefficient
$\dot{Q}$ = Heat release rate of fire (kW)
H = Height above plume source (m).

Available correlations of fire plume data have been developed in this form.

The theory of ceiling jet flows is more complicated, as evidenced by

Alpert's[6] detailed analysis of this region. It involves consideration of the rate of entrainment into the ceiling jet as well as the viscous effects and heat transfer associated with the flow of buoyant gases beneath and in contact with the ceiling. The maximum temperature rise occurs within the area where the fire plume impinges the ceiling and falls off as a function of the radius beyond this zone. The ceiling jet data correlations of Alpert, Heskestad and Delichatsios, and Alpert and Ward can all be expressed in the form of Equation 1, but in the ceiling jet region, the coefficient k_T is also a function of the nondimensional radial distance from the plume centerline, r/H, to account for the temperature decay that occurs with increasing distance from the plume impingement region. Similarly, plume theory suggests that gas velocity in the plume region has the form:

$$U = k_u (Q/H)^{1/3} \qquad (2)$$

where:

U = Fire gas velocity (m/s)
k_u = Velocity correlation coefficient.

As with the temperature data, the velocity correlation coefficient, k_u, is expected to fall off as a function of the radial distance from the plume. Available velocity correlations have this characteristic form.

The coefficients, k_T and k_u, for the quasi-steady temperature and velocity data correlations of Alpert, Heskestad and Delichatsios, and Alpert and Ward are tabulated in Table 1. Where available, recommendations of Beyler, based on his review, also are tabulated. Normalized curves are illustrated in Figures 1a and 1b, which show the nondimensional temperature rise, dT^*, and velocity, U^*, respectively, as functions of the nondimensional radial distance, r/H, from the plume centerline. Two regions are used to correlate the data: a plume impingement region and a ceiling jet region. The plume impingement region occurs within a radius of approximately $0.2\,H$ $(r/H < 0.2)$.

The correlation coefficients provided in Table 1 are based on theoretical total heat release rates, which are determined as the product of the fuel mass loss rate and the theoretical heat of combustion. The heat release rate actually contributing to the velocities and temperatures in the plume and in the ceiling jet is the convective heat release rate. The convective heat release rate differs from the total theoretical heat release rate because of combustion inefficiency and radiative losses from the fire source. This can be expressed as:

$$Q_c = x_a (1 - x_r)\, Q_t \qquad (3)$$

Table 1: Quasi-steady correlations.

a. Temperature correlations: $dT = k_T Q^{2/3} / H^{5/3}$

	Values for k_T	
	Plume	Ceiling jet
Alpert	16.9	$5.4/(r/H)^{2/3}$
Heskestad and Delichatsios	$2.75/D^{4/3}$	$2.75/D^{4/3}$
Alpert and Ward	22.0	$6.8/(r/H)^{2/3}$
Beyler recommendation	22.0	H&D correlation

b. Velocity correlations: $U = k_u (Q/H)^{1/3}$

	Values for k_u	
	Plume	Ceiling jet
Alpert	0.95	$0.2/(r/H)^{5/6}$
Heskestad and Delichatsios	None	$0.21/[(r/H)^{0.63} D^{2/3}]$
Beyler recommendation	1.04	
$D = 0.25$	$r/H < 0.2$	
$D = 0.188 + 0.313\, r/H$	$r/H > 0.2$	

where:

Q_c = Convective heat release rate (kW)
x_a = Combustion efficiency factor (Q_a/Q_t)
x_r = Radiative fraction of actual heat release rate (Q_r/Q_a)
Q_t = Total theoretical heat release rate (kW)
Q_a = Total actual heat release rate (kW).

The ratio of the convective to theoretical heat release rate, Q_c/Q_t, is expected to remain fairly constant for a given material, but can vary considerably among different materials.[7] For wood, which serves as the primary basis for the available correlations, Heskestad and Delichatsios[8] suggest this ratio has a value of about 0.45. Adjustments should be made for application of the correlations to materials with convective ratios considerably different from this value. Tewarson[9] provides convective ratio data, measured in small-scale tests, for a range of materials.

According to Alpert and Ward, these correlations provide reasonable accuracy for predicted temperatures between approximately 70°C and 850°C (150–1500°F). Predicted temperatures above 850oC indicate the likelihood of flame at the location being evaluated. The low temperature

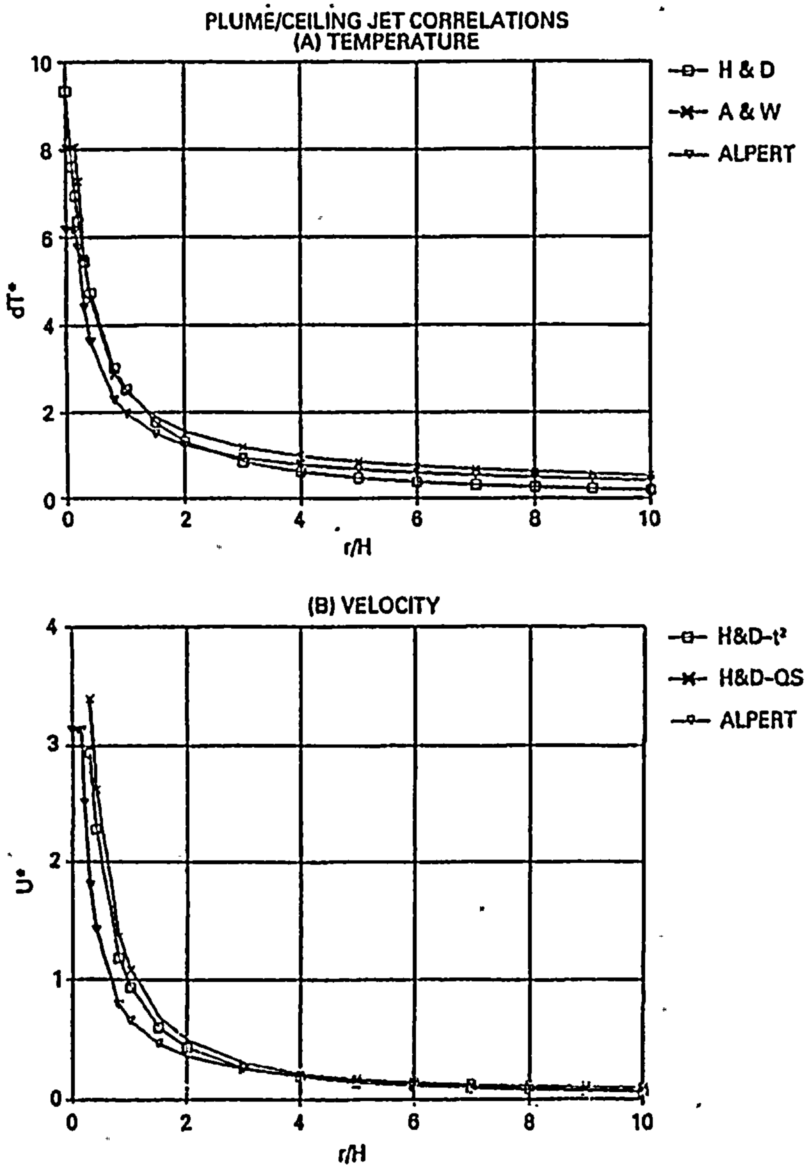

Figure 1. Illustration of the plume/ceiling jet correlations of Alpert (Alpert), Alpert and Ward (A&W), and Heskestad, and Delichatsios (H&D); (a) nondimensional temperature rise versus nondimensional radial distance, r/H, from the plume centerline, and (b) nondimensional velocity versus radial distance.

extreme is not representative of a threat to the building structure, so better accuracy is not normally warranted unless nonthermal damage is of interest.

Power Law Fires

Heskestad and Delichatsios also have correlated temperature and velocity relationships for idealized, yet realistic, classes of fires referred to as "power-law" fires because the heat release rate is considered to grow as some power of time:

$$Q = \alpha (t - t_o)^p \qquad (4)$$

where:

- α = Power law fire growth coefficient (kW/s^p)
- t = Time from ignition (s)
- t_o = Incubation time offset (s)
- p = Fire growth exponent.

This equation can be applied to either theoretical or convective heat release rates, provided appropriate values of α are used in conjunction with either the theoretical or convective heat release rate. The relationship between convective and total theoretical growth coefficients is the same as that between convective and theoretical heat release rates expressed in Equation 3:

$$\alpha_c = x_a (1 - x_r)\, \alpha_t \qquad (5)$$

For this class of fire characterizations, Heskestad and Delichatsios developed nondimensional correlations of the form:

$$dT^*_p = (gH^{(3-p)/(3+p)} / [A\alpha H]^{2/(3+p)})\,(dT/T_o) \qquad (6)$$

$$U^*_p = ((H^{(3-p)/(p+3)} / [A\alpha H]^{1/(3+p)})\, U \qquad (7)$$

$$t^*_p = (([A\alpha H]^{1/(3+p)} / H^{5/(3+p)})\, t \qquad (8)$$

where:

- dT^*p = Nondimensional temperature rise above ambient
- U^*_p = Nondimensional velocity
- t^*_p = Nondimensional time
- g = Gravitational constant (9.8 m/s^2)
- A = $g/(c\,p_a\,T_o)$ = (0.028 m^3/kg or m^4/kWs^3)
- T_o = Ambient temperature (298 K).

For the case of parabolic fire growth ($p = 2$), which has become widely used to represent a range of realistic fire growth rates, these relationships reduce to:

$$dT^*_2 = (gH/[A\alpha H]^{2/5})(dT/T_a) \quad (9)$$

$$U^*_2 = (1/[A\alpha H]^{1/5})\,U \quad (10)$$

$$t^*_2 = ([A\alpha H]^{1/5}/H)\,t \quad (11)$$

The t-squared temperature and velocity correlations originally developed by Heskestad and Delichatsios use the total theoretical heat release rate. These correlations, based on large-scale experiments with wood cribs, are:

$$dT^*_2 = 0 \text{ for } t^*_2 \le t^*_{2f}; \text{ and}$$

$$dT^*_2 = [(t^*_2 - t^*_{2f})/D]^{4/3} \text{ for } t^*_2 > t^*_{2f} \quad (12)$$

$$U^*_2/\sqrt{dT^*_2} = 0.59/(r/H)^{0.63} \quad (13)$$

$$t^*_{2f} = 0.954\,(1 + r/H) \quad (14)$$

where:
D = Nondimensional distance parameter
= 0.25 for $r/H < 0.2$; and
= $0.188 + 0.313\,r/H$; for $r/H > 0.2$
t^*_{2f} = Nondimensional transport time lag parameter.

Appropriate values for α_t must be substituted into Equations 9-11 to use the correlations in this form.

Recently, Heskestad and Delichatsios[8] have restructured their original correlations in terms of the convective heat release rate rather than the total theoretical heat release rate. These generalized correlations, which permit direct application to combustibles with convective fractions significantly different from wood, are expressed as:

$$dT^*_2 = 0 \text{ for } t^*_{2c} \le t^*_{2fc}; \text{ and}$$

$$dT^*_2 = [(t^*_{2c} - t^*_{2fc})/D_c]^{4/3}; \text{ for } t^*_{2c} > t^*_{2fc} \quad (15)$$

$$U^*_{2c}/\sqrt{dT^*_{2c}} = 0.59/(r/H)^{0.63} \quad (16)$$

$$t^*_{2fc} = 0.813\,(1 + r/H) \quad (17)$$

where:
D_c = Nondimensional distance parameter
= 0.17 for $r/H < 0.2$
= $0.126 + 0.210\,r/H$ for $r/H > 0.2$
t^*_{2fc} = Nondimensional transport time lag parameter.

These correlations have the same form as the original ones, but the coefficients are different to account for the difference between convective and total theoretical heat release rates. Appropriate values for α_c must be substituted into Equations 9–11 to use the correlations in the forms of Equations 15–17. These nondimensional forms are useful for the correlation of data over a wide range of fire test conditions, but they are cumbersome for engineering calculations. For engineering use and for comparison with the quasi-steady correlations, it is useful to rewrite the t-squared correlations of Heskestad and Delichatsios in dimensional form as:

$$dT = 0 \text{ for } t < t_l; \text{ and} \quad (18a)$$

$$dT = (A^{2/3}/gD^{4/3})T_a\, Q_s^{2/3}/H^{5/3} \text{ for } t > t_l \quad (18b)$$

For representative values of A, g, and T_a, this evaluates to:

$$dT = (2.75/D^{4/3})\, Q_s^{2/3}/H^{5/3} \text{ for } t > t_l \quad (18c)$$

$$U = (0.18/[(r/H)^{0.63} D^{2/3}])\,(Q_s/H)^{1/3} \quad (19)$$

where:
t_l = Transport time lag (s)
Q_s = Sensed heat release rate (kW).

These dimensional forms apply to both the original and convective correlations of Heskestad and Delichatsios, provided appropriate values for D, Q_s, and t_l are used.

The Relationship Between Quasi-steady and t^2 Correlations

The temperature correlation expressed by Equation 18c is identical to the quasi-steady correlation of Heskestad and Delichatsios once the instantaneous heat release rate, $Q(t)$, at any time is replaced by the heat release rate sensed at the location of interest, $Q_s(t)$, at that time. The

difference between these terms can be considered in terms of a simple translation along the time axis equal to the transport time lag:

$$Q_s(t) = 0 \text{ for } t < t_l \text{; and}$$

$$Q_s(t) = Q\,(t - t_l) \text{ for } t > t_l \quad (20)$$

Equation 20 applies to either the original or convective correlations, depending on which value of Q is specified. To use the original correlation, Q_t is substituted for Q; to use the convective correlation, Q_c is substituted for Q. The topic of transport time lags is developed in the next section.

The t-squared velocity correlation has the same functional form as the quasi-steady correlation, but has a magnitude approximately 15 percent less than the quasi-steady correlation. These similarities are more than fortuitous; Heskestad and Delichatsios formulated their t-squared correlation to asymptotically approach the quasi-steady limit.

The difference between the instantaneous heat release rate and the heat release rate sensed at a location is a function of the distance from the fire source to the location and the transport speed of the fire gases. For the t-squared correlations, this transport speed is expressed in terms of the parabolic fire growth coefficient, α. As developed in the next section, the difference between the instantaneous and sensed heat release rates can be significant and, according to the t-squared correlation, this difference continues to grow as long as the fire continues to grow parabolically.

Lag Times Associated With Fires

The potential for manual or automatic fire control based on the operation of fire detection and suppression systems relates directly to three distinct delay periods between fire initiation and the start of suppression. These three periods can be considered as (1) a transport time lag, t_l; (2) a detection time lag, t_d; (3) a suppression time lag, t_s.

The transport time lag, t_l, represents the time between the actual generation of heat or another fire signature and the transport of that signature to the fire detection device. The detection time delay, t_d, represents the time period from the first transport of a fire signature to a sprinkler or fire detector until the device actuates. The final lag period, the suppression time lag, t_s, represents the time from fire detection until the initiation of fire suppressant application. These periods are similar to ones suggested by Johnson[10] and by Newman.[11]

These three lag periods are illustrated schematically in Figure 2 for an idealized heat release history. The idealized fire history without suppression illustrates a period of accelerating fire growth, followed by

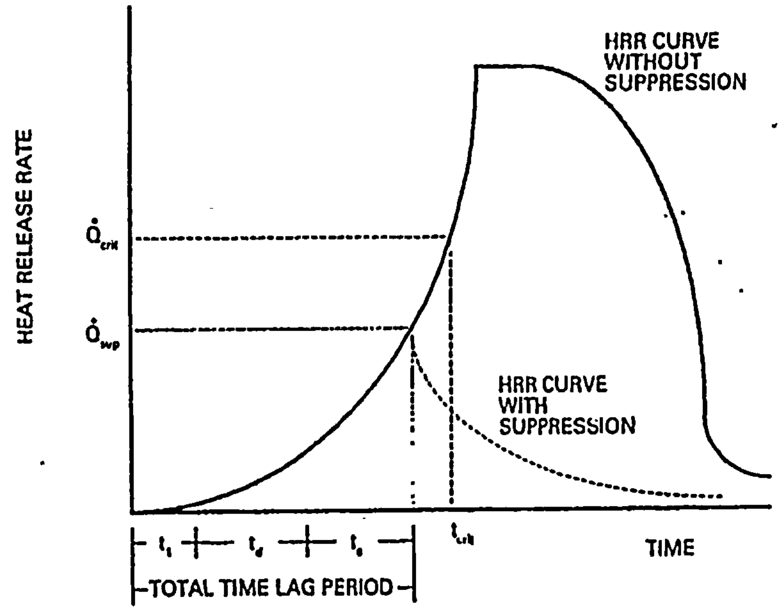

Figure 2. Schematic illustration of the influence of transport, detection, and suppression lag periods in terms of a representative heat release rate curve.

a period of steady heat release rate associated with full involvement of a burning object or room. The decay period that follows this steady period would be associated with fuel burnout in the absence of any fire suppression activity.

The suppression curve in Figure 2 illustrates an example of satisfactory performance because the total lag period is less than the time to critical damage. Unsatisfactory performance would result for situations where the total lag period exceeds the time to critical damage. To use this concept of performance-based criteria, the time to critical damage must be established by appropriate analyses of the expected rate of hazard development and the response of building systems, contents, and occupants to this development. For this example, the critical time is represented in terms of a critical heat release rate.

Transport Time Lags

Upon preliminary inspection of Figure 2, the transport lag does not appear to be important because it is represented at the start of a fire, before the heat release rate has grown to significant levels. But the influence of the transport lag propagates through the fire growth period. As illustrated in Figure 3, the heat release rate being sensed at a detector can lag the actual heat release rate by a significant margin. This

difference continues to grow as long as the fire continues to grow. The longer the three lag periods are, the larger this margin will be. The detector responds to the heat release rate sensed at the detector, while it is the actual heat release rate of the fire that must be suppressed.

Transport Lags Associated with t^2 Correlations

The t-squared correlation of Heskestad and Delichatsios considers the transport lag explicitly. The heat release rate sensed at a location in a fire plume or ceiling jet, Q_s, lags the instantaneous heat release rate by a transport lag time, t_l. This can be expressed as:

$$Q_s = 0 \text{ for } t \le t_l; \text{ and}$$

$$Q_s = \alpha (t - t_l)^2 \text{ for } t > t_l \qquad (21)$$

This can be applied to either the original or the convective correlations through use of appropriate α and t_l values.

The relationship between the instantaneous and sensed heat release rates for t-squared fire representations is illustrated in dimensionless terms in Figure 3. The curves differ only by a translation along the time axis equal to the transport time lag. Once this transport lag is considered, there is no difference between the quasi-steady and t-squared

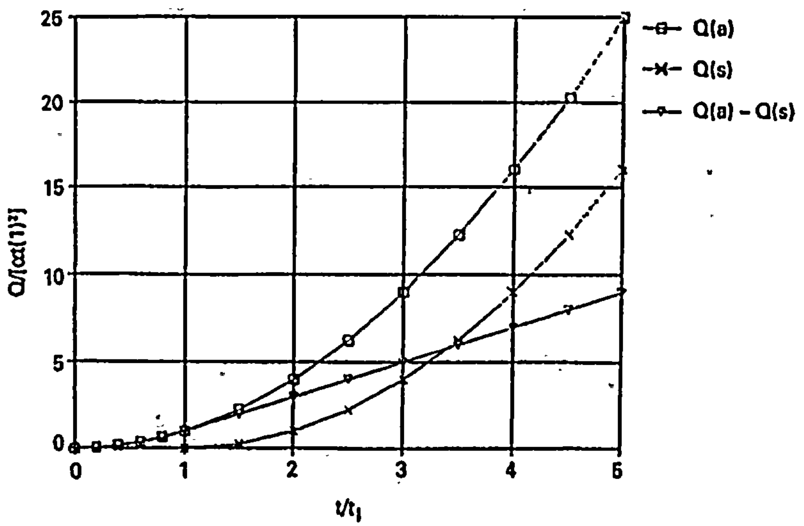

Figure 3. Illustration of the influence of the transport time lag on the response of thermal detectors to t-squared fires.

temperature correlations of Heskestad and Delichatsios.

The difference between the instantaneous and sensed heat release rates continues to grow with time. The rate by which the sensed heat release rate lags the instantaneous heat release rate can be expressed for t-squared fires as:

$$Q_l \,/\, \alpha t_l^2 = (t/t_l)^2 \text{ for } t < t_l; \text{ and}$$

$$Q_l \,/\, \alpha t_l^2 = (2t \,/\, t_l - 1) \text{ for } t > t_l \qquad (22)$$

This relationship is illustrated in Figure 3, where Q_a is the actual instantaneous heat release rate at any time, Q_s is the sensed heat release rate at any time, and Q_l is the difference between Q_a and Q_s. The longer the transport lag, the larger the lag will be between the instantaneous heat release rate and the sensed heat release rate at any time.

According to the Heskestad and Delichatsios correlations for t-squared fires, transport time lags can be calculated as:

$$t_l = [0.954\,(H + r)] / (A\alpha_t H)^{1/5} \text{ s} \qquad (23a)$$

$$= [0.813\,(H + r)] / (A\alpha_c H)^{1/5} \text{ s} \qquad (23b)$$

The term $(H + r)$ is the characteristic distance traveled by fire gases from the fire source to the ceiling location of interest. The term $(A\alpha H)^{1/5}$ has units of m/s and can be interpreted as a characteristic velocity of the fire gases.

Newman[11] suggests an alternative expression, based on a data correlation and applicable to power law fires, for calculating transport time lags:

$$t_l = (1.4\,(r/H) + 0.2)\,[H^5 / (A\alpha_t H)]^{1/(3+p)} \qquad (24)$$

For t-squared fires ($p = 2$), this expression evaluates as:

$$t_l = (1.4\,(r/H) + 0.2)\,[H^5 / (A\alpha_t H)]^{1/5} \qquad (25a)$$

$$= (1.4r + 0.2H) / (A\alpha_t H)^{1/5} \qquad (25b)$$

Newman's correlation for the transport time lag in t-squared fires (Equation 25b) makes more physical sense than the transport lag correlation of Heskestad and Delichatsios because it recognizes the difference between the average transport velocities in the plume and ceiling jet regions. Newman's correlation approximates this difference,

illustrated in Figure 1b, to be a velocity in the plume region that is seven times higher than in the ceiling jet region. While not exact because of the variable velocities in the ceiling jet region, this difference is consistent with the plume and ceiling jet velocities illustrated in Figure 1b.

Transport Lags Associated with Quasi-steady Correlations

The quasi-steady temperature and velocity correlations do not consider transport lags explicitly. Effects of the actual heat release are considered to propagate instantly throughout the fire plume and ceiling jet. The transport time lag for quasi-steady fires can be estimated to permit evaluation of its importance for different scenarios. The transport time lag can be calculated generally as:

$$t_t = d/\overline{u} \qquad (26)$$

where:

d = Distance traveled by the fire gases (m)
$\overline{u}$ = Average velocity of fire gases over distance d (m/s).

Within the plume region, the distance traveled by fire gases, d, is simply the height H from the fire source to the location being considered. Average velocity in the plume is calculated, using $u(z) = 1.0\,(Q_t/z)^{1/3}$, as:

$$\overline{u}_{pl} = \frac{1}{H}\int_0^H u(z)\,dz = \frac{1}{H}\int_0^H \left[1.0\left(\frac{Q_t}{z}\right)^{\frac{1}{3}}\right]dz = 1.5\,u(H) \qquad (27)$$

The average velocity over the height H is 1.5 times the local velocity at H. Therefore, within the plume region, the transport time lag can be evaluated as:

$$t_{t,pl} = H/[1.5\,u(H)] \qquad (28a)$$

$$= 0.67\,H^{4/3}/Q_t^{1/3} \qquad (28b)$$

The transport time lag within the ceiling jet region is the plume transport lag plus the transport lag within the ceiling jet. The distance traveled by gases in the ceiling jet is the radial distance R from the plume centerline to the object under consideration. Using Alpert's correlation for ceiling jet velocities, the average velocity of the jet is evaluated as:

$$\overline{u}_{cj} = \frac{1}{R}\int_0^P u(r)\,dr = \frac{1}{R}\int_0^P \left[0.2\left(\frac{Q_t}{H}\right)^{\frac{1}{3}} / \left(\frac{r}{H}\right)^{\frac{5}{6}}\right]dr = 6\,u(R) \qquad (29)$$

Consequently, the transport time lag within the ceiling jet can be evaluated as:

$$t_{t,cj} = R/[6\,u(R)] \qquad (30a)$$

$$= R^{11/6} / [1.2\,Q_t^{1/3}H^{1/2}] \qquad (30b)$$

The total time lag for the ceiling jet region then is evaluated as:

$$t_{t,tot} = t_{t,pl} + t_{t,cj} \qquad (31)$$

For heat release rates that vary with time, this analysis of quasi-steady fires suggests that the transport time lag also will vary with time. For example, if a t-squared representation of the heat release rate ($Q = \alpha t^2$) is substituted for Q into Equations 28 and 30, this time dependence is illustrated. Thus, due to differences in the forms of the quasi-steady and t-squared representations, they are not expected to yield identical results even if a transport time lag is added to the quasi-steady correlation.

The Newman correlation for transport time lags expressed by Equation 24 can also be applied to the case of quasi-steady fires by setting $p = 0$ and $\alpha = Q$. For this case, Equation 24 evaluates as:

$$t_t = (1.4\,(r/H) + 0.2)\,H^{5/3}/(AQH)^{1/3} \qquad (32)$$

which can be separated into plume and ceiling jet regions:

$$t_{t,pl} = 0.2\,H^{5/3} / (AQH)^{1/3} \qquad (33a)$$

$$= 0.66\,H^{4/3} / Q^{1/3} \qquad (33b)$$

$$t_{t,cj} = (1.4\,r/H)\,H^{5/3} / (AQH)^{1/3} \qquad (34a)$$

$$= 4.61\,r / (Q/H)^{1/3} \qquad (34b)$$

Thus, Newman's expression for the plume region transport lag is virtually identical to the one derived here and expressed by Equation 28b if the theoretical heat release rate is used.

Newman's expression for the ceiling jet transport lag differs in form from the one derived here; his expression demonstrates a first power dependence of the transport lag on radial distance, while the one derived here demonstrates almost a second power relationship. This difference is most likely due to the difference in form between the Alpert and the

Heskestad and Delichatsios velocity correlations in the ceiling jet region (see Table 1). The form derived here is more consistent with the decaying nature of the velocity as a function of radial distance in the ceiling jet region. But over radial distances normally of interest, either form should suffice.

Detection Time Lags

The detection time lag depends on the fire environment history at the detector and on the response characteristics of the device. For detection, a threshold magnitude of the fire signature being detected must be transported to the detector and maintained for a sufficiently long period to overcome inertial effects in the detector. Newman[12] discusses the methods available to evaluate these parameters for a range of detection devices. In this paper, models of heat detector response are used to illustrate the concept of detection time lags.

The DETACT models[13,14] of detector actuation developed by Evans and Stroup permit quantitative estimation of detection time lags for thermally actuated devices. These models use the Response Time Index (RTI) characterizations of heat detector reaction developed by Heskestad and Smith.[15] The DETACT-QS model[13] uses Alpert's quasi-steady correlations; it does not incorporate a transport time lag. The DETACT-T2 model[14] uses the t-squared correlations of Heskestad and Delichatsios, which incorporate the transport time lag represented by Equation 23. Analytical solutions of the detector response equations using the t-squared correlations have been developed by Beyler;[7] these also incorporate the transport lag.

Suppression Time Lags

The suppression time lag is fairly easy to assess for buildings with automatic suppression systems, but it's more difficult to consider where reliance is placed on manual suppression. For wet pipe sprinkler systems, the suppression time lag should be nil; water application begins immediately upon actuation of a sprinkler. This does not imply that the rate of water discharge will be adequate for fire control. A separate analysis is required to determine the adequacy of the water application rate; the discharge rate needed will depend on the transport and detection lag periods as well as on the rate of fire growth. The relationships between sprinkler actuation sensitivity and the required discharge density for effective fire control have been and continue to be explored in connection with the development of the Early Suppression Fast Response (ESFR) and Quick Response Sprinkler (QRS) technologies.

The suppression time lag for dry-pipe sprinkler systems can be

evaluated by actual test; it should not exceed one minute at the most remote sprinkler if the system conforms with the intent of NFPA 13,[16] although for systems with a piping capacity of less than 750 gallons, the sprinkler standard does not require this performance. In recognition of the impact of the suppression time lag on the potential for fire control, NFPA 13 requires that dry systems be designed for an area of operation 30% larger than for wet systems. Nonetheless, the better performance record of wet systems[17] is undoubtedly related to their reduced suppression lag times.

Suppression lags associated with manual suppression can be at least five minutes under good circumstances. Usually, it will be even longer before effective fire suppression activity commences. For example, under ideal conditions a capable urban fire department may be notified and respond within five minutes to a building fire. But it will take more time to evaluate the situation, make attack decisions, hook engines to hydrants, pull hoses to the fire floor, and ultimately put water effectively on the fire. Any uncertainty with respect to fire department notification and response can add significantly to this delay. In any case, typical suppression lags associated with manual fire fighting can make this protection strategy ineffective against rapidly developing fires even under optimum conditions of fire department notification and response.

Discussion

The general goal of fire mitigation strategies is to minimize the net effect of the three time lags discussed above. It is useful to consider fire growth scenarios and mitigation strategies in terms of these lag periods. This represents a convenient framework with practical physical significance; it also helps to illustrate why some fires are difficult to control, even with automatic fire suppression systems.

The transport time lag is primarily a geometric factor, although, as indicated by Equation 23, the fire growth rate has an influence on this parameter. Transport time lags are most significant in tall spaces and in spaces with thermally actuated fire detectors located at large spacings. It is not by coincidence that fires in tall spaces frequently result in high challenge fires. In such spaces, the transport time lag can be minimized through the use of line-of-sight detection devices, such as optical flame detectors, which respond to radiant energy emitted by a fire. This energy travels to the detector at the speed of light, thus eliminating the transport time lag. The detection lag for these devices is also minimal because of their sensitivity. Due to the potential for unwanted alarms with these devices, they rarely are used to actuate suppression systems automatically, so the suppression time lag still must be addressed where they are used.

The detection time lag is a function of both the fire environment and the detection device being used. For detection devices, such as sprinklers, heat detectors, and smoke detectors, that rely on the transport of buoyant gases to the ceiling for their operation, the primary environmental parameters are the heat release rate of the fire and the geometry of the space. For such devices, tall spaces have longer detection lag times than shorter spaces because of the additional entrainment of air that occurs over the additional height. According to plume theory and the available correlations, air entrainment varies as the 5/3 power of height. Coupled with the longer transport time lags for such spaces, this means the design of fire protection systems for such spaces requires special attention. In tall spaces with significant potential life safety implications, such as hotel atria, the control of combustibles to minimize the possibility of a serious fire may be the most reasonable alternative.

Examples

Two examples of t-squared fires will be considered to illustrate the potential impact of the transport, detection, and suppression time lags on the performance of fire protection systems. The first example considers "slow," "medium," "fast," and "ultrafast" t-squared fires[16] in a sprinklered space with a high ceiling, such as an atrium, an exhibition hall, or a warehouse. The second example considers the response to these same fires of a heat detection system installed in accordance with the listed spacing of the heat detectors in a large space with low ceilings, such as an open office area. The fire source is assumed to be at the floor level for both examples.

Example 1: Sprinklers in a Space with a High Ceiling

The space considered here has a ceiling height of 15.25 m (50 ft). Sprinklers with a temperature rating of 71°C and an RTI value of 150 $(ms)^{1/2}$ are spaced on a 3 m grid, representative of an ordinary hazard spacing. The maximum radial distance of a sprinkler to the plume centerline is given by:

$$r = s/\sqrt{2} = 2.1 \text{ m} \quad (35)$$

$$r/H = 2.1/15.25 = 0.14 \quad (36)$$

Assuming a fire located at floor level that develops with a theoretical heat release rate characterized as "ultrafast," this yields:

$$t_t = [0.954\,(15.25 + 2.1)] / (0.028 \times 0.188 \times 15.25)^{1/3} \text{ s} \quad (37)$$
$$= 27 \text{ s (12 s by Newman's method–Equation 25)}$$

The detection time delay, t_d, for this example is calculated to be 216 s, using the DETACT-T2 model.[14] Thus, a quasi-steady analysis would suggest sprinkler actuation at a heat release rate of 8.8 MW (αt_d^2), while a t-squared analysis yields a heat release rate at sprinkler actuation of 11.2 MW $[\alpha (t_t + t_d)^2]$, a 28% increase. The relative importance of this difference must be evaluated. For this example, the size of the fire before sprinkler actuation calculated by either analysis is perhaps of more concern than the differences between the two analyses. Nonetheless, the difference between the sensed and actual heat release rates at detection may be the difference between satisfactory and unsatisfactory sprinkler system performance and should be evaluated.

Results of similar analyses for slow, medium, and fast t-squared fires in this space are illustrated in Table 2. No suppression time lag was considered for these calculations, representative of a building with a wet pipe sprinkler system. The detection time decreases with increasing fire growth rate, but the heat release rate at detection increases with fire growth rate despite the faster detection. Similarly, the transport time lag decreases with increasing fire growth rate, but the ratio of actual to sensed heat release rates at detection increases with increasing fire growth rates.

Example 2: Heat Detectors in Large Spaces with Low Ceilings

In this example, the response of heat detectors listed for spacings of 15.25 m (50 ft) to the standardized t-squared fires is considered. Heat detectors that obtain this listed spacing commonly operate by rate-of-rise (ROR), but for the present discussion, fixed temperature detectors with ratings of 57.2°C (135°F) are assumed. This spacing and temperature rating yield an approximate RTI value[14] of 54 $(m - s)^{1/2}$. A ceiling height of 3 m is used, representative of typical office or similar commercial spaces.

The worst-case radial distance from a detector is calculated as:

$$r = s/\sqrt{2} = 10.8 \text{ m} \quad (38)$$

$$r/H = 10.8 \text{ m}/3 \text{ m} = 3.6 \quad (39)$$

Table 2. Example results for sprinklers in a 15.25 m tall space.

t^2 Growth Rate	α (W/s²)	t_t (s)	t_d (s)	Q_s (MW)	Q_a (MW)	Q_a/Q_s
Slow	3	63	1276	4.8	5.3	1.10
Medium	12	48	670	5.4	6.2	1.15
Fast	47	36	373	6.5	7.9	1.20
Ultrafast	188	28	216	8.8	11.2	1.28

Table 3. Example results for detectors at 15.25 m spacings.

t^2 Growth Rate	α (W/s²)	t_l (s)	t_d (s)	$\dot{Q}_s$ (MW)	$\dot{Q}_a$ (MW)	Q_a/Q_s
Slow	3	70	828	2.0	2.4	1.20
Medium	12	52	463	2.6	3.2	1.23
Fast	47	40	277	3.6	4.7	1.31
Ultrafast	188	30	172	5.6	7.7	1.38

For a fire with a theoretical heat release growth rate characterized as "fast," the transport lag is calculated as:

$$t_l = [0.954\,(3 + 10.8)]\,/\,(0.028 \times 0.047 \times 3)^{1/6}\ \text{s} \qquad (40)$$
$$= 40\ \text{s}\ \ (48\ \text{s by Newman's method–Equation 25})$$

For this case, a detection time of 277 seconds is calculated without the transport lag; the corresponding heat release rate is 3.6 MW. When the transport time is considered, the detection time becomes 317 seconds and the corresponding heat release rate is 4.7 MW. This represents an increase of 31 percent compared to the quasi-steady case. Results of similar calculations for the four standardized parabolic fire growth rates are tabulated in Table 3. These calculations show the same trends that are found in the first example.

These examples help to illustrate the potentially important role of the transport lag in the response of fire detection devices that rely on the transport of buoyant gases to and across the ceiling. Care must be exercised in the application of quasi-steady models of detector response, which do not consider the influence of this transport lag.

Summary

The relationship between quasi-steady and power law data correlations for fire plumes and ceiling jets has been discussed. Available correlations reduce to the same form, once a transport time lag is considered. The roles of this transport lag, a detection lag, and a suppression lag on the development and suppression of building fires have been considered. The evaluation of fire protection strategies can be considered in terms of these three time lags.

Methods to evaluate existing or proposed fire protection strategies in terms of the three lag periods have been presented for large spaces with flat, unobstructed ceilings. In many spaces, particularly tall ones and spaces with large detector spacings, traditional thermally actuated fire detection and suppression systems may not provide an adequate level of protection. These systems may not provide fire control or suppression before an unacceptable hazard develops. In such spaces, a number of alternative fire protection strategies can be considered:

1. The use of more fire resistant materials and products to reduce the rates of fire growth and hazard development;

2. The use of fire detection devices that do not rely upon the transport and detection of thermal fire signatures;

3. The use of automatic suppression systems to minimize suppression lag times.

The expected effectiveness of these alternatives can be evaluated separately and jointly by the methods discussed here.

Nomenclature

A	$g/(c\,\rho_o\,T_o)$ (0.028 m²/kg or m⁴/kW s³)
c	Specific heat of air (kJ/kg – K)
d	Distance traveled by fire gases (m)
D	Nondimensional distance parameter
dT	Temperature rise above ambient (K)
dT^*	Nondimensional temperature rise above ambient $[gH^{5/3}/(AQ)^{2/3}]\,(dT/T_o)$
g	Gravitational constant (9.8 m/s²)
H	Height above plume source (m)
k_T	Plume/ceiling jet temperature coefficient (K – m$^{5/3}$/kW$^{2/3}$)
k_u	Plume/ceiling jet velocity coefficient (m$^{4/3}$/s – kW$^{1/3}$)
p	Fire growth exponent
ρ_o	Density of air (kg/m³)
$\dot{Q}$	Total heat release rate of fire (kW)
r	Radial distance from fire axis (m)
s	Detector or sprinkler spacing (m)
t	Time (s)
t_o	Incubation time offset (s)
t^*	Nondimensional time
T	Temperature (K)
$\bar{u}$	Average velocity of fire gases (m/s)
U	Fire gas velocity (m/s)
U^*	Nondimensional velocity $[H/(AQ)]^{1/3}\,U$
z	Coordinate above plume source
α	Power law fire growth coefficient (kW/s^p)

Subscripts

a Actual
c Convective
cj Ceiling jet
crit Critical
d Detection lag
f Pertaining to the heat front
l Transport lag
o Ambient
pl Plume
s Sensed, suppression lag
sup Suppression
t theoretical
tot Total

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NRC/FPL/FPC LICENSING WORKSHOP

St. Lucie Plant

February 1-2, 2000

AGENDA

NRC, FP&L and FPC Licensing Workshop

February 1-2, 2000

Plant St. Lucie

February 1st

8:00 – 8:15	Introduction/Orientation	Facility Host Herb Berkow
8:15 – 8:45	Electronic FSAR	Paul Infanger -Crystal River
8:45 - 9:15	Electronic Technical Specifications	Margaret DiMarco -St. Lucie
9:15 – 9:45	NOEDs : (inc. Weather Related)	Herb Berkow
9:45 – 10:00	Break	All
10:00 – 10:30	Regulatory Issues: Status of Design Bases, FSAR, and 10 CFR 50.72/73 Projects	Rich Correia
10:30 - 11:00	10 CFR 50.59	Len Wiens
11:00 - 11:30	Attributes of a Good Relief Request	Kahtan Jabbour
11:30 – 12:30	Lunch	
12:30 – 12:45	ADAMS Status	Karen Cotton
12:45 – 1:45	Licensing Processes - NRC Perspective - Environmental Assessments	Robert Martin Len Wiens
1:45 – 2:45	Licensing Processes - FP&L - FPC	Ed Weinkam Steve Franzone Sid Powell
2:45 – 3:00	Break	
3:00 – 4:15	Attributes of a Good Submittal Breakout	Facilitators: Ed Weinkam Steve Franzone Sid Powell
4:15 – 5:00	Summary/Conclusions Breakout	Facilitators

AGENDA (Continued)

NRC, FP&L and FPC Licensing Workshop

February 1-2, 2000

Plant St. Lucie

February 2nd

8:00 – 8:30	Risk Informed Applications - Rule-Making	Rich Correia
8:30 - 9:00	Role of Project Manager	Kahtan Jabbour
9:00 – 10:15	Critique Licensing Submittals Breakout	Facilitators
10:15 – 11:00	Summary/Conclusions from Breakout	Facilitators
11:00 – 11:30	Workshop Conclusions and Closing Comments	Herb Berkow Facility Host
11:30	End of Workshop	

FINAL SAFETY ANALYSIS REPORT

ELECTRONIC FSAR

Presented by:

Paul Infanger

February 1, 2000

FINAL SAFETY ANALYSIS REPORT

- **Electronic Format**
  - Ease of use
    - FPC workers and vendors familiar with Adobe Acrobat (free viewer)
    - Built-in search tools
    - "Perfect" printouts
    - Cross-platform
  - Convenient and portable
    - Loaded on FPC LAN
    - CD-ROM copies available
  - Improved change history and tracking

FINAL SAFETY ANALYSIS REPORT

- **Saves production cost**
  - Reduced the number of paper Controlled Copies on-site from 63 to 9
  - Issue about 20 CD-ROMs to vendors and employees
  - Reduced NRC copies from 11 paper to 2 paper and 4 CD-ROMs

FINAL SAFETY ANALYSIS REPORT

- Living FSAR
  - Interim Revisions “quarterly”
  - Keeps FSAR current
    - NRC will get update mid-February current to 12/31
  - Projected changes file
  - Reduces burden for NRC revision

FINAL SAFETY ANALYSIS REPORT

- Software
  - Native files in Microsoft Word
  - Process into PDF with Adobe Acrobat Version 4.0
  - Add Hyperlinks and Bookmarks with Ambia Compose
    - Autobookmarker (uses Word Styles to make TOC)
    - Hyperlinks for Tables and Figures

FINAL SAFETY ANALYSIS REPORT

- **Summary**
  - Saves money, time and effort
  - Improved product, more current and accessible
  - Workers and vendors like it
  - NRC acceptance
  - Eleven plants have inquired on "How to"

St. Lucie Nuclear Plant

Sea Turtle Refuge

Electronic Technical Specifications

Presented by:

George Madden &Margaret Dimarco

February 1, 2000

ELECTRONIC TECH SPECS

- **Objective:**
  - Place Unit 1 and Unit 2 Technical Specifications On-Line in a Controlled environment
  - Ability to retrieve, view, search and print Controlled Technical Specifications from desktop

ELECTRONIC TECH SPECS

- **Project Plan**
  - Replicated Electronic Procedures
  - Word Processed Tech Specs When Time Allowed
  - Created PDF Files And Links
  - Proof Reading Final Product Prior To Implementation
  - Target Implementation May 2000

ELECTRONIC TECH SPECS

- Each TS Page Is Controlled As a Separate File in Word and Adobe Acrobat (PDF)
- Individuals PDF Pages Are Combined Into One PDF Document Per Unit
- Created Hyper Links by Section Within the PDF Document

ELECTRONIC TECH SPECS

- **Organization**
  - Technical Requirements Manual
    - This Is Relocated Tech Specs
  - Facility Operating License
  - Tech Specs Appendix A
  - Tech Specs Appendix B

ELECTRONIC TECH SPECS

- **Appendix A - Unit 1 Tech Specs**
  - List of Effective Pages
  - Index
  - Section 1.0 Definitions
  - Section 2.0 Safety Limits and Limiting Safety System Settings
    - Bases for 2.0 Safety Limits and Limiting Safety Settings
  - Sections 3.0 and 4.0 Limiting Conditions for Operation and Surveillance Requirements
    - Sections 3/4.0 Through 3/4.11
    - Bases for Sections 3.0 and 4.0
  - Section 5.0 Design Features
  - Section 6.0 Administrative Controls

FPL ELECTRONIC TECH SPECS

- **Benefits**
  - Approximately 50 Hard Copies of Controlled Tech Specs
    - This Can Be Reduce to Less Than 10
  - Less Time to Make Revisions
  - Each Employee Will Have Access to Tech Specs From Their Desktop
  - Ability to Perform Word Search More Accurately and in Less Time
  - Support NRC Electronic License Submittal
    - Ability to Submit Electronic Mark-Ups Opposed to Pen and Ink
    - Ability to Email Final Pages in PDF Format

FPL ELECTRONIC TECH SPECS

- **Potential Improvement Opportunities:**
  - Administrative Change to Replace Existing Tech Specs With the Electronic PDF Version
  - Administrative Change to Re-number Tech Spec Section Pages (Change 3/4 1-1a, 3/4 1-1b, etc. To 3/4 1-1, 3/4 1-2, etc. By Renumbering the Existing Pages by Section)
  - Eliminate Blank Pages

NOTICES OF ENFORCEMENT DISCRETION

REVISED STAFF GUIDANCE - PART 9900

UNITED STATES NUCLEAR REGULATORY COMMISSION

Herb Berkow
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

SIGNIFICANT CHANGES TO THE NOED GUIDANCE

PART 9900 GUIDANCE WAS REVISED ON JUNE 29, 1999

- PROCESS IMPROVEMENTS FOR NOEDs RELATING TO SEVERE WEATHER OR OTHER NATURAL EVENTS
  - Previously an enforcement discretion, now an NOED
  - Prior Commission approval not required
- STAFF DOCUMENTATION CHANGES

PROCESSES FOR ADDRESSING NON-COMPLIANCE WITH REQUIREMENTS

- **NOEDS ARE APPROPRIATE ONLY FOR NON-COMPLIANCE WITH TS OR OTHER LICENSE CONDITIONS**

- **NOEDS ARE NOT APPROPRIATE FOR NON-COMPLIANCE WITH:**
  - REGULATIONS -PROCESS EXEMPTIONS -10 CFR 50.12
  - CODES -PROCESS RELIEFS -10 CFR 50.55a
  - UFSAR -CHANGE PER 10 CFR 50.59 OR OPERABILITY DETERMINATION GL 91-18 REV. 1 AND PROCESS LICENSE AMENDMENT -10 CFR 50.90

TWO TYPES OF NOEDs

- (1) **RADIOLOGICAL SAFETY CONSIDERATIONS (REGULAR NOED)**

  FORCED COMPLIANCE WITH LICENSE WOULD INVOLVE PLANT-RELATED RISKS DUE TO UNNECESSARY TRANSIENT

- (2) **OVERALL PUBLIC HEALTH AND SAFETY CONSIDERATIONS (A SEVERE EXTERNAL CONDITION - RELATED NOED).**

  FORCED COMPLIANCE WITH LICENSE MAY AFFECT GRID STABILITY, EXACERBATING IMPACTS OF SEVERE WEATHER OR OTHER NATURAL EVENTS ON OVERALL PUBLIC HEALTH AND SAFETY

SEVERE WEATHER/NATURAL EVENT NOEDS

- HISTORY & EVOLUTION
- CURRENT GUIDANCE & PRACTICE
  - •• government or responsible independent entity makes assessment that need for power and overall public health & safety considerations constitute an emergency situation
  - •• staff must balance public health & safety implications with potential radiological risks
  - •• risks must be acceptably small
- EXAMPLES
  4 granted
- WEATHER-RELATED VS. “REGULAR” NOED
  compliance issue vs. degraded or inoperable component/system

OTHER PROCESS CHANGES

- ALL NOED-RELATED TELECONFERENCES ARE MADE THROUGH THE NRC HEADQUARTERS EMERGENCY OPERATIONS CENTER RECORDED TELEPHONE LINE (301) 816-5100.

- LICENSEES ARE NO LONGER REQUIRED TO STATE WHETHER:

  - prior adoption of TS enhancement initiatives (GL 87-09, Line Item Improvements or the Improved Standard TS) would have obviated the need for the NOED

  - the noncompliance involves a USQ

- FOR ALL NOEDs (REGIONAL OR NRR) REGION TO OPEN AN UNRESOLVED ITEM (URI).

- This will facilitate:
  - tracking
  - verification of resolution activities
  - documentation and closure of inspection
  - enforcement action determination

NRC, FP&L and FPC LICENSING WORKSHOP

STATUS OF DESIGN BASES, UFSAR, and 50.72/73 PROJECTS

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DESIGN BASES

OBJECTIVE

- Provide clear guidance on what constitutes design bases information as defined in 10 CFR 50.2

DESIGN BASES

BACKGROUND

- Engineering team inspections (late 1980s)
- Industry Guidelines (NUMARC 90-12) - design bases reconstitution
- NUREG-1397 - assessment of design control practices and reconstitution programs

DESIGN BASES

BACKGROUND (CONT.)

- Commission Policy Statement (August 1992)
  - Acknowledged industry efforts
  - Emphasized importance of understanding and maintaining design bases
    - Plant physical and functional characteristics are maintained and are consistent with the design bases as required by regulation
    - SSCs can perform their intended functions
    - Plant is operated in a manner consistent with design bases
- Millstone and Maine Yankee Lessons Learned
- 10 CFR 50.54(f) Letters
- Enforcement issues

DESIGN BASES

RELEVANCE OF DESIGN BASES

- Design Bases used in the following regulations:
  - 50.34 (FSAR content)
  - 50.59 (Changes - effective 2000)
  - 50.72, 50.73 (Reporting)
  - Appendix A to part 50 (GDC)
  - Appendix B to part 50 (QA)

- Used to evaluate degraded and nonconforming conditions

DESIGN BASES

NRC ACTIVITIES

- Interact with Industry on NEI 97-04
- Publish *draft* Regulatory Guide (RG) endorsing revised NEI 97-04 (11-17-99)
- Consider changing 10 CFR 50.2 definition

DESIGN BASES

STAFF ACTIVITIES and TENTATIVE SCHEDULES

- Draft Commission Paper under Management review (Jan. 2000)
- Publish draft RG after Commission approval (Feb. 2000)
- Resolve comments on draft RG (June 2000)
- ACRS and CRGR briefings (July 2000)
- Commission Paper with final RG (Aug, 2000)

REGULATORY GUIDE for the CONTENT of UFSARs

UFSARs

BACKGROUND

- FSAR updates required by 10 CFR 50.71(e)
- Guidance contained in:
  - RG 1.70, rev. 3 (November 1978)
  - Generic letter 80-110 (December 1980)
- NRC determined additional guidance was needed (Millstone Lessons Learned -February 1997)
  - Ensure UFSARs updated to reflect changes to design bases
  - Reflect effects of other analyses performed since original licensing
  - Suggested guidance include:

UFSARs

BACKGROUND (cont.)

- Commission Direction (June 1998)
  - Disapproved staff recommended Generic letter
  - Continue to work with Industry on NEI 98-03
  - Establish enforcement discretion period for 6- to 18-month period after final guidance issued, depending on risk significance

UFSARs

MORE RECENT ACTIVITIES

- NRC Staff and Industry public meetings to resolve differences
- DG-1083 and SECY 99-001
- DG-1083 published for comment endorsing NEI 98-03, rev. 0

UFSARs

PUBLIC COMMENTS ON DG-1083

- Incorporation by reference
  - Position: Part of UFSAR, therefore, docketed and subject to 50.59 and 50.71(e)
  - Resolution: reference materials on file, but not on docket
- Information retention for safety significant SSCs
  - Position: NEI 98-03 not to be used to remove information on safety significant SSCs
  - Resolution: NEI 98-03 clarified consistent with staff position

UFSARs

PUBLIC COMMENTS ON DG-1083 (CONT.)

- Removal of drawings
  - NEI 98-03 added guidance on conditions for removal of drawings
- Removal of commitments
  - NEI 98-03 changed to clarify that only obsolete or less meaningful commitments may be removed

UFSARs

SECY 99-203 and REGULATORY GUIDE 1.181

- Endorses NEI 98-03, rev. 1 as acceptable to meet 10 CFR 50.71(e)
- NEI 98-03, rev. 1 acceptable for allowing improvements and simplification of content and format of UFSARs
- Does not supersede any prior commitments

UFSARs

SRM -SECY-99-203

- Commission approved publication of RG 1.181
  - Inform Commission on results of FSAR updates monitoring efforts
    - Whether guidance for UFSAR updates or design bases needs revision
    - Whether additional regulatory oversite is warranted
    - Ensure a representative sample of FSARs is examined
- Clarified certain RG language
- Ensure consistency with regulatory guide for design bases

UFSARs

Staff Activities

- Developing monitoring program per Commission direction
- Enforcement discretion for risk-significant matters expires March 31,2000
- Enforcement discretion for less risk significant matters expires March 31, 2001

10CFR50.72,50.73 RULEMAKING

BACKGROUND

- SECY-98-036 (March 4, 1998)
  - Proposed rulemaking plan
- SRM-98-036 (May 14, 1998)
  - Commission approved plan
- ANPR published (July 23, 1998)
  - Requested public comments
  - Public meetings
  - NEI "table top exercises"

10CFR50.72,50.73 RULEMAKING

PROPOSED RULES OBJECTIVES

- Better align reporting requirements with NRC needs for information
- Reduce reporting burden
- Clarify reporting requirements where needed
- Maintain consistency with NRC actions to improve integrated plant assessments

10CFR50.72,50.73 RULEMAKING

COMMISSION DIRECTION

- SRM 99-119 (June 15, 1999)
  - Commission approved staff recommendations to publish proposed rules
  - Invite comment and determine need for reports on historical problems
  - Seek comment on new requirement to report component problems:
    - Significantly degrade ability to fulfill safety function
    - Could affect similar components

10CFR50.72,50.73 RULEMAKING

RECENT ACTIVITIES

- Proposed Rule published (June 25, 1999) for 75 day comment period
- Staff currently preparing final rule

10 CFR 50.59 RULEMAKING

LEN WIENS

NRC/FP&L/FPC

LICENSING WORKSHOP

SCHEDULE

- FINAL RULE ISSUED IN FR ON 10/4/99
- NEI SUBMITTED NEI 96-07, REV 1 IN DECEMBER 1999
- NRC REG GUIDE TO BE ISSUED IN LATE 2000
- IMPLEMENTATION IS 90 DAYS AFTER RG ISSUED

MAJOR CHANGES

- REMOVAL OF REFERENCE TO USQ
- TERM "SAFETY EVALUATION" CHANGED TO "10 CFR 50.59 EVALUATION"
- ADDED DEFINITION OF "CHANGE" AND "FACILITY AS DESCRIBED IN THE FINAL SAFETY ANALYSIS (AS UPDATED)"

MAJOR CHANGES (continued)

- WILL ALLOW FOR MINIMAL CHANGES, WITHOUT REQUIRING PRIOR NRC APPROVAL
- CHANGED “PROBABILITY” TO “INCREASE IN FREQUENCY” OR “LIKELIHOOD OF OCCURRENCE”
- MALFUNCTION OF A DIFFERENT TYPE IS BEING REPLACED WITH “MALFUNCTION WITH A DIFFERENT RESULT”

MAJOR CHANGES (continued)

- MARGIN OF SAFETY EVALUATION CRITERIA IS REPLACED WITH 2 NEW CRITERIA:
  - CRITERIA (vii) - EVALUATION OF INTEGRITY OF FISSION PRODUCT BARRIERS
  - CRITERIA (viii) - CHANGES TO APPROVED EVALUATION METHODS

IMPACTS AND BENEFITS

- IMPACTS
  - WILL REQUIRE MAJOR REVISION TO 50.59 PROCEDURES
  - WILL REQUIRE NEW TRAINING STANDARDS TO BE DEVELOPED
- BENEFITS
  - OVERALL IMPROVEMENT OVER PREVIOUS RULE LANGUAGE
  - AGREED UPON INDUSTRY/NRC GUIDANCE

Submitting Relief Requests to the NRC

Kahtan Jabbour, NRC Project Manager

10 CFR 50.55a Subjects

Subjects	**10 CFR 50.55a Paragraph**
Reactor Coolant Pressure Boundary	50.55a(c)
Quality Group B Components	50.55a(d)
Quality Group C Components	50.55a(e)
Inservice Testing Items	50.55a(f)
Inservice Inspection (examination) Items	50.55a(g)
Protection Systems	50.55a(h)

Methods to Use to Ask for Relief

I. Propose an alternative to the code requirement and show that:

- the alternative provides an acceptable level of quality and safety pursuant to **10 CFR 50.55a(a)(3)(i)**, or

- complying with the code requirement would result in hardship or unusual difficulty without a compensating increase in quality or safety pursuant to **10 CFR 50.55a(a)(3)(ii).**

II. Show that the code requirement is impractical (not just inconvenient) pursuant to **10 CFR 50.55a(f)(6)(i)** for inservice testing items or **50.55a(g)(6)(i)** for inservice inspection (examination) items.

Methods the NRC Can Use to Authorize an Alternative or Grant Relief

- Authorize a licensee-proposed alternative in accordance with **10 CFR 50.55a(a)(3)(i)** if NRC determines that the alternative provides an acceptable level of quality and safety, or

- Authorize a licensee-proposed alternative (if any) in accordance with **10 CFR 50.55a(a)(3)(ii)** if NRC determines that complying with the specified requirement would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety, or

- Grant relief and impose alternative requirements in accordance with **10 CFR 50.55a(f)(6)(i)** for inservice testing items if NRC determines that the code requirement is impractical, or

- Grant relief and impose alternative requirements in accordance with **10 CFR 50.55a(g)(6)(i)** for inservice inspection (examination) items if NRC determines that the code requirement is impractical.

Table 1 — Relief Request Guidance

10 CFR 50.55a Section	Applicable Table
10 CFR 50.55a(a)(3)(i)	see Table 2
10 CFR 50.55a(a)(3)(ii)	see Table 3
10 CFR 50.55a(f)(6)(i)	see Table 4
10 CFR 50.55a(g)(6)(i)	see Table 5
10 CFR 50.55a(g)(6)(ii)(A)(5)	see Table 5

☞ Note: Pick the single, most applicable 10 CFR 50.55a section to address.

☞ Note: The NRC can only authorize an alternative that the utility proposes in their written submittal. The utility must prepare another written submittal proposing (other) alternatives if they decide or agree with the NRC to use (other) alternatives.

Table 2 — Authorizing a Proposed Alternative in Accordance with 10 CFR 50.55a(a)(3)(i)

Purpose	Authorize a utility-proposed alternative in accordance with **10 CFR 50.55a(a)(3)(i)**.
Necessary Determination	Determine if the utility-proposed alternative provides an acceptable level of quality and safety.
Guidance	➣ Indicate the applicable Code edition and addenda, and describe the Code requirement.
	➣ Describe the proposed alternative and bases.
	➣ Discuss why the proposed alternative provides an acceptable level of quality and safety.
	➣ Specify the duration of the proposed alternative.
	➣ Do not mention impracticality, burden, unusual difficulty or hardship.

Table 3 Authorizing a Proposed Alternative in Accordance with 10 CFR 50.55a(a)(3)(ii)

Purpose	Authorize a utility's proposed alternative in accordance with **10 CFR 50.55a(a)(3)(ii).**
Necessary Determinations	Determine if complying with the specified requirement would result in hardship or unusual difficulty (rather than being impractical) without a compensating increase in the level of quality and safety.
	For ISI items — Determine if the proposed alternative provides reasonable assurance of pressure boundary integrity.
	For IST items — Determine if the proposed alternative provides reasonable assurance that the component or system is operationally ready (capable of performing its intended function).
Guidance	➢ Indicate the applicable Code edition and addenda, and describe the Code requirement.
	➢ Describe the utility-proposed alternative and bases.
	➢ Discuss why complying with the specified requirement would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.
	➢ For IST items: Discuss why the proposed alternative provides reasonable assurance that the component or system is operationally ready.
	➢ For ISI items: Discuss why the proposed alternative provides reasonable assurance of pressure boundary integrity.
	➢ Specify the duration of the proposed alternative.
	➢ Do not mention impracticality.

Table 4 Inservice Testing — Granting Relief in Accordance with 10 CFR 50.55a(f)(6)(i)

Purpose	Grant relief and impose alternative requirements in accordance with **10 CFR 50.55a(f)(6)(i)** for inservice testing items.
Necessary Determinations	Determine if the code requirement is impractical.
	Determine if the proposed testing provides reasonable assurance that the component is operationally ready (capable of performing its intended function).
Guidance	➼ Indicate the applicable Code edition and addenda.
	➼ Describe the utility's proposed alternative (if any) and bases.
	➼ Describe why it is impractical for the utility to comply with the specified requirement.
	➼ Describe the burden on the utility created by imposing the requirement (e.g., having to replace a component, redesign the system or shutdown the plant).
	➼ Discuss why the proposed testing provides reasonable assurance that the component is operationally ready.
	☞ Note: **10 CFR 50.55a(f)(6)(i)** allows the NRC to impose additional requirements without having the utility first commit to them. **10 CFR 50.55a(a)(3)** does not allow this.
	➼ Specify the duration of the alternative.
	➼ **Do not mention hardship or unusual difficulty.**

Table 5 Inservice Inspection — Granting Relief in Accordance with 10 CFR 50.55a(g)(6)(i)

Purpose	Grant relief and impose alternative requirements in accordance with **10 CFR 50.55a(g)(6)(i)** for inservice inspection (examination).
Necessary Determinations	Determine if the code requirement is impractical.
	Determine if the proposed inservice inspection (examination) provides reasonable assurance of component or structure pressure boundary integrity.
Guidance	➤ Additional guidance in Generic Letter 90-05
	➤ Indicate the applicable Code edition and addenda, and describe the Code requirement.
	➤ Describe the proposed alternative (if any) and bases
	➤ Describe why it is impractical to comply with the specified requirement.
	➤ Describe the burden created by imposing the requirement (e.g., having to replace a component, redesign the system or shutdown the plant).
	➤ Describe why the proposed inspection (examination) provides reasonable assurance of component or structure pressure boundary integrity.
	☞ Note: **10 CFR 50.55a(f)(6)(i)** allows the NRC to impose additional requirements without having the utility first commit to them.
	➤ Specify the duration of the alternative.
	➤ Do not mention hardship or unusual difficulty.

☞ Note: For augmented reactor vessel shell weld examination reliefs we authorize a proposed alternative IAW **10 CFR 50.55a(g)(6)(ii)(A)(5)** if we determine that the alternative provides an acceptable level of quality (rather than the code requirement being impractical).

AGENCYWIDE DOCUMENT MANAGEMENT & ACCESS SYSTEM (ADAMS)

NRC/FP&L/FPC WORKSHOP
FEBRUARY 1-2, 2000
LEN WIENS

WHAT IS IT?

- MAINTAIN READ-ONLY RECORDS THAT CAN BE READ FROM MULTIPLE SITES
- FULL TEXT SEARCH CAPABILITY BY NRC AND PUBLIC
- ELECTRONIC DOCUMENTS BECOME OFFICIAL RECORD
- REPLACES NUDOCS

STATUS

- 11/1/99 - STEPPED IMPLEMENTATION STARTED WITH SCANNING OF DOCUMENTS INTO ADAMS - PAPER COPIES REMAINED OFFICIAL RECORD
- 1/1/00 - NRC STAFF COMMENCED ENTERING INTERNAL DOCUMENTS INTO ADAMS - PAPER COPIES REMAIN OFFICIAL RECORD

STATUS (cont)

- TBD - TERMINATE PAPER RECORDKEEPING -ADAMS DOCUMENTS ARE OFFICIAL RECORDS
  - TERMINATE PAPER DISTRIBUTION OF INCOMING DOCUMENTS, WITH LIMITED EXCEPTIONS
  - LIVING DOCUMENTS (TECH SPECS, UFSAR) WILL CONTINUE TO HAVE PAPER DIST.

ELECTRONIC INFORMATION EXCHANGE (EIE)

- FUTURE SYSTEM TO PROVIDE ELECTRONIC DOCUMENT EXCHANGE TO AND FROM NRC
- PARTICIPATION IS VOLUNTARY

PARTICIPATION IN EIE

- MUST HAVE ACCESS TO INTERNET VIA INTERNET EXPLORER OR NETSCAPE
- APPLY FOR AND BE GRANTED A "DIGITAL CERTIFICATE".
- 5 MEG (1000 PAGES) LIMIT. LARGER DOCUMENTS WITH PRIOR NOTICE.

PARTICIPATION IN EIE (cont)

- DOCUMENT SUBMITTALS:
  - PDF NORMAL
  - PDF
  - WORD
  - WordPerfect
- MAY BE EXPANDED LATER (ASCII)

EIE PROCESS

- ELECTRONICALLY SIGN DOCUMENT
- PLACE ON EXTERNAL SERVER
- SEND EMAIL TO RECIPIENT
- NO PUBLIC ACCESS TO EIE

EXTERNAL ACCESS

- ACCESS NRC EXTERNAL WEB (NRC.GOV)
- CLICK ON "PUBLIC ELECTRONIC READING ROOM" AT BOTTOM OF PAGE
- FOLLOW INSTRUCTIONS OR CALL LISTED NUMBERS FOR HELP

SENSITIVE INFORMATION

- PROPRIETARY, SECURITY, PRIVACY INFORMATION PROTECTED BY ADAMS PROCEDURES AND SOFTWARE
- SAFEGUARDS INFORMATION WILL NOT BE INCLUDED IN ADAMS

NUDOCS

- DOCUMENTS PRIOR TO 11/1/99 WILL CONTINUE TO BE KEPT IN MICROFICHE
- WILL NOT BE CONVERTED TO ADAMS
- CAN SEARCH FOR DOCUMENT BY TITLE IN ADAMS LEGACY LIBRARY

LICENSE AMENDMENT REVIEW PROCEDURES
NRR OFFICE LETTER 803, REV 3

BOB MARTIN
NRR PROJECT MANAGER

Policy

- Atomic Energy Act Section 182a
- 10 CFR 50.36, Technical Specifications
- 10 CFR 50.90, Application for Amendment of License
- 10 CFR 50.91, Notice for Public Comment; State Consultation
- 10 CFR 50.92, Issuance of Amendment

Objectives of OL 803

- Ensure public health and safety
- Promote consistency in processing of license amendments
- Improve internal and external communications
- Increase technical consistency for similar licensing actions
- Reduce delays in issuance of license amendments
- Ensure that staff RAIs are adding value to the regulatory process
- Provide NRR staff with an improved framework for processing license amendment applications

Initial Processing

- Amendments
  - Acceptance review
  - Work planning
  - Prioritization

Acceptance Review

- Oath & Affirmation, State copy
- Clear description of change
- Safety analysis and justification
- NSHC and EA (or exclusion)
- Approval and implementation schedules
- Is it risk-informed?

Work Planning

- PM and technical staff
  - Search for precedents
  - Review method (PM or tech staff)
  - Scope & depth of review
  - Resource planning and schedule
  - Priority

Priority

- Priority 1
  - Highly risk-significant safety concern
  - Issue involving plant shutdown, derate, or restart
- Priority 2
  - Significant safety issue
  - Support continued safe plant operations
  - Risk-informed licensing action
  - Topical report with near-term or significant safety benefit

Priority

- Priority 3
  - Moderate to low safety significance
  - Cost beneficial licensing actions
  - Generic issue or multi-plant action
  - Topical report with limited benefit

NSHC Determination

- NSHC Based on 50.92 (51 FR 7751)
  - Significant increase in probability or consequences of an accident
  - Possible new or different accident
  - Significant reduction in margin of safety
- If proposed NSHC, hearing *can* be after amendment
- If SHC or no determination, any hearing would precede amendment

Noticing

- "Normal" amendments, 50.91(a)(2)
  - Bi-weekly or individual Federal Register notices-30 day comment period
  - Notice of proposed amendment, proposed NSHC, hearing opportunity
  - Notice of issuance
- If a proposed NSHC determination is not made, use individual notices
  - Can't be handled as an exigent or emergency

Noticing- Exigent Amendment

- Notice in Federal Register (FR) if amendment is to be issued after 15 days but before 30 days
  - Individual FR notice
  - Repeat in bi-weekly FR notice
- Notice in local media if amendment is to be issued after 6 days but before 15 days
  - Repeat in bi-weekly FR notice
- Amendments require a final NSHC determination

Noticing - Emergency Amendment

- Emergency amendments noticed after issuance for comment and an opportunity for hearing

Reviewer Assignments

- Reviews can be performed by PM or technical staff, considerations include:
  - Technical complexity & risk significance
  - PM technical expertise
  - Conformance to improved Standard Technical Specifications (STS) guidance
  - Conformance to precedents
  - Resource availability & schedule needs

Review Process and Documents Preparation

- Review process
  - Precedents
  - Requests for additional information (RAIs)
  - Regulatory commitments
- Document preparation
  - Safety evaluation
  - Concurrence review
  - Amendment issuance

Review Process and Documents Preparation

- Precedents
  - Ensure request meets current expectations
    - Format
    - Guidance to industry
    - Technical content

Review Process and Documents Preparation

- Requests for additional information
  - Staff goal: 1 RAI per reviewing technical branch
  - Notify the licensee
    - Discuss questions
    - Resolve minor issues
    - Answers needed to make regulatory finding are placed on the docket
    - Establish reasonable response date
    - Document conversation on cover letter
  - Questions should be developed with consideration of regulatory basis of the request

Commitments

- Regulatory commitments are information relied on by the staff in making its conclusion but are not included in the TS
- Current staff practice outlined in SECY-98-224, NRC guidance on commitment management
- Office letter 900 to be issued Spring 2000
  - Will provide further guidance

Commitments

- Hierarchy of licensing basis information
  - Obligations - license, TS, Rules, orders
  - Mandated licensing-basis information - UFSAR, QA/security/emergency plans
  - Regulatory Commitments - docketed statements agreeing or volunteering to take specific actions
  - Non-licensing basis information

Commitments

- Commitments stated in the safety evaluation are considered part of the licensing basis but are not legally binding requirements
- Safety evaluation should clearly state what actions are considered regulatory commitments
- Control of commitments is in accordance with licensees' programs

Commitments

- Escalation to license conditions reserved for safety-significant matters (e.g., those that meet 10 CFR 50.36 criteria for inclusion)
- Staff is continuing to include license conditions for relocation of information to UFSAR or other controlled documents in amendment implementation

Safety Evaluation

- Routinely included
  - Staff evaluation - why the request satisfies regulatory requirements
  - State consultation
  - Environmental considerations
- As needed
  - Regulatory commitments
  - Emergency/exigent provisions
  - Final NSHC determination

Concurrence

- Licensing Assistant
  - Format and revised TS pages
- Technical Branch
  - Technical adequacy
- Technical Specifications Branch
  - Significant deviations from ISTS guidance or changes consistent with ISTS
  - Use of 10 CFR 50.36 criteria
- Office of the General Counsel
  - Legal defensibility and completeness

Amendment Issuance

- Ensure that we've addressed all comments from public and state
- Transmitted to licensee via letter
  - Issued after associated EA
  - Standard distribution (cc) list
    - Notify NRC staff of licensee's organization changes to list via docketed letter
    - Federal Register notice of issuance

ENVIRONMENTAL ASSESSMENTS

UNITED STATES NUCLEAR REGULATORY COMMISSION

LEN WIENS

ENVIRONMENTAL ASSESSMENTS

- REQUIREMENTS
  - 10 CFR 51.21
    - ALL LICENSING ACTIONS UNLESS
      - REQUIRE EIS
      - MEETS CATEGORICAL EXCLUSION
      - OTHER ACTIONS PER 51.22(d)
    - SPECIAL CIRCUMSTANCES
      - NRC DISCRETION DUE TO UNIQUE, UNUSUAL OR CONTROVERSIAL CIRCUMSTANCES

CATEGORICAL EXCLUSIONS

10 CFR 51.22

- C.8 OPERATOR LICENSING
- C.9 OPERATING REQUIREMENTS
- C.10 ADMINISTRATIVE PROCEDURES
- C.12 SAFEGUARDS
- C.21 TRANSFERS

10 CFR 51.22C.9

- APPLIES TO:
  - REQUIREMENTS WITHIN THE RESTRICTED AREA AS DEFINED BY 10 CFR 20, OR
  - CHANGES TO INSPECTIONS OR SURVEILLANCE REQUIREMENTS
- PROVIDED:
  - NSHC, AND
  - NO SIGNIFICANT CHANGE IN TYPES OR SIGNIFICANT INCREASE IN AMOUNT OF EFFLUENTS, AND
  - NO SIGNIFICANT INCREASE IN INDIVIDUAL OR CUMULATIVE EXPOSURE

10 CFR 51.22(C)10

- CHANGES TO SURETY, INSURANCE AND/OR INDEMNITY REQUIREMENTS
- CHANGES TO RECORDKEEPING, REPORTING, OR ADMINISTRATIVE PROCEDURES OR REQUIREMENTS
- GENERALLY APPLIES TO ADMINSTRATIVE CONTROLS SECTION OF TS
- DOES NOT INCLUDE CHANGES TO CORRECT TYPOGRAPHICAL ERRORS OR EDITORIAL CHANGES

PROCEDURAL GUIDANCE

- NRR OFFICE LETTER 906
- TYPES OF ACTIONS REQUIRING EA
  - EXEMPTIONS
  - AMENDMENTS WHICH INCREASE SFP STORAGE CAPACITY
    - NRC DISCRETION
  - POWER UPRATES (IF INCREASED POWER NOT COVERED UNDER ORIGINAL FES)
  - LICENSE RENEWAL
  - DECOMMISSIONING
  - EPP CHANGES

RESPONSIBILITY

- NRC STAFF RESPONIBLE FOR PREPARATION
- MAY REQUEST INFORMATION FROM LICENSEE IN ORDER TO MAKE FINDING

GENERALLY, IF IN DOUBT AS TO WHETHER AN ENVIRONMENTAL ASSESSMENT WILL BE REQUIRED, ASK THE PROJECT MANAGER

LICENSING PROCESSES

Presented by:
Sid Powell

February 1, 2000

LICENSING PROCESSES

- LICENSE AMENDMENT REQUEST (LAR) PREPARATION
- LICENSE AMENDMENT IMPLEMENTATION

LICENSE AMENDMENT REQUEST

- INITIATION and EVALUATION
- RESOURCES
  - Recent History
  - Future Plan
- DEVELOPMENT
  - Technical Resources
  - Licensing Engineer
- TRACKING

LICENSE AMENDMENT REVIEW BOARD (LARB)

- CONCEPT
- QUORUM
  - Chairman (MNL or Designee)
  - Operations
  - Engineering
  - Licensing (not the responsible Licensing Engineer)
  - Others as designated
- RESPONSIBILITIES
  - Technical content
  - Workability
  - Schedule
  - Implementation Plan

APPROVAL PACKAGE (THE RED FOLDER)

- CONTENTS
  - Cover Form
  - Draft Submittal
  - Support Organization Review/Concurrence Form
    - Includes Peer Review
  - Commitment Identification Form
  - Applicable Regulatory and Internal Correspondence
  - Validation Package
- RESPONSIBILITIES
  - Licensing Engineer
  - Technical Lead

APPROVAL PATH

- LARB
- PLANT REVIEW COMMITTEE
  - One Week Prior to Meeting
- TECHNICAL and MANAGEMENT REVIEW
- ADMINISTRATIVE REVIEW (Parallel Process)
- NUCLEAR GENERAL REVIEW COMMITTEE
  - Quarterly Meetings
  - Briefings and Telecon Votes
- FINAL SIGNATURE

LICENSE AMENDMENT APPROVAL

Time Goes By

LICENSE AMENDMENT IMPLEMENTATION

- IMPLEMENTATION PLAN
  - Developed and Approved by the LARB
  - Input to Corrective Action System by Licensing Engineer
    - Precursor Card (PC)
  - Actions Assigned to Responsible Organizations
    - Completed Actions Approved by Responsible Organizations
    - PC Closure Approved by Licensing
- LICENSE AMENDMENT REVIEW
  - Licensing Engineer
  - LARB
  - Administrative
- DOCUMENT CONTROL DISTRIBUTION

PTN LICENSING PROCESS

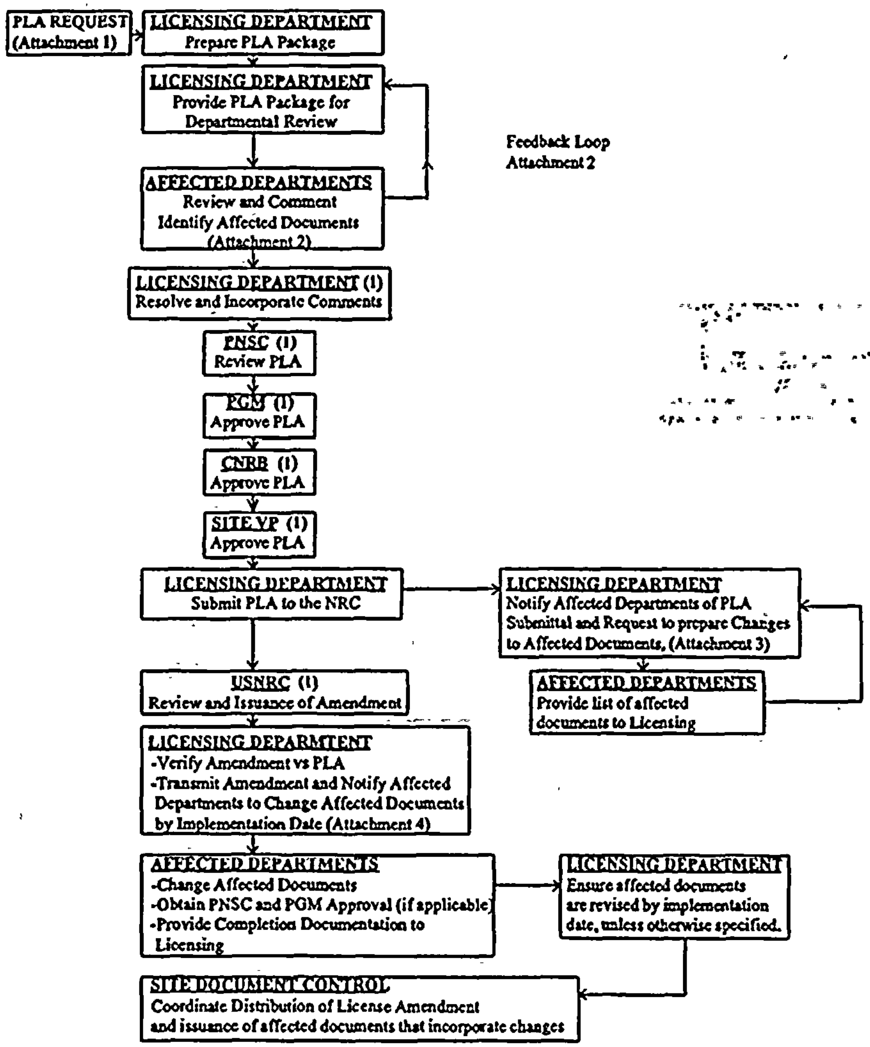
Presented by:

Steve Franzone

February 1, 2000

PTN LICENSING PROCESS

ENCLOSURE 1
(Page 1 of 1)
PROPOSED LICENSE AMENDMENT FLOWCHART



NOTE (1): If PLA is cancelled, all affected Departments shall be notified accordingly. Attachment 5 or similar form.

PTN LICENSING PROCESS

SITE LICENSING CORRESPONDENCE REVIEW SHEET

L-2000-018

SITE VP DUE DATE 1/26/00
NRC DUE DATE: 2/3/00

SUBJECT: Reactor Operator - License Renewal

Please identify on the attached copy those action items, which are your responsibility, and have not been completed/implemented. Licensing will track the identified items on CTRAC.

Note: Nuclear Policy NP-309 states that the person whose signature or initials have been applied to this document acknowledges personal knowledge of and accepts full responsibility for the correctness of the information contained in the document. If a person is only initialing a particular element of this document, that in turn is the extent of his responsibility, and shall be identified as such.

PLEASE REFER ALL QUESTIONS TO RESPONSIBLE LICENSING ENG.: OLGA HANEK X-6607

DOCUMENT REVIEW

REVIEWER	TITLE/DEPARTMENT	SIGNATURE/DATE
T. O. Jones	Operations Manager	
S. M. Franzone	Licensing Manager	

PNSC REVIEW: N/A
PNSC CHAIRMAN

PNSC MEETING No. N/A

Plant General Manager

See Attached
Vice President

Proofread: ____________
(Name)

CNRB REVIEW: N/A
(Meeting Number / Date)

DOCUMENT NOTARIZED N/A
(Name)

DOCUMENT DATE STAMPED ____________
(Name)

I have opened and/or closed the items listed below in CTRAC: ____________
(Originator/date)

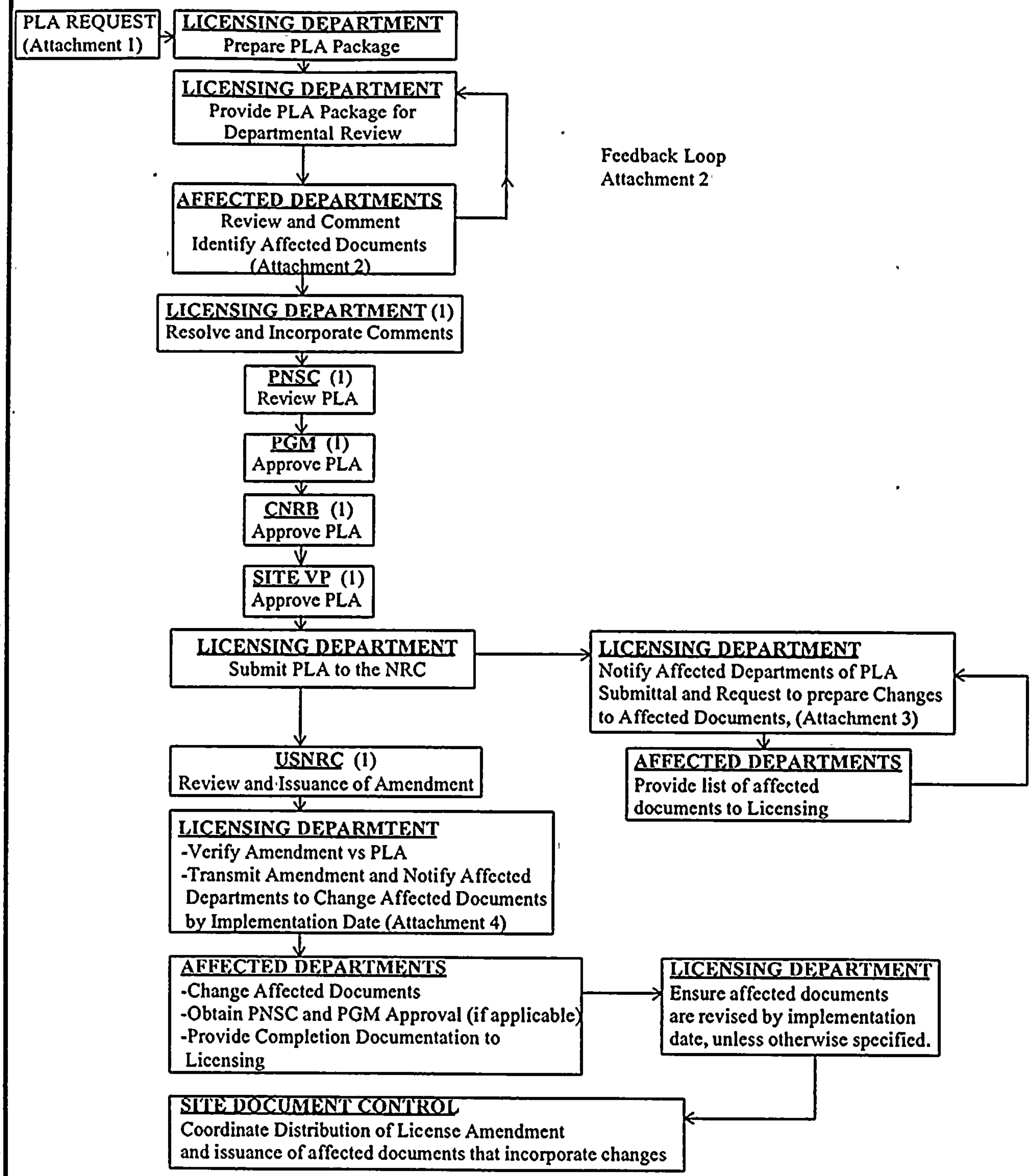
CTRAC CLOSED:
980273, 940217

CTRAC OPENED:

Letter mailed to NRC ____________
(Name/date)

Emailed to PCC ____________
(Name/date)

ENCLOSURE 1
(Page 1 of 1)
PROPOSED LICENSE AMENDMENT FLOWCHART



NOTE (1): If PLA is cancelled, all affected Departments shall be notified accordingly. Attachment 5 or similar form.

SITE LICENSING CORRESPONDENCE REVIEW SHEET

L-2000-xxx

SITE VP DUE DATE 1/26/00
NRC DUE DATE: 2/3/00

SUBJECT: Reactor Operator - License Renewal

Please identify on the attached copy those action items, which are your responsibility, and have not been completed/implemented. Licensing will track the identified items on CTRAC.

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PLEASE REFER ALL QUESTIONS TO RESPONSIBLE LICENSING ENG.: OLGA HANEK X-6607

DOCUMENT REVIEW

REVIEWER	TITLE/DEPARTMENT	SIGNATURE/DATE
T. O. Jones	Operations Manager	
S. M. Franzone	Licensing Manager	

PNSC REVIEW: N/A
PNSC CHAIRMAN

PNSC MEETING No. N/A

Plant General Manager

See Attached
Vice President

Proofread: ______________
(Name)

CNRB REVIEW: N/A
(Meeting Number / Date)

DOCUMENT NOTARIZED N/A
(Name)

DOCUMENT DATE STAMPED ______________
(Name)

I have opened and/or closed the items listed below in CTRAC: ______________
(Originator/date)

CTRAC CLOSED:
980273, 940217

CTRAC OPENED:

Letter mailed to NRC. ______________
(Name/date)

Emailed to PCC ______________
(Name/date)

Risk-Informed Regulatory Activities

UNITED STATES NUCLEAR REGULATORY COMMISSION

Risk-informed regulation

PRA results/insights + deterministic insights

SECY-95-126
NRC Policy Statement on use of PRA

- PRA should be used in regulatory matters to the extent supported by the state of the art
- PRA should be used to reduce unnecessary conservatism
- PRA evaluations should be as realistic as possible
- PRA uncertainties need to be considered in applying Commission's safety goals

Major Areas of Risk-Informed Regulation

- Licensing
- Inspection
- Enforcement
- Performance Assessment

Significant Licensing Documents

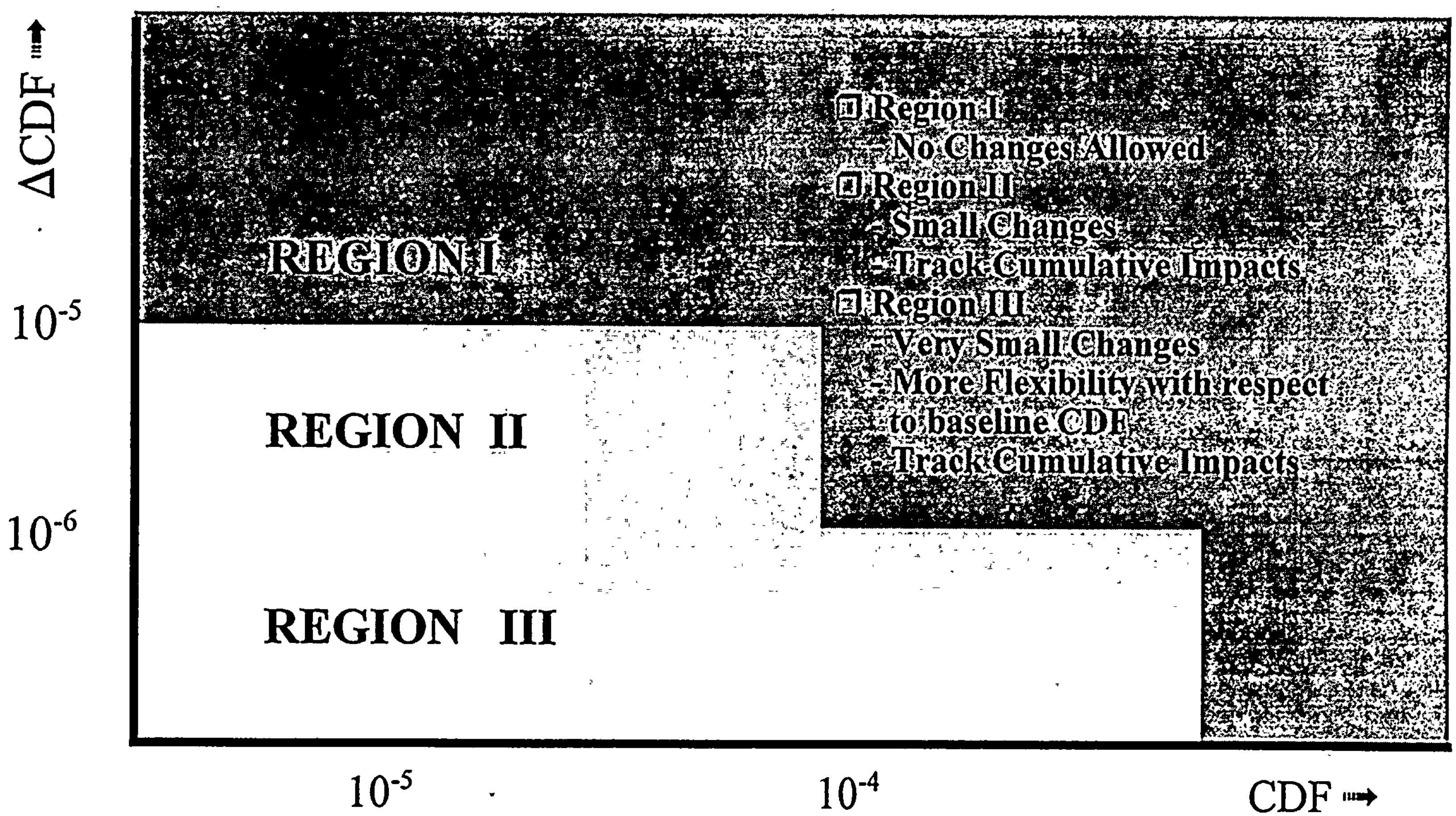
- RG 1.174 Changes to licensing basis
- RG 1.175 Inservice Testing
- RG 1.176 Graded Quality Assurance
- RG 1.177 Technical Specifications
- RG 1.178 Inservice Inspection

Principles

Risk-informed Integrated Decisionmaking

- Meets current regulations
- Defense-in-depth
- Maintain safety margin
- Increased CDF or risk is small
- Monitoring

RG 1.174 Figure 3



Acceptance Guidelines for Core Damage Frequency (CDF)

Risk-Informed Licensing Action

...any activity that uses risk assessment insights or techniques to provide a key component for determining acceptability of the proposed action

Risk-Informed Licensing Actions

- Special administrative handling
  - Unique identifier
  - Priority 2
  - Management review
- Technical review
  - Traditional deterministic review
  - Assessment of strengths and weaknesses of risk evaluation
  - Balance between deterministic and risk components

Risk-Informed Licensing Actions

- Most common types
  - Diesel generator allowed outage time extension
  - ECCS allowed outage time extension
  - Risk-informed ISI, IST
- Statistics
  - Total RILA: ~110
  - Approved to date: ~70

Management Oversight

- Risk-Informed Licensing Panel
- Resolution of conflicts
- Improved timeliness and efficiency

- SECY 99-246 (10/12/99)
  - Requested approval of proposed interim guidelines
- SRM-99-246 (1/5/00)
  - Commission approved staff approach

Risk-Informed Technical Specifications

- LCO required action end states
- Mode change flexibility
- Missed surveillances
- Risk-informed completion times
- LCO 3.0.3
- Operability definition
- Surveillance requirements coordinated with Maintenance Rule

Risk-Informed Part 50

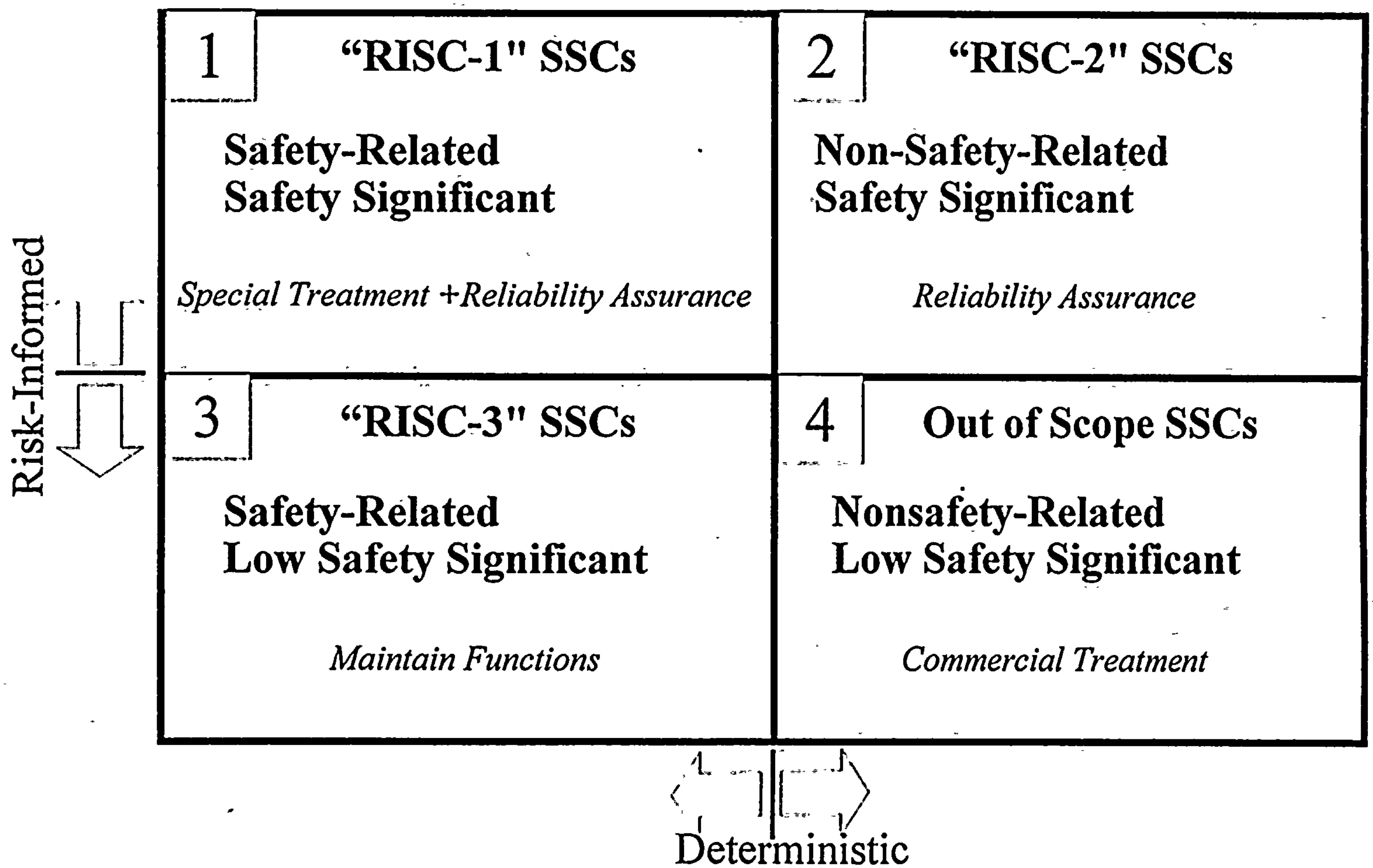
- SECY-98-300: Options for Risk-informed Revisions to 10 CFR Part 50, December 23, 1998

- "Option 1" - Current rulemaking activities
  - 10 CFR 50.59
  - 10 CFR 50.72, 50.73
  - 10 CFR 50.55a

Risk-Informed Part 50 (cont.)

- SECY-99-256, "Rulemaking Plan for Risk-Informing Special Treatment Requirements"
  - Modified scope of SSCs subject to special treatment requirements such as EQ
  - Reduce unnecessary burden for large number of low safety-significant SSCs
  - Pilot plant exemptions: South Texas, others
  - Final rule planned for early 2002

Risk Categorization and Regulatory Treatment



Risk-Informed Part 50 (cont.)

- SECY-99-264, “Proposed Staff Plan For Risk-Informing Technical Requirements in 10 CFR Part 50"
- Office of Nuclear Regulatory Research study underway

DIVISION OF LICENSING PROJECT MANAGEMENT

ROLE OF PROJECT MANAGER

UNITED STATES NUCLEAR REGULATORY COMMISSION

KAHTAN JABBOUR

DLPM FUNCTIONS

- ***LICENSING AUTHORITY***
  - ***Licensing Actions***
  - ***Mandated Controls***
  - ***Other Licensing Tasks***
- ***INTERFACES***
  - ***Licensees/Owners Groups***
  - ***Regions***
  - ***Headquarters***
  - ***Public***
- ***REGULATORY IMPROVEMENTS***
- ***TOTAL OF 75 SPECIFIC TASKS***

EXAMPLES OF LICENSING AUTHORITY TASKS

LICENSING ACTIONS

- Amendments (TS & USQ)
- Exemptions
- Reliefs
- License Transfers
- NOEDs
- Lead Plant Reviews

MANDATED CONTROLS

- Bases Changes
- UFSAR Reviews
- 50.59 Reviews
- QA, Security, EP Reviews

OTHER

- TIAs
- 2.206s
- Backfits
- Plant-Specific MPAs
- Commitment Management
- Hearing Support

EXAMPLES OF INTERFACE TASKS

LICENSEES/ OWNERS GROUPS

- ROUTINE COMMUNICATIONS
- SITE VISITS/DROP-INS
- LEAD ON TECH ISSUES (MPAs, GSIs, USIs)

NRC REGIONS

- MORNING CALLS
- MGMT. OVERSIGHT PANELS
- ROUTINE COMMUNICATIONS
- TS INTERPRETATIONS
- ENFORCEMENT SUPPORT
- EVENT FOLLOWUP

NRC HQ

- MGT. INFO. & STATUS REPORTS
- MISC. LICENSEE REPORTS
- INCIDENT RESPONSE
- LIC. RENEWAL SUPPORT
- GENERAL SUPPORT TO OTHER OFFICES
- SURVEYS

PUBLIC

- CONTROLLED CORRESPONDENCE
- ALLEGATIONS
- FOIAs
- PLANT INFO WEB PAGE SUPPORT

EXAMPLES OF REGULATORY IMPROVEMENTS TASKS

- *LATF*
- *OWNERS GROUP INTERACTIONS*
- *NRR OFFICE LETTERS*
- *REDEFINITION EFFORT*
- *DLPM HANDBOOK*
- *RULEMAKING*
- *RISK INFORMED EFFORTS*
- *LICENSING WORKSHOPS*

TASK EVALUATION

- ***PERFORMANCE MEASURES INCLUDE:***
  - *Timeliness*
  - *Effectiveness*
  - *Efficiency*
  - *Quality*
  - *Quantity*

- ***TASKS PRIORITIZED WITH RESPECT TO STRATEGIC OUTCOME GOALS***
  - *Maintain Safety*
  - *Reduce Unnecessary Regulatory Burden*
  - *Increase Public Confidence*
  - *Increase Internal Efficiency & Effectiveness*

- ***RESOURCE ESTIMATES***

FP&L/FPC/NRC LICENSING WORKSHOP
St. Lucie site
Jensen Beach, Florida
February 1-2, 2000

On a scale of 1 to 10, please provide an *overall* rating for workshop effectiveness_______.

Excellent	Very Good	Good	Fair	Unsatisfactory
10--------9-	--8-------7-	--6-------5--	--4-------3-	----2------1--

1. COMMENT ON FORMAT AND CONTENT OF THE WORKSHOP.

____

____

____

____

2. WHAT WERE THE WORKSHOP'S STRENGTHS?

____

____

____

____

3. WHAT WERE THE WORKSHOP'S WEAKNESSES?

____

____

4. WHAT WOULD YOU CHANGE FOR FUTURE WORKSHOPS?

5. HOW WILL YOU USE WHAT YOU'VE LEARNED AT THE WORKSHOP?

6. SHOULD THESE WORKSHOPS BE HELD PERIODICALLY AND, IF SO, AT WHAT FREQUENCY?

7. OTHER COMMENTS?