Florida Power
CORPORATION
Crystal River Unit 3
Docket No. 50-302

August 8, 1995
3F0895-12

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 2055

Subject: Information on the EPRI TC Tools Fire Model

Reference: FPC to NRC letter, 3F0795-02, dated July 6, 1995

Dear Sir:

Florida Power Corporation (FPC) submitted information on the development and use of the EPRI Tailored Collaboration (TC) Fire Modeling Tools in response to NRC staff questions from our April 25, 1995 public meeting on the subject. The information was submitted as Attachment 2 to the above referenced letter. Also submitted were affidavits requesting that the information contained in the Attachment be withheld from public disclosure on the grounds that it contained information proprietary to EPRI.

The attached information on the TC Tools is being submitted as a non-proprietary version of the proprietary document that was previously submitted.

Sincerely,

P. M. Beard, Jr.
Senior Vice President
Nuclear Operations

PMB/SCP:ff

Attachment

xc: Regional Administrator, Region II
Senior Resident Inspector
NRR Project Manager

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Additional Information on Derivation and Use of the EPRI TC Tools

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Total Heat Load Concept

A total heat load concept has been postulated as a method to assess the response of fire barrier systems to realistic fire exposure conditions. This concept suggests that the area under the incident heat flux-time curve, which is the total heat load incident on a fire barrier assembly, will be approximately the same to cause failure of a fire barrier assembly independent of the exposure history. The concept permits ASTM E-119 fire endurance test results to be interpreted in terms of other, more realistic fire exposure conditions.

Traditionally, fire exposure conditions have been expressed in terms of a temperature history. The standard time-temperature curve specified in the ASTM E-119 standard is an example of such a specification. In the past, an "equal area" concept first proposed by Ingberg has been used, despite the lack of a physical basis, to equate the "severity" of fires with different time-temperature histories. This concept postulates that the area under the time-temperature curve above a baseline temperature of 68°F (20°C) is representative of the fire severity. Under this concept, two fires with different temperature histories are considered to have equivalent severities when the areas under the two time-temperature curves are the same.

A major limitation of the Ingberg "equal area" hypothesis is its failure to account for the fourth power dependence of radiative heat flux on temperature. In large part, the incident heat flux on a fire barrier imposes the potential for damage and destruction of the fire barrier. In a fully-developed enclosure fire, radiative heat flux dominates the heat transfer mechanisms because of the relatively high temperatures involved and the optical thickness of the fire gases. Consequently, the "severity" of a fire can be better described in terms of the incident radiative heat flux, and its fourth power dependence on temperature, than in terms of the first power temperature dependence of the area under the time-temperature curve.

Here, a different "equal area" concept, called the total heat load concept, is postulated. The total heat load concept is based on the premise that the area under the incident heat flux-time curve, rather than the time-temperature curve, will be approximately the same to cause failure of a given fire barrier assembly independent of the exposure history. A sample of published references that suggest the value and validity of the total heat load concept include:

- Harmathy and Mehaffey (1983) developed the concept of a normalized heat load to characterize the destructive potential of a post-flashover fire in terms of the heat flux history penetrating the fire barriers. This concept is similar to the total heat load concept proposed here.

- Harmathy (1980) also suggested that a single parameter referred to as the 'heat load' and obtained as the time integral of the heat flux history is sufficient to uniquely characterize the destructive potential of fires with respect to fire barriers made from the same materials.

- Bletzacker (1986) developed a total heat load concept to evaluate the fire exposure of exterior walls. He notes that the severity of a room fire in terms of the fire barriers can be measured as the incident thermal flux during the exposure fire. He further notes that early in the stage of full

fire development, convective heating builds to a maximum level, then remains essentially constant, usually constituting 20 percent or less of the total heat flux on the fire barrier.

Physically, the area under the incident heat flux-time curve is the total heat load per unit surface area incident on the fire barrier assembly. Only a fraction of this incident heat load will actually be absorbed by the fire barrier assembly. The rest will be rejected by radiation and convection from the surface of the fire barrier assembly. For the total heat load concept to work, it is considered that this fraction remains fairly constant regardless of the fire exposure history. It is also considered that the total heat load incident on a fire barrier assembly required to cause "failure" of the assembly is relatively constant and is relatively independent of the exposure history of the fire barrier system.

1. Fire Test Conditions

The heat flux incident on the surface of the fire barrier assembly is considered to be dominated by radiation from the fire gases in the ASTM E-119 fire test and therefore can be characterized in terms of the effective radiant flux from these gases. Further, the effective radiant flux emitted by the gases in the fire test furnace is considered to be equivalent to the blackbody radiation from a source whose temperature varies in accordance with the E-119 temperature-time curve. This is consistent with work by Lie (1973) who noted that the effective flux in the fire test furnace can be taken as equivalent to the blackbody radiation from a source whose temperature varies in accordance with the standard E-119 temperature-time curve.

The incident heat flux, q_i, at the surface of a fire barrier assembly in an ASTM E-119 test can be estimated as:

$$q_i = \sigma T_g^4 \qquad \text{(eq. 1)}$$

where:

σ is the Stefan-Boltzmann constant, equal to 1.714×10^{-9} Btu/hr-sq. ft.-R^4, and

T_g is the absolute temperature of the gases in the enclosure ($^\circ$R) which follows the ASTM E-119 temperature-time curve.

The total heat load per unit area of fire barrier surface (under E-119 test exposure) is equal to the area under the incident heat flux-time curve. Its value is determined by integrating the heat flux-time curve with respect to time:

$$q_t = \int q_i \, dt \qquad \text{(eq. 2)}$$

Typically for qualification, fire barrier assemblies are subjected to the time-temperature history specified in the ASTM E-119 fire test standard. This standard time-temperature history and the incident heat fluxes and total heat loads associated with it are tabulated in Table 1 and plotted in Figures 1a, 1b, and 1c.

The total heat load values in the table were evaluated by integrating the incident heat flux values using the trapezoidal rule.

Table 1

Heat Flux and Heat Load Calculations - ASTM E-119

Time (min)	Temperature (F)	Temperature (R)	Inc Heat Flux (Btu/s-sf)	Total Heat Load (1000Btu/sf)
0	68	538	0.0	0.0
5	1000	1470	2.2	0.34
10	1300	1770	4.7	1.37
15	1399	1869	5.8	2.94
20	1462	1932	6.6	4.81
25	1510	1980	7.3	6.90
30	1550	2020	7.9	9.18
60	1700	2170	10.5	25.80
90	1792	2262	12.5	46.51
120	1850	2320	13.8	70.12
150	1888	2358	14.7	95.76
180	1925	2395	15.7	123.08

See Figures 1a, b. and c on the next page.

Figure 1a
Time Temperature Profile for E-119

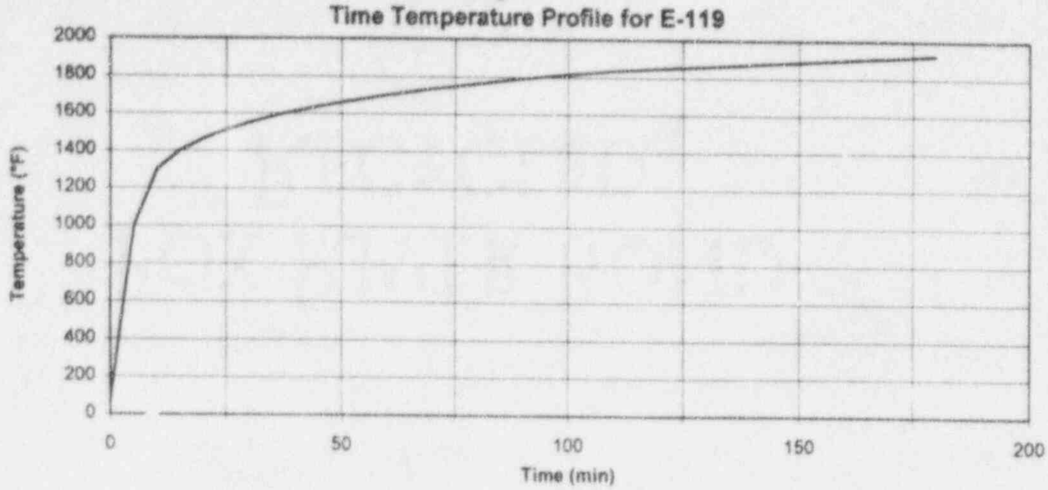


Figure 1b
Time Heat Flux Profile

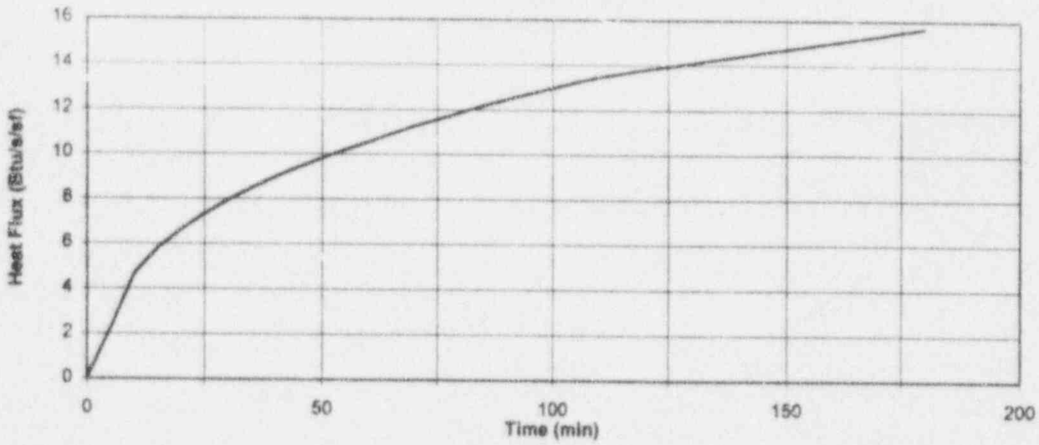
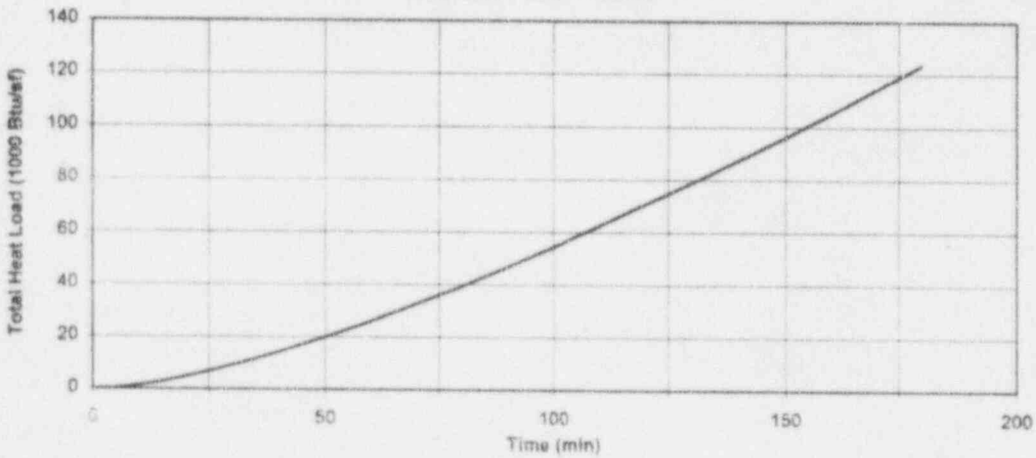


Figure 1c
Total Heat Load Profile



2. Actual Fire Conditions

The total heat flux incident on the surface of a fire barrier assembly under actual fire conditions is a combination of radiation and convection. Convection dominates at relatively low exposure temperatures, when the total incident heat load is relatively low in comparison with actual post-flashover fire conditions. Radiation dominates at relatively high exposure temperatures, representative of actual post-flashover fire conditions, when the total incident heat load is relatively high. For typical post-flashover scenarios, the convective component of the total incident heat load will be negligible compared with the radiant component.

The relative roles of radiative and convective heat fluxes on fire barriers are considered from a theoretical standpoint. Consider a conduit or some other target immersed in a layer of gases at uniform temperature T_g. The target has a surface temperature of T_s. The target is heated by both radiation and convection from the gases in which the target is immersed. The layer of gases is considered to be optically thick, such that the target views only the gases at temperature T_g.

(Equations removed as Proprietary Information)

The relationship is plotted in Figure 2 for a range of gas and surface temperatures, using a value of h_c = 0.00122 Btu/s/ft^2-R, a value suggested in the literature for post-flashover fires. Data is plotted for $T_g - T_s$ = 5, 100 and 500°F. Because Thermo-Lag has been shown to be a relatively good insulator, it is expected that the difference between surface temperature and gas temperature will be small; the data for $T_g - T_s$ = 5 and 100° is therefore taken as representative of actual conditions. The figure shows that radiation dominates the total heat flux for gas temperatures in the range of interest (between where cable damage may occur without wraps and the E-119 gas temperature at the completion of a test), accounting for more than 70% of the total heat flux for all gas temperatures in the range of interest. For relatively high gas and surface temperatures, radiation typically accounts for more than 90% of the total heat flux. Convection is most important at temperatures near room temperature, when it accounts for up to about 80% of the total heat flux according to these calculations. However, this is outside the range where wraps perform a useful function.

The total incident heat flux of the surface of a fire barrier under actual fire barrier conditions is the radiative heat flux plus the convective heat flux.

(Equations removed as Proprietary Information)

Figure 2 also shows the contributions of radiation and convection to the total incident heat flux over temperatures from 100°F to 2000°F. Note that the convection contribution is minor at all temperatures.

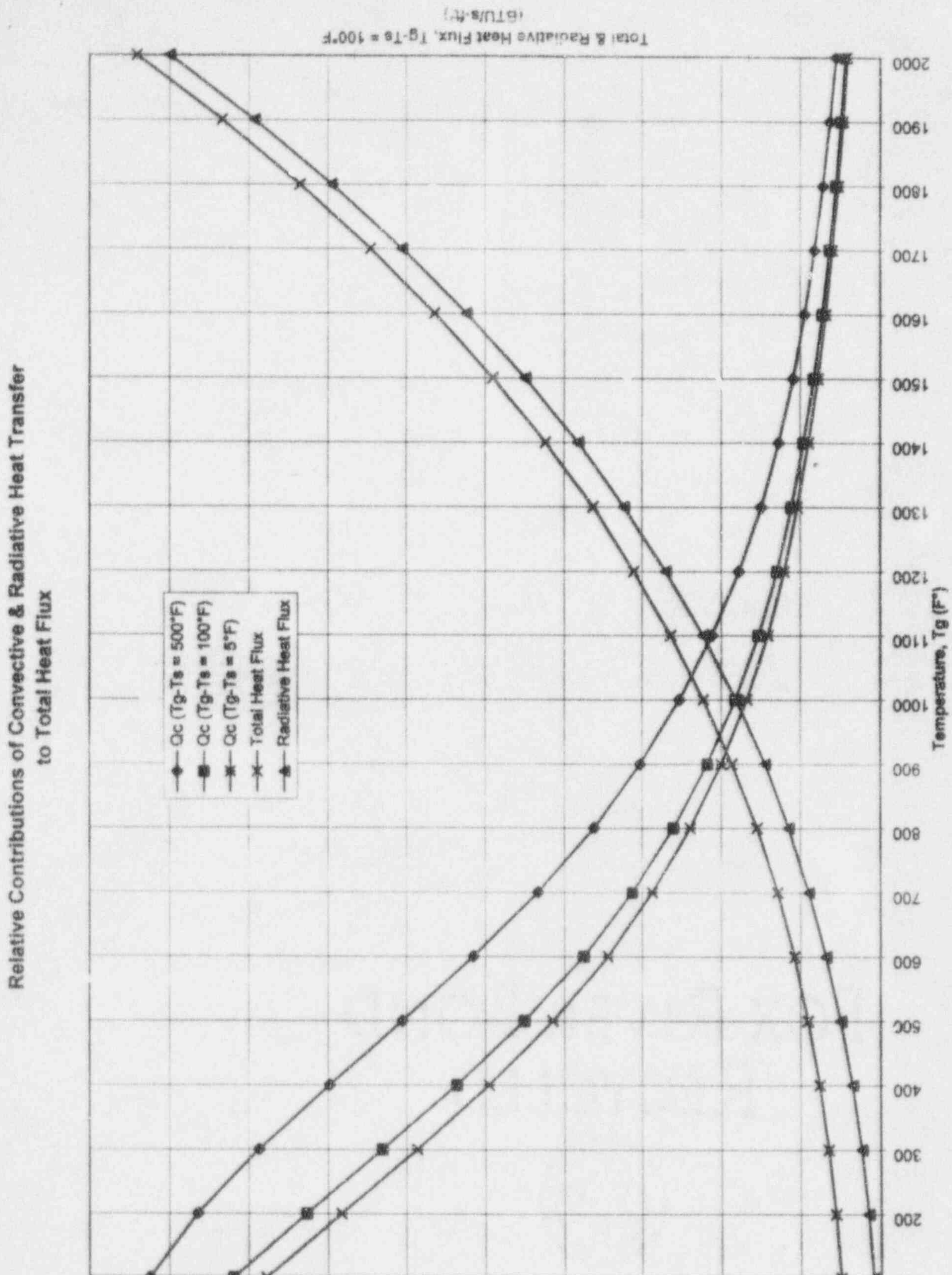

Relative Contributions of Convective & Radiative Heat Transfer
to Total Heat Flux
Qc (Tg-Ts = 500°F)
Qc (Tg-Ts = 100°F)
Qc (Tg-Ts = 5°F)
Total Heat Flux
Radiative Heat Flux
Total & Radiative Heat Flux, Tg-Ts = 100°F
(BTU/s-ft²)
Convective Contribution to Total Heat Flux
Temperature, Tg (F°)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

Figure 2

APPLICATION PROCEDURE

The procedure for using the total heat load concept to evaluate the expected response of a fire barrier assembly to fire conditions different from the ASTM E-119 standard time-temperature history can be summarized as follows:

1. Determine the time to failure of the fire barrier assembly in the standard ASTM E-119 fire test.

2. Use Table 1 or Figure 1 to evaluate the total heat load (Btu/ft^2) required to cause failure of the tested assembly in the standard ASTM E-119 test.

3. Determine the time-temperature history at the fire barrier assembly for a realistic fire scenario. The hazard tool or other analysis tools can be used for this evaluation.

4. Convert the realistic time-temperature curve to an incident heat flux-time curve.

5. Evaluate the area under the realistic incident heat flux-time curve. This is the actual heat load.

6. Determine the time when the actual total heat load equals the failure total heat load determined in Step 2. This is the actual fire barrier failure time for the realistic fire scenario being evaluated.

EXAMPLE APPLICATION

A thermo-Lag raceway with a 20-minute fire rating is subjected to the temperature profile shown in Figure 3. Determine the duration of cable protection provided under the actual fire exposure.

1. Figure 4 shows the incident heat flux calculated for the E-119 exposure and shows the total heat flux for the actual exposure in Figure 3.

2. Figure 5 shows the calculated total heat load

3. The 20-minute E-119 exposure to which the Thermo-Lag covered raceway was exposed is determined from figure 5 to be approximately 5000 BTU/ft^2 (4810 per Table 1). By comparison, the total heat load for the actual exposure is also approximately 5000 BTU/ft^2 at 60 minutes.

4. Therefore, the cable protection provided by the installed Thermo-Lag is approximately 60 minutes under the actual exposure.

Figure 3
Time Temperature Exposure for Example Application

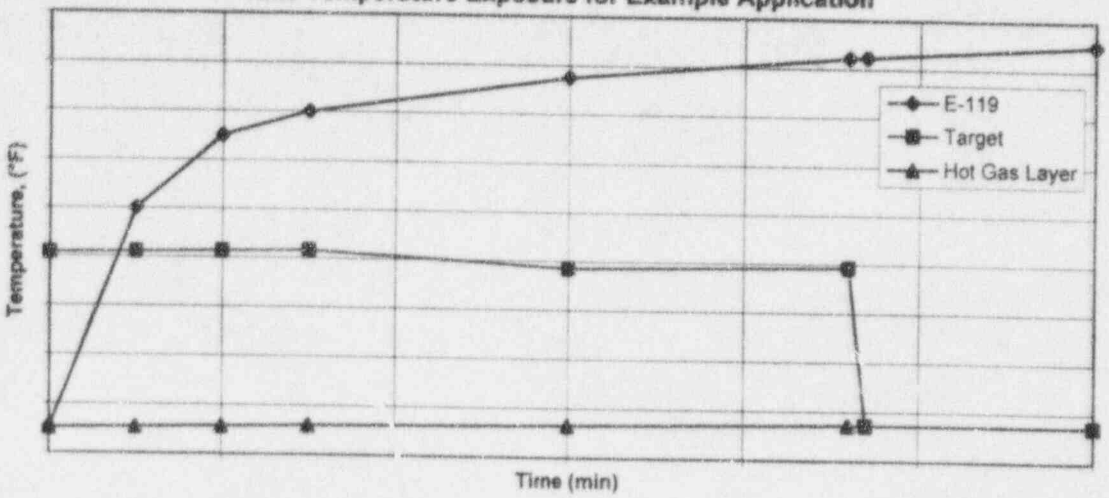


Figure 4
Incident Heat Flux for Example Application

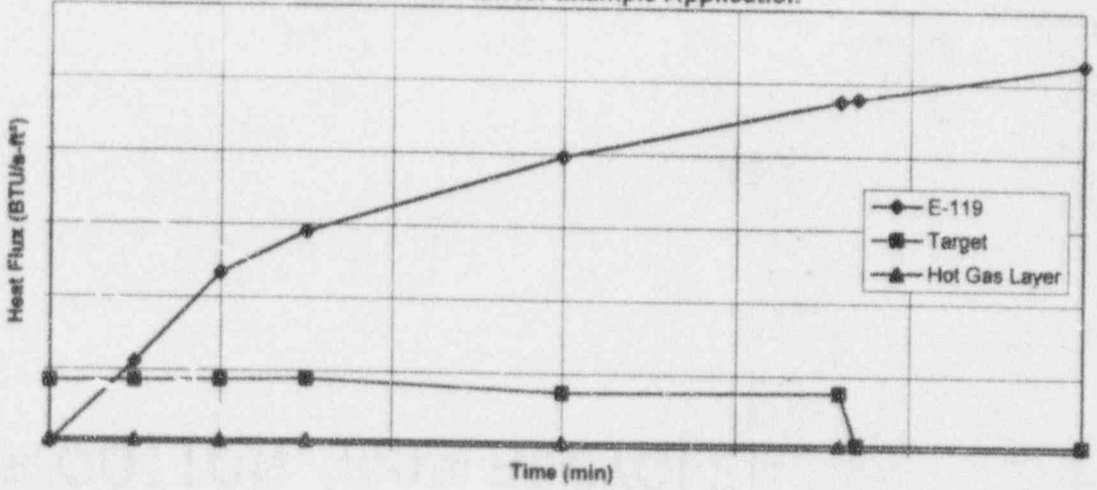
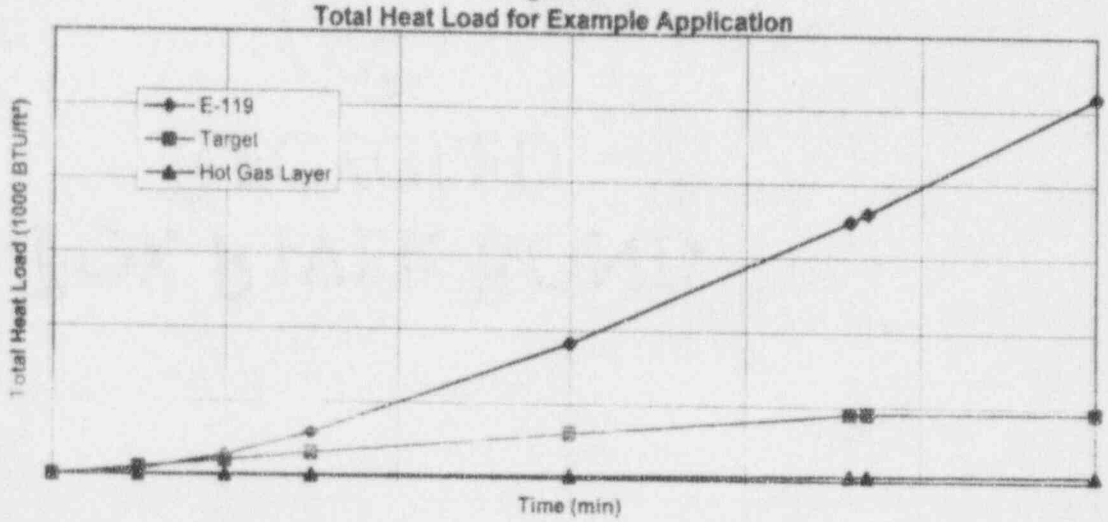


Figure 5
Total Heat Load for Example Application



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1. Bletzacker, R.W., "Fire Exposure of Exterior Walls," *Building Standards*, International Conference of Building Officials, Whittier, CA, September-October 1986.

2. Harmathy, T.Z., "The Possibility of Characterizing the Severity of Fires by a Single Parameter," *Fire and Materials*, Vol. 4, p. 71, 1980.

3. Harmathy, T.A. and J.R. Mehaffey, 1983, "Post-Flashover Compartment Fires," *Fire and Materials*, Vol. 7, No. 2, pp. 49-61, 1983.

4. Lie, T.T. and W. W. Stanzak, 1973, "Fire protection of Unprotected Steel Members," *Journal of Structural Division, National Research Council of Canada*, May 1973.

IMPACT OF ROOM CHARACTERISTICS

The FIVE models are based on correlations developed in square, empty rooms with smooth walls and ceilings. Typical power plant rooms rarely exhibit these properties. Fortunately, the room configurations used to develop and test the correlations used by FIVE can be shown to be conservative when applied to typical power plant rooms.

The concerns about differences between lab and actual room configurations are:

- The test rooms were empty except for the fire source. Plant rooms typically are crowded with piping, cables, etc.
- Power plant rooms may have obstructions and/or pockets that will trap hot gases and increase fire severity.
- The fire sources used to develop the correlations were located in the middle of the room.
- Because power plant rooms are not rectangular, the models will have to determine the effects of a fire on targets around corners.

The presence of intervening objects will decrease the severity of a plume or ceiling jet exposure by breaking the plume up. This will diffuse the plume and cause it to entrain more cool air. Intervening objects may also act to shield potential targets from the full effects of a plume or ceiling jet exposure.

The Fire Hazard Tool has the flexibility to deal with irregular room geometries. The effects of trapping air pockets can be evaluated by calculating the hot gas layer for the smaller volume. The model also differentiates between a confined and unconfined ceiling jet condition. When a fire is located such that ceiling obstructions limit ceiling jet dispersal, the appropriate exposure temperature calculation method is applied.

The Hazard Tool allows location factors to be applied to fire sources located against a wall or in a corner. The actual heat release rates are multiplied by a location factor to determine a virtual heat release rate that is used for the modeling calculations. The location factors are applied to account for reradiation and geometry effects of the plume and ceiling jet temperatures.

The major concern with regard to room corners is the effect on ceiling jet. The presence of a corner will act to diffuse and distort the ceiling jet, causing it to mix more quickly with the hot gas layer. Using the ceiling jet correlations developed for a straight room will therefore be conservative.

EFFECTS OF FORCED VENTILATION

The EPRI Hazard Tool uses a simplified approach which is shown below to account for any potential effects of forced ventilation.

Potential concerns associated with this issue are that forced air may:

- increase the heat release rate (HRR) of a fire by fanning.
- cause a fire to propagate faster than it would in still air.
- distort the plume and/or ceiling jet and radically change the level of exposure to intervening combustibles or targets.

A simplified approach which is applicable for both ventilated and unventilated areas will be technically adequate in assessing potential hazards at Crystal River. Several cable fire tests have been conducted to judge the effects of ventilation on cable fires. The results and conclusions of these tests indicate that while ventilation may affect fire severity in some cases, the effects of the ventilation are small and are enveloped by the conservative assumptions in the EPRI Hazard Tool. Fire test data indicates that forced ventilation reduces plume and hot gas layer temperatures. Therefore, ignoring ventilation would be conservative. Tests of both burning and smoldering groups of cables in a well ventilated corridor, shows peak temperature reductions of approximately 25% and 40% for low and high ventilation rates respectively. Additionally, the Tool uses conservative combustible material burning characteristics and conservative field identification of fire scenarios which, through comparison with actual test data, are adequate to account for the potential concerns, should they actually exist in real plant situations. Also, in the event that forced ventilation is an issue in some plant compartments, its impact on fire severity may be very limited as many plant ventilation systems are tripped and isolated in the event of a fire.

Ventilation Effects on Hazard Tool Heat Release Rates

Two separate fire tests done to study the effects of ventilation on cable fires indicate that forced ventilation does not cause a measurable change in cable heat release rates. The first test report lists heat release rates that are in agreement with values recommended for use by the Hazard Tool. It should be noted that because the testers wanted to test the adequacy of a sprinkler system for a very robust fire, the cables in the cable trays for test 3 were arranged (low cable density and weaving) in order to achieve maximum fire burn rates.

The second test report states that "the effects of ambient ventilation on the burning rate of the fuel are small." The tests, which were performed to study the effects of ventilation on the ability to detect cable fires in a corridor, shows that the measured temperatures for the fires decrease in the presence of ventilation.

In the unlikely event that the heat release rate is increased by forced ventilation, the Hazard Tool will still produce conservative results because it uses very conservative effective heat release rates (HRR) to determining plume/ceiling jet temperatures. The heat release rates were determined by bench scale tests which included forced ventilation.

Conservatisms related to plume temperature calculation are as follows:

- HRR is taken to be the peak HRR occurring during a "free burn". In reality, if IEEE 383 cable is ignited (which can be difficult), the HRR grows from zero at time = 0, to a peak value over 10 to 30 minutes, depending on the cable type. The HRR used is therefore very conservative, especially in the early period of the fire development.
- The highest cable Peak HRR is typically selected from the values available. The value is approximately twice the average peak HRR for all the IEEE 383 cable types listed.
- All cable tray judged to burn is assumed to start burning at time = 0. The area selected is based on a conservative interpretation of test data and accounts for potential cable fire propagation. As with the use of the peak HRR, the assumption that the entire area is burning in the beginning of the event introduces considerable conservatism especially in the early period of the fire development.
- The Hazard Tool ignores compartment heat losses due to ventilation. Under high ventilation conditions, this can represent a significant decrease in the peak hot gas layer temperature resulting in a substantial decrease in plume temperature. Again, this is peak temperature, and the temperatures early in the event may be significantly lower.

This conservatism is sufficient to account for any potential increase in HRR from forced ventilation.

Ventilation Effects on Flame Spread

For additional information, see the discussion on "Fire Propagation in Cable Trays."

Plume and Ceiling Jet Distortion Due to Forced Ventilation

The potential issue here is that a plume may not be completely vertical in the presence of forced ventilation, and that this could cause intervening combustibles and/or targets not expected to be in the plume to see plume type exposures.

The hazard tool procedure employs field engineering inspection to define the combustibles potentially involved in fire scenarios. In distinguishing between plume or hot gas layer exposure for a specific target which is close to the boundary, the most conservative is selected.

In order to quantify the change in plume geometry occurring in a compartment with high ventilation rate, the following calculations are performed:

- The deflection angle of a plume can be simply calculated by comparing the upward velocity of the fire plume with the room air velocity due to ventilation. Observations of cable fires have found plume vertical velocities on the order of 2 m/s (6.6 ft./s) for IEEE-383 cable fires. For the purposes of evaluating the deflection of a plume, this number is conservative, because any fire with a smaller upward velocity would be too small to be considered a serious hazard. A room air velocity can be calculated by dividing the volumetric flow due to forced ventilation by the cross sectional area of the room.

  Va = Volumetric Flow/Room Cross Sectional Area
  Vp = Upward Velocity of the Plume
  $\alpha_p = \text{Tan}^{-1}\, Va/Vp$

- This angle α_p is in the 1° to 10° range for a typical room with 10 air changes per hour. The 10° translates to a 1.8 foot offset for a target 10 feet above the fire source. This small offset puts the target sufficiently close that it would be considered, under field judgment conditions, to be on the boundary and, therefore, within the plume region. Additionally, as a high ventilation rate is expected to substantially cool the buoyant gases in the plume, the impact of the combustibles located on the fringes of the plume region is expected to be minimal.

If the fire is immediately in front of a ventilation supply duct, the possibility of high localized air velocities could impact plume geometry. However, test data indicates that strong local ventilation tends to weaken plume effects by causing plume diffusion and entraining cooler air. EPRI NP-1630 demonstrates a 40% drop in peak temperatures when the fire source is approximately 4 feet from the ventilation duct. In the event the source is close enough to displace the plume significantly, the temperature exposure to adjacent targets, that would not already have been in the plume, is expected to be less than ignition or damage temperatures.

FIRE PROPAGATION IN CABLE TRAYS

The EPRI Hazard Tool accounts for fire propagation in a simple, yet conservative fashion. The total area of cable tray shown to burn in fire tests is assumed to burn at the start (time = 0) of a fire scenario. This simplified approach eliminates the need to account for time-dependent fire propagation, yet it is conservative in that it includes all cables that burn in the test.

The properties of cable tray fires are described below. The ignition temperature is 932°F, which is consistent for a variety of sources.

The heat release rate for cable fires is 0.45 times the values repeated in Table 1-E of FIVE. If plant specific cable types are not known or not found in the table, the highest value for (qualified or non-qualified) cable should be used.

The initial affected area for a horizontal tray is the area (footprint) of the plume, unless the ceiling jet causes a larger region to be above 932°F.

The heat content for cable should be the value used in the FHA times (a fractional factor) to account for incomplete burning.

For calculating the tray area invloved in a fire, assume the following:

In vertical trays propagation is assumed from the point of ignition to the top. Inclined trays are treated as vertical trays. In horizontal trays the fire is modeled differently for qualified and non-qualified cable. For qualified cable, assume horizontal spread only when fire spreads from one tray to the next, and then at an angle on either side of the vertical according to the description in "A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories 1975-1987" by S.F. Nowlen. The tested configuration was a 7 x 2 array of cable trays separated per Regulatory Guide. 1.75. Trays with less separation would have tray covers to meet the requirements of R.G. 1.75, and would exhibit substantially less propagation. Trays with any greater separation would exhibit less propagation. (The specific cable tray configurations will be verified and documented for areas under consideration when this process is used for a specific exemption request.) This test provides a realistic yet conservative basis for a horizontal flame spread model for the following reasons:

- The ignition source was approximately 40 Btu/s, which is representative of actual potential fire plant scenarios in which the cables are near the source.
- The cables used in the test were XPE/XPE jacketed. (This is typical of the cable used at CR-3.)
- The purpose of the test was to evaluate cables under exposure fire conditions. Most of the other cable tray tests were created to judge extinguishment methods, so steps were taken to create fully involved fires which unfairly skew the results. Additionally, the SNL test mentioned above clearly states observations regarding the extent of horizontal fire spread, circumventing the need to derive spread rates from secondary test data.

Other testing by EPRI provides good insight regarding the difficulty involved in igniting IEEE-383 qualified cables. These tests were designed to evaluate extinguishment methods and employed an ignition fire with a heat release rate on

the order of 1650 Btu/s for approximately 6.5 minutes in order to ensure a fully developed fire. This size ignition fire, which was placed only 8 inches below the cable trays, is extremely large when compared with common plant ignition sources, such as electrical cabinets (HRR = 65 Btu/s). Fire test nos. 10-12 on EPR/Hypalon cables shows that these cables were very difficult to ignite even with such a robust source. Ignition was only achieved when the cables were loosely arranged in the trays with alternating layers of one-cable, S-shaped rows interspersed, maximizing surface area and air supply (a configuration similar to wood cribbing). An ignition fire of this magnitude and duration tended to volatilize the cables being tested, exaggerating fire propagation.

In addition to explicitly accounting for the burn area as described in the SNL test, the Hazard Tool employs other conservative simplifying assumptions to account for variations in plant specific configurations:

- Ignited cable trays are assumed to be fully involved at time zero. Tests show a considerable time interval before full development is reached, especially for IEEE-383 qualified cables. Even the extremely severe tests indicate that it takes cable tray fires at least 10 minutes to become fully developed.
- XX% of the cable insulation is assumed to burn.
- The full footprint of the source is considered to burn in the lowest cable tray, even for sources with only small openings, e. g. cabinets.
- Self sustaining ignition is always assumed, even though data shows that cable fires are difficult to ignite.

For non-qualified cable, propagation should be allowed beyond that calculated for qualified cable. Spread rates of XX linear feet per hour should be used.

COMBUSTIBILITY AND FLAME SPREAD OF THERMO-LAG IN THE HAZARD TOOL

Thermo-Lag Combustibility

The TC Hazard Tool treats Thermo-Lag as a combustible material. When the material is exposed to sufficiently high temperature or sufficient heat flux it is assumed to burn. The ignition temperature, heat flux and other burning characteristics are based on the test data presented in the NEI Combustibility Guide.

The test data in the NEI Combustibility Guide establishing the following values:

- Piloted ignition temperature for Thermo-Lag is approximately 1000°F. This value is determined from the LIFT test (ASTM E1321). The NEI Guide states that it was very difficult to ignite the Thermo-Lag (obtain and maintain an attached flame).
- Radiation flux required to cause ignition is approximately 25 kW/m^2 (2.2 Btu/s/sf). This value was also determined from the LIFT test. The value is considered conservative because the pilot ignitor of the LIFT device actually contributes added radiant energy which is not included in the 25 kW/m^2 value and also because in the Cone Calorimeter test (ASTM E1354), the Thermo-Lag would not ignite at 25 kW/m^2.
- Horizontal flame spread temperature and flame spread heat flux were determined to be equal to the ignition temperature and radiation flux (1000°F and 25 kW/m^2) based on the LIFT test.
- Vertical flame spread is assumed to occur without external heat source as a result of energy feedback to itself.
- Heat release rate was determined to equal 100kW/m^2 (9 Btu/s/sf). This data was determined from a bomb calorimeter test and is conservative as it uses a 100% oxygen environment.
- Heat content of the Thermo-Lag material was determined to be 16.3 KJ/Kg (7000 Btu/lb). This value is very conservative compared to the values determined from the ICAL test performed for TU Electric which showed heat content on the order of 10.2 KJ/Kg or less.

The Hazard Tool considers Thermo-Lag a combustible and includes it in the fire scenarios as follows:

- The material is considered to burn at 1000°F or 2.2 Btu/s/sf radiant exposure. It burns with a heat release rate (HRR) = 9 Btu/s/sf and has a heat content that it may contribute to the fire of XX x 7000 Btu/lb.

  This is a conservative estimate of the burning efficiency of the material. Based on observed Thermo-Lag fire tests, a burning efficiency of 0.5 to 0.7 is appropriate for Thermo-Lag.

Plume and Ceiling Jet Scenarios

Where Thermo-Lag is located in the plume or ceiling jet the following describes how it is handled:

* For horizontal raceways, that portion of Thermo-Lag in the plume/ceiling jet at 1000°F or higher is assumed to burn.
* Horizontal Thermo-Lag is not assumed to propagate fire beyond the point where the temperature is 1000°F or radiant flux is 2.2 Btu/s/sf. The basis for this is the LIFT test results which concluded that the fire would not propagate if the threshold ignition/ flame spread values were not maintained.
* Burning Thermo-Lag contributes to the fire intensity at 9 Btu/s/sf for that surface area burning.
* Vertical Thermo-Lag is assumed to propagate the fire along its vertical length and is assumed to contribute to the intensity of the fire at 9 Btu/s/sf of surface area burning.

Hot Gas Layer Scenarios

Where Thermo-Lag is located in the hot gas layer (HGL) the following describes how it is handled:

* In most situations the Thermo-Lag in the HGL will not burn, because the HGL only exists in pre-flashover conditions. Once the HGL reaches 1000°F, flashover is assumed to occur with all combustibles in the compartment burning (including the Thermo-Lag).

When Thermo-Lag is Burning

When Thermo-Lag is burning, its exposure is considered to be the plume/ceiling jet/hot gas layer temperature at that location. The basis for this is as follows:

* In furnace tests, the Thermo-Lag is burning if it is in an exposure above 1000°F. The resulting fire rating therefore reflects the burning Thermo-Lag.
* As in a fire test, when the Thermo-Lag burns the compartment temperatures are increased. The Hazard Tool takes the BTUs released from the burning Thermo-Lag and adds them to the HGL which raises the plume/ceiling jet/HGL temperatures.

OVERVIEW OF THE DEVELOPMENT OF THE BARRIER RATING TOOL

Thermo-Lag Barrier Rating Tool

The purpose of this write-up is to demonstrate that Thermo-Lag behaves in very predictable and consistent manner and that the fire rating of untested configurations can therefore be determined with confidence. This is a brief overview of the detailed discussion which will be used to support specific barrier rating evaluations.

The majority of Thermo-Lag fire testing available in the industry has been performed by NEI, TU and TVA. Although the fire rating of similar test assemblies can vary considerably, it has been shown that the fire rating (or behavior) of individual segments (when they are constructed in a similar manner) are very consistent and predictable. There are two primary reasons for the apparent inconsistency in the fire rating of tested assemblies as follows:

1. The acceptance criteria for cable wrap fire tests is analogous to searching for the weakest link of a chain. When the weakest link reaches the limit, the chain fails.
2. The assemblies are made of individual segments. Each type of segment has a representative behavior which is different than the behavior of other segment types. When the segments are assembled, their individual behavior is masked because the fire rating of assembly is determined primarily by the weakest segment.

The barrier rating tool focuses on the behavior of individual segments. With an understanding of the segment behavior, it is possible to determine the parameters which impact the rating and to quantify the impact. Knowing the behavior of individual segments, it is possible to determine the fire rating of entire assemblies. Segment behavior can also provide a basis for selecting localized upgrades or other location specific remedies.

The discussions that follow provide a description of the development of the barrier rating tool.

Test Data Used

The test data used to develop the tool was selected to quantify the significant behavioral characteristics of the segment type. For each segment type evaluated, all available data was used in the development of the tool. The individual tests used were primarily for un-upgraded test specimens. In a limited number of instances, data for upgraded test configurations was used where the upgrade did not affect the segment of concern.

Data Reduction

Data reduction was performed on a segment basis to determine the performance of individual segments and their fire rating as distinct from the rating of the overall barrier envelope.

In order to reduce the data in a manner where the results from one tested segment could be compared directly with the results of another similar segment, a fire rating was determined for each tested segment of interest as follows:

1. Segment fire rating = the average of the times when each individual thermo-couple in the tested segment reached 250°F + ambient.
2. A fire rating was therefore established for each segment of each test assembly evaluated.

In order to determine the behavior of specific types of segments, the fire rating of similar segment types are plotted. Each plotted point represents the average time to reach 250°F + ambient for a tested segment. When the fire rating of all the segments is compared to raceway size and Thermo-Lag thickness, a consistent relationship is demonstrated.

This consistent relationship enables the development of a family of curves. Similar curves are developed for the following segment types:

1. conduit radial bends
2. conduit LBDs
3. cable tray straight segments
4. conduit radial bends

Observation of Behavior

The observed results of the different segment types indicates that there are two primary types of behavior which define segment fire rating:

1. Heat transfer - where there is no joint failure, such as straight conduit sections, the fire rating varies with T-L thickness, raceway size and raceway shape(cylindrical or rectangular).
2. Structural - for flat panels held in place with bands or wires, the structural capacity of the structure has a dominant effect on fire rating. The structural capacity is dependent on the temperature-dependent material properties, the time dependent material temperatures, and the mechanical load on the structure.

Although the details of the heat transfer and structural behavior are not specifically attainable from the data available, the results of the complex behavior can be expressed in terms of exposure time (fire rating), Thermo-Lag thickness, raceway shape and size, for segments of the same construction and type.

By combining basic behavior of materials theory with observed segment failure modes, it is possible to rank construction techniques with respect to fire rating. The following are examples of observed structural behavior:

1. Longer unsupported spans show increased deformation and lower fire rating.
2. Panels supported by the inside layer of T-L and stress skin exhibit far superior performance to panels supported by the outside surface Thermo-Lag which softens early in an exposure.

This structural behavior can be quantified with the segment data available for un-upgraded cable trays and LBDs. By identifying the credible failure modes of untested configurations and matching those failure modes with the quantified

segment data, the fire rating of the untested configuration can be determined.

Critical Installation Parameters

Having defined the physical parameters which dominate the behavior of the installed Thermo-Lag it is possible to determine what field data is required in order to be able to determine fire rating. It is assumed that the plant specific Thermo-Lag material is the same as that tested by NEI, TVA and TU. The following addresses the required data for selected configurations:

- Conduits - The fire rating is dependent on T-L thickness, raceway size. Band spacing should be verified to be within the bounds of the tested configurations (I.e., 12").

- LBDs - Fire rating, such as that described in the figures above, is based on the configurations tested by NEI, which are basically a worst case configuration. Field verification, therefore, need not determine joint construction or orientation, but simply T-L thickness, raceway size and verification that band spacing is within tested bounds.

- Cable Trays - The fire rating defined in the figures is based on the weakest orientation/configuration of the following:
    * Internal rib orientation
    * internal banding
    * butt joint splices

    These parameters, therefore do not need to be determined to define the fire rating of the installed Thermo-Lag.

    Parameters which do need to be verified are:
    * T-L thickness
    * raceway size
    * band spacing
    * joint buttering (figures are based on pre-buttered configurations)
    * stress skin location (inside on 1-hour panels; inside and outside on 3-hour panels)

- Untested Configurations Such as Junctions Between Segments - The fire rating of untested configurations such as the interface between cable trays and multiple conduits can be evaluated assuming the worst case joint configuration. Therefore, only the following parameters need be determined:
    * T-L thickness
    * raceway size
    * band spacing
    * joint buttering (figures are based on pre-buttered configurations)
    * stress skin locations