EQUIPMENT AGING

B.9.1 THERMAL AGING

B.9.1.1 Arrhenius Methodology

In general, organic materials degrade continuously after becoming fully cured, the rate of which is strongly affected by temperature and material characteristics. Per IEEE 101-1972, it has been established that the Arrhenius Equation, which describes the temperature dependence of the velocity coefficient of chemical reactions, can be adapted to approximate the relationship between material life and temperature. Since the NRC has endorsed Arrhenius methodology as an acceptable means to address the effects of time/temperature aging, the following form of the Arrhenius Equation will be used to determine the thermal degradation equivalency between the component accelerated aging conditions and SONGS 2&3 service conditions:

$$t_1 = t_2 \exp[(E_a/k_B)(1/T_1 - 1/T_2)] \quad \ldots\ldots (1)$$

where,

t_1 = Qualified Life at T_1, hours
t_2 = Accelerated Aging Duration, hours
E_a = Activation Energy, eV
k_B = Boltzmann's Constant, 8.617E-5eV/K
T_1 = Service Temperature, Kelvin (K)
T_2 = Accelerated Aging Temperature, Kelvin (K)

Unless otherwise noted, this form of the Arrhenius Equation will be used for all qualified life calculations.

B.9.1.2 Component Service Temperatures

In general, the service temperatures specified in the EQ Topical Report (Reference 65) have been used to establish the qualified lives of safety-related equipment at SONGS 2&3. However, in this EQDP, it is very conservatively assumed, that the operating temperature of Rockbestos Firewall SIS and Firewall III cable is equal to the maximum operating temperature of the conductor as 90°C.

B.9.1.3 Limiting Activation Energies

Rockbestos Power, Control and Instrumentation cables contain two age-sensitive non-metallic materials. These materials are the Cross-Linked Polyethylene Insulation (XLPE) and the Chlorosulfonated Polyethylene (Hypalon) or Neoprene Jacket. This EQDP does not consider the cable jacket material in this aging evaluations for the following reason:

D/4

- Qualification of the jacket is not required since both type tests (References 7 and 8) utilized samples of unjacketed singles and there was no indication of any jacket failure in a manner which would prevent proper operation of the cable. Therefore it has been established that the functional integrity of the cable is not dependant on the presence of the jacket. A Sandia Laboratory report on performance of XLPE cables (Reference 25, Page 75) indicating no adverse affect on the cable performance due to failure of jacket, reinforces the above conclusion.

B.9.1.3.1 Cross-Linked Polyethylene (XLPE)

Rockbestos Long Term Thermal Aging Characteristics for Chemically Cured XLPE (Reference 7) and Irradiation Cured XLPE (Reference 8) which provide the time-temperature relationship of Rockbestos XLPE material using an Arrhenius regression line based on 60% retention of elongation after air oven aging, are shown in Figures B.9-1 and B.9-2. These thermal aging characteristics result in an activation energy of 1.34 eV for the Rockbestos XLPE material, which is utilized throughout this package.

B.9.1.4 Test Program Aging

The cables were subjected to accelerated thermal aging for 941 hours at 150°C (Reference 7, Page 49) and 900 hours at 150°C (Reference 8, page 42) for Chemically Cross-Linked XLPE (KXL-760D) and Irradiation Cross-Linked XLPE (KXL-760G).

B.9.1.5 Thermal Qualified Life Calculations

Employing Equation (1), the accelerated aging conditions of 900 hours at 150°C (423°K) can be converted to an equivalent life at the maximum normal service temperature of 90°C (363°K):

$$t_1 = t_2 \exp[(E_a/k_B)(1/T_1 - 1/T_2)]$$
$$t_1 = 900 \exp[(1.34/8.617E-5)(1/363 - 1/423)] \text{ hours}$$
$$t_1 = 391{,}949 \text{ hours or 44 years at } 90°C$$

FIGURE B.9-1
(Reference 7, page 50)

QR-5804

Data Section 3

Arrhenius Data

(Thermal Aging Characteristic)

Calculation of Arrhenius regression line based on 60% retention of elongation after air oven aging.

The equation has the form, Ref. IEEE-101A-1974,

$$\text{Life (hours)} = A \exp B/T$$
or
$$\ln \text{(hours)} = \ln A + B/T$$

A. For FW III Chemically Cross-Linked Insulation, KXL-760D there are three data points:

Hours	Temperature Deg. C	ln Hours	Recip Abs Temp (1/Deg K x 1000)
825	150	6.7153	2.3641
4300	136	8.3663	2.4450
12600	121	9.4414	2.5381

Linear regression analysis results:

Slope (B) = 15564.38
Intercept (ln A) = 29.9439
Correlation Coefficient = .9866

Calculated regression point temp. for 40 years = 91.4 Deg. C
Calculated regression point temp. for 100 hours = 177.5 Deg. C
Activation Energy = 1.3412 eV

941 hours aging @ 150 Deg. C represents 412,000 hours, or 47 years t a 90 Degree C service temperature.

FIGURE B.9-2
(Reference 8, page 42)

QR-5805

Data Section 3

Arrhenius Data

(Thermal Aging Characteristic)

Calcultion of Arrhenius regression line based on 60% retention of elongation after air oven aging.

The equation has the form, Ref. IEEE-101A-1974,

$$\text{Life (hours)} = A \exp B/T$$
or
$$\ln \text{(hours)} = \ln A + B/T$$

A. For FW III Irradiation Cross-Linked Insulation, KXL-760G there are three data points:

Hours	Temperature Deg. C	ln Hours	Recip Abs Temp (1/Deg K x 1000)
625	150	6.4377	2.3641
3300	136	8.1016	2.4450
9650	121	9.1747	2.5381

Linear regression analysis results:

Slope (B) = 15624.9
Intercept (ln A) = 30.3618
Correlation Coefficient = .9861

Calculated regression point temp. for 40 years = 89.3 Deg. C
Calculated regression point temp. for 100 hours = 173.8 Deg. C
Activation Energy = 1.3464 eV

900 hours aging @ 150 Deg. C represents 403,490 hours, or 46 years at a 90 Degree C service temperature.

B.9.2 RADIATION AGING

As documented in the test reports data sheets (Reference 7, Page 55 and Reference 8, p. 47), Isomedix used a Cobalt 60 gamma source to apply a TID of 1.84E8 rads (minimum applied dose due to instrumentation tolerances). Dose rates were maintained at levels which did not exceed 9.4E5 rads/hour (Reference 17).

B.9.3 CYCLIC WEAR AGING

Cables are passive components which are not subject to cyclic wear aging. Per IEEE 383-1974, "IEEE Standard for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations" does not consider cyclic wear aging as part of a typical cable type test program which may be used for qualifying Class IE electric cables. Therefore, this Subsection is not applicable.

B.9.4 NONSEISMIC VIBRATION AGING

As discussed in IEEE 323-1974, the requirement to simulate the potential degradation effects of in-service mechanical vibration aging as part of a test sequence is typically associated with two categories of components:

- Equipment subject to self-induced vibration (such as the starting and running of a motor).
- Equipment subject to vibration from nearby equipment or vibration from devices which provide the mounting support for the equipment (such as pipes, generators, motors, etc).

Cables may be categorized as passive components which are not subject to self-induced vibration. Consequently, this equipment is subject only to vibrational excitation from other sources to which it may be mechanically coupled. Since the cables in use at SONGS Units 2&3 are located in trays or in conduit except for short supported runs to devices, they will not be susceptible to nonseismic vibration degradation or damage over their installed life. Therefore, a consideration of vibration aging effects is not required to demonstrate qualification.

B.9.5 SYNERGISTIC EFFECTS

One of the requirements of 10 CFR 50.49 is an assessment of the synergistic effects of radiation in combination with other environmental stresses.

A synergistic relationship is observed when two or more stresses applied simultaneously produce degradation of a different type or magnitude than the same stresses applied sequentially. A review of industry published data has revealed that research has generally been limited to electric cables used inside containment for a limited range of specific environmental conditions. Given the limited scope and applicability of available synergistic documentation, the effects of the various service conditions are typically addressed individually.

The synergistic relationship between multiple stresses usually cannot be deduced from physical principles, rather, an experimental approach must be employed. Synergistic stresses usually require extensive testing to reveal their magnitudes, since most interaction effects are minute by comparison to the primary effects, and thus require significantly more experimental evidence to identify. Current research indicates that synergistic effects can typically be categorized under two main headings:

- Test Sequence Effects - The sequence in which radiation and thermal aging exposures occur is an important consideration. Radiation combined with elevated temperatures or radiation followed by elevated temperatures typically produces more material degradation than when thermal aging precedes radiation exposure (References 4 and 5).

- Radiation Dose Rate Effects - For many materials, it has been observed that lower dose rates produce significantly more degradation than a higher dose rate for the same total applied dose (Reference 6).

Although most IEEE Standards pertaining to equipment qualification (323, 334, 382, 383, etc.) specify a test sequence where accelerated thermal aging precedes radiation exposure, recent studies indicate that radiation exposure prior to thermal aging is the most conservative test sequence for the majority of organic materials (note that synergistic degradation mechanisms have not been established for inorganic and metallic materials operating within the specified range of service conditions).

However, in accordance with IEEE 323-1974, the Rockbestos test program selected a sequence where the normal radiation exposure was applied after accelerated thermal aging and combined with the accident radiation exposure. The LOCA simulation was performed after the thermal and radiation aging (Reference 7, Page 1 and Reference 8, page 1). The combination of LOCA environment with thermal and radiation conditions more than adequately simulates the sequence of radiation followed by elevated temperatures.

Per IEEE 383-1974, paragraph 2.4.2, the maximum allowed radiation dose rate on cable specimens is 1.0E6 rads per hour. The dose rate used on both type Rockbestos tests for Firewall SIS and Firewall III XLPE cables is 0.94E6 rads per hour. This is a 6% more conservative dose rate than the maximum allowed by IEEE 383-1974.

Reference 25 also confirmed that there is no significant difference between the single conductor and multiconductor cable insulation resistance. As an additional conservatism, the combination of environmental stresses impressed upon the test specimens during the qualification program are judged of sufficient severity to adequately account for any unknown or unaccounted for synergistic degradation mechanisms. Since the multiconductor cables in use at SONGS Units 2&3 are being applied well within their design ratings, synergistic effects are considered an insignificant degradation mechanism over the specified range of environmental conditions.

Thermal Qualified Life Calculations

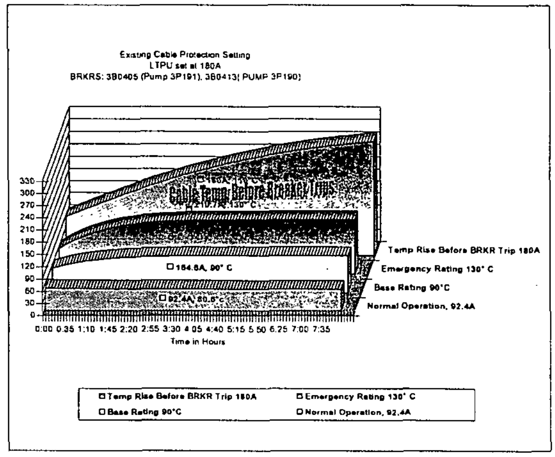
$$t_1 = t_2 \exp\{ (E_a / K_b)^*(1/T_1 - T_2)\}$$

t_1 =	Qualified Life at T_1, hours	
t_2 =	Qualified Life at T_2, hours	
E_a =	Activation Energy, eV	
K_b =	Boltzmann's Constant, 8.617E-5eV/k	
T_1 =	Service Temperature, Kelvin (k)	90°C +273
T_2 =	Accelerated Aging Temperature, Kelvin (k)	

	t_1= t_2 Hours	Ea Kb	T_1 T_2
Test Program Aging as described on page B.9-2	391,941 900 exp 391949 or 44 years at 90°C	1.34 8.617E-5 (Ea / Kb) 15551 435.499	363 423 (1/T1 - T2) 0.000391
During Abnormal condition the aging would be as follows: scenario Description 1 Abnormal Load Currrent 129A Conductor temperature will be 132°C in 5 Hours Calculate aging at this temperature.	900 exp 4611 or six months	1.34 8.617E-5 (Ea / Kb) 15551 5.123825 at 132°C	405 423 (1/T1 - T2) 0.000105
2 Abnormal Load Currrent 180A Conductor temperature will be 238°C in 5 Hours Calculate aging at this temperature.	900 exp 2 Hours at 238°C	1.34 8.617E-5 (Ea / Kb) 15551 0.00178	511 423 (1/T1 - T2) -0.000407

BREAKERS: 3B0405 (Pump 3P191), 3B0413 (Pump 3P190)

IE	IN	I0	T0	TN	TA	K	I	TE FLA	Time	CONDUCTOR TEMPERATURE 92.4	101.0	129.3		180.0
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.08	58.8	0:00	55.6	58.1	60.4		93
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.17	61.7	0:05	55.5	60.3	64.9		96
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.25	64.5	0:10	55.4	62.4	69.2		99
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.33	67.0	0:15	55.3	64.3	73.3		102
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.42	69.5	0:20	55.2	66.2	77.2		105
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.50	71.8	0:25	55.1	67.9	80.9		108
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.58	73.9	0:30	55.0	69.5	84.4		111
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.67	75.9	0:35	54.9	71.0	87.7		114
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.75	77.8	0:40	54.9	72.4	90.8		117
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.83	79.6	0:45	54.8	73.7	93.7		120
180.0	164.6	92.4	40.0	90.0	40.0	1.0	0.92	81.2	0:50	54.7	74.9	96.4		123
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.00	82.7	0:55	54.7	76.0	99.0		126
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.08	84.2	1:00	54.6	77.1	101.4		129
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.17	85.5	1:05	54.6	78.1	103.7		132
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.25	86.7	1:10	54.5	79.0	105.8	134	
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.33	87.9	1:15	54.5	79.8	107.8		137
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.42	89.0	1:20	54.4	80.6	109.6		140
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.50	90.0	1:25	54.4	81.3	111.4		143
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.58	90.9	1:30	54.4	82.0	112.9		146
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.67	91.7	1:35	54.4	82.6	114.4		149
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.75	92.5	1:40	54.3	83.2	115.8		151
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.83	93.3	1:45	54.3	83.7	117.1	154	
180.0	164.6	92.4	40.0	90.0	40.0	1.0	1.92	93.9	1:50	54.3	84.2	118.3		157
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.00	94.6	1:55	54.3	84.7	119.4		159
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.08	95.1	2:00	54.2	85.1	120.4		162
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.17	95.7	2:05	54.2	85.5	121.4		165
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.25	96.2	2:10	54.2	85.8	122.2		167
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.33	96.6	2:15	54.2	86.1	123.0		170
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.42	97.0	2:20	54.2	86.4	123.8	173	
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.50	97.4	2:25	54.2	86.7	124.5		175
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.58	97.8	2:30	54.1	87.0	125.1		177
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.67	98.1	2:35	54.1	87.2	125.7		180
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.75	98.4	2:40	54.1	87.4	126.3		182
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.83	98.7	2:45	54.1	87.6	126.8		184
180.0	164.6	92.4	40.0	90.0	40.0	1.0	2.92	99.0	2:50	54.1	87.8	127.2		187
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.00	99.2	2:55	54.1	88.0	127.7		190
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.08	99.4	3:00	54.1	88.2	128.1		192
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.17	99.6	3:05	54.1	88.3	128.4		194
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.25	99.8	3:10	54.1	88.4	128.8		197
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.33	100.0	3:15	54.1	88.6	129.1		199
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.42	100.2	3:20	54.1	88.7	129.4		201
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.50	100.3	3:25	54.1	88.8	129.6		203
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.58	100.4	3:30	54.1	88.9	129.9		205
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.67	100.6	3:35	54.1	89.0	130.1		207
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.75	100.7	3:40	54.0	89.1	130.3		209
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.83	100.8	3:45	54.0	89.1	130.5		211
180.0	164.6	92.4	40.0	90.0	40.0	1.0	3.92	100.9	3:50	54.0	89.2	130.7		213
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.00	101.0	3:55	54.0	89.3	130.8		215
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.08	101.1	4:00	54.0	89.3	131.0		217
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.17	101.1	4:05	54.0	89.4	131.1		219
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.25	101.2	4:10	54.0	89.4	131.3		221
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.33	101.3	4:15	54.0	89.5	131.4		222.9
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.42	101.3	4:20	54.0	89.5	131.5		224.7
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.50	101.4	4:25	54.0	89.6	131.6		226.5
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.58	101.4	4:30	54.0	89.6	131.7		228.3
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.67	101.5	4:35	54.0	89.6	131.8		230.0
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.75	101.5	4:40	54.0	89.7	131.8		231.6
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.83	101.6	4:45	54.0	89.7	131.9		233.3
180.0	164.6	92.4	40.0	90.0	40.0	1.0	4.92	101.6	4:50	54.0	89.7	132.0		234.9
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.00	101.6	4:55	54.0	89.7	132.0		236.5
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.08	101.7	5:00	54.0	89.7	132.1		238.1
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.17	101.7	5:05	54.0	89.8	132.1		239.6
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.25	101.7	5:10	54.0	89.8	132.2		241.1
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.33	101.7	5:15	54.0	89.8	132.2		242.6
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.42	101.8	5:20	54.0	89.8	132.3		244.0
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.50	101.8	5:25	54.0	89.8	132.3		245.4
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.58	101.8	5:30	54.0	89.8	132.3		246.8
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.67	101.8	5:35	54.0	89.9	132.4		248.1
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.75	101.8	5:40	54.0	89.9	132.4		249.5
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.83	101.8	5:45	54.0	89.9	132.4		250.8
180.0	164.6	92.4	40.0	90.0	40.0	1.0	5.92	101.9	5:50	54.0	89.9	132.4		252.0
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.00	101.9	5:55	54.0	89.9	132.5		253.3
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.08	101.9	6:00	54.0	89.9	132.5		254.4
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.17	101.9	6:05	54.0	89.9	132.5		255.7
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.25	101.9	6:10	54.0	89.9	132.5		256.9
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.33	101.9	6:15	54.0	89.9	132.5		258.0
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.42	101.9	6:20	54.0	89.9	132.6		259.1
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.50	101.9	6:25	54.0	89.9	132.6		260.2
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.58	101.9	6:30	54.0	89.9	132.6		261.3
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.67	101.9	6:35	54.0	89.9	132.6		262.3
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.75	101.9	6:40	54.0	90.0	132.6		263.4
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.83	101.9	6:45	54.0	90.0	132.6		264.4
180.0	164.6	92.4	40.0	90.0	40.0	1.0	6.92	102.0	6:50	54.0	90.0	132.6		265.3
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.00	102.0	6:55	54.0	90.0	132.6		266.3
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.08	102.0	7:00	54.0	90.0	132.6		267.2
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.17	102.0	7:05	54.0	90.0	132.6		268.1
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.25	102.0	7:10	54.0	90.0	132.6		269.0
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.33	102.0	7:15	54.0	90.0	132.7		269.9
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.42	102.0	7:20	54.0	90.0	132.7		270.7
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.50	102.0	7:25	54.0	90.0	132.7		271.6
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.58	102.0	7:30	54.0	90.0	132.7		272.4
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.67	102.0	7:35	54.0	90.0	132.7		272.3
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.75	102.0	7:40	54.0	90.0	132.7		273.9
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.83	102.0	7:45	54.0	90.0	132.7		274.7
180.0	164.6	92.4	40.0	90.0	40.0	1.0	7.92	102.0	7:50	54.0	90.0	132.7		275.4
180.0	164.6	92.4	40.0	90.0	40.0	1.0	8.00	102.0	7:55	54.0	90.0	132.7		276.1
180.0	164.6	92.4	40.0	90.0	40.0	1.0	8.08	102.0	8:00	54.0	90.0	132.7		276.8
180.0	164.6	92.4	40.0	90.0	40.0	1.0	8.17	102.0	8:05	54.0	90.0	132.7		277.5
														278.7
														278.9
														279.5
														280.1



IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

IEEE 242-1986 Section 8 5 2 4

where	IE =	Emergency operating current A	TE RATED =	Emergency operating temp ; °C
	IN =	Normal current rating (Ampacity) A	TN =	Normal temp rating, °C
	I0 =	Operating current prior to emergency, A	T0 =	Operating temp prior to emergency °C
	t	Time of overload/accident (hours)	TA =	Ambient temp ; °C
	k	Constant dependent on cable size and installation		
	234 0	Zero resistance temperature value for copper		
	e =	2 7183		

TE RATED	130	°C
TN	90	°C
TA	40	°C
K	1 00	For 800V # 2 Cable

Table 43
K Factors for Eqs in 8.5.2.4

Cable size	Air: No Conduit	Air: In Conduit	UG Duct	Direct Buried
< # 2	0 33	0 67	1	1 25
# 2 - # 4/0	1 00	1 50	3	3 00
>= 250 MCM	1 50	2 50	4	6 00

TE Calculated	189.7	°C	M
IE	180 00	Amps	3P100
IN	101 00	Amps	Charging Pump
I0	101 00	Amps	
T0	40 00	°C	
t	1 00	Hrs	

TE Calculated	142.3	°C	S
IE	63 80	Amps	77000
IN	42 20	Amps	
I0	42 20	Amps	
T0	40 00	°C	
t	1 00	Hrs	

TE Calculated	107.4	°C	M
IE	51 20	Amps	E433
IN	42 20	Amps	
I0	42 20	Amps	
T0	40 00	°C	
t	1 00	Hrs	

TE Calculated	97.1	°C	H
IE	26 50	Amps	E148
IN	24 20	Amps	
I0	24 20	Amps	
T0	40 00	°C	
t	1 00	Hrs	

TE Calculated	109.2	°C	S
IE	29 80	Amps	CONT
IN	24 20	Amps	SHAFT
I0	24 20	Amps	3A
T0	40 00	°C 30	
t	1 00	Hrs	

solve for time using the original equation

Ie	26 80	
In	24 20	
(Ie/In)²	1 510	1 617
Io	24 20	
e-t/k	0 001	
Te	173 70	
Tn	90 00	
Ta	40 00	
K	1 00	
t	7 00	

5	99 0
10	106 0
15	117 0
20	126 0
25	134 0
30	143 0
35	151 0
40	159 0
45	167 0
50	175 0
55	182 0
60	190 0
65	197 0
70	203 0
75	209 0
[illegible]	[illegible]

TE Calculated	281.9	°C	
For IE	180 00	Amps	
IN	101 00	Amps	
I0	101 00	Amps	
T0	40 00	°C	
t	2 02	Hrs	

TE Calculated	189.3	°C
IE	63 80	Amps
IN	42 20	Amps
I0	42 20	Amps
T0	40 00	°C
t	8.00	Hrs

TE Calculated	120.5	°C
IE	51 20	Amps
IN	42 20	Amps
I0	42.20	Amps
T0	40 00	°C
t	7 00	Hrs

TE Calculated	102.2	°C
IE	26 50	Amps
IN	24 20	Amps
I0	24 20	Amps
T0	40 00	°C
t	5 60	Hrs

TE Calculated	123.7	°C
IE	29 80	Amps
IN	24 20	Amps
I0	24 20	Amps
T0	40 00	°C
t	7 00	Hrs

100	80
200	90
300	99
400	102
500	105
600	108
700	111
800	114
900	117
1000	120
1100	123
1200	126
1300	129
1400	132
1500	134
1600	137
1700	140
1800	143
1900	146
2000	148
2100	151
2200	154
2300	157
2400	159
2500	162
2600	165
2700	167
2800	170
2900	173
3000	175
3100	177
3200	180
3300	182
3400	184
3500	187
3600	190
3700	192
3800	194
3900	197
4000	199
4100	201
4200	203
4300	206
4400	207
4500	209
4600	211
[illegible]	[illegible]

TE Calculated	250	°C
IE	12550	Amps
IN	101	Amps
I0	101	Amps
T0	40	°C
t	0 0001	Hrs

TE Calculated	189	°C
IE	64	Amps
IN	42	Amps
I0	42	Amps
T0	40	°C
t	8	Hrs

TE Calculated	121	°C
IE	51	Amps
IN	42	Amps
I0	42	Amps
T0	40	°C
t	8	Hrs

TE Calculated	102	°C
IE	27	Amps
IN	24	Amps
I0	24	Amps
T0	40	°C
t	6	Hrs

TE Calculated	124	°C
IE	30	Amps
IN	24	Amps
I0	24	Amps
T0	40	°C
t	8	Hrs

IE	Time
2800	14
2980	8
3140	8
3365	7
3620	6
3985	5
4440	4
5120	3
6270	2
8875	1
12550	0 5