

TMI-1 EVALUATION OF THERMO-LAG FIRE BARRIERS

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ABSTRACT

The purpose of this report is to provide the methodology for establishing the fire endurance rating of installed Thermo-Lag fire barrier raceway systems. This report summarizes the results of the evaluations which establish the aforementioned fire endurance ratings and identifies those Thermo-Lag fire barrier raceway systems which meet the requirements of Appendix R, Section IIIG, those barriers which do not meet Appendix R and will be modified or upgraded to meet Appendix R, and those barriers which do not meet Appendix R and for which an evaluation will be performed to justify the fire endurance rating in an exemption request.

This report also provides the methodology used to evaluate the hazards in each fire area or fire zone where Thermo-Lag fire barrier raceway systems are installed. These hazard evaluations will be documented in exemption requests and will serve as the basis for supporting such exemptions where the fire endurance rating of the Thermo-Lag fire barrier raceway system does not meet the requirements of Appendix R, Section IIIG.

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## 1.0 PURPOSE

The purpose of this report is to provide the methodology for establishing the fire endurance rating (equivalent rating by test comparison) of installed Thermo-lag fire barrier raceway systems at TMI-1. Fire endurance rating is established by identifying the "Actual Fire Rating" or the rating consistent with the fire endurance test acceptance criteria as defined in NRC Generic Letter 86-10 Supplement 1, "Fire Endurance Test Acceptance Criteria for Fire Barrier Systems Used to Separate Redundant Safe Shutdown Trains Within the Same Fire Area". Fire endurance rating is also established by identifying the "Cable Qualification Rating" or the rating which is based upon establishing the maximum temperature inside a fire barrier envelope that is considered acceptable to demonstrate cable functionality. Use of the "Cable Qualification Rating" is a deviation from the GL 86-10 acceptance criteria but is acceptable based upon an engineering evaluation as described herein. Results of these evaluations are reported in Section 3.

This report also provides the methodology used to evaluate the hazards in each fire area or fire zone. The hazard evaluation will serve as the basis for supporting exemptions from Appendix R, Section IIIG.

## 2.0 METHODOLOGY

### 2.1 Establishing Actual Fire Rating

To assess material performance and provide a basis for evaluation of installed Thermo-Lag fire barriers, an industry fire endurance test program was conducted by the Nuclear Energy Institute (NEI). To address issues with the fire endurance capability of installed barrier configurations, the industry test program:

- Assessed current industry configurations through the use of survey data,
- Conducted tests to establish performance of various baseline and upgraded fire barrier system assemblies, and
- Developed a guideline to assist utilities in evaluating installed barrier configurations

The guideline developed by NEI is known as the "NEI Application Guide for Evaluation of Thermo-Lag 330 Fire Barrier Systems" (Report no. 0784-00001-TR-02 Revision 1) or the "Application Guide". The Application Guide provides a process and data for evaluation of installed Thermo-Lag fire barrier configurations using information obtained from NEI and utility fire endurance test programs. GPU Nuclear has used this process to

- Establish the extent that installed barrier configurations can be bounded by previous tests,
- Determine the fire endurance capability (or "Actual Fire Rating") that installed barrier configurations, which are bounded by test, can be reasonably expected to provide, and
- Propose upgrades to installed barrier configurations where deemed necessary to achieve an acceptable fire rating.

In order to evaluate the extent that installed barrier conditions at TMI-1 can be bounded by test configurations and data in the Application Guide, GPU Nuclear performed the following:

- A walkdown of the fire areas/zones was conducted to document the installed barrier configurations with digitized computer images.
- The parameters identified by NEI during the industry fire endurance test program which pertain to fire endurance capability, as identified in the Application Guide, were included by GPU Nuclear in an electronic database. (Doc. No. TLDB-TMI-775-1)
- Each fire barrier system was separated into individual segments or elements for evaluation purposes. Individual elements are constituted by one or more of the following distinguishing characteristics:
  - 1) change in barrier construction technique;
  - 2) significant change in protected raceway or contents;
  - 3) variation from applicable barrier installation requirements;
  - 4) change in type of barrier material; or
  - 5) change in orientation of protected raceway or change which necessitates a change in barrier construction technique.
- Data collected during the walkdown and collected by a review of the original fire barrier construction details were entered into the database to permit detailed comparisons of relevant parameters from the NEI, Texas Utilities (TU), and TVA programs.
- Each of the test assemblies in the industry test programs was separated into individual segments or elements for evaluation purposes as were the installed fire barrier systems and entered into the data base in order to permit the detailed comparisons of relevant parameters with the installed fire barrier systems.
- The quality of the barrier installation was originally verified by installation process step sign-offs and final inspections performed by GPUN Quality Control and Fire Protection Engineers. No significant deviations from the original design/installation are expected or were noted. Plant repair procedures perform repairs to the same requirements as the initial installation. Surveillance procedures ensure a refueling interval inspection to verify the integrity of the installed fire barrier envelopes.

A quality control program as described in the FHAR-Section 5 (and implemented by the TMI-1 QA Plan) was applied to the material, process and installation and inspection personnel. TMI-1 did not contract out the installation work to a third party licensed by TSI but rather contracted TSI to train and license GPUN personnel.

GPUN's initial experience with TSI's material shipments resulted in returning the initial shipment. Some of these problems are described as follows:

### Thickness

Material that was shipped excessively thick was a concern with hanger loading and cable derating. GPUN receipt inspectors verified thickness by taking many readings on each piece. If any piece had more than a few deviations that could not be economically repaired, it was shipped back to TSI.

### Voids and Porosity

Since the material was subject to considerable field work (cut and fit) voids were filled with TSI trowel grade material when exposed during installation. Material which had severe porosity was returned.

To insure receipt of consistent quality material from TSI, GPUN instituted 100% QC checks by GPUN at TSI's factory prior to release for shipment. Thorough receiving inspection checks were maintained.

### Density

Prior to and after assignment of the Manufacturing Assurance representative to the TSI factory, on site QC receipt inspection was relied upon to verify that material weight and density specifications were met.

In order to establish the actual fire rating of the installed fire barrier assemblies, the industry test data was evaluated. Actual fire rating is a term used to designate the fire endurance rating of the barrier consistent with the acceptance criteria contained in NFPA 251 (ASTM E-119), "Standard Fire Tests of Building Construction and Materials". NRC Generic Letter 86-10 Supplement 1, adapts the acceptance criteria of NFPA 251 to cable tray fire barrier wraps.

In 86-10, Supp.1, the staff bases acceptability of a fire endurance qualification test for fire barrier materials applied directly to a raceway or component to be successful if the "average" unexposed side temperature of the fire barrier system, as measured on the exterior surface of the raceway or component did not exceed 250 deg F above its initial temperature and a visual inspection of cables inside the raceway should show no signs of degraded conditions. Also, individual temperature readings should not exceed the 250 deg F temperature rise by more than 30 percent, or 325 deg F above the initial temperature.

To establish the barrier rating (ACTUAL RATING) of a test assembly, GPU Nuclear reviewed the temperature data for the test and identified that point in time when the first individual temperature reading on the unexposed side of the fire barrier for the entire raceway in the test assembly, as measured on the exterior surface of the raceway or component, exceeded 325 deg F above the initial temperature. Note that this method establishes a rating for all elements of a particular raceway size based upon the weakest link in the raceway. While it is possible to establish individual ratings in a test involving straight conduit, radial bends and condulets based upon thermocouple readings restricted to these elements in a test assembly, it is conservative to establish a common rating for all elements of a raceway based upon the a single



high reading for the entire raceway. For cable tray, the bare copper conductor temperature under the rungs of the tray exceeded 325 deg F before any other temperature reading and was therefore used to establish a conservative actual rating.

To establish the actual rating for an installed configuration or element, the installed configuration's relevant parameters were compared with those of the industry tested configurations. If an acceptable match was found, it was selected and the installed configuration is considered bounded by an acceptable industry test configuration. The actual rating of the matching industry configuration becomes the actual rating of the installed configuration or element as documented by a detailed evaluation. The results of these detailed comparisons and evaluations will be listed in this submittal only. These results will be retained in the electronic database (Doc. No. TLDB-TMI-775-1) and digitized computer image library mentioned previously and will be available for NRC review or audit.

## 2.2 Establishing Cable Qualification Rating

In addition to establishing the "Actual Fire Rating" as previously described, GPU Nuclear has utilized a combination of actual test data and theoretically derived data to document raceway temperatures inside the Thermo-Lag fire barrier envelopes which deviate from the acceptance criteria used for qualifying fire barrier configurations as outlined in Generic Letter 86-10 Supp. 1. This section outlines the method that serves as the basis for establishing the fire endurance rating of the barrier when considering the cable qualification temperature or the maximum temperature inside the fire barrier envelope that is considered acceptable to demonstrate cable functionality. The acceptable fire endurance rating is termed the "Cable Qualification Rating". GL 86-10 Supp. 1 permits an evaluation which demonstrates that cables would perform their intended function during and after a postulated fire exposure when the internal raceway temperatures exceed the GL 86-10 Supp.1 acceptance criteria. GPU Nuclear considers the Cable Qualification Rating directly comparable to the requirement of III.G for one hour fire barriers. In other words, a fire barrier having a cable qualification rating of at least 60 minutes is considered to be a one hour fire barrier as required by III.G. If less than 60 minutes, the cable qualification rating is being applied to establish the basis for an exemption from the requirement for a one hour fire barrier.

In order to compare the internal raceway temperatures to cable failure temperatures, GPU Nuclear performed the following:

### 2.2a Identification of Protected Circuits

The FHAR's Fire Area Layout Drawings and Attachments were compared with the as built Thermo-Lag Installation Drawings to identify those circuits required for safe shutdown which are protected by the Thermo-Lag fire barriers.

### 2.2b Identification of Cable Qualification Temperatures

(Note this is not to be confused with environmental qualification temperatures)

Generic Letter 86-10, Supplement 1, Attachment to Enclosure 1, "Acceptable Methods for Demonstrating Functionality of Cables Protected by Raceway Fire Barrier Systems During and After Fire Endurance Test Exposure" provides the means for establishing the

maximum temperature inside the fire barrier envelope that is considered acceptable to demonstrate cable functionality. GPU Nuclear used the recommended analysis of Section VI in the aforementioned attachment entitled "Cable Thermal Exposure Threshold" to perform this analysis.

After identifying the circuits required for safe shutdown as described in "2.2a" above, the cable manufacturer was identified and the thermal exposure threshold (TET) temperature limit or insulation failure threshold temperature limit was obtained from Sandia Test Report SAND90-0696 May, 1991 "An Investigation of the Effects of Thermal Aging on the Fire Damageability of Electrical Cables". Additional information on the process of assigning cable failure temperatures to specific cable types is provided in GPUN memo 5350-95-063. Insulation damage leading to a short circuit per the tests conducted in the aforementioned investigation is defined as 15 milliamps (mA) leakage current. The insulation failure threshold temperature limit is the temperature beyond which the insulation is expected to degrade causing a short circuit. While not the same as the short circuit rating as defined in Generic Letter 86-10, Supplement 1, these tests conclusively demonstrate cable functionality at elevated temperatures because under fire conditions, the endurance rating of the barrier is based upon the point in time when the threshold temperature is reached. The aforementioned Sandia tests on the other hand, subjected cables to the insulation failure threshold temperature for at least 80 minutes without failure. Fire endurance ratings do not assume sustained operation under these elevated temperature conditions. The rating is based upon the duration of the test and the point in time of the test when the insulation failure threshold temperature is reached. This method is conservative because, as stated above, the Sandia tests subjected cables to the insulation failure threshold temperature for AT LEAST 80 MINUTES.

#### 2.2c Raceway Temperatures Inside Thermo-Lag Fire Barrier Envelopes

In order to follow the guidance of Generic Letter 86-10, Supplement 1 for establishing maximum allowable raceway temperatures inside the fire barrier envelope, additional evaluation of industry test data and consideration of the operating cable temperatures within the fire barrier system at the onset of the fire exposure were performed. This is necessary in order to compare test results with the TET temperature limit and establish a "cable qualification rating" for the fire barrier envelope.

Industry test data which was used to establish the "actual" fire rating described previously was further evaluated to document internal raceway temperatures beyond NRC acceptance criteria as defined in GL 86-10. To be consistent, the evaluation was limited to the temperature readings on the unexposed side of the fire barrier as measured on the exterior surface of the raceway or in the case of cable tray, the bare copper conductor temperature under the rungs of the tray. The evaluation documented the temperatures and the duration of the fire test at the aforementioned locations in increments of approximately 100 deg F up to the point where the test was terminated; eg. for 3/4 in. conduit in NEI test 2-1, the actual rating is based upon a conduit surface temperature of 387 deg F at 27 minutes. Since the test was continued beyond this point, the following data was utilized to compare conduit surface temperatures with the insulation failure threshold temperature mentioned in 2.2b.



## 3/4" Conduit Outside Surface Temp (Maximum)

TIME (MIN)	TEMP (DEG F)
28	396
36	499
41	609
44	720

If the test was terminated before a duration of 60 minutes, it was necessary to develop a multi-dimensional heat transfer model to extrapolate temperatures inside the raceway out to 60 minutes since no temperature data was available. The model was verified against actual industry test data to establish confidence in its validity. By establishing said confidence, it is considered reasonable to extrapolate internal raceway temperatures out to 60 minutes for the purpose of comparison with cable qualification temperatures. The results of this model is documented in calculation C-9000-814-5310-002. This calculation is not included here but is available for NRC review or audit.

It is necessary to account for the initial temperature of the cable within the fire barrier prior to the onset of the fire as compared to the test configurations. As such, the cable qualification rating is established based upon the time it takes for the internal raceway temperature to get within no less than 70 deg F of the insulation failure threshold temperature. This 70 deg F value provides the margin to account for the differences between actual room ambient temperatures plus cable temperature rise due to the insulating effects of the barrier and those ambient temperatures measured during industry testing. The industry tests were performed with initial ambient temperatures no less than 50 deg F while the maximum design room ambient temperatures are 104 deg F at TMI. The additional temperature rise inside the fire barrier envelopes due to operating cables is 7 deg F maximum based upon test results documented in letter G/C/TMI-1CS/16503 dated September 15, 1988, J. Brendlen to J.W. Langenbach, "TSI Derating Check". Adding the difference between the max room ambient temperature and the minimum ambient test temperature (104-50=54deg F) to the temperature rise of 7 deg F yields a total factor of 61 deg F. This establishes that the cable qualification rating is consistent with maximum cable operating temperatures. This meets the guidance in GL 86-10 for an engineering analysis to demonstrate the functionality of cables inside fire barrier envelopes.

## 2.2 Evaluating Fire Hazards

To evaluate the cable qualification ratings of the Thermo-Lag fire barriers which do not meet the requirements of Appendix R Section III.G (ie. less than 1 hour or 3 hour), the following method is employed:

The method is typical of the "traditional approach". A comparison of the cable qualification rating with the overall fire loading is performed using 80,000 BTU/Ft<sup>2</sup> as equivalent to a one hour fire to develop a fire load to rating factor herein referred to as the rating factor. A combustible loading of 80,000 BTU/Ft<sup>2</sup> has been considered as equivalent to the heat release in an ASTM E-119 Test Oven for a one hour fire duration test. A source reference to support this assumption is Table 6-6a of the NFPA Fire Protection Handbook, Seventeenth Edition. If the Thermo-Lag fire barrier is located in a fire area/zone which is provided with an area wide fire suppression system, the aforementioned factor is multiplied

by an additional factor of 3 to account for the additional margin provided by the suppression system. This factor is an assumption based upon the fact that Appendix R Section III.G.2.c reduces the requirement for a 3 hour barrier in III.G.2.a to 1 hour with the presence of a suppression system; hence the additional factor of 3.

The rating factor is used for assessing the fire hazard with the actual rating of a raceway fire barrier that does not meet the requirements of Appendix R. No strict acceptance criteria is established as the acceptability of a rating factor must consider all fire hazards and fire protection features where the raceway fire barrier is located. Acceptability is therefore based upon engineering judgment.

The following reference point will be taken into consideration in judging the acceptability of a rating factor. The basis for this is drawn from the TMI-1 FHAR, paragraph 2.3.2.1 "Identification of Fire Areas and Zones". To summarize, this section of the FHAR established criteria for "evaluating the adequacy of fire zone boundaries which permits analysis to determine compliance with Appendix R, Section III.G of fire zones by themselves." Fire zones are subdivisions of fire areas which take into consideration the physical boundaries which exist between one fire zone and another in the same fire area. Fire zone boundaries can consist of non-rated physical boundaries with penetrations sealed with at least one hour fire rated non-combustible material. The criteria for acceptability of such a configuration is that the combustible loading on either side of the boundary is less than 40,000 BTU/Ft<sup>2</sup>, or 1/2 the equivalent of a one hour fire duration as discussed above or a rating factor of 2.

The following example is provided to illustrate how the cable qualification rating factor (RF) is calculated for a 9 x 6 cable tray having a cable qualification rating of 48 minutes in an area provided with automatic fire suppression having a fire load of 14,755 BTU/FT<sup>2</sup>:

FIRE LOAD (FL)	CABLE QUAL. RATING (CQR)	RESULT (RF)=CQR/FL
11 min. (14,755 BTU/Ft <sup>2</sup> )	144 min. (= 48 min.x 3 w/suppression)	RF=13.1

NOTE THAT THIS METHOD IS CONSERVATIVE BECAUSE IT PRESUMES COMPLETE COMBUSTION OF ALL COMBUSTIBLES IN THE FIRE AREA OR ZONE OF CONCERN.

### 3.0 SUMMARY OF RESULTS

The results of applying the above methodology towards establishing an actual fire rating and a cable qualification rating for Thermo-Lag fire barriers are as follows:

## 3.1 Intake Screen and Pumphouse Fire Zone ISPH-FZ-1

ENVELOPE NO.	TYPE	NO. ELEMENTS	ACTUAL QUALIFICATION RTG.	CABLE QUALIFICATION RTG.	NEI Test
1SHD-FB01	5"Conduit	2	91 min.	102 min.	2-3
	5"Conduit	1	91 min.	102 min.	2-3
	Radial Bend				
	4"Cable Bundle	1	50 min	60 min	2-1
	4"Cable Bundle	2	50 min	60 min	2-1
	Radial Bend				
	42"x30"x8" Box	1	60 min.	60 min.	2-2
	*33"x13"x12"Box	1	0	0	n/a
1SHD-FB02	8"x48"x8"Box	1	60 min.	60 min.	2-2
	1"Air Drop	2	0	0	n/a
1SHD-FB05	3"Armored Cable	3	39 min.	60 min.	2-1
	3"Armored Cable	2	39 min.	60 min.	2-1
	Radial Bend				
	9x6 Cable Tray	1	47 min.	48 min.	2-7

\* This box element is also part of envelope no. 1SHD-FB02

To summarize the above results, 5"conduit and 5"conduit radial bend elements meet the requirements of III.G.2.c because their "ACTUAL RATING" and "CABLE QUALIFICATION RATING" exceeds one hour. These fire barrier envelopes exceed the one hour requirement because they were constructed as three hour barrier envelopes using one inch thick Thermo-Lag panels even though the required rating is one hour. The two box configurations rated at 60 minutes meet the requirements of III.G.2.c. No additional justification is required for these barriers.

The 3"Armored Cable, 3"Armored cable radial bend, 4" Cable bundle, 4" Cable bundle radial bend meet the requirements of III.G.2.c because their "CABLE QUALIFICATION RATING" is at least 60 minutes. The heat transfer model which projects temperatures inside these raceways out to 60 minutes was used to compare raceway temperatures at 60 minutes to the cable insulation failure threshold temperatures for required safe shutdown circuits inside these raceways. For these raceways, the projected raceway temperatures at 60 minutes are below the cable insulation failure threshold temperatures by more than 70 deg F; therefore these raceway barriers have a rating of 60 minutes.

The two air drop elements and the 33x13x12 box elements will be upgraded to provide an "actual" fire rating of one hour and will therefore meet the requirements of III.G.2.c. GPU Nuclear is currently planning on designing and installing the upgrade for the air drops to conform to Texas Utilities test 11-1 and Texas Utilities test 12-2 for the 33x13x12 box. These tests were successful in establishing a 60 minute fire endurance rating for an air drop and box configuration. Note that this is GPU Nuclear's current design detail for the aforementioned upgrades. If other types of upgrades which provide an "actual" fire rating of 60 minutes are identified due to more industry testing, an alternative configuration could be used. Such changes will not be submitted for NRC approval but handled under existing licensing conditions;

ie. 50.59 process. The commitment is to upgrade these envelopes to an "actual" fire rating of 60 minutes. Note that any upgrades will consider the impact on existing cable derating on the cables inside these elements as part of the modification process.

The 9x6 cable tray will be the subject of an exemption request.

#### 4.0 REFERENCES

- 4.1 NRC Generic Letter 86-10, Supplement 1, Enclosure 1, "FIRE ENDURANCE TEST ACCEPTANCE CRITERIA FOR FIRE BARRIER SYSTEMS USED TO SEPARATE REDUNDANT SAFE SHUTDOWN TRAINS WITHIN THE SAME FIRE AREA", dated March 25, 1994.
- 4.2 10 CFR Part 50 Appendix R, "FIRE PROTECTION PROGRAM FOR NUCLEAR POWER FACILITIES OPERATING PRIOR TO JANUARY 1, 1979".
- 4.3 NEI Report No. 0784-00001-TR-02, Revision 1, "NEI APPLICATION GUIDE FOR EVALUATION OF THERMO-LAG 330 FIRE BARRIER SYSTEMS".
- 4.4 GPU Nuclear Three Mile Island Unit No.1 Fire Hazards Analysis Report (FHAR) No. 990-1745, Revision 15.
- 4.5 NFPA 251 (ASTM E-119), "STANDARD FIRE TESTS OF BUILDING CONSTRUCTION AND MATERIALS".
- 4.6 Sandia Test Report SAND90-0696 May, 1991 "AN INVESTIGATION OF THE EFFECTS OF THERMAL AGING ON THE FIRE DAMAGEABILITY OF ELECTRICAL CABLES".
- 4.7 Gilbert Commonwealth Letter G/C/TMI-1CS/16503 Sept. 15, 1988, J. Brendlen to J.W. Langenbach, "TSI DERATING CHECK".
- 4.8 NFPA Fire Protection Handbook, Seventeenth Edition.
- 4.9 GPUN Document No. TLDB-TMI-775-1, "TMI THERMO-LAG DATA BASE".
- 4.10 GPUN Memo 5350-95-063 dated April 25, 1995, R. Pruthi to F. P. Barbieri, "OC/TMI-1 TSI Wrap for Raceways-Cable Failure Temperatures".



