TEST REPORT

M.T. (3-Hour) Electrical Raceway Fire Barrier Systems Performance Testing

Conduit, Junction Box & Electrical Cable Air Drop Raceways

Project No. 14790-123265

FINAL REPORT

May 14, 2005

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Abstract

This document describes the evaluation of three standard conduit raceway sizes, one junction box, one electrical cable air drop and several support systems, all protected with the M.T. Three Hour System, when exposed to the ASTM E119 time-temperature heating curve. Each conduit size was tested empty and heavily loaded with bare #8 AWG copper wire. Results are given in the Conclusion Section of this report.

The details, procedures and observations reported herein are correct and true within the limits of sound engineering practice. All specimens and test sample assemblies were produced, installed and tested under the surveillance of either Sandia National Laboratories, the manufacturer's or the testing laboratory's in-house Quality Assurance Program. This report describes the analysis of a distinct assembly and includes descriptions of the test procedure followed, the assembly tested, and all results obtained.

Deggary N. Priest, President — May 14, 2005 Date

Reviewed and approved:

Constance A. Humphrey, QA Director — May 14, 2005 Date

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PURPOSE AND SCOPE

Note: This section has been reproduced in part from the Test Plan contained in Appendix A.

Section 50.48, "Fire Protection," of 10 CFR Part 50 requires that each operating nuclear power plant have a fire protection plan that satisfies General Design Criterion 3 of Appendix A to 10 CFR Part 50. Criterion 3 requires that structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components. Section 50.48 also requires that all plants with operating licenses issued prior to January 1, 1979, satisfy the requirements of Sections III.G, III.J, and III.O of Appendix R to 10 CFR Part 50. (Post 1979 plants (per 10 CFR Part 50.48) have to comply with the provisions of their licenses.)

Section III.G of Appendix R, which addresses fire protection of safe shutdown capability, requires that fire protection features be provided such that one train of systems necessary to achieve hot shutdown conditions remains free of fire damage. One acceptable means of satisfying this requirement is to separate cables and equipment and associated non-safety circuits of redundant systems necessary to achieve and maintain hot shutdown conditions located in the same fire area by a fire barrier having a 3-hour fire rating (Section III.G.2.a). Another means is to enclose cables and equipment and associated non-safety circuits of one redundant train in a fire barrier having a 1-hour fire rating and install fire detectors and an automatic fire suppression system in the fire area (Section III.G.2.c).

The scope of this [project] is to describe the overall plan for investigating the fire resistance rating of [the] M.T. (3-hour) … electrical raceway fire barrier system (ERFBS). The primary approach … [was] to perform [an] … ASTM E 119 furnace test on a number of cable raceway types that [were] protected by … the M.T. … fire barrier material. The M.T. test [was] performed for a period of 180-minutes, followed by a hose stream test and post-test visual inspection of the ERFBS. . . .

OBJECTIVE

Note: This section has been reproduced in part from the Test Plan contained in Appendix A.

The objective of this program [was] to assess the fire resistance rating of M.T. ERFBS by subjecting various test specimens (conduits, electrical cable air drop and junction box) to standard temperature-time conditions as specified in ASTM E 119 and criterion stipulated in GL 86-10, Supplement 1. The types and characteristics of the ERFBS enclosing the test specimens [were] intended to simulate as-installed configurations.

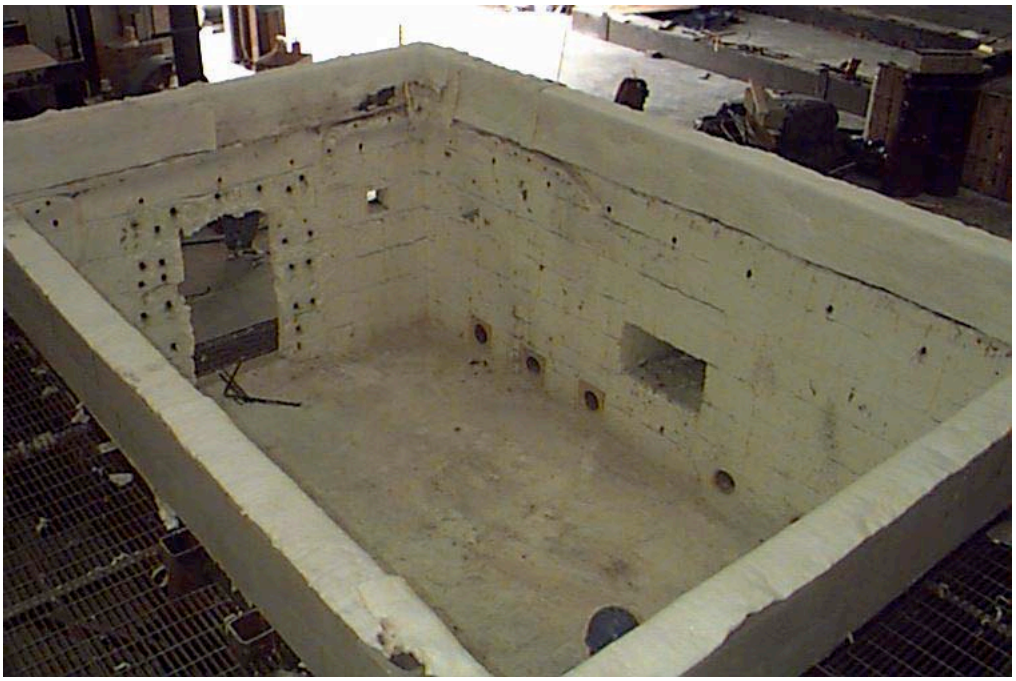
These tests [were intended to] provide additional data in that redundant conduits loaded to their maximum capacities with cables [were] included in the test. Also, [two] support structure analogs partially enclosed in the ERFBS [were] exposed to the three-hour test conditions.

TEST PROCEDURE

Note: Since the Test Plan (Appendix A) includes an accurate and complete description of the test procedure to be followed, much of these details have not been reproduced in the main body of this report.

Horizontal Test Furnace

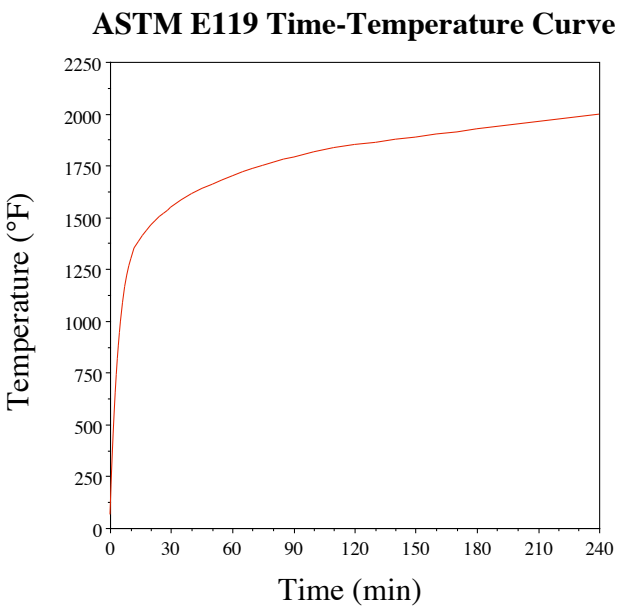
The 12' x 18' x 7' deep horizontal test furnace used in these evaluations was designed to allow the specimen to be uniformly exposed to the specified time-temperature conditions. It is fitted with 12 symmetrically-located premixed air/propane gas burners designed to allow an even heat flux distribution across the exposed surface of a horizontal test specimen. Furnace pressures may be maintained at any value from +0.03" W.C. to -0.05" W.C. The furnace consists of a structural steel frame, lined with sheet metal and insulated with a six inch thick layer of ceramic fiber.



12' x 18' Horizontal Furnace (Overhead View)

The temperature within the furnace is determined to be the mathematical average of thermocouples located symmetrically within the furnace with half positioned twelve inches below the bottom surface of the test deck and the other half located 12" below the bottom of the test specimens. In this manner, an average exposure on the entire assembly can be determined by averaging the readings in real time and adjusting the average temperature to follow the standard time-temperature curve. The materials used in the construction of these thermocouples are those suggested in the E119 test standard. During the performance of a fire exposure test, the furnace temperatures are monitored at least every 15 seconds and displayed for the furnace operator to allow control along the specified time-temperature curve. All data is saved to hard disk at intervals of once per minute unless more often is requested.

The fire exposure is controlled to conform with the standard time-temperature curve shown in Figure 1, as determined by the tables below:



Time (min)	Temperature (°F)
0	68
5	1000
10	1300
20	1462
30	1550
60	1700
90	1792
120	1850
180	1925
240	2000

Figure 1 E119 Temperature Exposure

The furnace interior temperature during a test is controlled such that the area under the time-temperature curve is within 10% of the corresponding area under the standard time-temperature curve for 1 hour or less tests, 7.5% for those less than 2 hours and 5% for those tests of 2 hours or more duration.

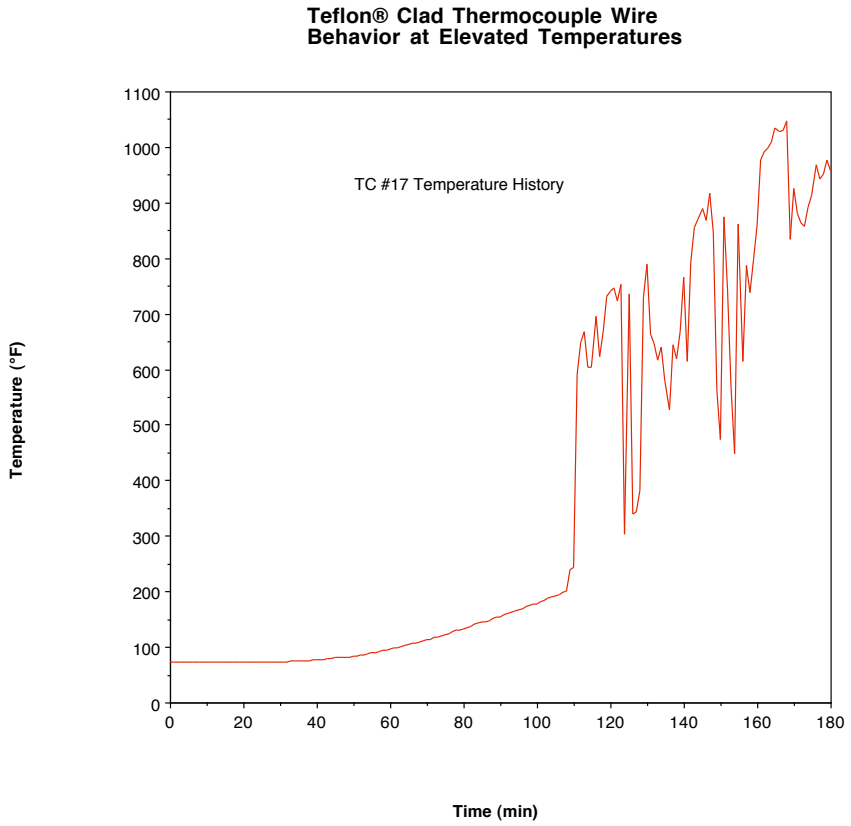
Furnace Pressure

The pressure differential between the inside of the furnace (as measured approximately 12" below the exposed surface of the test support slab) and the laboratory ambient air was maintained at 0.00 inches of water column for the duration of the fire exposure test (after the first five minutes, during which furnace stabilization was achieved). This was achieved and controlled by adjusting the inside furnace pressure until slight puffs of intermittent flames extended through unused thermocouple probe holes in the sides of the furnace, indicating a very slight positive pressure at these locations.

Thermocouple Locations

All six conduit systems were instrumented with 24 GA. Type K Teflon® insulated thermocouples (Special Limits of Error: ±1.1°C) purchased with calibration certifications and lot traceability. The thermo-junctions were mechanically attached along the side of each conduit which faced the bottom or sides of the furnace (that is, along the outside and bottoms of the conduit) by clamping them under the heads of #8x32 stainless steel machine bolts placed into holes drilled and threaded to receive them, spaced 6" o.c. Bare #8 AWG, multiple-strand copper conductors were instrumented with similar thermocouples attached every 6 inches along the wire's length. These thermocouples were attached by placing the thermo-junction in direct contact with the surface of the wire and crimping the junction to the copper wire with a copper Buchanan 2011S open end splice cap fastened in place with a Buchanan C-24 "pres-SURE" tool. An instrumented bare #8 AWG conductor was then pulled through the inside of each conduit. In conduits which contained additional bare #8 AWG conductors as thermal mass, the instrumented conductors were placed inside the bundle, to avoid abrasive damage to the thermocouples during installation of the bundle into the conduit. The support systems contained thermocouples installed as indicated in the Test Plan (Appendix A).

Due to the fact that the M.T. system releases moisture upon activation, and that water vapor can condense upon contact with metal cooler than 212°F, it was necessary to utilize thermocouples which can withstand being wetted without affecting their readings. Due to the excessive cost of metallic-clad thermocouples (such as those utilized on the junction box below, but chosen for use there because they also had to traverse a very hot section of the junction box supports), the decision was made to use Teflon® clad thermocouple wire (Teflon® PFA [perfluoroalkoxy] insulation extruded on the single conductors which are then laid parallel and jacketed with Teflon® PFA, manufactured by PMC Corporation). This wire, while completely unaffected by moisture, does have an upper temperature limitation of around 700°F (depending upon the time spent at elevated temperatures). Above that, the Teflon® cladding can melt and allow the chromel and alumel thermocouple wires to touch and short out; thus giving intermittent and unreliable results. However, since this temperature is hundreds of degrees above the failure temperatures for the raceway systems, this was not considered to be a significant factor. This factor should be borne in mind however, when irregular ("jumpy") thermocouple readings are encountered in the data (see example below).



As a typical example, the graph above shows the behavior of TC #17 (located in Item 3A, empty 4" conduit). The temperatures are well-behaved until a temperature of around 650°F was reached. At that point the insulation melted and the leads shorted together, yielding unreliable information. It must be considered that the observed temperatures in this situation may or may not be indicative of the temperatures at the location of the intended thermojunction.

The junction box was instrumented with $^{1}/_{16}$" diameter Inconel® sheathed, 30 Ga. Type K thermocouples, to allow them to withstand the temperatures which may be experienced by their leads passing between the junction box and outside the heated area. These thermocouples were not purchased with calibration certificates, but instead were numbered and sent to Sandia National Laboratories, which performed a series of multi-temperature point calibrations of them. The results of these calibrations are presented in Appendix D, Quality Assurance.

See Appendix C Thermocouple Locations for exact locations of all test item thermocouples.

Data Acquisition Systems

The outputs of the thermocouples were monitored by 300 channel and 100 channel Yokogawa, Inc., Model Darwin Data Acquisition Units, driven by Macintosh computers. The furnace control thermocouples were monitored by a separate 100 channel Yokogawa, Inc. Model Darwin Data Acquisition Unit and Macintosh computer. The computers were programmed in LabVIEW 5.0 to send the commands to the data acquisition systems to sample the data input lines and to convert the raw data into a usable format (i.e., degrees Fahrenheit) for display on screen and storage as an ASCII tab-delimited text file. Those files were then, after the test, imported into MS Excel for tabular and graphical display.

Correction Factor

In accordance with ASTM E119, when the indicated resistance period is $^1/_2$ h or over, determined by the average or maximum temperature rise on the unexposed surface or within the test sample, or by failure under load, a correction shall be applied for variation of the furnace exposure from that prescribed, where it will affect the classification, by multiplying the indicated period by two thirds of the difference in area between the curve of average furnace temperature and the standard curve for the first three fourths of the period and dividing the product by the area between the standard curve and a base line of 68°F (20°C) for the same part of the indicated period, the latter area increased by 3240°F•min to compensate for the thermal lag of the furnace thermocouples during the first part of the test. For a fire exposure in the test higher than standard, the indicated resistance period shall be increased by the amount of the correction. For a fire exposure in the test lower than standard, the indicated resistance period shall be similarly decreased for fire exposure below standard. The correction is accomplished by mathematically adding the correction factor, C, to the indicated resistance period.

The correction can be expressed by the following equation:

$$C = \frac{2I(A - A_s)}{3(A_s + L)}$$

where:

C = correction in the same units as I,
I = indicated fire-resistance period,
A = area under the curve of indicated average furnace temperature for the first three

fourths of the indicated period,

A_s = area under the standard furnace curve for the same part of the indicated period, and

L = lag correction in the same units as A and A_s (54°F•h or 30°C•h (3240°F•min or 1800°C•min))

Hose Stream Test

Immediately following the fire endurance test, a hose stream test was performed in accordance with USNRC Generic Letter 86-10, Supplement 1, Enclosure 1, Section VI. The hose stream was "applied at random to all exposed surfaces of the test specimen through a 1-1/2" fog nozzle set at a discharge angle of 15 degrees with a nozzle pressure of not less than 75 psi and a minimum discharge rate of 75 gpm with the tip of the nozzle at a maximum of 10 feet from the test specimen. Duration of the hose stream application is 5 minutes." Prior to the hose stream application, the laboratory ensured the correct angle spray pattern, pressure and flow was achieved through calibrated gauges and other equipment as required.

Assessment Criteria

The test specimens were subjected to the ASTM E 119 temperature-time profile in the test furnace. An assessment of the ERFBS performance was based on two principal factors, as stated in Generic Letter 86-10, Supplement 1:

1. *The time at which the average unexposed side temperature of the fire barrier system, as measured on the exterior surface of the raceway or component, exceeds 139°C (250°F) above its initial temperature. Or the time at which a single temperature reading of a test specimen exceeds 30% of the maximum allowable temperature rise (i.e., 180°C [325°F]) above its initial temperature.*
2. *The fire barrier system remains intact during the fire exposure and water hose stream test without developing any openings through which the cable raceway is visible.*

TEST SPECIMEN CONSTRUCTION

Supporting Deck

A 13' x 19' insulated 10 GA. steel deck was designed to accept the test items in this project. The deck was continuously welded and reinforced with 4" structural steel channel, as indicated in the drawings in Appendix B. The placement of all test items in the deck was adjusted to maximize

distances between items and between items and furnace walls, and to minimize shadowing effects between items.

Each of the conduits were designed to pass through the test deck, extend 36" below the insulated lower surface of the deck, turn 90° (through a zero radius turn) to horizontal, extend a total of 60", and then turn 90° upwards (through a sweeping radius turn) and pass back up and through the supporting deck. All test items were supported by structural elements on the unexposed side of the test deck at distances of 12" and 30" above the deck. The underside of the deck was insulated with 5" of ceramic fiber blanket, held in place with impaling pins spaced nominally 18" o.c. or as needed.

One specimen of each conduit contained a heavy loading (nominally 30%) of bare #8 multi-strand copper conductor. The length and weight of each bundle was determined, as well as the weight of each assembled conduit system and its weight per unit length. The junction box weight is reported as a single item.

Raceway	Raceway Weight Per Unit Length* (lb/ft)	No. of Strands of Bare #8 Conductor	Bare #8 Weight per Unit Length (lb/ft)	% Fill by Actual Area	Total Weight per Unit Length (lb/ft)
3A (4" conduit)	9.4	1	n/a	n/a	9.4
3B (4" conduit)	9.4	291	14.84	30.0	24.24
3C ($2^1/2$" conduit)	5.1	1	n/a	n/a	5.1
3D ($2^1/2$" conduit)	5.1	113	5.85	29.8	10.95
3E (1" conduit)	1.5	1	n/a	n/a	1.5
3F (1" conduit)	1.5	18	1.02	29.7	2.52
3G (Unistrut)	1.67	n/a	n/a	n/a	1.67
3H (2"x2" steel)	2.76	n/a	n/a	n/a	2.76
3I (junction box)	26.18 lb	n/a	n/a	n/a	n/a
3J (cable air drop)	-	7	0.36	n/a	0.36

* Note: this is the weight of the raceway only, before the bare #8 was installed.

CONDUCT OF TEST

Preburn Inspections

As required in the Test Plan, prior to the commencement of the fire endurance test, a thorough check of the test assembly and associated equipment (including calibration of the data recording equipment) and completion of applicable Laboratory QA/QC checklists were performed and documented by the testing laboratory.

Written approval of the construction, assembly, installation and instrumentation was supplied by OPL and signed by Sandia National Laboratories' representative prior to performance of the fire exposure test (a sign-off sheet for this purpose was supplied by the Laboratory).

The test assembly was then placed on the large scale horizontal fire resistance furnace and the thermocouples connected to the data acquisition system and their outputs verified. The test assembly was inspected one last time before the furnace was closed prior to the test. Upon receipt of approval to proceed, the test was initiated. Following the fire exposure test, all data acquisition systems were recalibrated in accordance with the Test Plan.

TEST RESULTS

The thermocouples were connected to the data acquisition systems and their outputs verified on April 21, 2005. The furnace was fired on April 25, 2005, and computer data collection of thermocouple data continued for 180 minutes. The ambient temperature at the start of the test was 67°F, with 76% relative humidity. The furnace was fired at 9:02 AM and the standard time-temperature curve followed for 180 minutes. The pressure differential between the inside of the furnace (as measured 12" below the exposed surface of the test slab) and the laboratory ambient air was maintained at 0.00 inches of water column for the duration of the fire exposure test (after the first five minutes, during which furnace stabilization was achieved).

Persons present to perform or witness the test were as follows:

Deggary Priest	-	Omega Point Laboratories, Inc.
Connie Humphrey	-	Omega Point Laboratories, Inc.
Mike Dey	-	Omega Point Laboratories, Inc.
Cleda Patton	-	Omega Point Laboratories, Inc.
Troy Bronstad	-	Omega Point Laboratories, Inc.
Oscar Estrada	-	Omega Point Laboratories, Inc.
Richard Beasley	-	Omega Point Laboratories, Inc.
Laudencio Castanon	-	Omega Point Laboratories, Inc.
Frank Wyant	-	Sandia National Laboratories
Bruce Levin	-	Sandia National laboratories
Chuck Girard	-	URS Corporation
Mark Salley	-	US Nuclear Regulatory Commission
Kendra Hill	-	US Nuclear Regulatory Commission
Jason Dreisbach	-	US Nuclear Regulatory Commission
Mike Jordan	-	Promatec
Frank Haese	-	Promatec
Jose Espanosa	-	Promatec

Observations made during the test were as follows:

TIME (min:s)	OBSERVATIONS
0:00	Furnace ignited at 9:02 AM.
3:00	Tape on the exterior of various conduits has ignited and is burning steadily.
5:00	Furnace pressure adjusted to neutral 12" below test deck.
9:00	Exterior surfaces of the protected items turning white. Tape on junction box supports is burning.
14:00	Joints on conduit outer wrap systems are beginning to open slightly.
17:00	Residual flaming continues on junction box supports and conduit 3D. Others, also, but visibility is limited.
33:00	Residual flaming continues on most visible conduits, mostly at zero-radius turns.
60:00	All surfaces red hot. Most joints are continuing to open.
120:00	Same.

TIME (min:s)	OBSERVATIONS (continued)
157:00	Aluminum oxide observed pouring out of several of the raceways.
180:00	Furnace extinguished. Specimen thermocouples were disconnected and the test assembly lifted from the furnace, observed, photographed and moved to the hose stream test area. Open joints were observed on virtually all raceways.
185:56	Hose stream began at a nozzle spray angle of 15°, pressure at 75 psi and from a distance of 10 ft. The entire test assembly was slowly spun and the hose stream operator remained stationary and applied the hose to the test items as they passed in front of him.
190:56	Hose stream stopped. The test assembly was then observed, photographed and allowed to drip for several hours before being placed on 8' tall 24" ø pipe stands and undergoing post-test disassembly. There were no significant changes in any of the exterior claddings on the raceways due to the hose stream test. The outer insulation wraps all showed significant openings through to the stainless steel foil, due to shrinkage. No raceways could be seen through the M.T. system.

Post-test examination of the test items revealed that virtually all exterior insulation pads had shrunk enough to result in 2-3" wide openings between pads. Visible between the gaps was the stainless steel foil wraps which were positioned beneath the aluminum trihydrate-containing sacks. No significant shrinkage was noticed beneath the stainless steel foil. All of the systems which were disassembled for observation had no insulation left on the thermocouple wires within, indicating that the maximum temperatures for these thermocouples had definitely been exceeded. All internal raceways showed heat scorching and other damage.

Other than small pieces of the deck insulation falling to the laboratory floor, the test assembly showed no visible effect due to the hose stream test. No openings through to the raceway item were noticed on any of the test items. None failed the hose stream test. Much steam and dripping hot water remained after the hose stream was stopped.

In accordance with the E119 test standard, a calculation for any correction to the indicated fire resistance period was done. The correction factor was then mathematically added to the indicated fire resistance period, yielding the fire resistance period achieved by this specimen:

ITEM	DESCRIPTION	TEST VALUE
C	correction factor	-0.04 min (-3 seconds)
I	indicated fire-resistance period	180 min
A	area under the curve of indicated average furnace temperature for the first three fourths of the indicated period	212 335°F•min
As	area under the standard furnace curve for the same part of the indicated period	212 410°F•min
L	lag correction	3240°F•min
	FIRE RESISTANCE EXPOSURE RECEIVED BY THIS SPECIMEN ==>	180

Note: The standard specifies that the fire resistance be determined to the nearest integral minute. Consequently, if the correction factor is less than 30 seconds, and the test specimen met the criteria for the full indicated fire resistance period, no correction is deemed necessary. That was the case for this project.

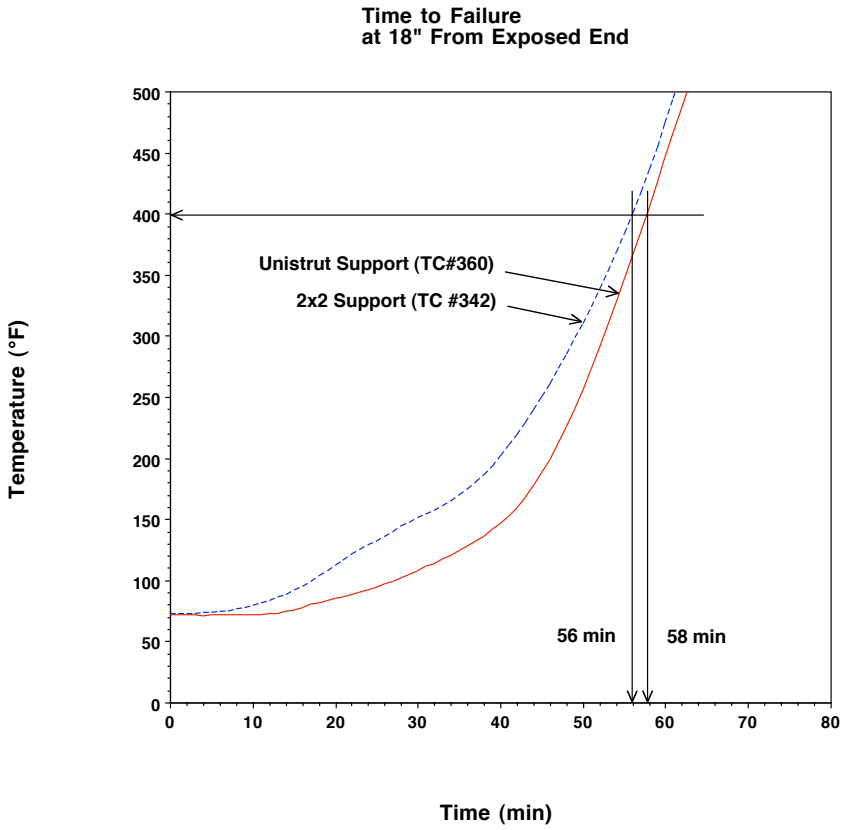
CONCLUSIONS

In accordance with the assessment criteria listed in the Test Plan, all raceway systems failed to meet a 3h fire endurance period. The table below summarizes the results for each item. Note that the instrumented bare #8 copper wires with the thermocouples attached were buried within the bare copper wire bundles to protect the thermocouples from damage while the bundles were being pulled through conduit raceways.

Raceway		Time to $\Delta T_{avg} \geq 250°F$ (min)	Time to $\Delta T_{ind} > 325°F$ (min)	Max. Temp Bare #8@1h (°F)	Burn-Through/ Structural Failure Yes/No	Pass Hose Stream Yes/No	Final Fire Endurance (min)
3A	4" Conduit (empty)	121	110	961	No	Yes	110
3B	4" Conduit (loaded: fill=30.0%, 14.84 lb/ft)	143	113	374	No	Yes	113
3C	2 1/2" Conduit (empty)	119	103	1119	No	Yes	103
3D	2 1/2" Conduit (loaded: fill=29.8%, 5.85 lb/ft)	126	112	577	No	Yes	112
3E	1" Conduit (empty)	98	87	1314	No	Yes	87
3F	1" Conduit (loaded: fill=29.7%, 1.02 lb/ft)	108	96	1084	No	Yes	96
3I	Junction Box (empty)	122	134	n/a	No	Yes	122
3J	Cable Air Drop (seven pcs of bare #8)	169	159	607	No	Yes	159

Item #3G: Unistrut Support & Item #3H: 2" x 2" Steel Support

The temperatures at a location 18" from the edge of the cladding on the exposed end of each of the two supports were determined, and are shown in the graph below. Item 3G, TC#360 and Item 3H, TC #342 were located at that distance. As the graph indicates, the temperature 18" from the edge of the cladding on Item 3G (Unistrut®) achieved a fire endurance rating of 58 minutes, while the fire endurance rating at the same position on Item 3H (2" x 2" steel support) was reached at 56 minutes. These comparative results are as expected, since the 2" x 2" steel material has a higher cross-section of metal, and hence will conduct more heat.



Shrinkage of the outer M.T. insulation pads

During the fire exposure, shrinkage of the Hemyc insulation pads appeared to be caused by the heating of the surface fabric. The end result, was that as adjacent insulation pads withdrew from each other during the shrinkage process, gaps of 3 – 4" appeared, which allowed the furnace heat to attack the stainless steel foil layer within each system. As previously mentioned, the hose stream test did not appear to cause any change in the opening sizes, but the hose stream test can be judged as successful, since the openings did not extend past the layer of stainless steel foil.

Loaded Conduits versus Empty Conduits

Due to the significant effects of the shrinkage of the outer insulation pads of the M.T. system (and the subsequent opening of joints down to the stainless steel layer), the effects of the heavy loadings were overshadowed. No useable information could be extracted from these systems concerning the effect of loading.