Mr. Ajit K. Gwal, Technical Specialist
Defense Nuclear Facilities Safety Board
625 Indiana Avenue
Washington, D.C. 20004

Dear Mr. Gwal:

I would like to inform you of several staff concerns regarding the draft version of IEEE P848, "Procedure for the Determination of the Ampacity Derating of Fire Protected Cables," and to ask you to bring them to the attention of Task Force 12-45 of Tests and Measurements Subcommittee No. 12 of the Insulated Conductors Committee for the IEEE Power Engineering Society. These issues arose during tests conducted by Texas Utilities Electric (TUE) and Tennessee Valley Authority for application of Thermo-Lag fire-retardant material at Comanche Peak Steam Electric Station Unit 2 and Watts Bar Nuclear Plant, respectively.

Briefly, the following issues need to be addressed by IEEE P848: (1) conduit surface emissivity variations and effects, (2) wall temperature effects, and (3) inductive current effects. Enclosed is a paper with Appendices A and B that gives greater detail regarding the staff concerns.

In addition, Mr. Ronaldo Jenkins of my staff is available to work with your group members to resolve these and other emerging issues and share the nuclear regulatory perspective on the use of the proposed test method. Since the Nuclear Energy Institute (NEI) has sought to utilize the TUE test results generically, we want to ensure that the procedure provides consistent and conservative test results.

We hope that you, as Chairman of the working group, will present these concerns to the other group members for appropriate review and discussion. We request that the next draft of the subject procedure address these concerns. If you have any questions, please call Ronaldo Jenkins at (301) 504-2985 or Paul Gill at (301) 504-3316. Thank you for your assistance.

Sincerely,

Original Signed By
Carl H. Berlinger

Carl H. Berlinger, Chief
Electrical Engineering Branch
Division of Engineering
Office of Nuclear Reactor Regulation

Attachment: As stated

Enclosure

STAFF REVIEW OF CONDUIT AMPACITY DERATING EXPERIMENTS

INTRODUCTION

Fire protection in nuclear power plants is an ongoing concern of the Nuclear Regulatory Commission (NRC), which was intensified in 1975 by the fire at the Browns Ferry Nuclear Power Plant. As a result, redundant electrical equipment trains that are necessary for safe shutdown are required to be separated by either a 1-hour fire barrier, a 3-hour fire barrier with other protective measures, or 6.10 meters (20 feet) of horizontal spatial separation with no intervening combustible materials. American Society for Testing and Materials (ASTM) E119, "Fire Test of Building Construction and Materials," describes in detail the fire endurance test that has been used to determine the fire rating for a barrier configuration on the basis of specified time-temperature curves. Since the 20-foot separation requirement is generally very difficult to achieve in existing plants, licensees have often decided to protect the applicable electrical equipment trains with 1- or 3-hour fire barriers.

Rubber or plastic insulation on an electrical cable is susceptible to degradation over time. Heat accelerates rubber and plastic embrittlement. This phenomenon is known as thermal aging and is represented mathematically by the Arrhenius relationship. Electrical current in cables produces heat as a result of resistive losses in the cables. Electrical system designers limit the electrical current so that cables do not exceed their temperature rating. A typical cable is rated for 40 years at 90°C (194.0°F). For a given cable, the ampacity or current rating depends on the size of the cable, whether or not the cable is jacketed, the number of conductors in the cable, and the type of conductor in the cable.

Fire barriers insulate cables from heat and flames. However, these same insulation properties result in the reduction of the cable ampacity or the need to determine an ampacity derating factor for that fire barrier.

There are two primary methods for measuring ampacity derating. The first method is to experimentally quantify the thermal properties of the fire barrier system for any electrical equipment configuration. The ratio of ampacity measurement for the configuration while protected by the fire barrier to the ampacity measurement for the unprotected configuration is the ampacity correction factor (ACF). The widely used ampacity derating factor (ADF) is related to the ACF as follows: ADF=1-ACF. This methodology, embodied in the draft version of IEEE P848, has been followed in one form or another by most fire barrier manufacturers to determine the ADF.

The second method involves building a physical model of the actual plant installation and demonstrating by measuring the temperature of the energized configuration that the plant-specific configuration would not result in the cables being heated above their temperature ratings. This method is expensive and very specific for a particular set of cables carrying normal currents and is more likely to be used in marginal case-specific situations.

Heat flow away from the cables depends on the geometry and material around the cables. As shown by Dykhuizen's (1993) calculations, variations that seem insignificant can significantly influence the heat flow and change the ampacity derating factor. A more attractive solution would be the use of a mathematical model instead of expensive experiments. Unfortunately, the existing mathematical models do not sufficiently match experimental results to eliminate the need for experiments.

This paper will examine past experiments on conduits conducted by Thermal Sciences, Inc. (TSI), Underwriters Laboratories (UL), Texas Utilities Electric (TUE) Company, and Tennessee Valley Authority (TVA). Sandia National Laboratories (SNL) has completed extensive work on this subject under Office of Nuclear Reactor Regulation Technical Assistance Contracts JCN J-2017 and J-2018. The procedure in IEEE P848 attempts to standardize the measurements of ampacity derating for different configurations such as conduits, trays, fire stops, and free-air drops. This draft procedure has been used by TUE (Draft 11) and TVA (Draft 12) to conduct their ampacity derating measurements. In this paper, the staff identifies its concerns regarding recent ampacity derating tests and makes recommendations for enhancing IEEE P848.

THERMO-LAG 330 CONDUIT TEST RESULTS

Several different laboratories have measured the ampacity of cables in cylindrical conduits covered with Thermo-Lag. Table 1 lists the ACFs reported for these tests. For the TSI and Industrial Testing Laboratories (ITL) reports, corrections have been made for errors in normalization. The range of these values is not very large (0.9 to 1.05), although the Thermo-Lag nominal thickness ranges from 3.8 cm (1/2 inch) to over 2.5 cm (1 inch). These values are for conduits that range from 1.9 cm (3/4 inch) to 12.7 cm (5 inches) nominally in diameter. The TVA (1993) report shows that up to 1 1/2 inches of Thermo-Lag can be applied to a nominal 1-inch barrier.

All of the conduit tests consisted of energizing one type of cable within a straight, horizontal conduit that was at least 1.5m (5 feet) in length. For its experiments, TVA varied the conductor wiring and cables between tests. It also varied the Thermo-Lag thicknesses. Wiring changes significantly changed ampacity but had little affect on ACF.

REPORT	CONDUIT SIZE	ACF	BARRIER THICKNESS	CABLE INFORMATION
UL 86NK32826	4"	1.02	1/2"	(7) 3/c 6AWG
UL 86NK32826	4"	0.905	1"	(7) 3/c 6AWG
TSI 111781	2"	0.924	1/2"	(3) #00 AWG
ITL 84-10-5	2"	0.906	1" min.	(3) #00 AWG, 600V
SwRI 01-8818-208/209C	4"	0.994	3/4"	(20) 3/c 3AWG; .75"
TVA 93-0501	4"	1.052	5/8"	3/c 6AWG, 600V
TVA 93-0501	4"	0.975	1"	3/c 6AWG, 600V
TVA 93-0501	4"	0.918	3/4"	3/c 6AWG, 600V
TVA 93-0501	4"	1.038	5/8"	4 conductor
TVA 93-0501	4"	0.998	1"	4 conductor
TVA 93-0501	4"	0.977	3/4"	4 conductor
TVA 93-0501	4"	1.033	5/8"	24 conductor
TVA 93-0501	4"	1.006	1"	24 conductor
TVA 93-0501	4"	0.997	3/4"	24 conductor
TVA 93-0501	4"	1.018	5/8"	3 phase power used
TVA 93-0501	4"	1.009	1"	3 phase power used
TVA 93-0501	4"	0.949	3/4"	3 phase power used
TVA 93-0501	1"	0.965	5/8"	3/c 6AWG Rockbestos
TVA 93-0501	1"	0.956	1"	3/c 6AWG Rockbestos
TVA 93-0501	1"	0.969	1/2"	3/c 6AWG Rockbestos
TVA 93-0501	1"	0.982	5/8"	4 conductor
TVA 93-0501	1"	0.967	1"	4 conductor
TVA 93-0501	1"	0.99	1/2"	4 conductor
TVA 93-0501	1"	1.027	5/8"	3 phase power used
TVA 93-0501	1"	1.002	1"	3 phase power used
TVA 93-0501	1"	1.016	1/2"	3 phase power used
TUE 12340-94583	3/4"	0.907	1/2"+ 1/4"	3/c 10AWG, 600V
TUE 12340-95165	2"	0.933	1/2"+ 1/4"	3/c 6AWG, 600V
TUE 12340-95246	5"	0.893	1/2"	4-1/c 750 KcMil

Notes:
ACF = ampacity correction factor; UL = Underwriters Laboratories;
TSI = Thermal Sciences, Inc.; ITL = Industrial Testing Laboratories;
SwRI = Southwest Research Institute; TVA = Tennessee Valley Authority;
TUE = Texas Utilities Electric.
Number in parentheses = lengths.
Minimum ACF = 0.893; average ACF = 0.977; maximum ACF = 1.05.

The ACF for many of these tests seems to indicate that adding Thermo-Lag material actually improves heat dissipation. Simple calculations of a model conduit were performed to understand the increase in ampacity for clad conduits that is implied by this result. The formulas for these calculations are included in Appendix A. The staff assumed that the cable was in intimate contact with the conduit. As a result of these calculations, it is plausible that the clad conduit may have a higher ampacity than a bare conduit. Calculations show that the heat transfer with the thermal protection is similar to, if not better than, that for a plain steel conduit for two reasons: (1) Heat transfer increases with the diameter of a cylinder (because the area for the transfer is larger) and (2) Thermo-Lag 330-1, a white matte surface, has a higher radiative emissivity than a steel conduit.

These calculations also show that the magnitude of radiative transfer of heat is comparable to that of the convective transfer for the clad conduit. If the temperatures of the test enclosure walls are cooler than the air surrounding the conduit, the ACF is increased because of the high radiative heat transfer of the Thermo-Lag material. The radiative exchange is much more important for the clad conduit because of the higher outer surface emissivity. Radiative heat transfer is highly dependent on the temperature differences between the emitting and absorbing surfaces.*

Hence, if the walls of the room are at 35°C (95°F) instead of 40°C (104°F), the overall rate of heat transfer increases. Since the baseline conduit has a much lower emissivity, the effect of wall temperature on the overall rate of heat transfer is less significant and can largely be ignored. Reduced wall temperature enhances the heat transfer capability of the clad conduit and, hence, enhances the ampacity measurement. This results in an artificial increase in the value of the ACF of 1.5 percent. As shown in Appendix A, even relatively modest changes in the wall temperature could result in ACF values greater than unity. This is the most likely explanation for the scatter in the TVA results. That is, variation in wall temperature and conduit surface emissivities could have resulted in the variation in the ACF values. Since wall temperatures were not measured in these experiments, there is no way of knowing how much this phenomenon will affect the ACF during tests.

TVA TESTS

For the TVA tests, the baseline measurements and the clad measurements were performed on the same cables but in different conduits (i.e., the cables were pulled into the "baseline" conduit, a measurement was taken, and the cables were then pulled into a clad conduit where another measurement was taken). The temperature on one end of the conduit was significantly different from that on the other end. Since two sections of conduit had been used in each test, TVA cut one section of the conduit in half and reassembled it so that the temperatures on the two ends were similar. It is believed that the differences in the surface emissivity of the conduit sections may have caused this temperature difference.

---

*The radiative heat transfer is $q=2\pi r_o \sigma \epsilon_o (T^4_o - T^4_\infty)$ where T_o is the absolute temperature of the conduit surface and T_∞ is the absolute temperature of the walls of the test enclosure.

Overall, there are two possible effects that could account for the negative derating factors (i.e., ADF=1-ACF): (1) the difference between the wall temperature and the ambient air temperature as described above and (2) the effects of conduit surface emissivities associated with the use of two different conduit test specimens for the baseline and clad ampacity tests.

TUE TESTS

In addition to taking into account the wall temperature variations and surface conduit emissivities concerns noted in the TVA tests, TUE conducted the 3/4-inch and 2-inch conduit tests using a three-conductor configuration in accordance with IEEE P848. The three-conductor configuration exhibits inductive current heating effects due to unbalanced currents in the different conduit specimens used in the baseline and clad tests. The inductive heating effects lead to indeterminate ACF results. The effect of inductive current heating is discussed further in Appendix B.

RECOMMENDED CHANGES FOR IEEE P848

The staff review of the applicable test data using the current draft of IEEE P848 indicates the need for the working group to address the following:

(1) Potential test enclosure wall temperatures should be monitored and controlled to preclude any emissivity effects resulting from radiant energy losses from affecting measured ACF values.

(2) The procedure should address potential inductive heating effects associated with three-conductor, single-phase configuration.

(3) The procedure should address the possible effect resulting from variability in conduit surface emissivities. The use of the same test specimen in both the baseline and clad ampacity tests seems to be an appropriate recommendation for the procedure.

(4) The provisions of the procedure need greater definition in order to obtain more consistent application of test results. For example, the current draft of the procedure prescribes the conditions necessary to reach thermal equilibrium but not the conditions that must be maintained in order to keep subsequent current measurements valid. The 90±1.1°C (194±4°F) criterion does not specify the use of the individual hot spot temperatures rather than the 60-minute running average hot spot temperature.

CONCLUSION

The ampacity derating experiment or mathematical model must resemble the actual plant installation as closely as possible. Ampacity measurements are highly dependent on the physical details of the experiment. For example, Dykhuizen (1993) shows that a thermal blanket placed above the cable in the cable tray can account for a 20-percent change in ampacity of the protected cable tray. Banding cables with steel tie wraps can also change the heat flow pattern so that the ampacity measurements are affected.

Mathematical models show that the ACF depends on the thermal conductivity of the cables. A literature search has not revealed an accurate scientific measurement for the bulk thermal conductivity of the cables. The values given by Stolpe and Engmann are still being used, although no laboratory reference is provided which validates this parameter.

The room must be held at a constant temperature of 40°C (104°F) and the cable at 90°C (194°F). To reach these temperatures, the room is typically heated with some kind of radiation or air heater. The test enclosure room should be held to a very narrow band of temperature but with minimal air movement. Test wall temperatures and the air temperature may be different, but typically only the air temperatures are specified and measured. The temperatures of the walls should also be measured because they can affect the radiative heat loss. The staff recommends that IEEE P848 be modified to take into account this issue and other issues involving physical parameters (surface emissivities and inductive current effects) which can affect ampacity measurements.

REFERENCES

American Society for Testing and Materials, ASTM E119, "Fire Test of Building Construction and Materials,"

Dykhuizen, R. C., Sandia National Laboratories, "Review of Ampacity Analyses for TSI Materials," Draft Letter Report to Nuclear Regulatory Commission, October 28, 1993.

IEEE Power Engineering Society, P848, "Procedure for the Determination of the Ampacity Derating of Fire Protected Cables," Task Force 12-45 of Test and Measurements Subcommittee No. 12 of Insulated Conductors Committee.

Industrial Testing Laboratories, 84-10-5, "Engineering Report on an Ampacity Test for 600 Volt Power Cables Installed in a Five Foot Length of Two Inch Conduit Protected With a Three Hour Fire Rated Design of the Thermo-Lag 330 Fire Barrier System," St. Louis, Missouri, September 29, 1984.

Southwest Research Institute, 01-8818-208/209C, "Ampacity Derating of Fire-Protected Cables in Conduit Using a One Hour Subliming Preform Board Provided by 3M, Incorporated," San Antonio, Texas, October 3, 1986.

Texas Utilities Electric Company, Omega Point Laboratories, Report 12340-94583, "Ampacity Derating of Fire Protected Cables," prepared for Texas Utilities Electric Comanche Peak Steam Electric Station, San Antonio, Texas, March 19, 1993.

Texas Utilities Electric Company, Omega Point Laboratories Report 12340-95165, "Ampacity Derating of Fire Protected Cables," prepared for Texas Utilities Electric Comanche Peak Steam Electric Station, San Antonio, Texas, March 19, 1993.

Texas Utilities Electric Company, Omega Point Laboratories Report 12340-95246, "Ampacity Derating of Fire Protected Cables," prepared for Texas Utilities Electric Comanche Peak Steam Electric Station, San Antonio, Texas, March 19, 1993.

Thermal Sciences Inc., 111781, "Engineering Report on an Ampacity Test for 600 Volt Power Cables Installed in a Five Foot Length of Two Inch Diameter Aluminum Conduit Protected With a One Hour Fire Rated Design of the Thermo-Lag 330 Fire Barrier System," St. Louis, Missouri, October 24, 1981.

TVA Central Laboratories, Report 93-0501, "Testing To Determine Ampacity Derating Factors for Fire Protected Cables for Watts Bar Nuclear Plant," Chattanooga, Tennessee, submitted to the Nuclear Regulatory Commission on June 22, 1993.

Underwriters Laboratories, Inc., 86NK32826, "Special Services Investigation of Ampacity Deratings for Power Cables in Steel Conduits and in Open Ladder Cable Trays With Field-Applied Enclosures," Northbrook, Illinois, January 21, 1987.

APPENDIX A: SANDIA NATIONAL LABORATORIES FORMULAS FOR CALCULATING CONDUIT HEAT FLOW

To understand the mechanism by which Thermo-Lag clad conduit can dissipate heat better than bare conduit, a few simple calculations will be made on ideal cylinders using information from TVA report 93-0501. Heat flow will be calculated per unit length because of the infinite length assumption. The heat conduction across a cylindrical shell with uniform temperatures inside and outside is (Holman, 1976):

$$q_{cond}=2\pi k\frac{T_i-T_o}{\ln\left(\frac{r_o}{r_i}\right)}$$

where k is the thermal conductivity of the cylinder material; r_i and r_o are the inside and outside radii, respectively; and T_i and T_o are the inner and outer surface temperatures in °K. The heat flows from the outer surface by two methods: convection and radiation. The heat flow per unit cylinder length due to radiation is (Holman, 1976):

$$q_{rad}=2\pi r_o\sigma\epsilon_o(T_o^4-T_\infty^4)$$

where ϵ_o is the emissivity of the cylinder surface, T_∞ is the temperature of the test enclosure walls, and σ is the Stephan-Boltzman constant (5.67×10^{-8} $W/m^2\text{-}°K^4$). The emissivity is a value between 0 and 1 that describes how well light is absorbed by a surface. Emissivity is determined not only by color, but also by surface roughness. The emissivity of wallboard (white) is approximately 0.9; shiny metals have values of 0.1 or less.

Convection depends on the shape of an object. Natural convection measurements are made in a still room. The convection coefficient for an infinite horizontal cylinder is $h = (k_a \mathrm{Nu})/(2r_o)$ where Nu is the Nusselt number for a cylinder and k_a is the conductivity of air (Holman, 1976). The Nusselt number is found experimentally for a particular geometry; empirical fits have been found for several simple shapes. The Nusselt number for a horizontal cylinder is given by Kreith and Bohn (1986):

$$\mathrm{Nu}=0.53(\mathrm{GrPr})^{1/4}$$

where the Grashof number, Gr, is

$$\mathrm{Gr}=\frac{g\beta(T_o-T_\infty)(2r_o)^3}{\nu^2}$$

and Pr, the Prandtl number, is 0.7 for the temperature range of interest here; g, the gravitational constant, is 9.8 m/s^2, while β is $1/T_o$ for gas.

Fitting the kinematic viscosity of air (Holman, 1976) in units of m^2/s, ν, with a cubic least-squares fit yields for T_o in °Kelvin:

$$\nu = -1.637 \times 10^{-7} + 5.038 \times 10^{-9}(T_o) + 1.7 \times 10^{-10}(T_o)^2 + 5.973 \times 10^{-14}(T_o)^3$$

The resulting heat transfer per unit length resulting from convection around a cylinder is:

$$q_{conv} = 2\pi r_o h (T_o - T_\infty) = \pi k_a Nu (T_o - T_\infty)$$

For the baseline case, the total heat loss resulting from the combination of radiation and convection must equal the conduction across the conduit wall.

The TVA (1993) report includes information on the temperature of the outside of the conduit for the bare conduit case. For a 1-inch conduit, the outer conduit temperature was 59.88°C (139.8°F) when the conductor temperature was 90°C (194°F) and the ambient temperature was 40.77°C (105.4°F) (see Figure A1).

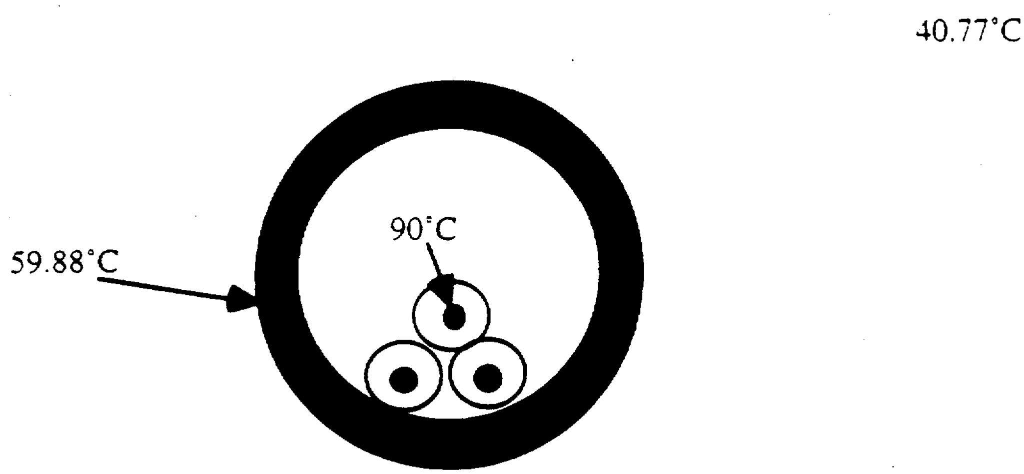

Figure A1: Schematic for calculation of conduit heat losses
Source: Tanaka, 1994

An effective thermal resistance (per unit length) from the conductor to the outside of the conduit can be calculated by equating the heat flow from the conductor to the outside of the conduit to the heat flow from the conduit to the surrounding room:

$$q_{baseline} = \frac{T_i - T_o}{R_{eff}}$$

$$= 2\pi r_o h(T_o - T_\infty) + 2\pi r_o \epsilon\sigma(T_o^4 - T_\infty^4)$$

$$\approx 13.6 \text{ W/m}$$

Here the assumption is that ϵ=0.22, a typical value for steel. T_i is the temperature of the conductor, T_o is the temperature of the outside of the conduit, and T_∞ is the temperature of the surrounding enclosure. The assumption is that the surrounding air temperature used to calculate conduction is equal to the enclosure wall temperature used to calculate radiation.

For the clad case, the thermal resistance from the conductor to the outside surface of the Thermo-Lag is the effective resistance from the previous baseline case (R_{eff}) plus the resistance from the outer cylinder of Thermo-Lag, which is for this case a 0.5-inch-thick layer. The combined thermal resistance is calculated as:

$$R = R_{eff} + \frac{\ln(r_{Tlag}/r_o)}{2\pi k_{Tlag}}$$

$$\approx 2.23 \ \frac{°C\text{-m}}{W} + \frac{\ln\left(\frac{0.0254}{0.0127}\right)}{2\pi\left(0.211 \ \frac{W}{°C\text{-m}}\right)}$$

$$\approx 2.753 \ \frac{°C\text{-m}}{W}$$

where r_{Tlag} is the radius to the outside of the Thermo-Lag barrier (1 inch or 0.0254 m), r_o is the radius of the conduit (0.5 inch or 0.0127 m), and k_{Tlag} is the conductivity of Thermo-Lag material (0.211 W/°C-m). The heat flow equation for the clad case is:

$$\frac{T_i - T_{Tlag}}{R} = h2\pi r_o(T_{Tlag} - T_\infty) + 2\pi r_o \sigma\epsilon_{Tlag}(T^4_{Tlag} - T^4_\infty)$$

Here the assumption is that ϵ_{Tlag} = 0.9, a value tabulated for wallboard. The above equation allows us to solve for T_{Tlag}, the Thermo-Lag surface temperature, by plotting the heat flow across the conduit and Thermo-Lag and

the heat flow resulting from convection and radiation. This equation is solved graphically (see Figure A2) at the point of intersection between curves.

The resulting Thermo-Lag temperature was 48°C (118.4°F) and the heat flow from the surface was 15 W/m, a larger number than the value for the baseline (i.e., bare conduit) case. The radiative contribution to this calculation is 8 W/m, while the convective contribution is only 7 W/m. For the bare conduit, however, the radiative contribution is only 2.3 W/m compared with the convective contribution of 11.3 W/m (higher convection because the conduit was hotter). This simple calculation shows that the clad conduit can have higher heat dissipation than the bare conduit, provided the emissivity and increased surface area of the fire barrier surface are high enough to offset its insulating properties.

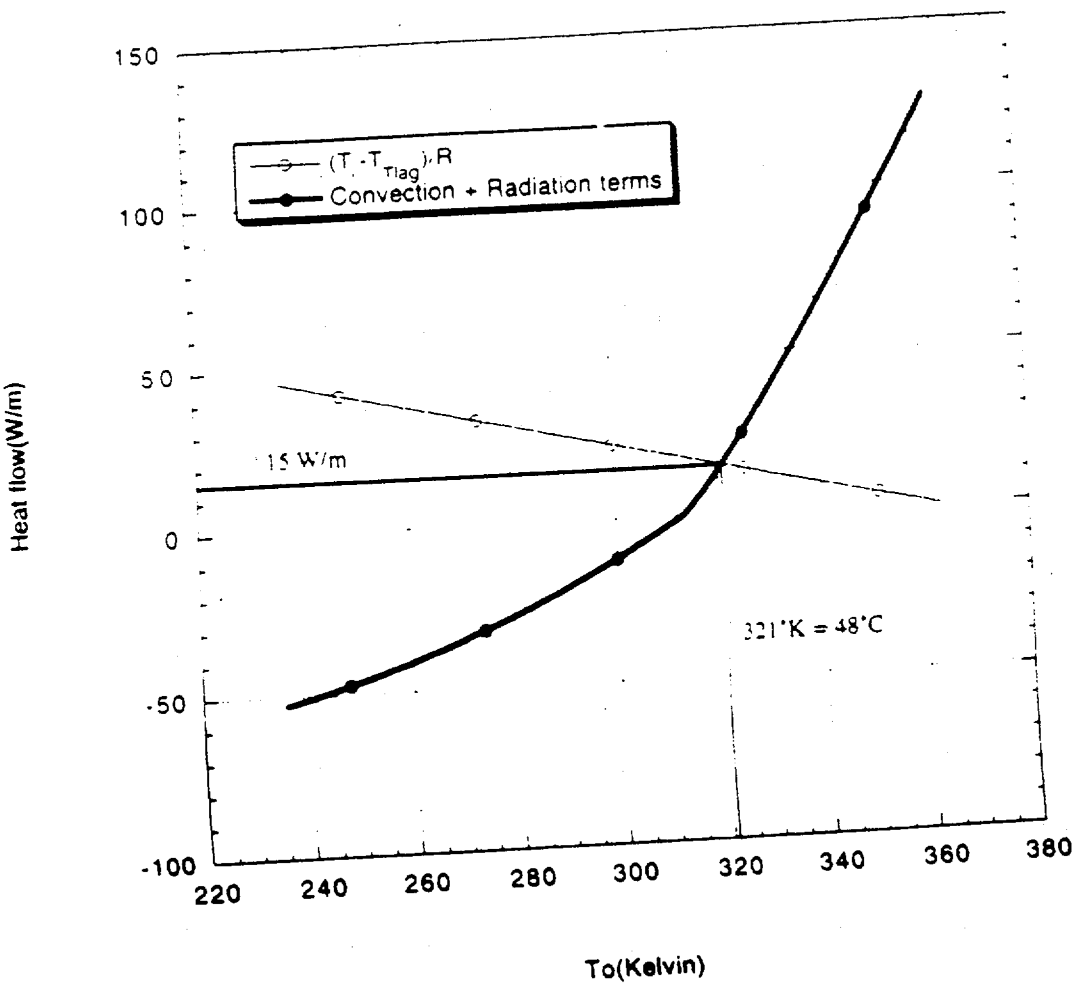

Figure A2: Protected 1-Inch Conduit Heat Flow Solution
Source: Tanaka, 1994

REFERENCES

Holman, J. P., *Heat Transfer*, Fourth Edition, McGraw-hill Book Company, 1976.

Kreith, F. and Bohn, M. S., *Principles of Heat Transfer*, Fourth Edition, Harper and Row, 1986.

Tanaka, T., Sandia National Laboratories, "Review of Experiments in Ampacity Derating," Draft Letter Report to Nuclear Regulatory Commission, March 15, 1994.

TVA Central Laboratories, 93-0501, "Testing To Determine Ampacity Derating Factors for Fire Protected Cables for Watts Bar Nuclear Plant," Chattanooga, Tennessee, submitted to the Nuclear Regulatory Commission on June 22, 1993.

APPENDIX B: AMPACITIES OF CABLES IN CONDUITS USING DIFFERENT WIRING SCHEMES AND INDUCTIVE CURRENT EFFECTS

The primary assumption inherent in earlier drafts of IEEE P848 is that tests using three conductors, fed single phase, will provide the same results as those performed with the same conductors powered with three-phase current. However, during single-phase testing, both Texas Utilities Electric (TUE) Company and Tennessee Valley Authority (TVA) determined that significant inductive heating in the conduit resulted from current "imbalance" (TVA noted a conduit surface temperature between 75°C (167°F) and 80°C (176°F)). Since the inductive heating may have influenced the results involving three-conductor tests, TVA undertook further testing to ascertain what effects the current imbalance may have had on the ampacity correction factors. The staff and Sandia National Laboratories examined the various cable configurations tested by TVA.

Cable ampacity is highly dependent on cable type and the wiring configuration. TVA report 93-0501 shows the effects of different cable configurations using 6 AWG 600-V cables and 1/C 750 Kcmil. The experiment included several variations on connecting cables in series with three- or four-strand cables and with the use of a three-phase power source. Tables B1 and B2 show the cable variations tested and ampacity results obtained for 1-inch and 4-inch bare conduits. The second column of Tables B1 and B2 shows the ampacity as normalized by the Neher and McGrath (1957) equation for the temperatures of the conductor and test enclosure. The third column of Tables B1 and B2 shows the total current flowing through the conduit in both directions.

Consider the third column shown in Table B1. The four-conductor configuration yielded a total current flow and ampacity value greater than the values for the three-conductor configuration for the same Thermo-Lag barrier construction and thickness. The difference in current values between the two cases is due to the inductive heating effects associated with the unbalanced currents and the conduit material. The inductive heating effects are minimized for the four-conductor configuration compared to the unbalanced three-conductor configuration. As a point of information, the three-conductor conduit tests, during which a simulated three-phase power source was used, had a normalized ampacity value of 64.2 amperes for the bare conduit and a calculated ampacity correction factor (ACF) of 1.00.

TABLE B1: TVA 93-0501 1-INCH CONDUIT AMPACITY EXPERIMENTS

CABLE CONFIGURATION	NORMALIZED BARE AMPACITY	AMPERE X NO. OF CONDUCTORS	AMPACITY CORRECTION FACTOR FOR 1/2-INCH THERMO-LAG
3/C cable 6 AWG connected in series	54.3	162.9	0.97
4/C cable 6 AWG connected in series	60.8	243.2	0.98

The electric current imbalance induces magnetic fields, which in turn induce currents in the shield of cables and in conduits. If two currents are in phase but in opposite directions, the magnetic fields will tend to cancel and the induced current is reduced. In the case of the series-connected 3/C (three-conductor) cable in Table B1, the currents along two lengths are traveling in one direction and the other length carries current traveling in the opposite direction. Therefore, the magnetic fields will not cancel very well. In the case of the 4/C (four-conductor) cable, however, the fields cancel very well.

TABLE B2: TVA 93-0501 4-INCH CONDUIT AMPACITY EXPERIMENTS

CABLE CONFIGURATION	NORMALIZED BARE AMPACITY	AMPERE X NO. OF CONDUCTORS	AMPACITY CORRECTION FACTOR FOR 1/2-INCH THERMO-LAG
3 conductors in series - 3 each 1/C 750 Kcmil cable	234	702	1.05
4 conductors in series - 1 each 4/c cable 6 AWG	420.3	1681.2	1.07
24 conductors in series - 8 each 3/C cable 6 AWG	32.1	770.4	1.07

Table B2 shows the same type of results for the 4-inch conduits in the 1-inch conduit tests; however, TVA used different cable sizes. As indicated by the test anomalies observed in TVA and TUE ampacity derating tests, inductive current heating effects associated with the use of two different test specimens in the baseline and clad ampacity measurements can result in errors in the ACF values.

First, conduit losses are inversely proportional to the square root of the product of the conduit electrical resistivity and magnetic permeability. The applicable literature suggests that under certain conditions of current imbalance, the losses in the conduit could be as much as 25 times those in the conductor where the conduit losses predominate; the specific conduit utilized for baseline and clad test specimens may significantly affect nominal equilibrium current. The above effect was noted during TVA conduit tests where the surface temperature of the specific conduit section was cooler than the other conduit section, independent of current and position in the test assembly.

Second, the elevated conduit temperature affects the effective thermal resistance from the conduit to the surrounding air. Using Equation 42 of the Neher and McGrath (1957) paper (cited below), effective thermal resistance (and hence the equilibrium current for the baseline conduit) varies inversely with a power function of the difference in temperature between the surface and the surrounding air. For example, a change in conduit temperature from 60°C (140°F) to 80°C (176°F) will decrease the effective thermal resistance of a 4-inch conduit to air by approximately 15 percent.

$$R_e = \frac{15.6n}{D_s\left(\frac{dT}{D_s}\right)^{1/4} + 1.6\epsilon(1+0.0167T_m)}$$

where

- R_e = the effective thermal resistance from the conduit (or Thermo-Lag) to air
- n = the number of conductors within the conduit
- D_s = the diameter of the conduit (or Thermo-Lag)
- dT = the temperature difference between the conduit surface (or Thermo-Lag) and air
- ϵ = the emissivity of the conduit (or Thermo-Lag)
- T_m = the average of the conduit surface temperature (or Thermo-Lag) and ambient air

Therefore, the effects resulting from inductive current heating and surface emissivities of conduits must be taken into consideration during the implementation of any ampacity derating test procedure.

REFERENCES

IEEE Power Engineering Society, P848, Procedure for the Determination of the Ampacity Derating of Fire Protected Cables," Task Force 12-45 of Test and Measurements Subcommittee No. 12 of Insulated Conductors Committee.

Neher, J. H., and McGrath, M. H., "The Calculations of the Temperature Rise and Load Capacity of Cable Systems," AIEE Transactions, pp. 752-772, October 1957.

TVA Central Laboratories, 93-0501, "Testing To Determine Ampacity Derating Factors for Fire Protected Cables for Watts Bar Nuclear Plant," Chattanooga, Tennessee, submitted to the Nuclear Regulatory Commission on June 22, 1993.

Mr. John Paul Cowan
Florida Power Corporation

CRYSTAL RIVER UNIT NO. 3

cc:

Mr. R. Alexander Glenn
Corporate Counsel (MAC-BT15A)
Florida Power Corporation
P.O. Box 14042
St. Petersburg, Florida 33733-4042

Mr. Charles G. Pardee, Director
Nuclear Plant Operations (PA4A)
Florida Power Corporation
Crystal River Energy Complex
15760 W. Power Line Street
Crystal River, Florida 34428-6708

Mr. Michael A. Schoppman
Framatome Technologies Inc.
1700 Rockville Pike, Suite 525
Rockville, Maryland 20852

Mr. William A. Passetti, Chief
Department of Health
Bureau of Radiation Control
2020 Capital Circle, SE, Bin #C21
Tallahassee, Florida 32399-1741

Attorney General
Department of Legal Affairs
The Capitol
Tallahassee, Florida 32304

Mr. Joe Myers, Director
Division of Emergency Preparedness
Department of Community Affairs
2740 Centerview Drive
Tallahassee, Florida 32399-2100

Chairman
Board of County Commissioners
Citrus County
110 North Apopka Avenue
Inverness, Florida 34450-4245

Ms. Sherry L. Bernhoft, Director
Nuclear Regulatory Affairs (NA2H)
Florida Power Corporation
Crystal River Energy Complex
15760 W. Power Line Street
Crystal River, Florida 34428-6708

Senior Resident Inspector
Crystal River Unit 3
U.S. Nuclear Regulatory Commission
6745 N. Tallahassee Road
Crystal River, Florida 34428

Mr. Gregory H. Halnon
Director, Quality Programs (SA2C)
Florida Power Corporation
Crystal River Energy Complex
15760 W. Power Line Street
Crystal River, Florida 34428-6708