61-1

**Westinghouse
Electric Corporation**

**Electronic Components
Divisions**

Westinghouse Circle
Horseheads New York 14845

PEN-TR-81-45

August 7, 1981

ANALYSIS AND REPORT ON THE SAFETY RELATED ELECTRIC PENETRATION FOR THE GINNA PLANT

WX32714

Ref. W IGTD P.O. #546-SG-435907-SN

R. L. Korner
Project Engineer

REGULATORY DOCKET FILE COPY

INDEX

1.0 IDENTIFICATION OF EQUIPMENT AND MATERIALS

Penet. Nozzle Number	Number of Cables	Type	W WX Number
AE-12	(1)	#16 TSP	WX32714
	(27)	#16 TSQ	
	(12)	#10 AWG	
	(4)	COAX	

This penetration consists of a 5" module inserted in a flange attached to the mating nozzle flange.

This report will be directed at the module and its cables.

This penetration is dedicated to instrumentation service;accordingly the effects of ohmic heating are minimal. Short circuit condition cannot occur in any of the circuits. The operating temperature will follow the ambient temperature of the containment.

2.0 PURPOSE OF THIS REPORT

To provide additional information to supplement W Report AB-11/12/73 "Qualification Tests For A Modular Penetration 5" Dia. (Prototype B-1)".

3.0 QUALIFICATION TEST PLAN

Additional test reports and analysis will be provided for both the penetration module and its cables.

4.0 REQUIRED ENVIRONMENTAL CONDITIONS

2:05 Design Requirements

2:05.1 Design Parameters:

The design parameters for the penetration are as follows:

1. Service life - 40 years
2. Design basis temperature (max) - 268 F
3. Design basis pressure (max) - 60 psig
4. Design basis relative humidity - 100%
5. Ambient temperature (max) - 120 F
6. Ambient pressure (max) - 0.3 psig
7. Integrated 40 year dose (max) - 1.5×10^8 Rads
8. Dose Rate (max) - 2.1×10^4 Rad/hr

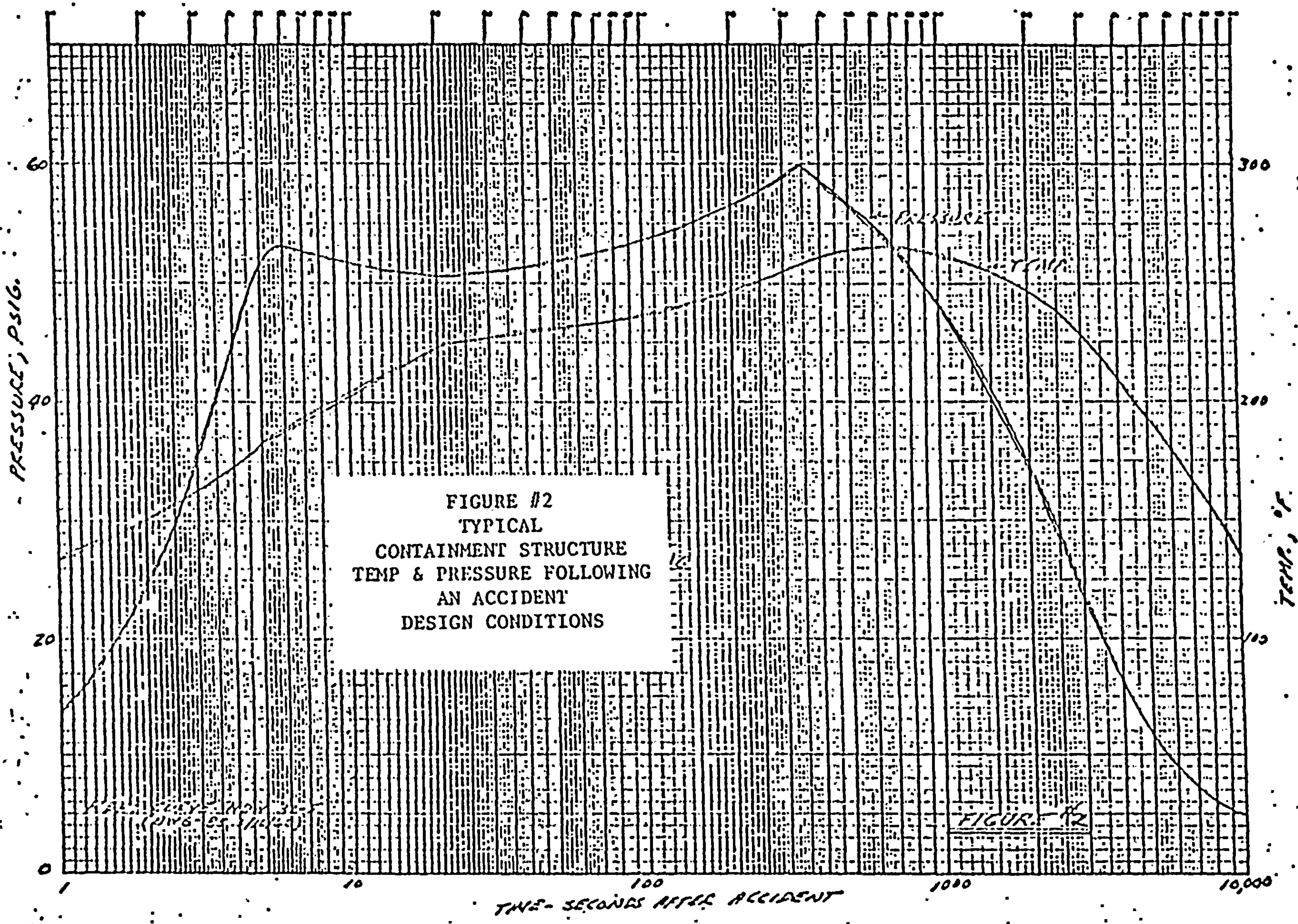


FIGURE #2
TYPICAL
CONTAINMENT STRUCTURE
TEMP & PRESSURE FOLLOWING
AN ACCIDENT
DESIGN CONDITIONS

LOCA CURVE FOR GINNA PLANT

5.0 QUALIFICATION DATA TO SUPPLEMENT REPORT #AB-11/12/73

At the time of manufacture, the aging data for the proprietary Q-1 epoxy was not available. Data is now provided in the form of the Arrhenius curve for the Q-1 epoxy used in the manufacture of the Ginna Penetration. See Research Report 75-7B5-BIGAL-R2 which follows.

Several explanatory remarks will be made to clarify this report.

1. The failure point was defined as 10^{-2} std. cc/sec; which is the same as the allowable leak rate for the penetration as installed as defined by IEEE 317-76.

2. Although only three or four samples were used for each temperature point, each sample contained 39 seals of various diameters (.041" to .437"). Therefore, the criteria that a large number of samples be used was complied with.

3. Electrical loading was not included in the test because the investigation was intended to establish the effects of heat caused by I^2R on the seal integrity. As reported in the Appendix #2 to 75-7B5-BIGAL-R2 dielectric strength and insulation resistance were not affected after seal failures occurred.

To be sure no synergistic effects occur due to the combination of high temperature and applied voltage, a module was successfully run for 84 days @ 125°C at 480 volts without seal or electrical degradation. (See enclosed report PEN-TR-79-73).

Research Report 75-7B5-BIGAL-R2 May 27, 1975

PREDICTING THE THERMAL LIFE OF MODULAR PENETRATIONS

J. F. Quirk
Insulation Chemistry

ABSTRACT

Accelerated thermal endurance tests, in compliance with IEEE standards, have been conducted using modular penetration specimens of a universal design.

These data have been treated by the Arrhenius technique to predict thermal endurance or thermal index (leak rate) of the modular penetration specimens over the temperature range of 70° to 200°C.

INTRODUCTION

Procedures for estimating the thermal life of insulation materials at room temperature require life tests at several temperatures, above the expected normal operating temperature.(1,2,3) By the selection of relatively high temperatures for the tests, life of the insulation samples is terminated, according to some selected failure criterion, within relatively short times (i.e., one week to one year). The result of these thermally accelerated life tests is a set of data of life times for a corresponding set of temperatures. This set of life times can be used to establish the mean life values at each temperature and the functional dependence of life on temperature, as well as the statistical consistency, the confidence to be attributed to the mean life values and the functional life temperature dependence.*

---

*IEEE Guide 101.

Accelerated thermal endurance tests, in compliance with IEEE standards 98 and 101, have been conducted using modular penetration specimens of a universal design. The results of these endurance tests are the subject of this report.

CONCLUSIONS

Using the Arrhenius relationship shown in Fig. 1, a lower 95% confidence limit or mean thermal life of the modular penetration seal is 350,000 h (40 yr) at 105°C.

RECOMMENDATION

We recommend that modular penetrations of the design described herein be used in nuclear power plants at an operating temperature range of 70°C to 105°C. They can be operated at higher temperatures but the life time is shortened significantly as shown in Fig. 1.

EXPERIMENTAL

A. The Modular Penetration Specimen

The test specimens, provided by the Westinghouse Industrial and Government Tube Division, were of a universal design and were produced in a pilot production facility. The conductor sizes and spacing are shown in Fig. 2. All specimens were subjected to five cycles from -30° to 100°C prior to the start of elevated temperature aging.

B. Selection of Test Temperature and Failure Criterion

IEEE 98 was used as a guide in selecting the exposure temperatures and times, both of which are given in Table I. According to the guide, these temperatures and times per cycle are suitable for a material with a temperature

index in the range of 130° to 154°C. The epoxy resin used to manufacture the test specimens has a temperature index of 135°C.

After each high temperature exposure, specimens were subjected to helium leak testing to determine the degree of deterioration. High temperature cycles were continued until the specimen displayed a leak rate of $\geq 1 \times 10^{-2}$ std cc/sec. Leak rates were determined by a mass spectrometer leak detector with a sensitivity of 2×10^{-11} std cc/sec. A specimen and the detector are shown in Fig. 3.

C. Ovens

The ovens used to provide the temperatures required were of the forced-air circulating type. These ovens were thermally mapped to locate zones within which the required temperature was being maintained. The test specimens were then located in that zone.

D. Failure Data

Accelerated thermal endurance aging was continued until the test specimens displayed a leak rate of $\geq 1 \times 10^{-2}$ std cc/sec. The test temperature and time required to produce the failure criterion are given in Table II.

These data were analyzed according to the procedure specified in IEEE standard 101 using a computerized standard linear regression analysis program. A summary of the results of that analysis follows.

E. Life Test Values

The following tabulation gives the mean and standard deviation of the life data.

Test Temp. °C	Mean life - h	Std. Dev. - h
200	129	48
187.5	343	162
175	1142	61
150	7709	481

F. The Fitted Arrhenius Model

The Arrhenius model which best fits this set of data is
LN h = A + B (1/273 + temp. °C)

where LN h = natural log of life in hours at temp. °C.

Using linear regression, we estimate A = -30.13 and B = 16562.8. The Arrhenius model used to predict the mean life of the test specimens at the test temperatures gave the following predictions:

Temp. °C	Mean·Life Predicted - h
200	132
187.5	342
175	935
150	8317

Mean life predictions are shown in Fig. 1 as the solid line drawn between the coordinates 200°C, 130 h; and 150°C, 8,300 h. This solid line was extrapolated to temperatures below 150°C (broken line Fig. 1) to form an estimate of the mean life predictions at temperatures less than those selected for test. The correlation between the observed and predicted life times, r^2, is 0.96 indicating the model fits the data quite well.

G. Confidence Limits

The lower and upper 95% confidence limits, determined using the predicted mean values of life represented by the solid and broken lines in Fig. 1, are given below:

Temp. °C	Mean Life Predicted - h	Life - h Lower 95%	Life - h Upper 95%
200	133	99	176
187.5	343	277	424
175	936	782	1,119
150	8,318	6,097	11,347
105	879,866	390,314	1,983,439

These upper and lower 95% confidence limits are represented, graphically, in Fig.1 as the envelope about the generated Arrhenius model. The computerized program predicts, with 95% confidence, that the specimens will maintain a leak rate of $\leqq 1 \times 10^{-2}$ std cc/sec for 390,000 h, $\sim$40 yr, at 105°C.

Since the expected in-service operating temperature is in the range of 70-105°C, it can be predicted, with at least 95% confidence, that the specimen will maintain a $\leqq 1 \times 10^{-2}$ std cc/sec leak rate for 350,000 h or 40 yr in that temperature range.

H. Thermal Endurance of "O" Ring Seals

The seal between the modular penetration and the containment wall is provided by a series of silicone "O" rings. Mock-ups of these external seals were tested in the same manner as the penetration specimens. The thermal endurance of the external silicone "O" seals compared to that of the modular test specimens are tabulated below:

Temp. °C	Penetration Specimen Mean Life - h	"O" Ring Mock-up Total h Exposed	"O" Ring Mock-up Leak Rate @ Total h
200	129	535	$<1 \times 10^{-9}$ std cc/sec
175	1142	1758	$<1 \times 10^{-9}$ std cc/sec
150	7709	9000	$<1 \times 10^{-9}$ std cc/sec

It appears from these results that the thermal endurance of the external silicone "O" ring seals exceeds the estimated thermal endurance of the modular penetration test specimens; however, this is not based on a statistical test. Such a relationship eliminates the external seals from consideration in estimating useful thermal life (leak rate) of the design.

I. Estimation of Equivalent Thermal Life

The Arrhenius estimate of seal life, Fig. 1, can be used to approximate the equivalent thermal degradation which could be expected during 40 yr of service at a normal plant ambient of 70°C. The method used to make this approximation is as follows.

The relationship between seal life and temperature is such that an increase or decrease of ∿8°C in the test temperature results in a corresponding doubling or halving of the specimen life. Using this 8°C rule, an approximation of the equivalent thermal degradation expected during 40 yr of service at 70°C can be estimated.

A point representing 40 yr (360,000 h) at 70°C is located on Fig. 1. A line is drawn such that it passes through that point and is parallel to the line representing the Arrhenius estimate. The relationship between seal life and temperature represented by this second line is such that for every increase or decrease of ∿8°C in temperature results in a corresponding doubling or halving of the equivalent thermal degradation which could be expected. Estimates of the equivalent thermal degradation which could be expected in 40 yr at 70°C are ∿400 h at 125°C or ∿40 h at 150°C. Therefore, exposure of a specimen to ∿40 h at 150°C would produce the equivalent thermal degradation that could be expected at 260,000 h at 70°C.

ACKNOWLEDGEMENT

The author wishes to acknowledge the assistance rendered by T. W. Dakin through the use of his computerized Arrhenius program and his guidance in interpreting the results of that analysis.

REFERENCES

1. Berberich, L. J., T. W. Dakin, "Part I: Guiding Principles in the Thermal Evaluation of Electrical Insulation," Insulation Magazine, p. 21-27, Feb 1956.
2. Moses, G. L., et. al., IEEE Guide for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment, No. 99.
3. Berberich, L. J., T. W. Dakin, "Part II: Guiding Principles in the Thermal Evaluation of Electrical Insulation," Insulation Magazine, p. 21-26, March 1956.

PERMANENT RECORD BOOK ENTRIES

Fig. Book No. 205631...pp. 65-67 and 71.

J. F. Quirk
J. F. Quirk
Insulation Chemistry

APPROVED: R.H. Runk
R. H. Runk, Manager
Insulation Chemistry

TABLE I

TEST TEMPERATURES AND EXPOSURE TIMES

Test Temp. °C	Continuous Exposure - h	Followed by h/cycle
200 ± 4	72	24
187.5 ± 2	72	24
175 ± 2	166	168
150 ± 2	528	504

TABLE II

TEST TEMPERATURE AND LIFE VALUES

Test Temp. °C	No. of Specimens on test	Life Values - h
200	3	96, 108, 184
187.5	3	163, 390, 477
175	4	1051, 1173, 1173, 1173
150	4	7334, 7334, 7834, 8340

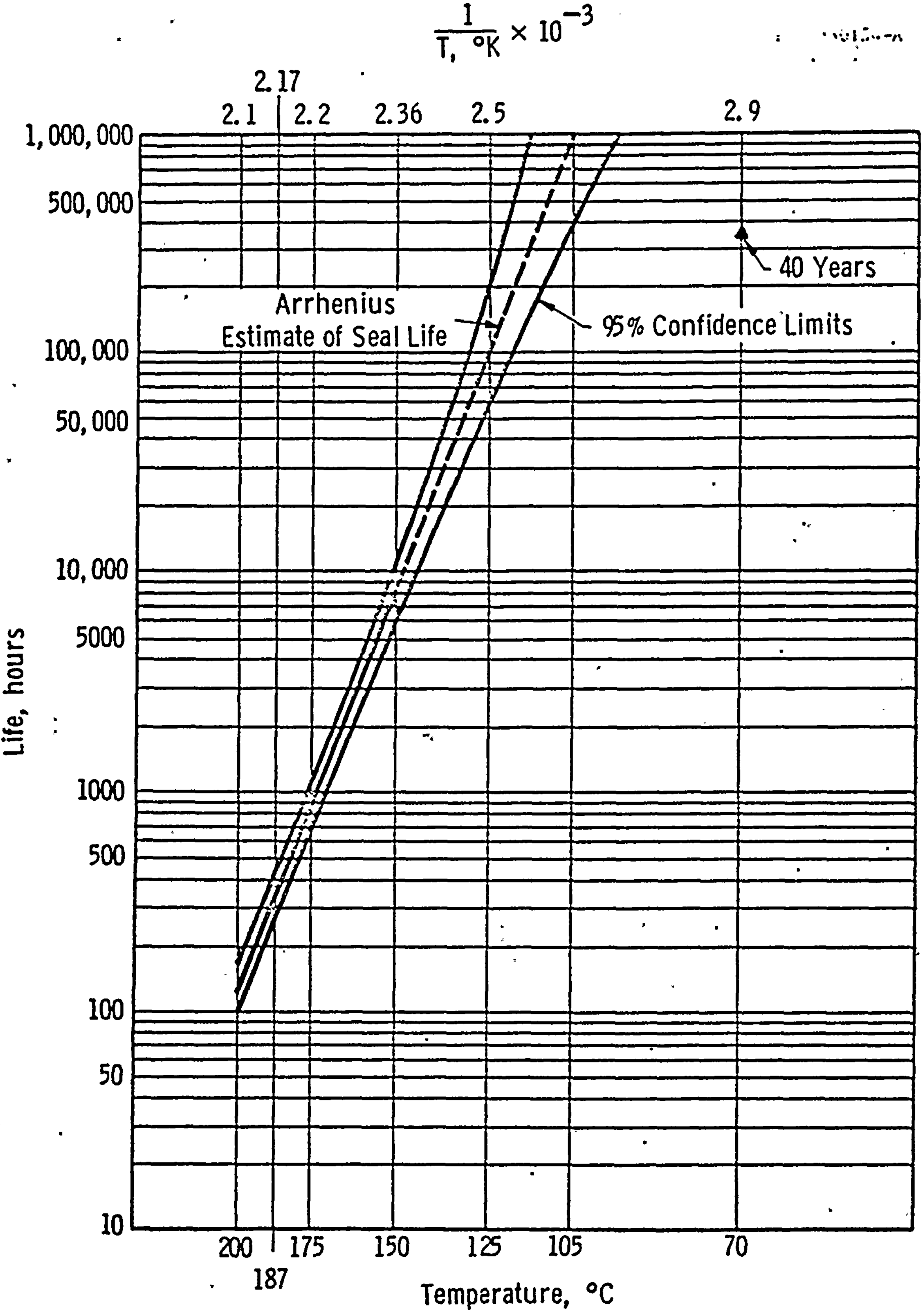


Fig. 1—Estimate of penetration life

DIST.

ET—47 WESTINGHOUSE ELECTRIC CORPORATION
ELECTRONIC TUBE DIVISION
SPECIFICATIONS & STANDARDS DEPT.
ELMIRA, N. Y.

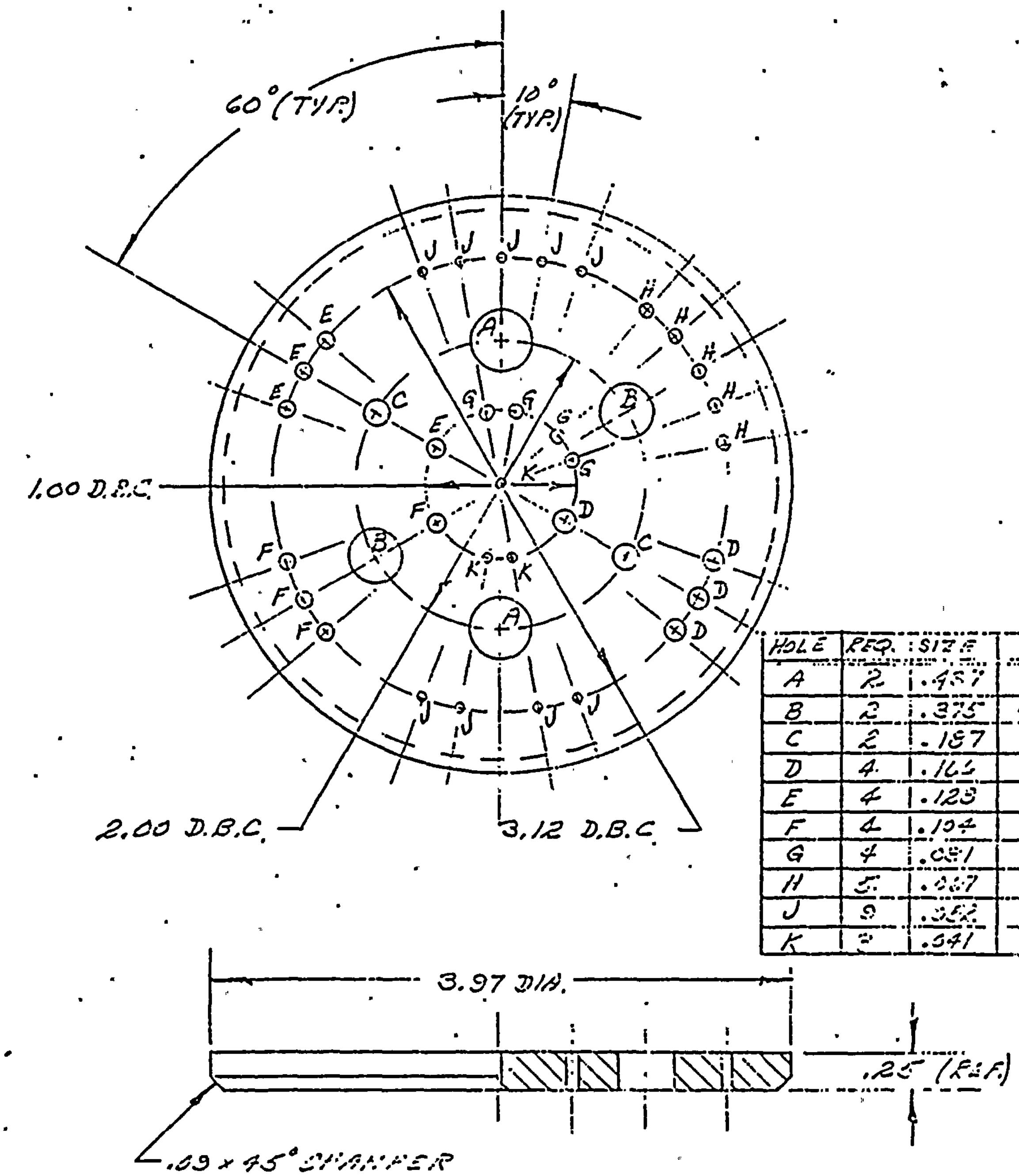
SUBJECT· MODULAR PROTYPE "B3"
MONITORING DISK

DATE

SPECIFICATION NO. E-2795

SUPERSEDED DATE

MATL: EPOXY GLASS LAMINATE #H2497G11



HOLE	REQ.	SIZE	COND.
A	2	.457	#4/0
B	2	.375	#2/0
C	2	.187	#4
D	4	.162	#6
E	4	.128	#8
F	4	.104	#10
G	4	.081	#12
H	5	.067	#14
J	9	.052	#16
K	3	.041	#18

UNLESS OTHERWISE SPECIFIED

Also see STD. ET 10 thru 36

TOLERANCES	NOTES	
DEC. .... .000 ± .005 .00 ± .01 FRAC. .... ± 1/64 ANGLES .... ± 1/2°	CONCENTRICITY .004 T.I.R. REMOVE ALL BURRS ALL TH'DS. CL.2A OR 2B F.A.O. 63	ALL DIM. IN INCHES * DENOTES CHANGE

1:1

P/C

BK. 5-1-74

Fig. 2. Conductor sizes and spacings

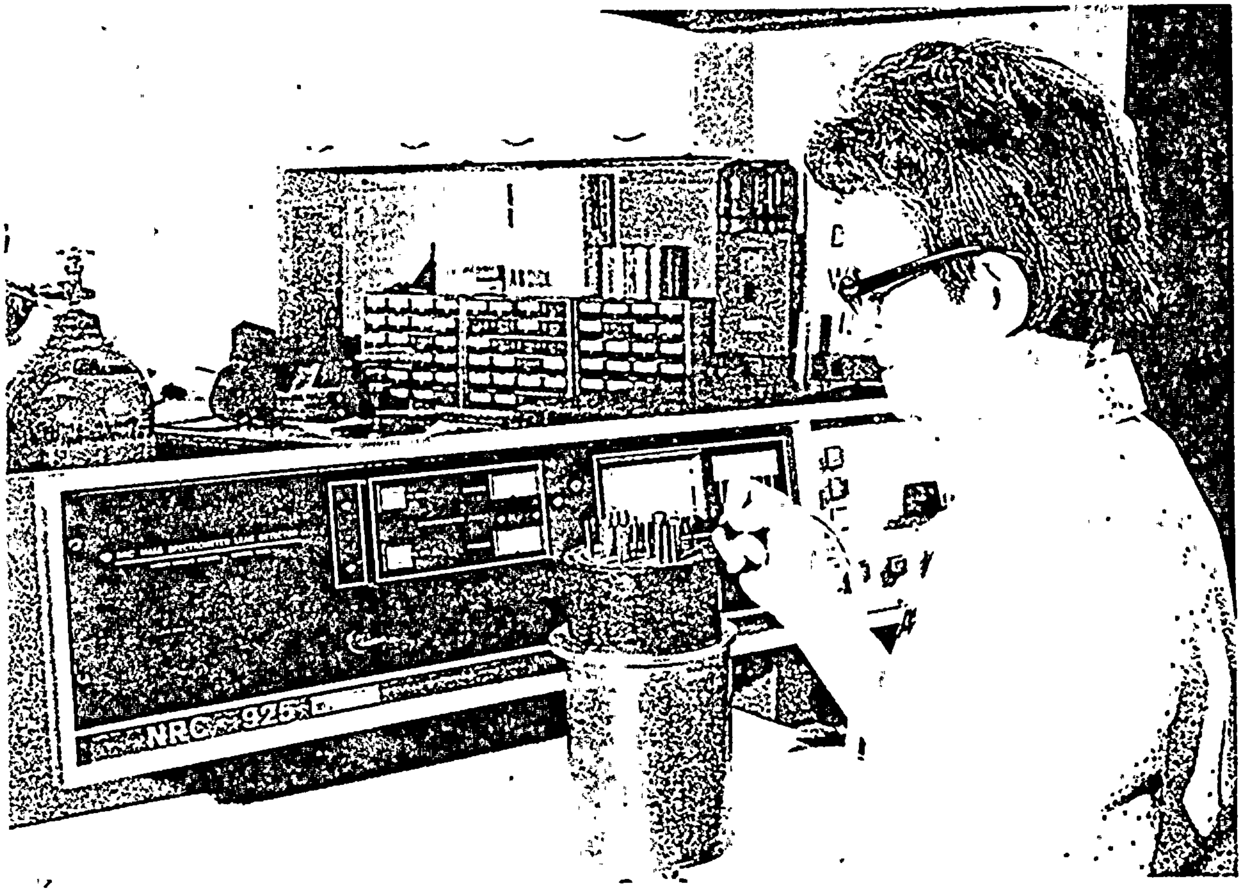


Fig. 3. Test specimen and leak detector

**Westinghouse
Electric Corporation**

**Electronic Components
Divisions**

Electronic Tube Divisions

Westinghouse Circle
Horseheads New York 14845

May 12, 1975

Test Report #PEN TR 75-10
Appendix #2 Report #75-7B5-BIGAL-R

SUBJECT: Dielectric Strength and Insulation Resistance Test Results of Ⓦ Modules which Were Subjected to Accelerated Heat Ageing at 150°C.

PURPOSE OF TEST

To demonstrate that the dielectric strength and insulation resistance remains at satisfactory levels after accelerated life heat ageing.

TEST PROCEDURE

Four modules were run at 150°C to the point where the leak rate reached 1×10^{-2} std cc/sec.

Dielectric Strength and Insulation Resistance tests were then performed; conductor to all other conductors and to ground.

TEST RESULTS

Failure point (based on 2×10^{-2} std. cc/sec. leak rate)

Module #	Hours
7	7332
8	7332
9	7836
10	8336

After the above tests all modules withstood 2,650 volts A.C. for five seconds.

Insulation resistance readings with megohmmeter at 500VAC were 1×10^{10} ohms or higher.

CONCLUSION

The results indicate that the dielectric strength and insulation resistance values remain at adequate levels after accelerated heat ageing.

Apparently the Arrhenius curve for the sealant material based on the electrical qualities is at a higher temperature level than the one based on leakage.

R. L. Korner

R. L. Korner
Project Engineer
Penetrations Dept.

/m

**Westinghouse
Electric Corporation**

**Electronic Components
Divisions**

Westinghouse Circle
Horseheads New York 14845

PEN-TR-81-46

August 7, 1981

EXPLANATION OF ACCELERATED AGING

R. L. Korner
Project Engineer

Attached Figure 2 shows how values of 150°C for 100 hours were obtained as representative of a life of 40 years at a 70°C normal temperature.

A parallel line was drawn to the 95% lower confidence limit starting at the intersection of 40 years and 70°C.

150°C was chosen as a reasonable temperature to produce accelerated aging.

The line starting from 70°-40 years is intersected by 150°C at 85 hours.

These two values 150°C-85 hours are the equivalent aging of 70°C-40 years.

One hundred hours was chosen to add some margin to the required time. Accelerated aging at 150°C-100 hours aged the sample to 49 years at 70°C.

At the time of the test for the Ginna penetration reported in AB 11/12/73, the Arrhenius curve for the Q-1 epoxy was not firmly established, therefore, a more conservative 504 hours at 150°C was used to pre-age prior to LOCA.

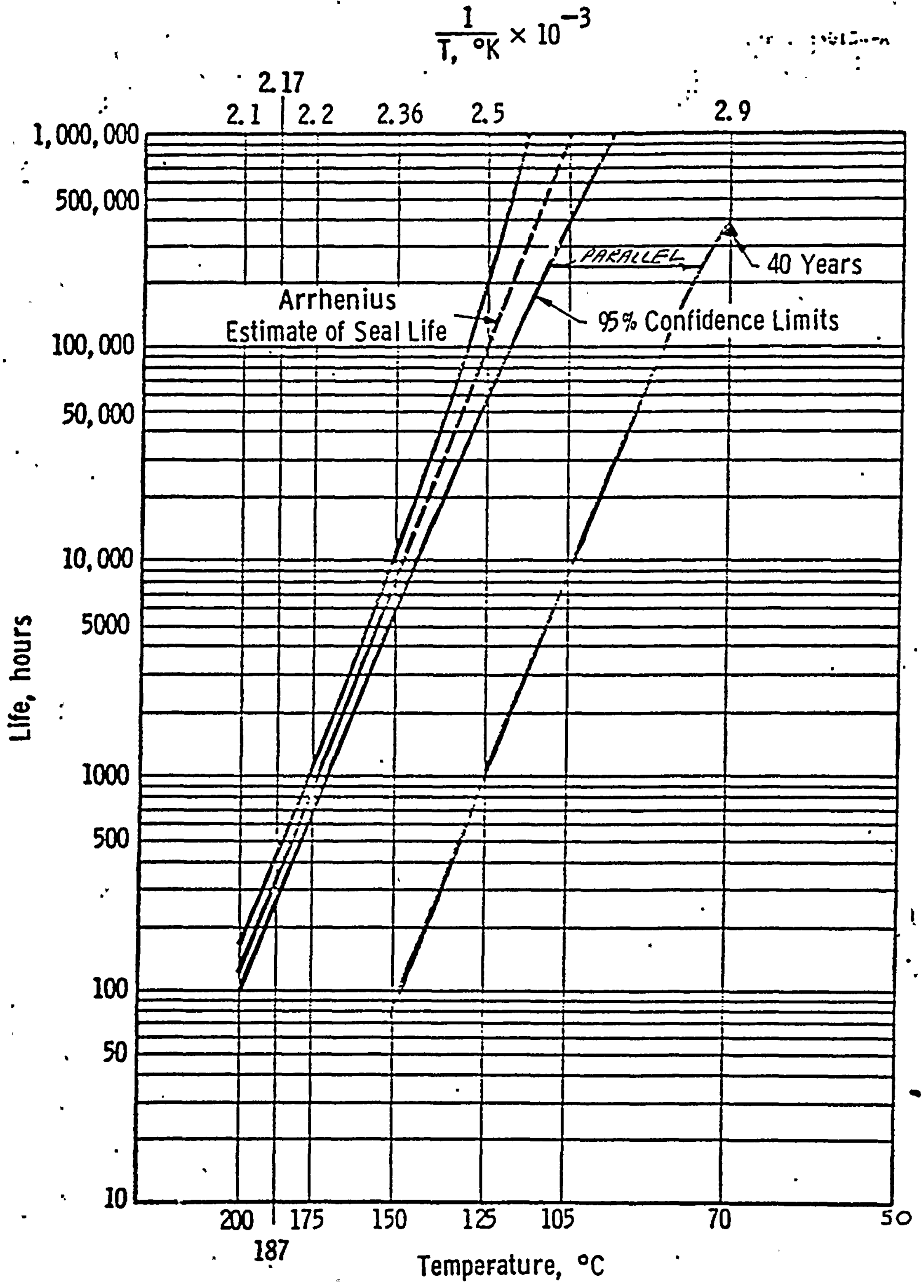


Fig. 2 —Estimate of penetration life

(Figure 1 is part of report entitled "Predicting the Thermal Life of Modular Penetrations," Research Report 75-7B5-BIGAL-R2).

Westinghouse
Electric Corporation

Electronic Components
Divisions

Westinghouse Circle
Horseheads New York 14845

PEN-TR-79-73

Sept. 18, 1979

ELECTRICAL PERFORMANCE OF AN ELECTRICAL PENETRATION MODULE UNDER ACCELERATED HEAT AGING CONDITIONS

Approved by:

R. L. Korner
Project Engineer

Test performed by:

Vito Liotino

Vito Liotino
Nuclear Electrical
Penetration Department

Purpose of Test

To examine the insulation resistance characteristics of a modular electrical penetration filled with W Proprietary Epoxy "Q" and 3M product XR5237 in a 125°C accelerated aging ambient with operation voltages applied.

The normal operating temperature of this device is 70°C.

Test Specimen Description

The test specimen is an electrical penetration module fitted with a mixture of cables and potted with a W proprietary epoxy designated as "Q" to form the primary seal of the module and a two part filled semi-flexible, flame retardant liquid epoxy XR5237 manufactured by 3M to form the secondary and finish seal. A cross-section of the test module is shown in Figure 2.

A mixture of cables has been included to qualify the module for various service requirements. The physical configuration of the cable electrodes in the module is shown on Drawing #E-2794. The B-2 type (Hanford) module was assigned #SN66.

History of Module #SN66

The module was preconditioned in a previous qualification test following the requirements of the IEEE standard #317-1972 and as reported in report #PEN-TR-75-6.

The module was subjected to 90 hours of cobalt 60 gamma radiation for a total integrated dose of 4.45×10^7 rads. The assembly was also subjected to 340°F - 52 psig steam - 100% humidity for six hours followed by eighteen hours at 280°F and 34 psig - 100% humidity. Insulation resistance readings of the subject cables, after manufacture taken at 500 Vdc, were in the 10^9 to 10^{11} ohm range. After irradiation and LOCA, with rated voltage and current applied, IR measurements were stable and in some cases greatly improved.

Test Procedure and Discussion

The module was placed in an air circulating oven and electrical power leads were attached to their respective cables. A voltage of 120-127 Vac was impressed on the #14AWG cables. The center electrodes were spaced .133" apart. The remaining cables were hooked up to 480 Vac. The center electrodes of the #10AWG cables were spaced .176 apart. The #6's were .303 apart and the #4's were spaced .348 apart.

The module insulation resistance measurements at 500 Vdc were taken prior to the elevated temperature test. The IR (ohms) values of all subject cables fell within a $1.2 - 1.8 \times 10^{11}$ range.

Periodic Insulation Resistance measurements were taken throughout the elevated temperature test. See the Insulation Resistance (ohms) versus Time (day) graph in Figure 1 for the IR plot.

Post test IR readings at room temperature were taken and all fell within a range of $1.1 - 1.5 \times 10^{10}$ ohms.

A problem developed when the oven controller developed an amplifier tube failure resulting in a rise in oven temperature. The temperature rose to 225°C. It is estimated that the oven was at this temperature for a period of approximately one day. The module temperature fell to room temperature during the oven controller repair period. The module insulation resistance measurements at room temperature were within the range of 1.1×10^{10} - 1.5×10^{10}. The controller was repaired and the test continued.

Test Results

Test Duration (Days)		Insulation Resistance (ohm) @ 500 Vdc			
Start	Temp °C	#14AWG	#10AWG	#6AWG	#4AWG Cable
0	(RT)	1.2E11	1.8E11	1.6E11	1.5E11
1	125°C	5.6E6	6.2E6	4.3E6	2.8E6
3	125°C	1.1E7	7.2E6	3.0E6	2.8E6
6	(a)225°C	(b)8E5	(b)2.5E5	(b)1.0E5	(b)8.0E4
7	125°C	1.2E7	1.4E7	2.8E6	2.1E6
14	125°C	1.7E7	1.2E7	4.2E6	2.3E6
21	125°C	2.0E7	7.0E6	3.0E6	2.7E6
28	125°C	1.0E7	8.6E6	3.4E6	2.3E6
35	125°C	1.0E7	8.8E6	3.5E6	2.5E6
42	125°C	1.6E7	7.0E6	3.5E6	2.6E6
49	125°C	1.3E7	1.1E7	4.0E6	3.3E6
56	125°C	1.4E7	1.2E7	3.7E6	3.2E6
63	125°C	2.0E7	6.8E6	2.5E6	2.8E6
70	125°C	5.0E7	1.3E7	4.0E6	5.0E6
77	125°C	8.0E7	4.0E7	5.0E6	8.0E6
84	125°C	8.5E7	3.5E7	6.0E6	9.0E6
85	(RT)	1.5E10	1.1E10	1.4E10	1.0E10

(a) Oven controller problem caused temperature to rise to 225°C for a duration of approximately 1 day.

(b) Insulation resistance reading taken at 100 Vdc. (Reading not attainable at 500 Vdc).

Discussion of Results

The first day of heating resulted in a drop of insulation resistance as expected due to the normal decrease of resistance of insulating materials with increase of temperature.

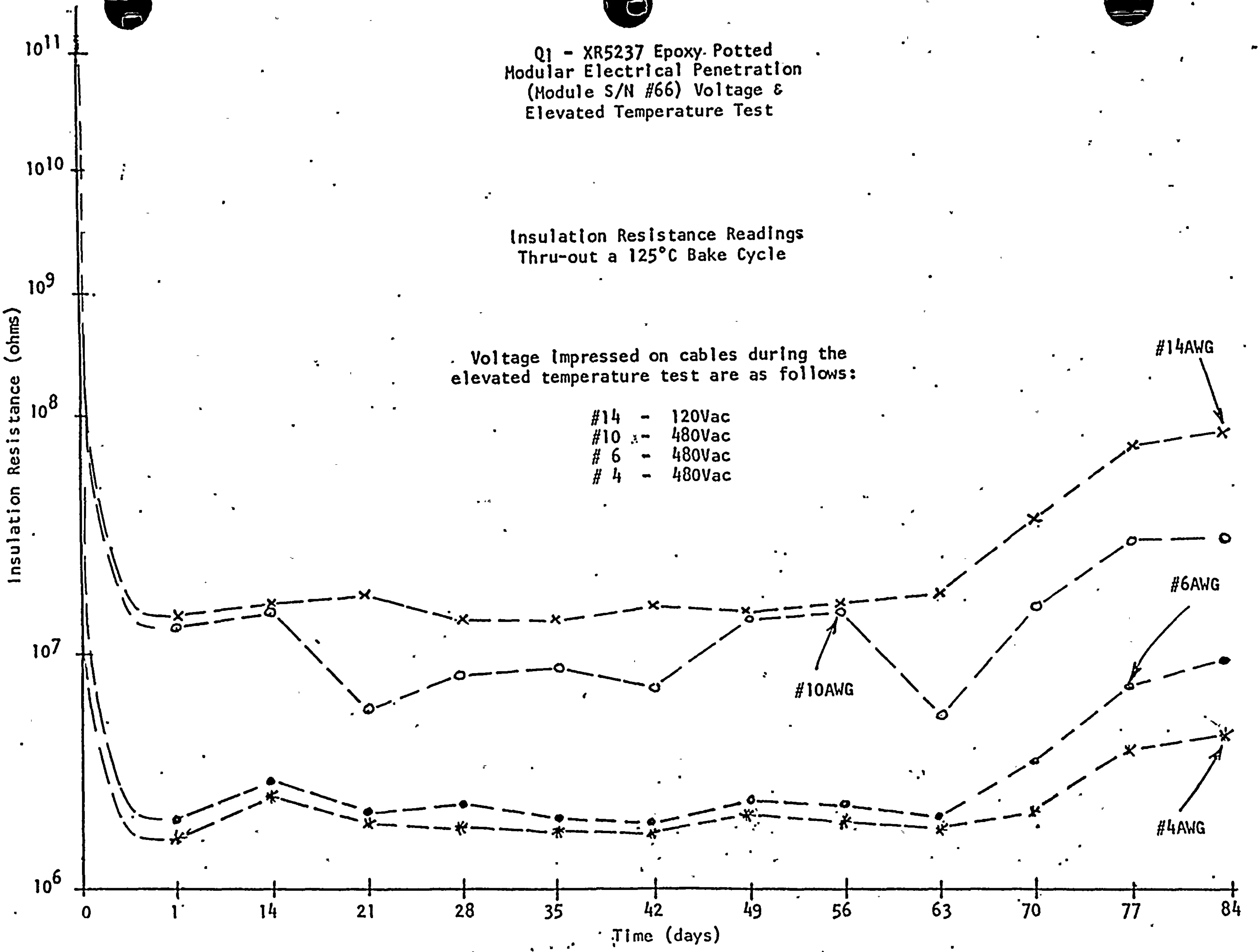
The resistance stabilized for 63 days and then took an unexplainable rise of about one half to one decade in the next 21 days. After the accelerated temperature test was completed, the module on return to room temperature exhibited IR readings approximately one decade lower than the initial room temperature IR readings.

The accidental transient to 225°C (437°F) did not damage the penetration and the insulation resistance returned to normal when the temperature was set at 125°C again.

Conclusion

1. The upward trend in the last 21 days of the test indicate that the accelerated electrical life of the epoxy is well beyond the 84 days tested at 125°C.

2. A one day accidental transient to 225°C did not cause electrical failure.



Q1 - XR5237 Epoxy Potted
Modular Electrical Penetration
(Module S/N #66) Voltage &
Elevated Temperature Test

Insulation Resistance Readings
Thru-out a 125°C Bake Cycle

Voltage impressed on cables during the elevated temperature test are as follows:

#14 - 120Vac
#10 - 480Vac
6 - 480Vac
4 - 480Vac

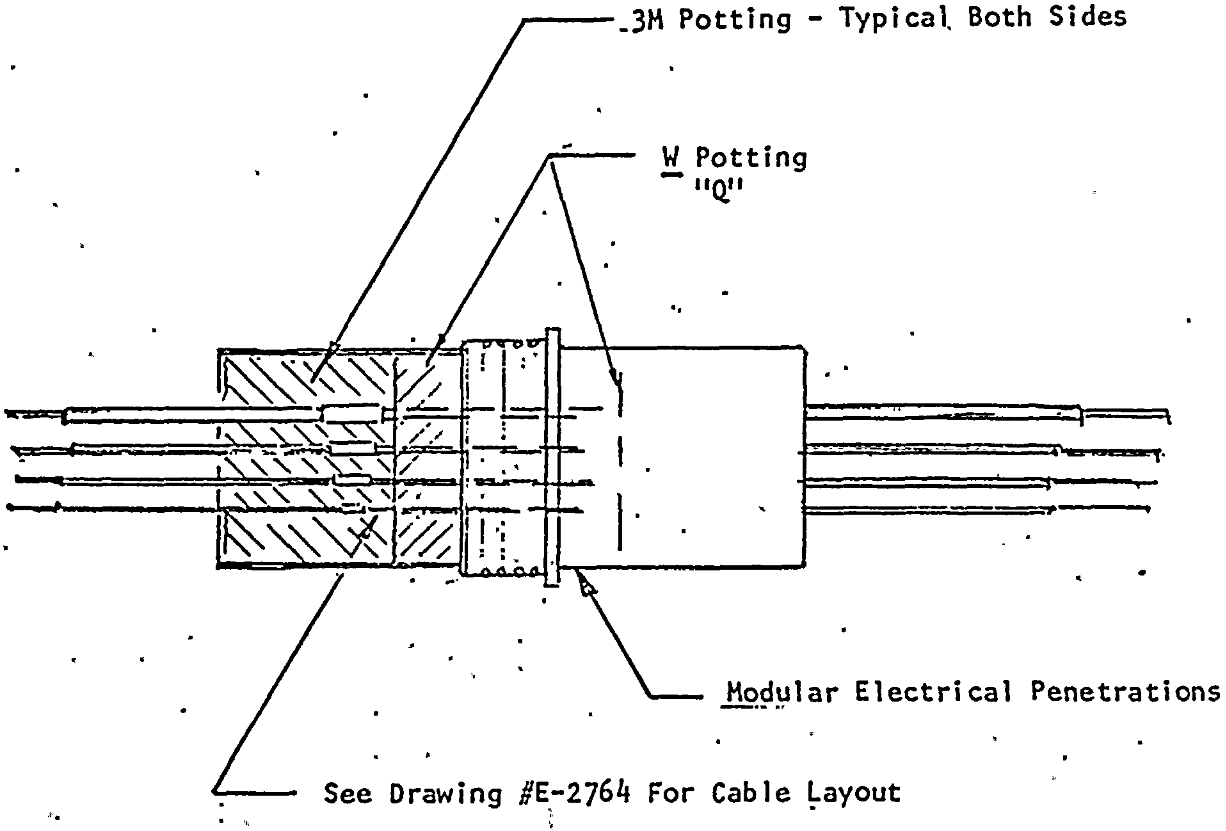

3M Potting - Typical Both Sides
W Potting
"Q"
Modular Electrical Penetrations
See Drawing #E-2764 For Cable Layout

Figure 2

WESTINGHOUSE ELECTRIC CORPORATION
ELECTRONIC TUBE DIVISION
SPECIFICATIONS & STANDARDS DEPT.
ELMIRA, N. Y.

MODULAR PROTOTYPE "B2"

DATE

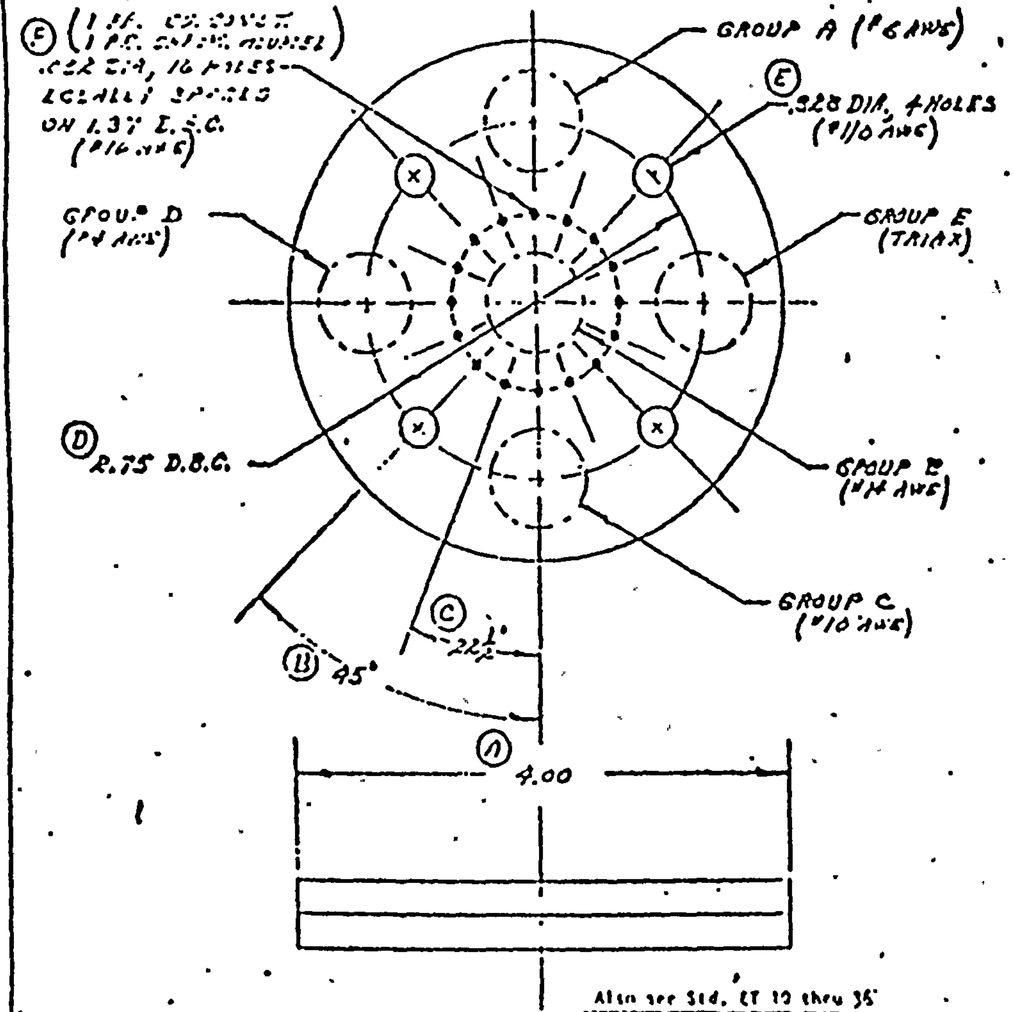
SPECIFICATION NO. E-2194 (REV. A)

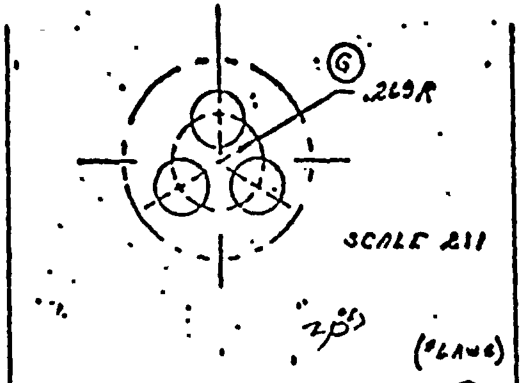
SUPERSEDED DATE

MCH, TOPINS

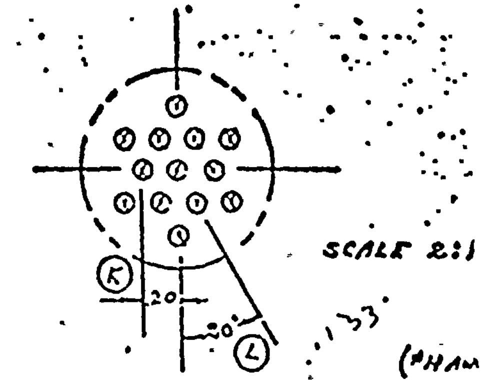
MAT'L: EPOXY GLASS LAMINATE # H2497611, .25 TK.

DRILL THE DISC TOGETHER AND MARK FOR MATCHING OF HOLES AS DRILLED.

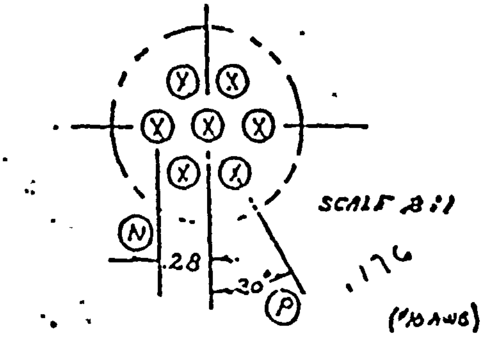




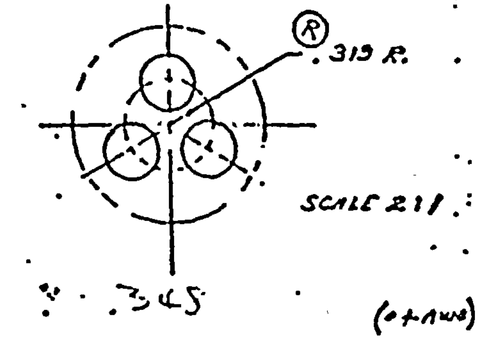
GROUP A – 1.15 HHDR. (.113"), 3 HOLES (J)



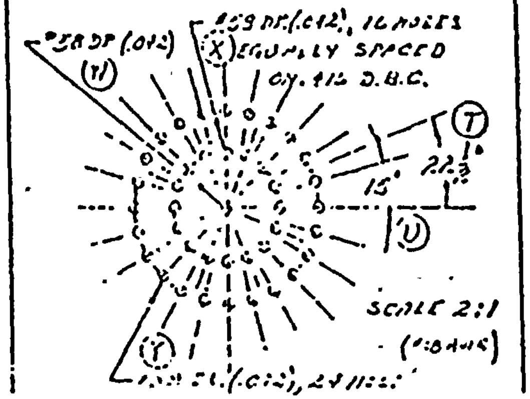
GROUP B – #51 DR. (.067), 13 (M)



GROUP C – #37 DR. (.104), 7 HOLES (Q)



GROUP D – #5 DR. (.205), 3 HOLES (S)



#59 DR. (.042), 24 HOLES EQUALLY SPACED ON .724 D.B.C.

Also see Std. ET 10 thru 35

1:1

P-5-74

6.0 IDENTIFICATION OF MATERIALS USED IN THE PRESSURE RETAINING PORTION OF THE PENETRATION MODULE

INGHOUSE ELECTRIC CORPORATION
ELECTRONIC TUBE DIVISION
PECIFICATIONS & STANDARDS DEPT.
ELMIRA, N. Y.
14

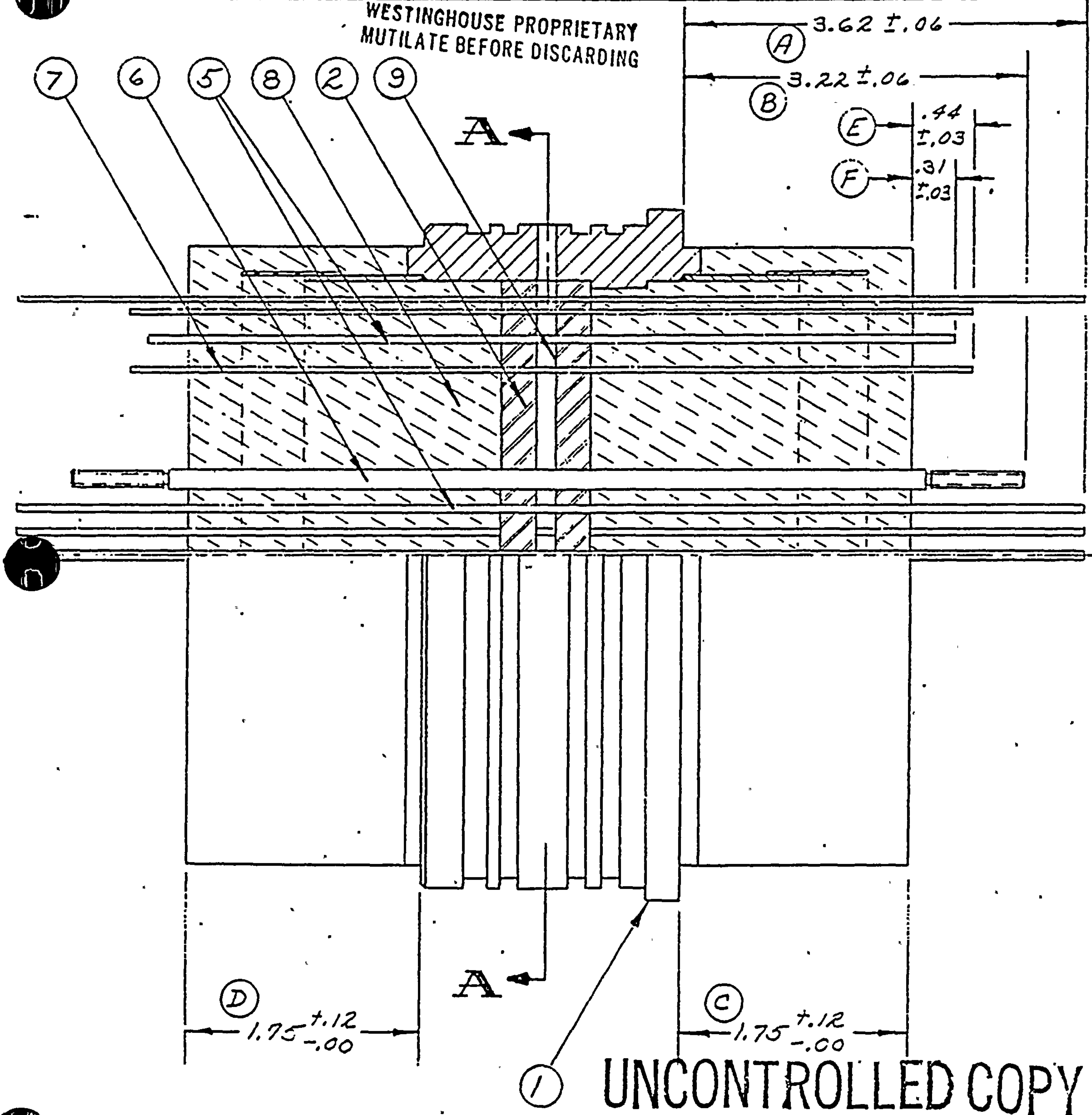
T STAGE POTTED ASSEM.

DATE 1-21-75

SPECIFICATION NO. 35-8388-1

SUPERSEDED DATE

WESTINGHOUSE PROPRIETARY
MUTILATE BEFORE DISCARDING



UNCONTROLLED COPY

Also see Std. ET 10 thru 36

UNLESS OTHERWISE SPECIFIED

	NOTES	
.0 ± .005	CONCENTRICITY .004 T I R	ALL DIM. IN INCHES
[illegible]	REMOVE ALL BURRS	⊿ DENOTES CHANGE
[illegible]	[illegible]	

SCALE 1/1	P	UA	QP	MP
11-8-71	F.	[illegible]		

IDENTIFICATION OF MATERIALS DWG. 35-8388

Item No.	Material
1*	Stainless Steel - Header
2	Epoxy Glass Laminate
5*	#14AWG Copper
6*	#10AWG Copper
7*	#18AWG Copper
8*	Epoxy - Q-1 - W PROPRIETARY
9	Silicone Varnish #991

Only Items marked with an asterisk (*) have pressure retaining function.

7.0 IDENTIFICATION OF MATERIALS USED IN THE PENETRATION MODULE ASSEMBLY

MODULE CONSTRUCTION

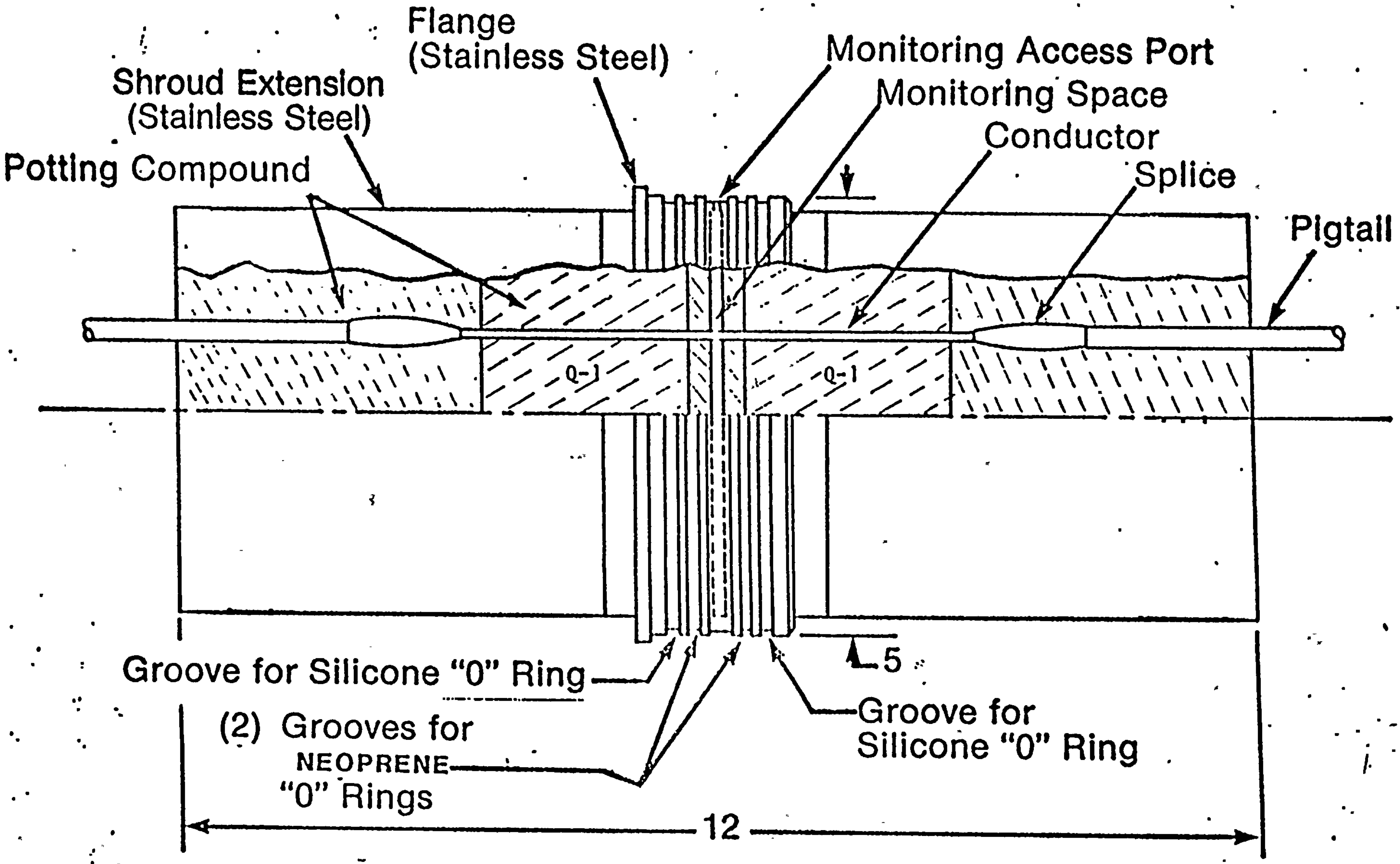


Figure 1

All materials except the silicone "0" rings were qualified as assembled in the test specimen of W Report #AB - 11/12/73. The neoprene "0" rings were not qualified as they are included as a third and fourth sealant to the two "0" ring seals which form the primary and secondary seal.

The silicone "0" rings were separately qualified.

Separate qualification data is provided for the Class I-E cable.

8.0 STATEMENT ON QUALIFIED LIFE

Based on the attached analysis by T. W. Dakin, the qualified life of the penetration is in excess of 50 years at 70°C.

This particular penetration however operates at the containment ambient of 120°F, (49°C) and therefore can be expected to have an even longer life.

From · RESEARCH LABORATORIES
WIN : 236-3424, 5134
Date : July 18, 1975
Subject LIFE PREDICTION OF
CAST EPOXY PENETRATION SEALS

To : Research Laboratories
J. F. Quirk

cc: Research Laboratories - R. H. Runk
Research Laboratories - J. Swiss

The results of your life tests on the cast epoxy penetration seals have been graphed and a log vs 1/T (Arrhenius) linear regression line, and its 95% confidence limits, calculated according to IEEE Standard 101. This calculation was accomplished with a computer using a program for this specific purpose.

The actual life tests were made at four temperatures from 150° to 200°C. At the lowest life test temperature, failure times averaged a little more than 8000 hrs, approximately one year, which is about as long as is usually ever used in an accelerated life test of this sort. The test values at all of the four test temperatures fit the calculated linear regression line, showing no tendency to deviate from a good fit to the theoretical linear dependence of log life vs reciprocal Kelvin temperature. This gives very good assurance that the linear extrapolation of this line is probably valid. The regression line extrapolates to predict an average life of 70 million hrs or about 8000 yrs at the expected use temperature, 70°C. The lower 95% confidence limit on the regression line is about 684 yrs at the expected use temperature, 70°C. This is more than 10X the required life of 40 yrs at 70°C. The data and this extrapolation from it also predict that the penetration seals would have an average life of 44 yrs at 105°C with greater than 95% confidence. This is 35° above the expected operating temperature life.

The above extrapolation applies only to the average life. Another factor to be considered is the statistical deviation of individual values from the average. The spread or range of test values here is rather moderate at each temperature. The calculated average σ, standard deviation, in terms of percent of the life values at each temperature is 16.7%.

If we subtract 3 σ, or 3 x 16.7% = 50.1% from the lower 95% confidence on the extrapolated average life of 684 yrs, this predicts (assuming a normal distribution) that 99.7% of the specimens should have a life of greater than 342 yrs at 70°C. This is obviously a very high estimated life expectancy. Both the possible statistical variability of the extrapolated average life and the statistical variation of individual

specimens from this average have been considered in making this estimate, which is based on a rational extrapolation from well behaved thermally accelerated life test data. While the extrapolation of 80° down to 70°C from the lowest test temperature of 150°C is large, the extremely high extrapolated value of life at 70° and the high degree of statistical confidence which can be placed on it, together with the long actual life of about 1 yr at 150°C, I believe justifies the long extrapolation and warrants very great confidence in much more than 50 yrs of life without failure due to thermal aging. It is not practical or possible to make a better prediction than this without many more years of testing.

T W Dakin

T. W. Dakin, Manager
Electrical Performance of Insulating Materials

jas

9.0 CABLE QUALIFICATION DATA FOR THE #10AWG - CLASS I-E OKONITE CABLE USED IN THE PENETRATION MODULE

QUALIFICATION TESTS OF ELECTRICAL CABLES THROUGH SEQUENTIAL EXPOSURE TO HEAT GAMMA RADIATION, LOCA, AND POST LOCA SIMULATIONS

Engineering Report No. 141 appended herewith is based on test programs performed by Franklin Institute Research Laboratories and reported under cover of their documents F-C 3094 of July 1971 and F-C 3171 of September 1971.

The date of ER No. 141 is February 29, 1972 and, therefore, it predates IEEE Standard 383-1974. Although the environmental simulations were more severe than called out in Standard 383, the note at the bottom of Table 5 indicates compliance with the final withstand test requirements.

The specimens listed in ER No. 141 successfully withstood both the PWR and BWR life, accident, and post accident simulations and are discussed in IEEE paper T 74-044-4, copy included.

These represent a more severe simulation than contemplated in #383, and is in harmony with the broader IEEE Standard #323-1974. The foregoing is ample evidence that the cables and splice listed therein are suitable for the designed service.

E. E. McIlveen

E. E. McIlveen
November 22, 1974

EEM/row

February 29, 1972

THE OKONITE COMPANY
Ramsey, New Jersey

ENGINEERING REPORT NO. 141

SUBJECT:

Aging, Exposure to 200 Megarads of Gamma Radiation and Accident Condition Qualification Testing of Power Cables, Control Cables and Splice

OBJECTIVE:

The purpose of the program was to determine if control cables, power cables and splices would function properly under the environmental conditions expected to be present within the containment of a nuclear-fueled electrical power plant, both during and following a design-basis event (loss of coolant accident). The program included subjecting the samples to thermal aging, radiation to 2×10^8 rads and to Pressurized Water Reactor (PWR) simulated accident, followed by exposure to a Boiling Water Reactor (BWR) simulated accident while carrying rated voltage and current.

CONCLUSIONS:

All samples successfully withstood both the PWR and the BWR accident conditions after heat aging at 121 C for 168 hrs. followed by exposure to total dose of 200 megarad of gamma radiation. During both the PWR and BWR accident conditions the cables were subjected to rated voltage and current. In addition, the cable samples and splice were subjected to and withstood high voltage proof tests of two times rated voltage plus 1000 volts for a period of five minutes at the peak temperature and pressure conditions as shown in Figures 1 and 2.

CABLE SAMPLES TESTED:

One sample of each of the following types of cable and splice was tested. The samples were designated as shown in Table I.

Table I

Sample No.	Cable Designation
A-4	1/C #14 0.030" Okonite, 0.015" Okoprene
D-4	4/C #14 0.030" Okonite, 0.015" Okoprene, 0.045" Okoprene
E-4	7/C #14 0.030" Okonite, 0.015" Okoprene, 0.045" Okoprene
B-4	1/C 4/0 0.055" Okonite, 0.045" Okoprene
F-4	4/C #12 0.047" Okonite, 0.015" Okolon, 0.045" Okolon
C-4	1/C 4/0 0.140" Okoguard, 0.065" Okolon with T-95 splice and T-35 jacketing tape

TEST PROGRAM:

(a) Thermal Aging

The cable samples and splice were initially aged in an air oven for 168 hours at 121 C.

(b) Radiation Exposure

The samples were then exposed to a dose rate of 1 Mrad per hour for one hour, then placed at positions to receive 300,000 rad/hour until a total dose of 2×10^8 rads was reached.

Irradiation was by cobalt-60 in air at ambient temperature (68-70°F) and a slight negative pressure (-1/2" water). Cables were rotated and turned at intervals to achieve a better dose uniformity. This, together with the distance from the source (24") yielded a dose rate variation of up to +10%. This is, all portions of the cables received at least the minimum dose requested, and some portions (i.e., outer circumference) received up to an additional 10% of the specified dose.

(c) PWR Steam/Chemical-Spray Exposure and Electrical Measurements

The cables were then installed in a test chamber for exposure to a PWR simulated accident consisting of a 7-1/2 day steam/chemical spray environment while being electrically energized. The cables were looped on a shelf of perforated sheet metal which simulated a cable tray.

Prior to initiating the environmental exposure in the test chamber, insulation resistance and high voltage (ac) tests were conducted. The insulation resistance was measured following the application of 500 V dc for a period of 1 minute. The high voltage tests consisted of applying 2.2 kV ac for a period of 5 minutes to the 600 V cables and applying 6.8 kV ac for a period of 5 minutes to the 5 kV cable. The IR measurements were performed on the multiconductor cables by grouping the terminal connections as shown in Tables 2 and 4.

The results of these insulation resistance measurements, as well as those taken periodically during the remaining portion of the PWR test, are also given in Table 2.

Subsequent to conducting the aforementioned electrical measurements, the steam/chemical-spray exposure was initiated with the cables carrying the current and voltage loadings as shown in Table 3.

Table 2

Insulation Resistance Measurements During PWR Exposure* (M. Ω)/1000 ft.

					← Daily Measurements at 16 psig/252° F →							
Cable Sample No.	Terminal Connections I	Terminal Connections II (Grnd.)	Cables in Test Chamber-Prior to Initiating Steam/Chemical Exposure	During 80 psig-324°F Dwell	First Day	Second Day	Third Day	Fourth Day	Fifth Day	Sixth Day	Seventh Day	At End of Steam/Chemical Exposure (At Ambient Cond.)
A-4	1	Grnd.	1110	.58	5.8	5.8	7.0	9.3	10.6	12.8	14.0	700
D-4	1,3	2,4	71.0	.76	1.45	1.58	1.84	2.90	3.56	3.04	.66	3.45
E-4	2,4,6	1,3,5,7	4.60	.0345	.066	1.72	1.64	2.25	2.50	2.78	3.45	1.19
B-4	1	Grnd.	235	.306	1.74	2.04	1.93	2.35	2.46	2.56	2.88	3600
F-4	1,3	2,4	52.0	.83	4.95	5.92	5.2	5.92	6.1	6.1	6.5	530
C-4	1	Grnd.	494	2.09	17.2	21.2	18.4	19.8	19.8	19.8	22.0	6500

* Measured after the application of 500 V dc for a period of 1 minute.

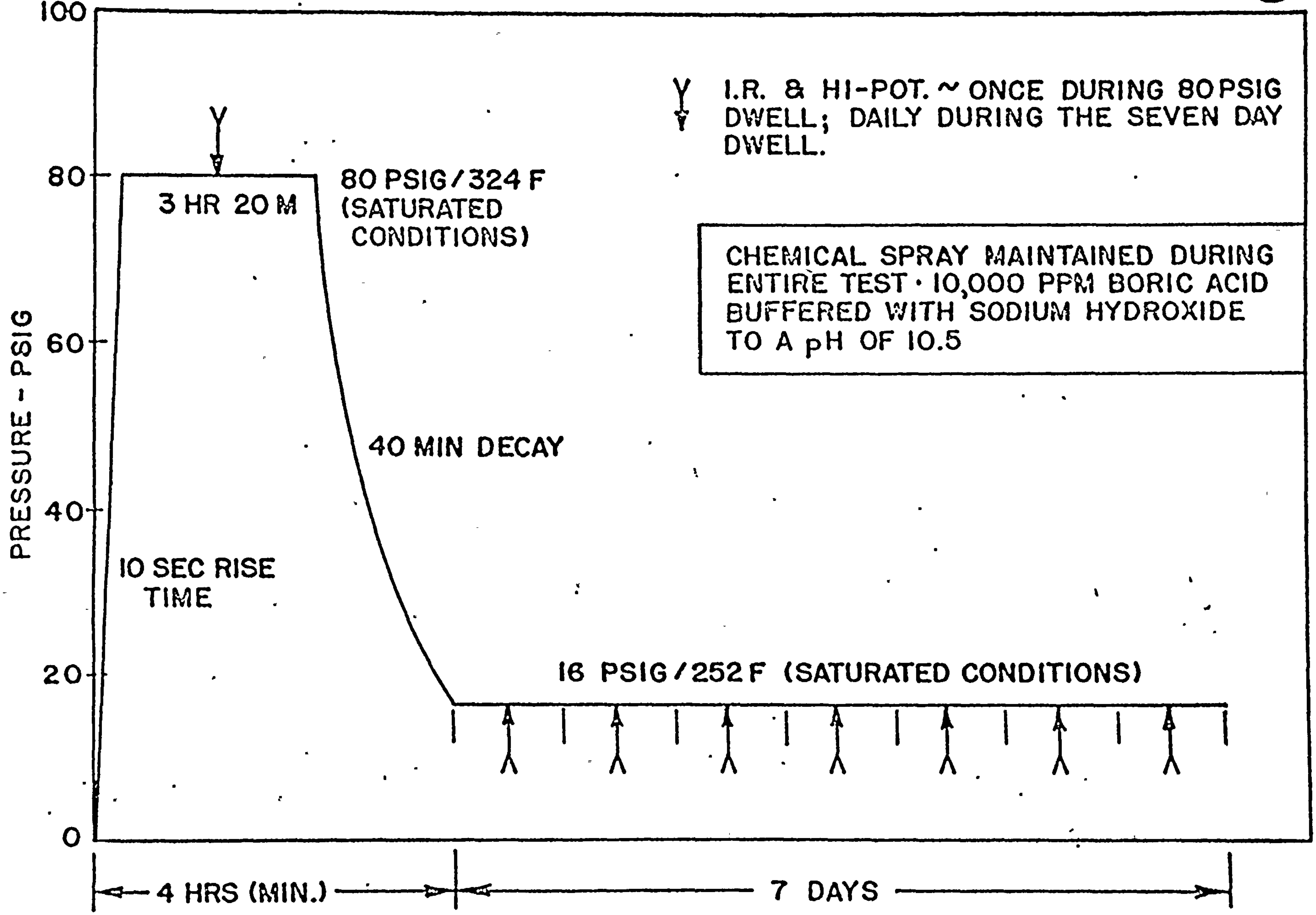


FIGURE I - TEST PROFILE OF PWR EXPOSURE

Table 3

Cable Current and Voltage Loadings During PWR and BWR Exposures

Sample No.	Current Loading (amp)	Voltage Loading (volt)
A-4	18.0	600
D-4	18.0	600
E-4	12.5	600
B-4	280	600
C-4	280	2900
F-4	21.0	600

The test profile is illustrated in Figure 1. It consisted of a 10 second rise time from normal room ambient conditions to a pressure and temperature of 80 psig/324°F. These conditions were maintained for a period of 4 hours, at which time the pressure and temperature were gradually reduced to 16 psig/252°F and maintained for a period of seven days. Throughout the test, the temperature was maintained as nearly as possible at values corresponding to saturated conditions, 100 percent relative humidity, while the cable samples were subjected to a chemical spray consisting of 10,000 ppm boric acid buffered with sodium hydroxide to a pH of 10.5.

Insulation resistance measurements were taken in a manner identical to those described above during the dwell at 80 psig/324°F, and daily thereafter. The results of these measurements are given in Table 2.

At the end of the steam/chemical exposure, at normal room ambient conditions and with the cable samples remaining in the test chamber, the aforementioned electrical measurements were again taken with the results given in Table 2.

(d) BWR Steam Exposure and Electrical Measurements

The same cables and splice that had been exposed to the PWR accident conditions were then exposed to a BWR simulated accident consisting of an environment of saturated steam while being electrically energized, with the same current and voltage loading as in the PWR exposure (Table 3).

The test profile is illustrated in Figure 2. It consisted of a series of transient cycles, each consisting of a rise to a specified pressure and temperature conditions, a hold at these conditions for a specified time, and a gradual return to the initial condition or to atmospheric pressure. Following the above transient cycles the samples were subjected to 100 days exposure to live steam 0 psig, 212°F. The temperatures were maintained as nearly as possible at values corresponding to saturated conditions, 100% relative humidity. During the 2nd, 3rd, and 5th constant pressure/temperature period, insulation resistance was measured. During these same periods and at the end of the 100 day test, the samples were subjected to the high potential ac tests. The tests were conducted as described in section (c) for the PWR exposure, at times indicated by broad lines in Figure 2. Table 4 gives the results of the insulation resistance tests for the BWR accident conditions.

Tables 5 and 6 present the electrical and physical properties after the postulated loss of coolant accidents. These tests establish the ability of the cables to perform their functions after LOCA. As a matter of information the initial values are also displayed.

F. M. McAvoy, Director
Cable Evaluation & Development

FMM/row

Sworn and subscribed to before me

this 3rd day of March 1972.

Notary Public of N. J.
My Commission Expires August 4, 1976

Table 4

Insulation Resistance Measurements BWR Exposure* MΩ/1000 ft.

Cable Sample No.	Terminal Connections		During 104 psig-345°F Period	During 75 psig-320°F Period	During 25 psig-272°F Period	At End of Exposure (At Ambient Temp.)
	I	II (Grnd.)				
A-4	1	Gnd.	5.8	1.0	5.3	160
D-4**	1, 3	2, 4	.0093	.053	.0069	7340
E-4	2, 4, 6	1, 3, 5, 7	.362	.61	2.24	5500
B-4	1	Gnd.	.092	.204	4.90	2550
F-4	1, 3	2, 4	.47	.14	1.96	65
C-4	1	Gnd.	.98	1.98	14.8	3460

* Measured after the application of 500 V dc for a period of 1 minute

** Sample D-4 was mechanically damaged at penetration resulting in lower reading.

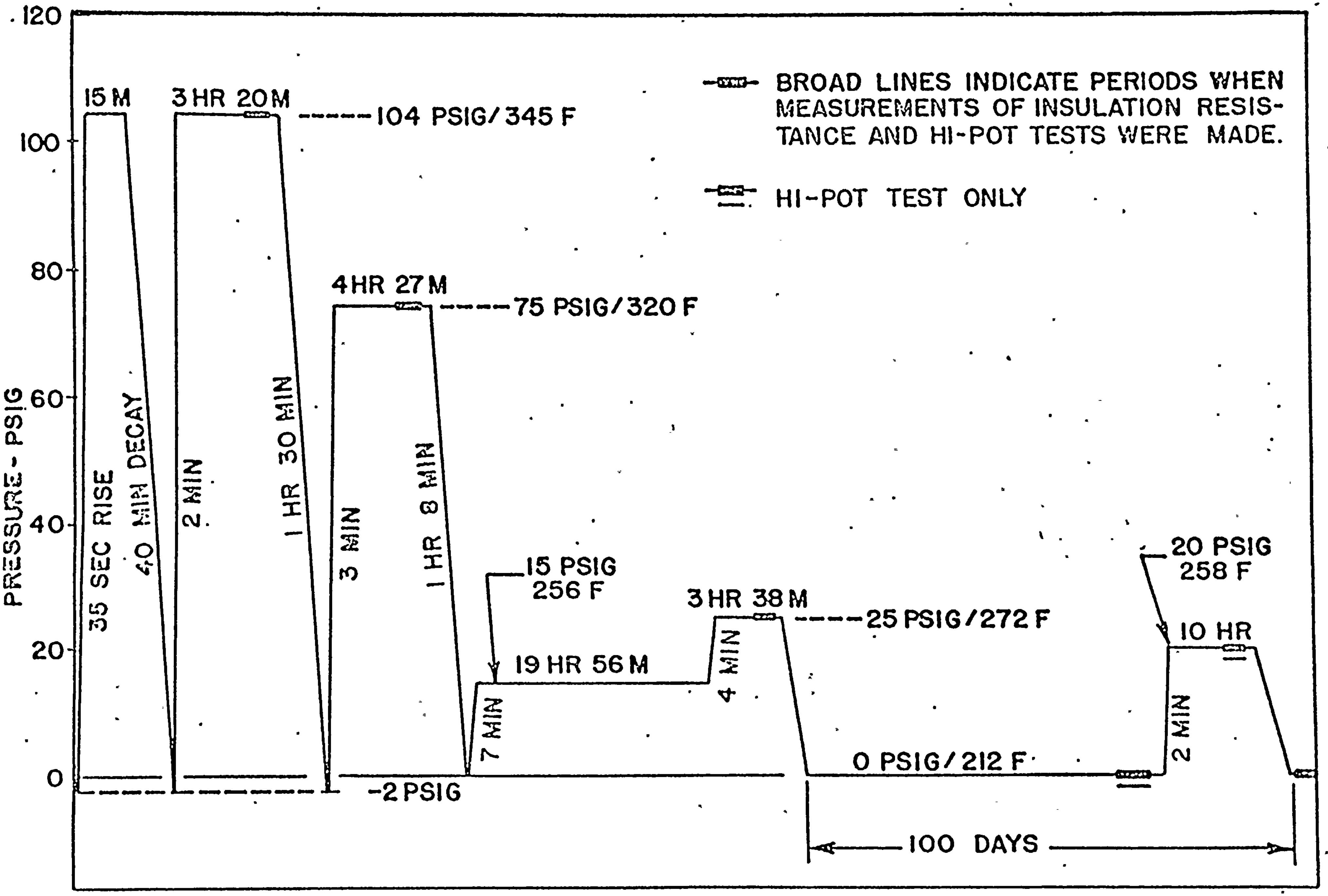


FIGURE 2 - TEST PROFILE OF BWR EXPOSURE

Table 5

Effect of Postulated LOCA - Electrical

Following exposure to 2×10^8 rads of gamma radiation and PWR and BWR accident conditions electrical measurements were made on Sample C - 4, 1/C 4/0 0.104" Okoguard cable with splice removed.

Initial Temperature °C	Stress V/Mil	SIC		P.F.	
		20°	75°	20°	75°
	40	4.24	4.64	1.19	1.74
	80	4.24	4.64	1.21	1.79
After 2×10^8 rads PWR & BWR accident conditions	40	3.79	4.24	1.24	1.84
	80	3.80	4.29	1.36	1.99

The following electrical measurements were made on singles of sample F-4, 4/C #12 0.047" Okonite, 0.015" Okolon, in 8" diameter coils.

Initial	40	3.41	3.96	0.51	1.37
	80	3.44	3.98	0.59	1.40
After 2×10^8 rads PWR & BWR accident conditions	40	3.21	3.84	2.12	2.92
	80	3.61	4.19	2.17	3.01

It should be noted that initial measurements were composite measurements of insulation and jacket, and the final measurements in the case of the Okoguard was without the jacket while the Okonite was with a deteriorated jacket. This obviously distorts these measurements. The important fact is that the cable will carry rated current at better than two times operating voltage plus 1000 volts and will allow an orderly shutdown of the station if an LOCA occurs.

Final withstand test: passed 3600 volts ac (80 V/mil) for 5 minutes.

Table 6

Effect of Postulated LOCA - Physical

Following exposure to 2×10^8 rads of gamma radiation and PWR and BWR accident conditions, physical measurements were made on the following samples:

Initial	Sample C-4 1/C 4/0 0.140" Okoguard	Sample F-4 4/C #12 0.047" Okonite-0.015" Okolon	Sample E-4 7/C #14 0.030" Okonite 0.015" Okoprene
Tensile Strength	912	1275	1310
200% Modulus	816	956	894
% Elongation	390	325	360
After Radiation 2×10^8 and PWR, BWR Accident Conditions			
Tensile Strength	900	600	578
% Elongation	100	90	30

Physical properties of the C-4 sample were on the insulation only. Physical properties on F-4 and E-4 were composite of jacket and insulation.

CLASS IE CABLES FOR NUCLEAR POWER GENERATING STATIONS

E. E. McIlveen V. L. Garrison G. T. Dobrowolski
The Okonite Company
Ramsey, New Jersey

ABSTRACT

With the publication of IEEE Guide P 383 For Qualification Testing, it is appropriate to present typical data relating to this document, and to briefly discuss its significance. Designed life performance for nuclear stations must be predicated for the most part on test data obtained from cable systems under simulated environmental conditions which are peculiar to this application. This paper presents data in the areas of (1) long time exposure to moisture at elevated temperature, (2) air oven heat aging, (3) simulated reactor radiation during normal operation as well as during and after a design basis event, and (4) flame testing of cables.

INTRODUCTION

With the advent of nuclear power plants in the early 1960's, a new set of operating conditions for electrical equipment had to be recognized by the design engineers. As demonstrated by the work in the Nuclear Power Engineering Committee, the evolution of design criteria has continued. The imminent publication of the IEEE Guide for Type Test to Qualify Electrical Cables and Connections,[1] is evidence of this activity, but it should be regarded as an interim document which will be up-dated from time-to-time.

This paper will present typical design and qualification data together with some explanation of its significance. Cable system designed life performance, when based on long service experience can be quite reliable, but significantly different conditions and materials have made simple projections questionable. Simulated service test data on representative cable constructions must, therefore, be relied upon; and it can provide a reasonable basis for power plant cable system design and qualification.

The areas to be studied for qualification through performance testing are: (a) moisture resistance, (b) long term physical aging properties, (c) normal radiation exposure, and design basis events postulated on loss of coolant accident (LOCA) and, (d) cable tray fires.

MOISTURE RESISTANCE

Moisture resistance is a major factor in determining the normal life of a solid dielectric insulated conductor. It has become traditional to gain assurance of long life performance by totally immersing a #12 or 14 conductor insulated with a 45 mil wall of dielectric in water at an elevated temperature to accelerate the deteriorating effects of moisture. Monitoring the electrical properties then provide an indication of long term behavior. In the 1950-57 era with service gained experience that negative dc potential presented the most severe condition, IPCEA developed[2] a 16 week test procedure along these lines based on a continuous immersion at 50°C while under 600 volts dc. At this time, more than sixteen years later, new generation moisture resisting insulations of similar geometry can be continuously immersed at 75°C while under the same dc potential, and survive from 1-1/2 to 2 years, or more. This is at least 5 times longer and at an effective temperature acceleration rate of 6 times greater than anticipated by that IPCEA procedure. Since insulated conductors of the 1957 vintage dielectrics installed at Shippingsport, Indian Point and Peach Bottom, among others, have not experienced distress due to moisture, it can be reasoned that control cable insulations now specified which have the capability of withstanding total immersion at 75°C under 600 V dc as discussed herein should develop the designed life of the cable plant. Fig. 1 presents data for a 45 mil wall of an ethylene-propylene base insulation conductor, and Fig. 2 illustrates the electrical behavior of a composite wall composed of 30 mils EP base plus 15 mils neoprene compound.

Reference to Table I discloses similar data for an ethylene-propylene base dielectric and also a flame resistant cross-linked polyethylene compound (FR-CLPE), but at 90°C continuous water immersion while under 600 V ac potential except when percent power factor (% PF) and the specific inductive capacity (SIC) are being measured at 40 and 80 V/mil ac. Following each test measurement the specimens were subjected to a 5 minute withstand test at 110 V/mil. The specific insulation resistance (SIR) were made at 500 V dc while at 90°C. The difficulty of predicting long term performance based on the customary 2 week test data is obvious. It may be of interest that the time to failure for a particular specimen is a complex function of several variables, one of which is the degree of mechanical perfection of the dielectric wall. Failure is often sudden with little or no forewarning, and occurs when the cable is undergoing 60 cycle power factor and capacity measurements, or during the subsequent withstand at 110 V/mil.

Fig. 3 not only shows the SIC values for an ethylene-propylene base insulation during a long term continuous water immersion study, but also the accelerating effect of temperature as manifested by a change in the 60 cycle capacity. The 142°C/42 psig steam autoclave exposure further accelerates the increase in the SIC value but could change the reaction mechanism. In any event, if plotted on Fig. 3 the end point is still some two years out on the time scale.

Paper T 74 044-4, recommended and approved by the IEEE Nuclear Power Engineering Committee of the IEEE Power Engineering Society for presentation at the IEEE PES Winter Meeting, New York, N.Y., January 27-February 1, 1974. Manuscript submitted August 31, 1973; made available for printing November 16, 1973.

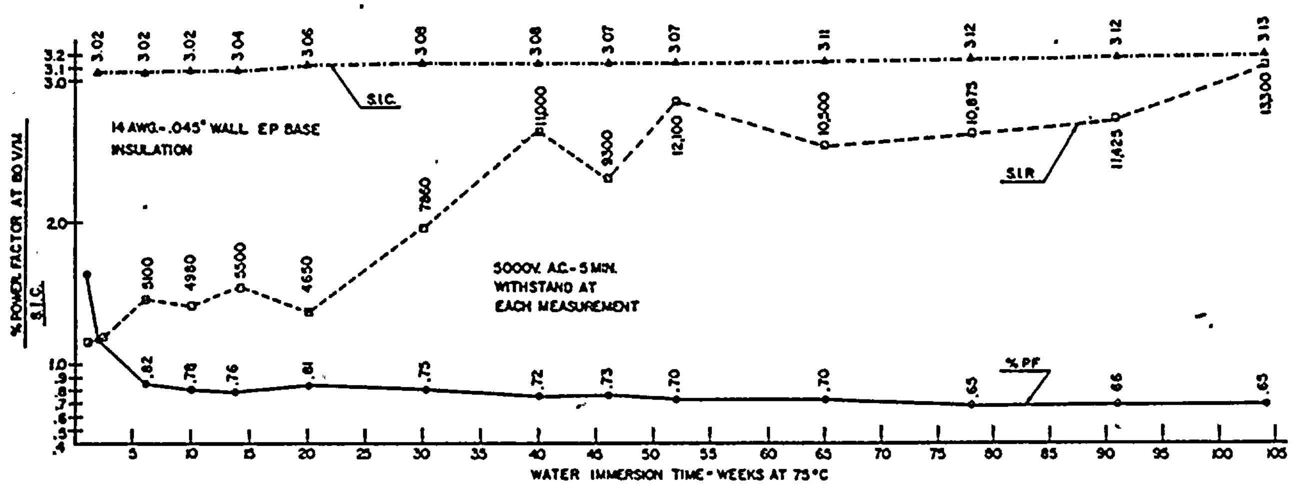


Fig. 1. Water Immersion Test of EP Dielectric Under 600 V Negative DC

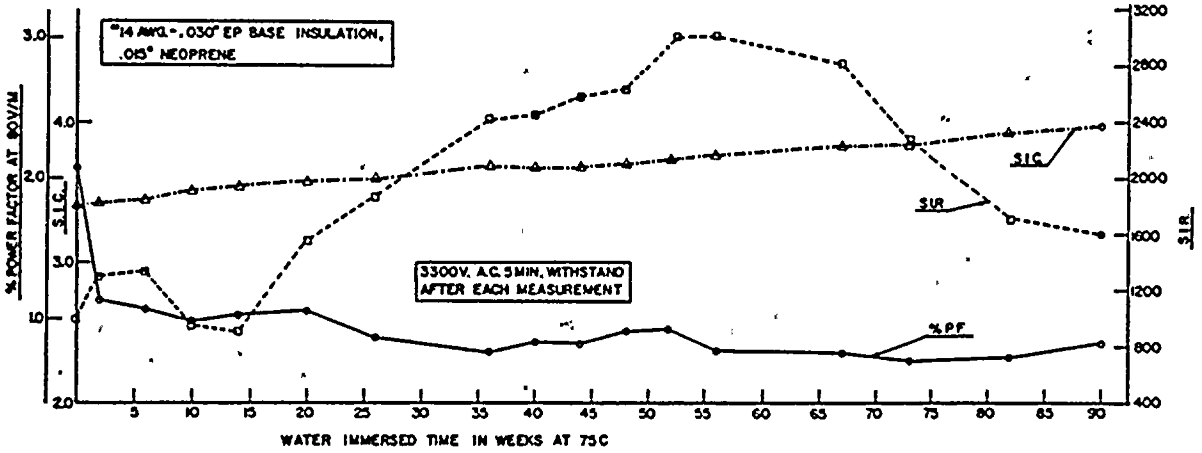


Fig. 2. Water Immersion Test of EP/Neoprene Under 600 V Negative DC

Table I

90°C Water Immersion--600 V AC

.045" Wall		EP Base			FR - CLPE		
Time Period	Stress V/mil	PF %	SIC @ 90°	SIR x 10^3	PF %	SIC @ 90 C	SIR x 10^3
1 day	40	2.84	3.09	1.3	1.06	2.88	2.0
	80	2.89	3.09	-	1.09	2.88	
7 "	40	1.52	3.05	1.8	1.07	2.94	3.0
	80	1.55	3.05	-	1.08	2.94	
14 "	40	1.36	3.07	2.1	1.09	2.95	2.9
	80	1.36	3.07		1.11	2.95	
28 "	40	1.13	3.08	2.3	1.24	2.96	2.8
	80	1.16	3.08		1.25	2.96	
2 mos.	80	1.10	3.09	3.1	1.51	3.11	3.5
6 "	80	0.87	3.17	3.5	2.37	3.17	4.5
12 "	80	0.79	3.20	4.3	3.31	3.28	4.7
18 "	80	0.70	3.26	4.7	3.43	3.36	5.4
24 "	80	0.70	3.30	5.1		continuing	

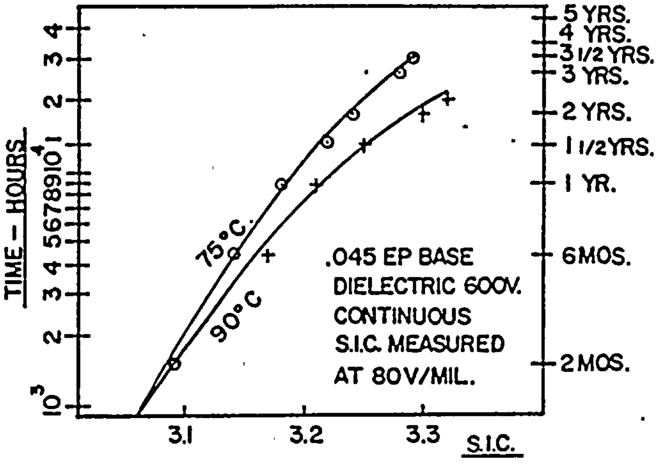


Fig. 3. Accelerating Effect of Temperature on SIC Values During Water Immersion

LONG TERM PHYSICAL AGING PROPERTIES

Data on electrical behavior in a combined heat and moisture environment, as covered in the previous section, may be a better guide to service related performance than that developed from simple physical aging in a dry air oven at elevated temperatures such as 136, 150, 165 and 180°C. The curves presented in Fig. 4, 5, 6 and 7 are based on such data obtained through standard procedures.[3] These can be analyzed by the Arrhenius technique and, by analogy the useful life may be predicted.

It should be recognized that the Arrhenius equation[4] is valid only if the data represents a single discreet chemical reaction and the activation energy of that single reaction is within the temperature limits of the data. This equation can be derived from collision theory and has been experimentally verified. It serves to define the temperature coefficient of a discreet chemical reaction and the activation energy of that reaction only within the temperature limits of the experimental data. The equation is:

$$k = Ae^{\frac{-\Delta E}{RT}}$$

k = specific rate constant,

A = frequency factor or collision frequency,

ΔE = activation energy - the difference in the energy of a chemical species in the ground state and its activated state. The activated state is not isolable and has a very short life time (in the order of nano or pico seconds) and collapses either to the original ground state of reactants or to the ground state of the products.

R = gas content,

T = absolute temperature

The specific reaction rate constant k represents a single discreet chemical reation. In the case of a simple uni-molecular first order reaction A ⟶ B, the following describes the rate where C = concentration:

$$\frac{-dC_A}{dt} = kC_{A_0}$$

that is -- the change in concentration of reactant A with time is proportional to the initial concentration of A. The differential equation is solved and k determined from experimental measurements of concentration vs. time. Distinct values of k must be determined at various temperatures and must be constant over a considerable range of conversion in the reaction, say from 20 to 80%, for the data to be considered valid. It can be used correctly only when there are discreet chemical reactions whose rate can be precisely measured, and described by a solvable differential equation. A straight line will result from a plot of the logarithem of the reaction rate k vs. 1/T provided there is no change in the reaction mechanism.

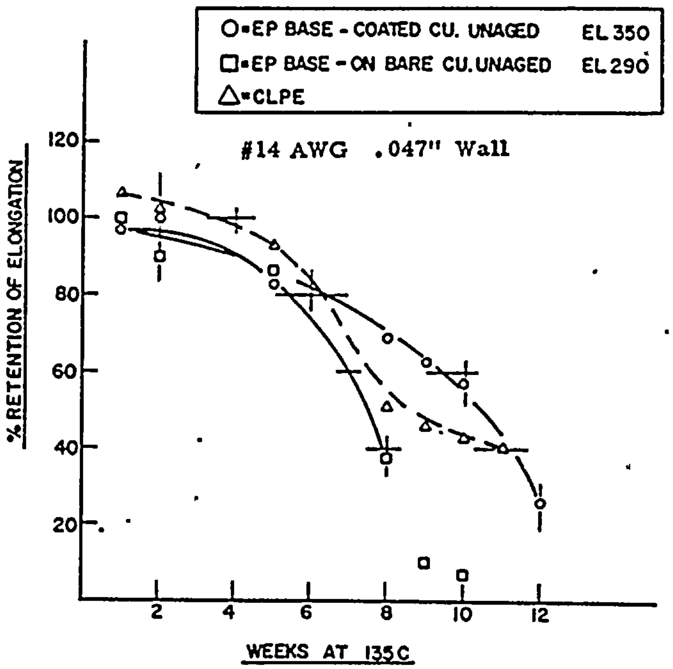


Fig. 4. Air Oven Aging at 135°C

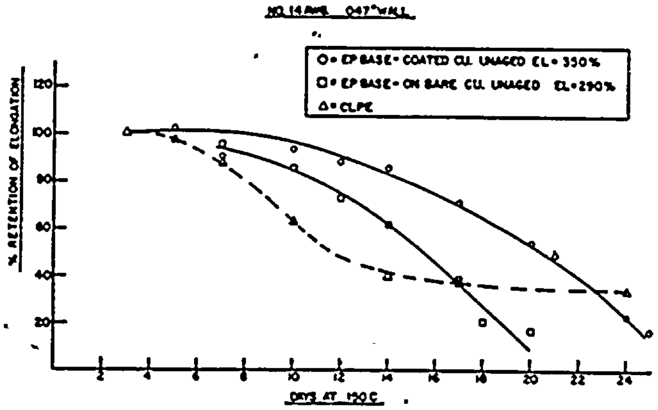


Fig. 5. Air Oven Aging at 150°C

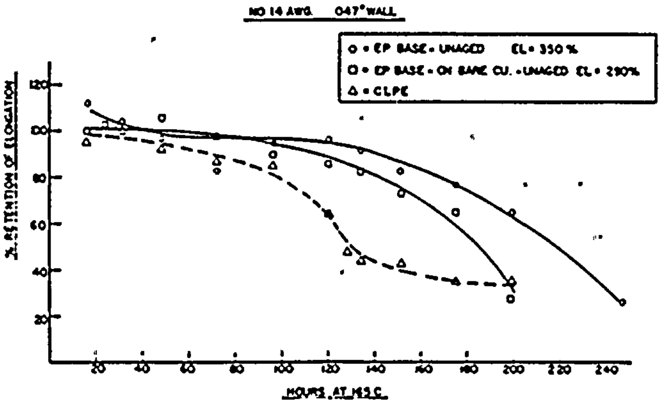


Fig. 6. Air Oven Aging at 165°C

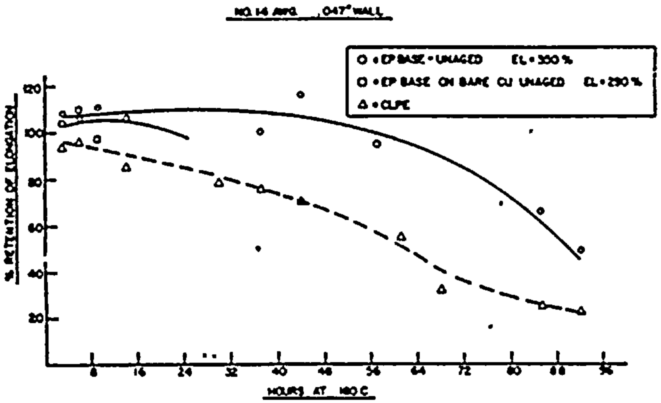


Fig. 7. Air Oven Aging at 180°C

In applying this Arrhenius analysis to the aging data, the time to 40% loss of elongation is plotted on semi-log paper against the reciprocal of the absolute temperature (T) in degrees Kelvin. This is presented in Fig. 8. In examining the validity of this treatment of the data obtained from Figs. 4 through 7 of this paper, note there are at least four simultaneous reactions: - (1) oxidative cleavage, (2) oxidative cross-linking, (3) thermal cleavage, (4) thermal cross-linking. The first two of these reactions are at least second order in their rate law and must depend at a minimum on the concentration of oxygen and the concentration of reacting chemical bonds. Since vulcanized rubber is a complex mixture of many chemical bond species, there are a multitude of individual rate constants that must be measured. This is an impossibility. From the above, it could be argued that the occurrence of a linear plot in Fig. 8 in an Arrhenius treatment of aging data is a fortuitous event, but it does provide a means of comparison within the temperature range of the data.

Nevertheless, the significance of loss in elongation is related to the ability of the insulation to withstand bending without physical cracking and ultimate electrical failure when moisture enters. A 40% loss still leaves 60% retention which probably represents an elongation on the order of 180% whereas 50% ultimate is usually reached before serious cracking develops.

Since thermosetting insulations of the 1957 type vintage have performed well in the nuclear plants cited herein and since Fig. 8 shows that the ethylene-propylene base and the cross-linked polyethylene insulations take 6 times as long to reach 40% loss of elongation as does butyl, it is safe to predict that these new insulations [5] will provide superior aging performance in service as far as this property is concerned.

During the development this aging data, it was observed, as shown in Figs. 4 through 7 that at these elevated temperatures an alloy-coated copper conductor specimen out-performed a non-coated copper conductor. This is due to the catalytic effect of the copper on the degradation of organic dielectrics.

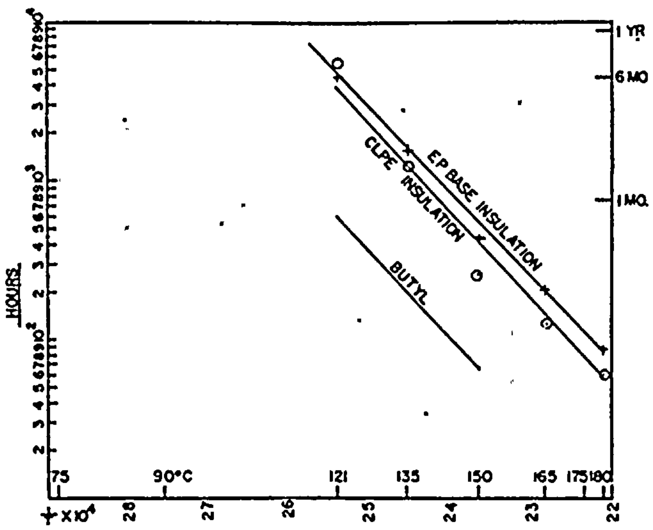


Fig. 8. Time to 40% Loss of Elongation

RADIATION EXPOSURE

In 1968 studies were made[6] on the performance of 13 elastomer-based insulation/jacket combinations after gamma irradiation in air. Based on the effect upon the physical aging, electrical properties, moisture and steam resistance, and flame resistance, specific ethylene-propylene and cross-linked polyethylene insulations were found to be suitable for nuclear power plant service.

By mid-1970 qualification testing of specimens pre-aged prior to gamma radiation to 3.5×10^7 rads followed by a simulated loss of coolant accident (LOCA) became necessary for design acceptance. Again a specific ethylene-propylene insulation proved to be suitable.[7] The amount of aging had no adverse effect on the electrical properties of the ethylene-propylene base insulations, . Table II presents the data. Further reference to Table II will disclose a number of interesting points. Sample B, a Hypalon base dielectric had good electrical and physical properties following the simulated aging, that is "before" radition. "After" the LOCA simulation in the autoclave the electrical properties fell of significantly. The physical appearance and resilience, however, were good.

Sample C represents two specimens which contained a hand-wrapped splice made with an ethylene-propylene base tape. Although not pre-aged, there was little or no deformation from the cables laid on top of these two splices, and they remained resilient and firm at all stages of the test.

TABLE II

Nuclear Simulation of October 1970

Samples:

A - 1/C 14 AWG coated copper, .060" EP Base insulation
B - 1/C 14 AWG (7X) coated copper, .030" Hypalon Base insulation
C - Hand wrapped EP tape splice

Heat Exposure: Samples A and B were aged in air oven at 150°C for 6, 10 and 14 days prior to being irradiated.

Radiation:[7] To total of 3.5×10^7 rads at rate of 5.2×10^4 rads/hr.

LOCA: 12 hrs. steam @ 305°F/60 psig + 168 hrs. 230°F/5 psig with PWR chemical srpay while energized at rated voltage. Sample A also received 10 hrs. steam at 350°F/120 psig.

	Days	Samples A 1-3		Samples B 1-3		Samples C 1-3	
Properties	Aged	Before	After	Before	After	Before	After
P.F. % @ 80 V/mil	(1) 6	.43	.63	5.76	--	.42	1.81
	(2) 10	.36	.61	3.52	--	(no pre-aging)	
	(3) 14	.31	.63	4.02	--		
S.I.C. @ 80 V/mil	(1) 6	3.12	3.26	6.16	--	---	
	(2) 10	3.12	3.31	6.32	--	---	
	(3) 14	3.13	3.30	6.33	--	---	
S.I.R. (x 10^4)	(1) 6	20	16	2.5	DL	---	
(megs-1000')	(2) 10	20	16	2.9	DL	---	
	(3) 14	20	16	2.2	DL	---	
Withstand, 5kV ac & dc		--	--	--	--	passed	
Tensile, % Loss	(1) 6	6	2	+23	+10		
	(2) 10	6	+5	B	+ 5		
	(3) 14	9	4	B	+ 1		
Elongation, % Loss	(1) 6	8	51	46	60		
	(2) 10	11	57	B	72		
	(3) 14	14	54	B	68		
Physical Condition		E	E	G	G	E	G

E = Excellent, resilient and firm
G = Good
B = Bonded so tight it could not be removed from the strand
DL = Dead Leak

Within a year, reassessment of design parameters dictated higher level of radiation exposure and new LOCA simulation-profiles for qualification. Table III exhibits the details for a total disage of 1×10^8 rads plus a LOCA for a boiling water reactor (BWR).[8] The steam exposure at 212°F was continued for 100 days at atmospheric pressure with a "kicker" to 20 psi for the last 10 hours. This was followed by a 500 volt insulation resistance measurement and a 5 minute ac withstand test. The specimens successfully withstood the simulations and proof test.

Table IV and Fig. 9 present the LOCA simulation for specimens radiated to a total dosage of 2×10^8 rads. This simulation is particularly severe because these specimens were loaded to rated current and voltage and tested to the pressurized water reactor (PWR) incident profile, and then these same specimens were subjected to a BWR profile.[9] It may be noted these profiles include one "peak" at 324°F/80 psig, two peaks at about 342°F/104 psig, and one at 320°F/75 psig plus the 100 day soak. These multiple transients demonstrate that these specimens have significant margin, a performance characteristic requested in the Guide.

Additional qualification tests covering several different cable constructions are in progress at this writing. The Appendix to the Guide P 383 suggests relative short term procedures in Section 2.4 which have evolved from the type of studies and testing described above. Eventually, new data obtained in environments more closely approaching long term operational conditions may show that sequentially synthesized effects of temperature, radiation, atmosphere and movement are unnecessarily severe.

TABLE III
Nuclear Simulation of July 1971

Samples:

A - 1/C 14 AWG .030" EP Base insulation + .015" Neoprene Base Cover.
B - 7/C 14 AWG same as A, cabled, + tape and .060" Neoprene Jacket.
C - 1/C 4/0 5kV EP Base + Hypalon with EP/Neoprene Splice.

Radiation:[8] To total of 1×10^8 rads at rate of 1×10^6 rads for the first hour followed by 3×10^5 rads per hr. for 330 hrs.

LOCA Periods: BWR sequence of 55 minutes steam @ 304°F/104 psig + 3 hrs. 20 min. @ 346°F/104 psig + 4 hrs. 27 min. @ 320°F/75 psig + 1 day at 256°F/15 psig minimum + 100 days at 212°F/0 psig, with last 10 hrs. @ 259°F/20 psig.

Electricals During LOCA:

	Loading		Insulation Resistance *			
Sample	Amperes	Volts	@ 346°	@ 320°	@ 272°	Periodic ac Withstand **
A	18	600	165	350	2700	1.3 kV OK
B	12.5	600	525	420	2600	1.3 kV OK
C	280	2900	950	1800	12000	6.8 kV OK

NOTE: * megohms-foot, ** 5 minutes at end each period.

TABLE IV
Nuclear Simulation of September 1971

Samples: Same as in Table III

Heat Exposure: Air oven for 168 hrs. @ 121°C

Radiation:[9] To total of 2×10^8 rads

LOCA Periods: Current and voltage loadings as in Table III during 4 hrs. @ 324°F/80 psig + 7 days @ 252°F/16 psig in addition and prior to the same BWR sequence detailed in Table III. Fig. 9 shows this profile.

Electricals During LOCA:

	Insulation Resistance *				
Sample	@ 346°	@ 320°	@ 272°	Megs - 1000 ft. Final @ 70°	Periodic ac Withstand **
A	500	850	4500	160	2.2 kV OK
B	270	460	1700	5500	2.2 kV OK
C	800	1600	12000	3460	6.8 kV OK

NOTE: * megohms-foot, ** 5 minutes at end each period.

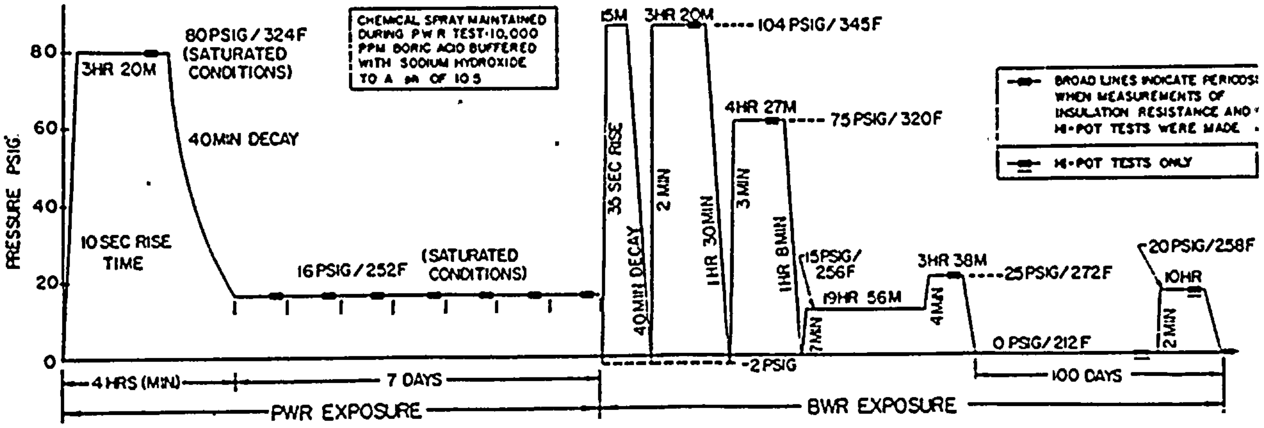


Fig. 9. Combined LOCA Simulations

CABLE TRAY FIRES & TESTS

While not confined to nuclear plants, the losses incurred through cable fires in such installations has focused attention on not only the flame resistance of the trays, both with and without covers or baffles, the degree of separation, the matter of circuit redundancy, and the effectiveness of various fire extinguishing systems. Studies on cable behavior, and the effect of physical arrangement and separation have been covered in an earlier paper.[10] Redundancy and fire extinguishing systems are subjects not relevant to type testing to qualify cables and connections other than to note that the redundancy concept among other things, has made obsolete the requirement of "time to short-circuit". Also note that thermoset insulated and jacketed cables are relatively unaffected by CO_2 discharges from protective systems.

It follows that cable performance during a tray fire should be postulated as a design basis event (DBE), and a method of qualifying cable for tray systems had to be developed. The "Philadelphia" Tray Cable Fire Propagation Test, which was devised in 1965[11], simulates a fire in a vertical tray, a situation which is more severe than with a horizontal tray. The flame source in the original procedure was crumpled oil-soaked burlap rag. In the following years much effort was expended in trying to eliminate some uncontrollable variables. While a definite burlap folding sequence and oil dipping procedure were developed, and these did improve reproducibility somewhat, the replacement of the oil-soaked burlap with a large ribbon type gas burner together with instrumented control of the air/gas flow resulted in a completely reproducible flame environment. This inadvertently resulted in a more severe test because (a) the gas flame provides a constant heat input for the entire test period whereas the oil-soaked burlap flame reaches a maximum within several minutes and then tapers off until it finally flickers out. Furthermore, (b) the gas flame projects right through the cables thereby completely surrounding them whereas the oil-soaked burlap flame is vertical and in front of the cables so that the majority of the heat reaches about half the circumference. The procedures for both of these methods may be found in Section 2.5 of P383.

The type test data in Table V provides a comparison of the two different flame sources described in paragraphs 2.5.4.4 and 2.5.4.5 of the Guide, Part II. Table VI gives test data which establishes the similarity of results between specimens subjected to the Natural Grade propane gas flame and those tested with the commercial gas flame. Table VII presents data developed on small diameter cable constructions with different insulations.

The "time to short-circuit" range is noted in Tables V, VI and VII to permit cross-comparisons to illustrate the variations which, even for ostensibly identical cables, range from 5 minutes to 9 minutes with mavericks (unknown) in some test runs as low as 4 minutes in the gas fired test, and up to about 12 minutes with only one cable out of six failing in

Table V

Oil/Burlap vs. Gas Flame Tray Test

Specimen: 7/C 12 AWG Cu, .030"/.015" EP base + neoprene, cabled, .060" thermoset jacket, OD = 0.70".

Commercial Gas			Oil/Burlap	
Temp. °F Max.	Flame Height Inches	Test Time Minutes	Temp. °F Max.	Flame Height Inches
1450	16	0	0	0
1490	20	2	1260	30
1500	24	4	1190	30
1500	24	5	1190	24
1500	28	6	1190	22
1480	30	7	1190	20
1460	36	8	1180	15
1450	36	10	1170	12
1450	30	12	1140	10
1450	22	16	930	6
1450	16	20	820	5
All: in 5 to 9 minutes		Short Circuit Range	Three in 7 to 16 minutes	

1 min.:20 sec.	After Burn	2 min.:30 sec.
40 inches	Core Damage	15 inches
44 inches	Jacket Char	26 inches
No	Propagated	No

Table VI

Commercial vs. Propane Gas

Specimen: 7/C 12 AWG Cu, .030"/.015" EP base + neoprene, cabled, .060" thermoset jacket, OD = 0.73" and 0.71".

(From two different production runs)

Commercial Gas			Propane Gas	
Temp. °F Max.	Flame Height Inches	Test Time Minutes	Temp. °F Max.	Flame Height Inches
1450	16	0	1450	16
1480	24	2	1480	28
1490	28	4	1480	28
1490	30	5	1500	30
1480	32	6	1500	32
1480	36	7	1490	46
1480	42	8	1480	54
1480	48	10	1480	42
1460	40	12	1470	38
1460	28	16	1460	29
1450	16	20	1450	16
All: in 6 to 8 minutes		Short Circuit Range	All: in 6 to 8 minutes	

1 min.: 25 sec.	After Burn	0 min.: 20 sec.
41 inches	Core Damage	43 inches
45 inches	Jacket Char	51 inches
No	Propagated	No

the oil/burlap fired test. This "time" incidentally, is established when a 120/240 volt monitoring circuit lights a small lamp. It has already been demonstrated[10] that this "time" is also a function of the number of conductors in the cable and/or their size. Obviously it is the amount of heat sink provided by the metal that governs such results. Other independent variables are the type and volume of insulation and cover, fillers, cable tapes, jacket materials, and metallic armors. This complex array of variables alone precludes the establishment of a meaningful performance level denoted as "time to short-circuit" and is another reason why this was dropped from Section 5 of the original draft of the Guide Appendix.

Again referring to these variables, the flame height distances are subject to some error since they are visual and estimated at a stand-off distance. The core damage also involves judgment, as does the overall jacket char distance measurement.

The only practical clear cut observation that can be made is that of propagation. Failure by this mode is defined in paragraph 5.5 of the Appendix as occurring when the fire burns all the way up to the top of the tray, a distance of about 6 feet above the flame source center. None of the cables reported in Tables V and VI shows this distress, but a review of the data in Table VII will disclose a typical failure with Sample C.

In addition to vertical tray flame tests described herein, a specimen of each type of instrument cable or the individually insulated or insulated and jacketed conductors removed from each multiconductor control cable which is type tested should pass a flame resistance test in accordance with ASTM D2220-68, Section 5. This precaution is taken to not only insure that the small single conductor components or units are flame resistant, so as to not contribute to a tray fire, but to also minimize propagation in control cabinets where the outer flame resistant jacket, armor, or other covering had been removed to permit spreading these individual conductors or units for connecting to equipment.

DISCUSSION

It should be noted that the data presented herein was developed on cables with specific constructions, insulations, and coverings. It would be neither fair nor correct to assume that all insulations tagged as EP, or FR-CLPE, or silicone, for example, were identical to each other and would, therefore, perform the same. This is also true for jackets compounded with neoprene, Hypalon, or PVC.

While the moisture and aging data can be reproduced to a good degree of accuracy with a spread less than 10%, the flame test data is largely based on qualitative observations which, together with sample variations, result in considerable swings from one data sheet to the next. The consequence of the latter is a "go" or "no-go" criteria for propagation. Fortunately this is the only performance characteristic which is really necessary to check-out. It is practical and was developed for a 7/C 12 or 14 construction.

Table VII

Effect of Construction -- Tray Test

Specimens:

A - 7/C 16 AWG Cu, .031" silicone + glass braid cabled, tape, glass braid OD = 0.045"

B - 7/C 16 AWG Cu, .030" flame resistant CLPE, cabled, tape, neoprene jacket, OD = 0.50"

C - 7/C 12 AWG Cu, .020"/.010" PE + PVC, cabled, tape, .060" PVC jacket, OD = 0.58"

Test Time 1400° Gas Burner Minutes	Sample A Flame Height Inches	Sample B Flame Height Inches	Sample C Flame Height Inches
2	18	20	28
4	24	30	30
6	18	38	39
8	16	24	40
10	16	24	60
12	16	16	72
16	16	16	74
20	16	16	74+
Short Circuit	None	3' to 5'	3' to 4'
After Burn	None	None	Continued
Core Dam.	12"	28"	74" +
Jacket Char	22"	33"	74" +
Propagate	No	No	Yes

Table VIII

Unarmored vs. Armored Cable

Specimens: 19/C #14 AWG Cu, .030"/.015" EP/Neo.

A - cabled, tape, .060" general purpose thermoset

B - cable A plus .020" steel interlock armor

Sample A Temp. °F Max.	Sample A Flame Height Inches	Gas Burner Time Minutes	Sample B Temp. °F Max.	Sample B Flame Height Inches
1530	16	0	1530	16
1600	36	2	1560	16
1620	38	4	1580	16
1600	38	6	1600	36
1600	40	8	1630	46
1630	60	10	1650	42
1600	72	12	1670	42
1590	72 +	16	1640	24
1560	72 +	20	1650	16
All: 5':30" to 8':30"		Short Circuit	All: 5':25" to 6':10"	

11':20" - After Burn - 1':30"
66 inches - Core Damage - 28 inches
72 + inches - Cover Burned - 18 inches
Yes - Propagate - No

Note: - During the flame testing of the interlock armored cable, spasmodic gas bursts were observed up to the 20 inch level. After the test the steel was slightly rust colored and sooty.

It follows that numerical values should not be lifted out of context for use in purchase specifications. In general, the data presented herein is indicative of the type of information that could be useful in establishing long term behavior of a particular product to qualify a "line" for use in a nuclear power plant.

CONCLUSIONS

1. Based on the type of data presented herein, it can be logically shown that there are insulated cables which should survive the designed life events in areas of (a) moisture and steam, (b) heat, (c) radiation and LOCA, and (d) fire.

2. There are constructions whose performance excels in several of these four environments, but very few will do well in all of the situations cited in 1.

3. In view of the time element, namely 1-1/2 to 2 years for water immersion testing, the moisture resistance data must be handled by certified test reports. Note there is no proven method by which a two week test period can establish long term performance.

4. It is logical that if a "new" insulation which performs say 6 times better than a known dielectric that has a least a ten year established service record in a similar environment, the new insulation could be expected to achieve the cable system designed life in the same environment.

5. The designed life performance under radiation and LOCA should be considered acceptable if, assuming the two previous mentioned areas have been satisfied, the cable survives two or more LOCA peaks. This demonstrates extra margin.

6. While the cable tray flame test does not require more than a few hours to perform, the logistics dictate it be called-out as a type qualification test -- not a production test.

7. Lack of space precludes presentation of additional data upon which to base cable system design. The data presented does, however, indicate the acceptability of the EP base/neoprene cable with a flame resistant thermoset jacket. The addition of an interlock or corrugated armor improves the flame resistance and further reduces the possibility of tray fire propagation regardless of the cable size.

Note: Since P383 has not been published at the date of this writing, the final Section number references may be different.

ACKNOWLEDGEMENTS

This paper presents the results of work performed in The Okonite Company's Engineering and Research Laboratories. The authors wish to especially acknowledge the work on air oven aging and the Arrhenius equation analysis by Dr. J. S.Lasky, Vice President-Research and his associates. Mr.W.H. Steigelmann and Dr. S. Carfagno of Franklin Institute Research Laboratories deserve special mention for their work in the development of qualification testing.

REFERENCES

1. Guide for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations, IEEE/ICC WG 12-32 and NPEC S/C 2.4, IEEE P383, 1973.
2. Method for Determining the Suitability of Insulation Compounds for Use on D.C. Circuits in Wet Locations, IPCEA Handbook Procedure T-22-294 dated May 16, 1957.
3. Aging by the Air Oven Method, ASTM D 573-67.
4. Simplified Methods of Calculating Insulation Life Characteristics, L. C. Whitmann, AIEE Transactions, October 1961, Part III, Power Apparatus and Systems, Vol. 80, pp 683-685.
5. A New Corona and Heat Resistant Cable Insulation Based on Ethylene - Propylene Rubber, R. B. Blodgett and R. G. Fisher, AIEE Transactions Paper 63-162, New York Winter General Meeting, January 1963.
6. Insulation and Jackets for Control and Power Cables in Thermal Reactor Nuclear Generating Stations, R. B. Blodgett and R. G. Fisher, IEEE Transactions, Vol. PAS-88, No. 5, May 1969, pp 529-541.
7. The Franklin Institute Research Report F-C 2830, October 1970.
8. The Franklin Institute Research Report F-C 3094, July 1971.
9. The Franklin Institute Research Laboratories Report F-C 3171, September 1971.
10. Flame Tests -- A Systems Approach for Power and Control Cable, F. M. McAvoy, IEEE Conference Paper C 72 121-7, presented at the Winter Power Meeting, January 1972.
11. Report on Control Cable Flammability, R. H. Logue, Insulated Conductor Committee Minutes of November 17, 1965, Meeting in Philadelphia, Appendix F-4.

Discussion

T. H. Ling (Anaconda Wire and Cable Company, Marion, Indiana): I have the following two comments:

First. One of the author's major conclusion was that "a new insulation which performs say 6 times better than a known dielectric that has at least a ten year established service life in a similar environment, the new insulation could be expected to achieve the cable systems designed life in the same environment". As stated on page 4 of this paper, the known dielectric is Butyl. We wonder whether the authors have either physical or electrical test results on the specific butyl insulated wire which has served ten years inside nuclear containment. We all know that butyl's aging and radiation resistance is far poorer than EPR's. Does this offer us some indication that the current testing method for Class IE cable is rather unnecessarily severe?

Second. In this paper, the authors showed that the flame resistant cross-linked polyethylene insulated wire possesses acceptable moisture resistance, good aging and flame resistance. Unfortunately there is no LOCA testing data available. We suggest that LOCA simulation test results on flame resistant cross-linked polyethylene insulated wire be included in such a presentation in order to give a whole story of flame resistant cross-linked polyethylene insulated wire for Class IE application.

Manuscript received February 6, 1974.

E. J. McGowan and F. E. LaFetra (Raychem Corporation, Menlo Park, Ca.): The authors have presented a very timely paper since the P383 Guide will soon be issued. The data presented should offer considerable encouragement to the users of electric cable because it points out the work being done by manufacturers to provide reliable products for nuclear power generating stations. We would like to review several important aspects of the paper.

Manuscript received February 19, 1974.

The authors present long-time immersion data at 75°C with 600 volt negative d-c voltage applied to the specimens in Figures 1 and 2. In Table 1, additional data is presented using a 90°C water immersion temperature with a 600 V. a-c voltage potential applied to the specimens. Has any correlation been found between the effects of the a-c and d-c on these specimens?

In Tables II, III, and IV, the results of tests during and after "LOCA" simulation are presented. The physical condition of the specimens after test are described only after the 3.5×10^7 rads exposure and not after the 1.0 and 2.0×10^8 rads exposure. Are the specimens able to be straightened and recoiled around a mandrel with a diameter of approximately 40 times the overall cable diameter as described in paragraph 2.4.4 of the P383 Guide?

The theoretical discussion of thermal aging states that,

> "Distinct values of k must be determined at various temperatures and must be constant over a considerable range of conversion in the reaction, say from 20 to 80%, for the data to be considered valid. It can be used correctly only when there are discreet chemical reactions whose rate can be precisely measured, and described by a solvable differential equation. A straight line will result from a plot of the logarithm of the reaction rate k vs 1/T provided there is no change in the reaction mechanism."

The next paragraph goes on to say that the data of Figure 8 represents at least four different simultaneous reactions and that in vulcanized rubber there is a multitude of individual rate constants. In spite of these complicating mechanisms Arrhenius plots are straight lines and this is considered by the authors to be a fortuitous event. In point of fact, careful examination of their data points shows that the curves for CLPE and EP are not straight lines but in each case can be represented more accurately by two straight lines, indicating the presence of different rate controlling mechanisms over the pertinent

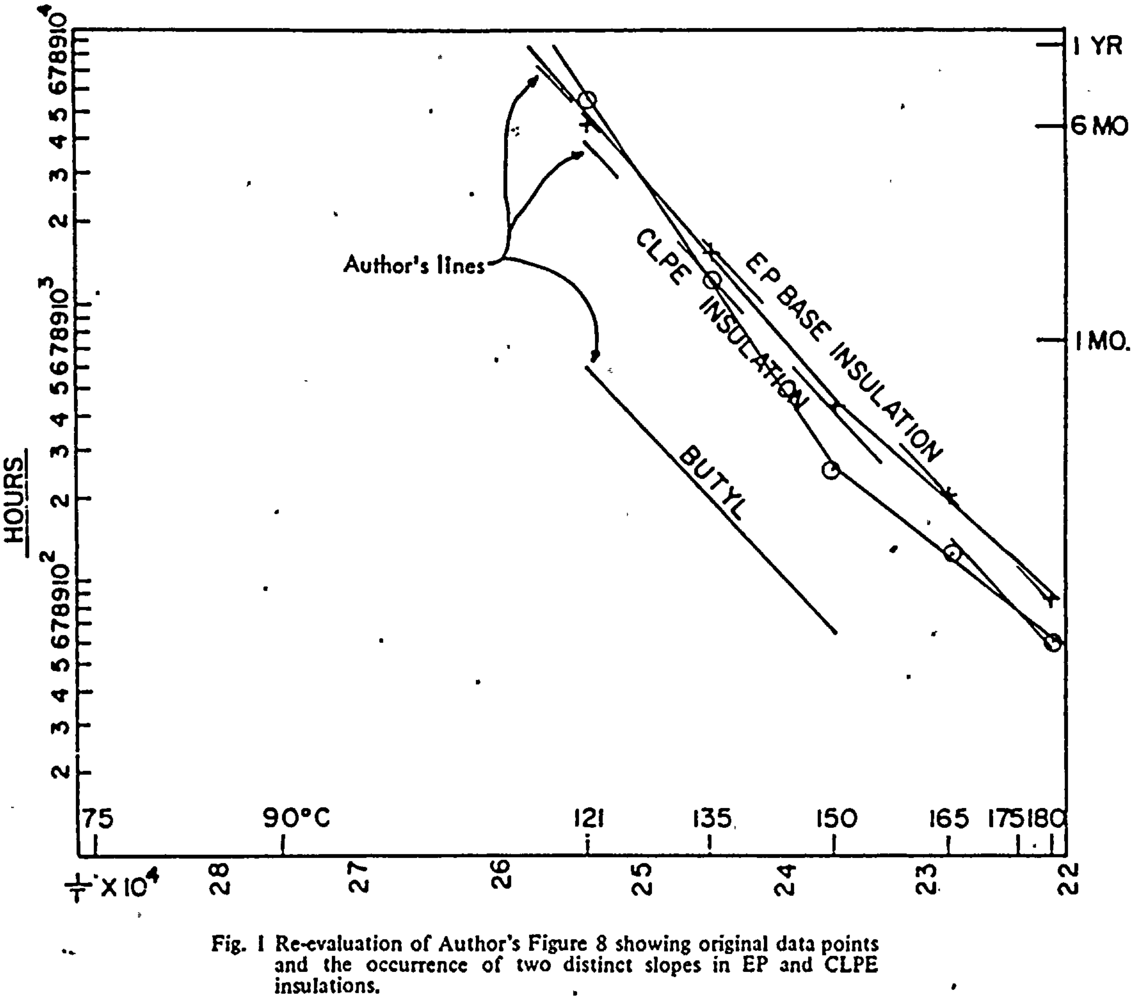


Fig. 1 Re-evaluation of Author's Figure 8 showing original data points and the occurrence of two distinct slopes in EP and CLPE insulations.

QUALIFICATION CERTIFICATION #F-C 3694-I

CLASS IE ELECTRIC CABLES
FOR NUCLEAR POWER GENERATING STATIONS

The cables listed below were subjected to a combined aging, radiation and LOCA, life simulation test by The Franklin Institute Research Laboratories. The test was performed in accordance with IEEE Standard #383 - 1974, but with simultaneous exposures to simulated life aging and a thirty day loss of coolant accident (LOCA) including multiple temperature/pressure peaks, all while exposed to radiation, the cumulative dose amounting to 2×10^8 rads. This was followed by a 100 day post LOCA steam exposure at 100°C, after which these insulated conductors withstood a 80 V/mil ac proof test as called out in #383.

This is a more severe simulation than contemplated in #383, and is in harmony with the broader IEEE Standard #323 - 1974.

The foregoing is ample evidence that the cables listed below are suitable for the designed service:

1/C #12 (7X) coated copper, .045" Okonite insulation
7/C #12 (7X) coated copper, .047" Okonite +.015" Okolon, Okolon jkt. overall
1/C #12 (7X) coated copper, .030" Okonite + .015" Okoprene
1/C # 6 (7X) 5kV Okoguard, copper tape shielded cable.

EEM/row

E. E. McIlveen
E. E. McIlveen

Sworn and Subscribed to before me
this 8th day of November 1974.

Notary Public of New Jersey

My Commission Expires August 3, 1976

Technical

Report

Final Report
F-C3694

TYPE TEST CABLE QUALIFICATION PROGRAM AND DATA FOR NUCLEAR PLANT DESIGNED LIFE SIMULATION THROUGH SIMULTANEOUS EXPOSURE

January 1974

Prepared for

The Okonite Company
Ramsey, New Jersey 07446

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
THE BENJAMIN FRANKLIN PARKWAY • PHILADELPHIA, PENNSYLVANIA [illegible]

PREFACE

Having qualified Okonite nuclear plant cables in previous tests, FIRL # F-C 2830, F-C 3094, and F-C 3171, through sequential exposures, it was felt that a behavioral study of various cable constructions under simultaneous radiation/aging and radiation/LOCA would be more meaningful and of value to engineers since these events would more closely approach a postulated service life than in prior studies.

The temperature-time profile, Figure #1, graphically shows, normal heat aging, simulated reactor life, and a 30 day LOCA, both while under radiation, and then a 100 day post LOCA steam exposure.

As a result of this broad study, relative performance ratings can be given for basic cable constructions. This investigation follows the guidance provided in IEEE Standard #383, and goes beyond it, embracing the concepts called out in #323.

It should be noted that these various simulated events were purposely designed to find "end points" rather than to simply reach a qualification level. As a result, even though the basic constructions did not finish in a "dead-heat", each one would provide the desired service.

1. INTRODUCTION

Nine electrical cable types manufactured by The Okonite Company were subjected to qualification tests to determine their acceptability for service within the containment of a nuclear power generating station. The environmental test program consisted of the following:

a) Nine cable types were thermally pre-aged by The Okonite Company at 250°F (121°C) for fourteen days.

b) The thermally aged cables plus seven non-aged cables were subjected to combined gamma radiation (for a total dose of 50 megarads) and thermal aging at 240°F for seven days.

c) All of the above cables were then subjected to a simultaneous exposure to steam, chemical-spray, and gamma radiation (S/C/R) (for an additional dose of 150 megarads) to simulate a loss-of-coolant accident and post-accident conditions. The temperature profile included two temperature/pressure transients to 346°F/113 psig and a 31-day post-LOCA simulation.

The electrical integrity of the cables was evaluated by means of insulation resistance measurements, ability to maintain electrical loading during the thermal/radiation aging and the S/C/R exposure and by high-potential withstand tests.

The thermal aging/radiation exposure and the steam/chemical-spray/radiation exposure were conducted by the Franklin Institute Research Laboratories (FIRL) from November 1973 through January 1974, using the services of a subcontractor for the radiation exposure.

2. IDENTIFICATION OF TEST SPECIMENS

CABLE NO.*	DESCRIPTION
Group I Cables - Ethylene-Propylene (EPR) Base Product Line	
1B	7/C #12 AWG (7X) coated copper, 0.047" Okonite plus 0.015" Okolon, cabled, no fillers, 11 mil asbestos - Mylar tape, 0.060" Okolon Jacket, pre-aged 336 hours at 121°C in an air oven.**
1C	Same as 1B except without pre-aging.
2B	7/C #12 AWG (7X) coated copper, 0.030" Okonite plus 0.015" Okoprene, cabled, 6 mil asbestos - Mylar tape, 0.060" experimental thermoset jacket, pre-aged 336 hours at 121°C in an air oven.**
2C	Same as 2B except without pre-aging.
9B	1/C #12 AWG (7X) coated copper, 0.045" Okonite pre-aged 336 hours at 121°C in an air oven.**
9C	Same as 9B except without pre-aging.
11B	1/C #6 AWG (7X) bare copper, Semicon tape, 0.090" Okoguard, Semicon tape, 0.003" bare copper tape, pre-aged 336 hours at 121°C in an air oven.**

---

*Throughout this report, the cables are identified as indicated in this column, except that the number and letter are reversed in the original data sheets (e.g., 1B and B1 refer to the same cable).

**Information on pre-aging was provided by The Okonite Company.

3. TEST PROGRAM

The test program involving simultaneous exposures was designed to more closely simulate actual service conditions than a sequential exposure does. The procedures were in accord with IEEE Std 383-1974* in so far as practical.

3.1 PRETEST ELECTRICAL MEASUREMENTS

Prior to the simultaneous radiation/thermal aging and the simultaneous steam/chemical-spray/radiation exposure, the cables were subjected to insulation resistance (IR) measurements at 500 Vdc and high potential withstand tests at 2200 Vac.

3.2 SIMULTANEOUS RADIATION/THERMAL AGING EXPOSURE

While electrically energized, the cables were exposed for 7 days to an air-equivalent dose** of 50 megarads of gamma radiation. During this exposure, the cables were thermally aged at 240°F and ambient chamber humidity.

3.3 LOSS-OF-COOLANT ACCIDENT (LOCA) ENVIRONMENT EXPOSURE

Following the simultaneous radiation/thermal aging, while electrical energized, the cables were simultaneously exposed to steam, chemical spray and gamma radiation (S/C/R) as illustrated in Figure 1 (Phase II). A chemical spray consisting of 2000 ppm boron as boric acid, buffered with

---

*IEEE Std 383-1974, IEEE Standard for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations, The Institute of Electrical and Electronics Engineers, Inc. New York, N.Y., 1974.

**An *air equivalent dose* means that the volume occupied by the cables receives an isotropic flux of gamma radiation such that this radiation dose would result if the volume contained air.

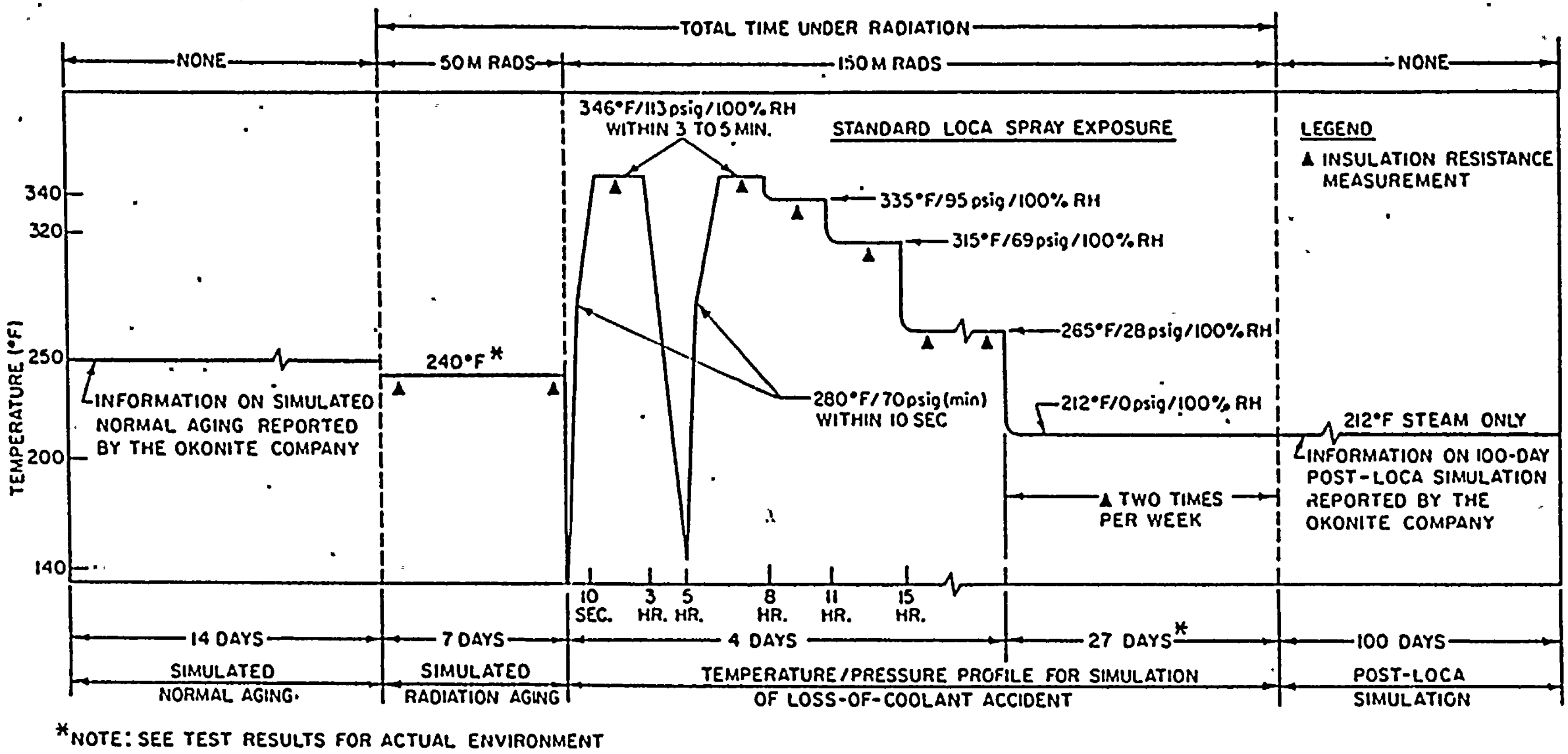


Figure 1. Cable Qualification Test Profile for Life, LOCA and Post-LOCA Simulation

F-C3694

NaOH to a pH of 9-11, was applied to the cables within one minute after reaching 346°F. The required rate of spray application was 0.15 gpm per square foot of spray area.

The gamma radiation dose rate was approximately 0.2 megarads per hour to arrive at an accumulated dose of 150 megarads for the 31-day exposure, yielding a total of 200 megarads for the test program.

During the test program, the cable IR was measured at the times indicated in Figure 1.

3.4 POST LOCA TESTS

After the 31-day LOCA environmental exposure, the cables were subjected to IR measurements and high potential withstand tests. The cable mandrels with cables installed were returned to The Okonite Company, which exposed the cables for an additional 100 days at 212°F with steam while under rated voltage.* There was no radiation during this period. At the conclusion of the additional 100-day exposure, the cables were subjected to IR measurements and high potential withstand tests, after which they were bent around a mandrel not greater than 40 times the overall diameter and then subjected to a final ac withstand test at a potential of 80 V/mil while immersed in tap water at room temperature.

---

*The conditions for the 100-day additional exposure were reported by The Okonite Company.

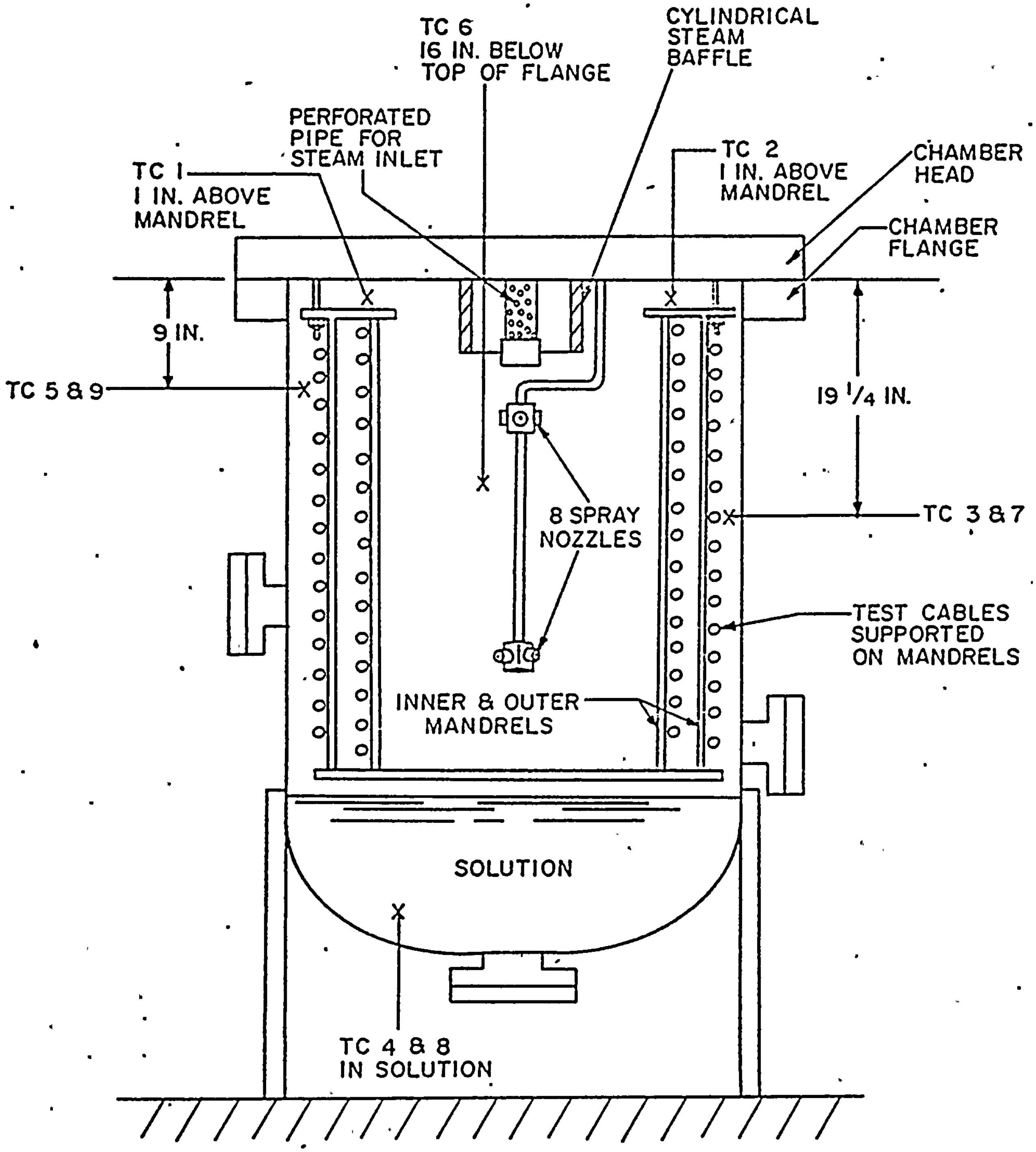


Figure 3. Sketch of Pressure Vessel Showing Salient Features and Location of Thermocouples.

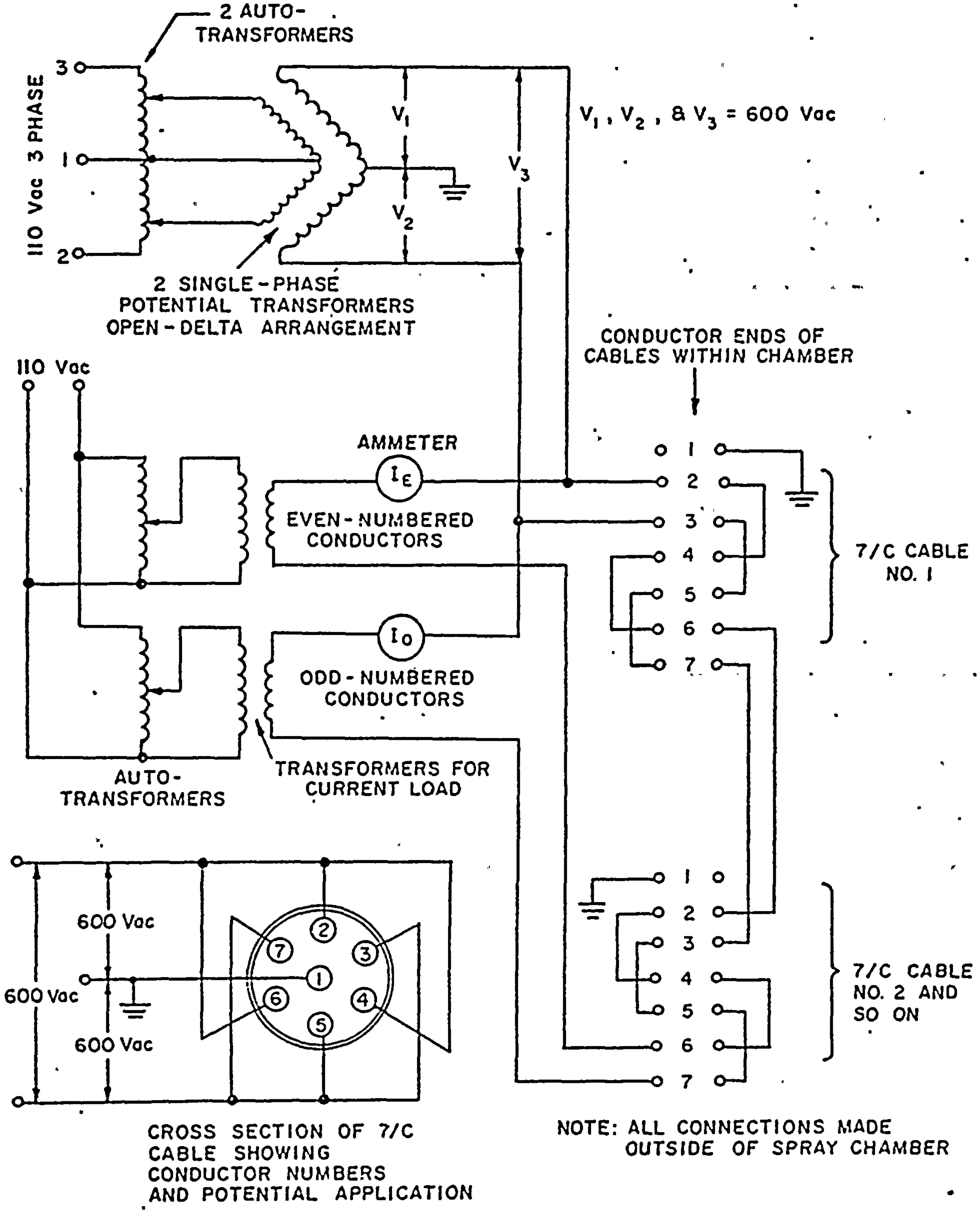


Figure 5. Diagram of Typical Energizing Circuit for Multiconductor Cables.

Table 5. Final Inspection and General Results

Group I Cables

Cable No.	Conductor Nos.	Ability to Hold Electric Load During LOCA	Insulation Resistance (Ohms) (Note 1)		Post-LOCA High Potential Withstand Test Results	Post-LOCA Visual Appearance
			Lowest Measurement	Post-LOCA Measurement		
1B	3, 5 & 7	Held 600 Vac and 17.5 A	6.5×10^5 @ 100 Vdc	2.4×10^{10}	Withstood 2200 Vac for 5 minutes	No general damage. Jacket near bottom of mandrel evidenced some fine blistering.
	2, 4 & 6	Same as above	8.0×10^5 @ 100 Vdc	2.8×10^{10}	Same as above	
1C	3, 5 & 7	Same as above	1.38×10^6	3.8×10^{10}	Same as above	Same as above except blistering more pronounced.
	2, 4 & 6	Same as above	1.75×10^6	3.8×10^{10}	Same as above	
2B	3, 5 & 7	Same as above	2.45×10^7	1.1×10^{10}	Same as above	Jacket swollen, shriveled and torn throughout the entire exposed length. Conductor insulation visible in many areas under the torn jacket and was blistered.
	2, 4 & 6	Same as above	1.28×10^7	1.0×10^{10}	Same as above	
2C	3, 5 & 7	Same as above	1.82×10^6	6.6×10^9	Same as above	Jacket torn in several places and swollen throughout. Adjoining sections of jacket telescoped one upon the other.
	2, 4 & 6	Same as above	1.85×10^6	5.8×10^9	Same as above	
9B	1	Held 600 Vac and 25 A	4.6×10^7	1.5×10^{11}	Same as above	No apparent damage to cable.
9C	1	Same as above	4.2×10^7	2.2×10^{11}	Same as above	Same as above.
11B	1	Held 2900 Vac and 85 A	2.1×10^8	2.0×10^{12}	Withstood 6800 Vac for 5 minutes	Same as above

Notes: 1. Insulation resistance measured at 500 Vdc held for 1 minute unless otherwise noted. Lowest measurement is the lowest reading obtained throughout the test program.

6. CONCLUSION

Sixteen samples of nine types of electrical cables manufactured by The Okonite Company were exposed simultaneously to thermal aging and gamma radiation, followed by simultaneous exposure to steam, chemical spray and gamma radiation in accordance with a program designed to simulate normal service, a loss-of-coolant accident (LOCA) and a 30-day cooldown following the LOCA. The cumulative dose of gamma radiation was 2×10^8 rads. Throughout the exposures, the cables were energized (except cables which failed during the program) with potentials and currents simulating field service use. At the conclusion of the above sequence of exposures, the cables were subjected to a high potential withstand test.

Summary statements on the performance of these cables are given below.

- <u>Group I Cables</u>: The EPR base product line demonstrated satisfactory electrical performance during the exposure simulating conditions of normal service, LOCA and 31-day cooldown following LOCA, and withstood high potential tests conducted at the end of the 31-day cooldown. The experimental outer jackets on two of the Group I cables (2B and 2C) underwent severe physical degradation, but the single conductors survived.

  A portion of the Group I cables withstood additional high potential tests after an additional 100-day exposure to steam (only) at 212°F.* The surviving cables were 9B, 11B, the 7 conductors of cable 1C, 4 counductors of cable 2B, and 1 conductor of cable 2C. The jackets of cables 1C, 2B and 2C were removed prior to the final electrical tests so that the individual conductors could be tested as single conductors.

---

*The environmental conditions were reported by The Okonite Company. FIRL witnessed the final bend and high potential withstand tests conducted in accordance with Section 2.4.4 of IEEE Std 383-1974. (See footnote on page 3-1.)

7. CERTIFICATION

The undersigned certify that this report constitutes a true account of the test conducted and results obtained.

D. V. Paulson

D. V. Paulson
Project Leader

L. E. Witcher

L. E. Witcher
Test Engineer

APPROVED BY:

Zenons Zudans, Director
Engineering Department

S P Carfagno

S. P. Carfagno, Manager
Performance Qualification Laboratory

February 24, 1975 Engineering Report No. 264

THE OKONITE COMPANY
Ramsey, New Jersey

SUBJECT: Qualification of Cables and Splices for Nuclear Plants Through Designed Life Simulation Testing.

OBJECT: To present summary data with back-up references that support this certification of suitability for The Okonite Company's ethylene-propylene base insulated cable line, and compliance with IEEE Std. Nos. 323 and 383-1974.

CONTENTS:

General Discussion and IEEE T 74-044-4	Section 1
Certified Water Immersion and Aging Test Data	Section 2
Sequential Exposures to Heat, Radiation, LOCA	Section 3
Simultaneous Exposures and Life Simulations	Section 4
Vertical Tray Flame Tests	Section 5

CONCLUSION: The simulated service data and references presented herein provide substantial evidence that the ethylene-propylene insulated cables listed below are suitable for service in nuclear plants with a designed life objective of forty years, and do exceed the requirements of IEEE Std. No. 323 and 383, 1974.

1/C	2000V	Okonite insulation
1/C	1000V	Okonite/Okoprene or Okolon
1/C	5-8 kV	Okoguard Okolon non-shielded
1/C	5 kV	Okoguard shielded
M/C	1000V	Okonite/Okoprene, Okoprene
M/C	1000V	Okonite/Okolon, Okolon
1/C	T95 and T35 hand-wrapped tape splice	
10k	1 Shielded Splice XLPE	

E. E. McIlveen

EEM/row

E. E. McIlveen
Vice President-Engineering

Sworn and Subscribed to before me
this 24th day of February, 1974

Notary Public of New Jersey

My Commission Expires 12/15/75

THE OKONITE COMPANY
Ramsey, New Jersey

ENGINEERING NOTE #74-1
Section: 3 Date: Feb. 8, 1974
Revised - February 24, 1975

SUBJECT: CABLES FOR NUCLEAR POWER GENERATING STATIONS

At the IEEE Winter Power Meeting in New York on January 28, 1974, we presented a paper T 74 044-4 on the above subject. Our final copy is attached for your information. Our verbal presentation is repeated below for your information.

INTRODUCTION: While this paper is concerned with Cables for Nuclear Power Generating Stations, it applies equally well to cables for any electric power facility except, of course, the need for resistance to radiation would be superfulous in non-nuclear applications. Interestingly enough though, even the loss of coolant accident simulation, better known as LOCA, happens to emerge in the laboratory as a steam autoclave exposure which had been used for many years to simulate long term exposure to water or moisture.

With the advent of nuclear power plants at Shippingsport, Indian Point and Peach Bottom to mention a few, a whole new set of operating conditions had to be recognized. As demonstrated by the work in the ICC and NPEC, the evolution of design criteria has continued. The imminent publication of the IEEE Guide P383 is evidence of only the present state of design.

In this paper we examine typical design and qualification data together with some explanation of its significance. Designed life performance, when based on long service can be quite reliable, but significantly different conditions and materials have come into use which made simple projections questionable. Simulated service test data must, therefore, be relied upon. The areas to be studied for qualification through performance testing are:

Moisture Resistance
Thermal Aging
Radiation and LOCA
Cable/Tray Flame Resistance

MOISTURE RESISTANCE

It has become traditional to gain assurance of long life performance by totally immersing a #12 or 14 conductor insulated with a 45 mil wall of dielectric in water at an elevated temperature to accelerate the deterioating effects of moisture, as shown in Fig. 1 on Okonite referred to herein as "EP". In the 1950-57 era with service experience that suggested negative dc potential presented the most severe condition, IPCEA developed a 16 week test procedure based on a continuous immersion at 50°C while under 600 volt dc. Now more than sixteen years later, new generation insulations can be continuously immersed at 75° or 90°C while under the same dc potential and survive 78 weeks or more. This is at least 5 times at an effective acceleration rate of 6 times greater than anticipated by that IPCEA procedure.

The composite insulation wall composed of an EP dielectric, Okonite plus a flame resistant thermoset cover, OKOPRENE, still only totaling 45 mils, also exhibits durability as shown in Fig. 2. A comparison of the EP with a FR CLPE insulation at 90°C may be noted in Table I, and the accelerating effect of temperature on the moisture absorption in Fig. 3.

THERMAL AGING

Data on electrical behavior in a combined heat and moisture environment may be a better guide to service performance than that developed from aging in a dry air oven at elevated temperatures. However, such data as shown in Fig. 4 thru 7 can be analyzed by the Arrhenius technique and, by analogy the useful life may be predicted.

In applying this Arrhenius analysis to the aging data, the time to 40% loss of elongation is plotted on semi-log paper against the reciprocal of the absolute temperature in degrees Kelvin. This is presented in Fig. 8. In examining the validity of this treatment, there are at least four simultaneous reactions. From this, it could be argued that the occurrence of a linear plot is a fortuitous event, but it does provide a means of comparison within the temperature range of the data.

The significance of loss in elongation is related to the ability of the insulation to withstand bending without physical cracking and ultimate electrical failure when moisture enters. A 40% loss still leaves 60% retention wheras 50% ultimate is usually reached before cracking develops upon flexure.

Since thermosetting insulations of the 1957 type vintage have performed well in early nuclear plants and the ethylene-propylene base and the cross-linked polyethylene insulations take 6 times as long to reach 40% loss of elongation as does butyl, it is safe to predict that new insulations such as Okonite and Okoguard will provide a superior thermal aging performance.

RADIATION AND LOCA

In 1968 the first of many increasingly searching studies were made of the effect of gamma radiation on the electrical and physical properties of 13 different insulations. By the criteria then existant the ethylene-propylene and the cross-linked polyethylene dielectrics were found to be suitable.

By the mid-1970 qualification testing of specimens pre-aged prior to gamma radiation to 3.5 x 10^7 rads followed by a LOCA became necessary for design acceptance. This work was done at FIRL. Again specific ethylene-propylene insulations, i.e. Okonite and Okoguard, proved to be suitable, the amount of aging having no adverse effect on the properties of this insulation..

The Hypalon compound in Table II had good electrical and physical properties following the simulated aging, that is, "before" radiation. "After" the LOCA simulation in the autoclave the electrical properties fell off significantly. The physical appearance and resilience, however, was good. Two specimens which contained a hand-wrapped splice made with an ethylene-propylene base tape remained resilient and firm at all stages of the test.

Within a year, July 1971, reassessment of design parameters dictated a higher level of radiation exposure and new BWR LOCA simulation profile for qualification. Again FIRL was called in. The details may be found in Tables II, III, and IV.

Fig. 9 presents double LOCA simulation for specimens radiated to a total dosage of 2 x 10^8 rads. This simulation is particularly severe because these specimens were loaded to rated current and voltage and tested to the pressurized water reactor (PWR) incident profile, and then these same specimens were subjected to a BWR profile at FIRL. It may be noted in Fig. 9 these profiles include one "peak" at 324°F/80 psig, two peaks at about 342°F/104 psig, and one at 320°F/75 psig plus the 100 day soak. These multiple transients demonstrate that these Okonite and Okoguard specimens have significant margin, a performance characteristic requested in the Guide.

Additional qualification tests covering several different cable constructions in simultaneous radiation/life tests have now been completed. The Appendix to the IEEE Std. No. 383-74 suggests relative short term procedures which have evolved from the type of studies and testing described herein. New data obtained in Okonite's latest test at FIRL in environments which more closely approach long term operational conditions indicates that sequential effects of moisture, thermal aging, radiation, LOCA and movement are no no less severe than simultaneous occurrences. In other words, the simultaneous simulation does not result in a synergistic effect. The cable specimens were removed from the radiation chamber on January 28, 1974 after receiving 2 x 10^8 rads of gamma radiation and FIRL Report F-C 3694 covers this.

CABLE TRAY FLAME TESTS

The losses incurred through cable fires has focused attention on not only the flame resistance in the trays, both with and without covers or baffles, but also the degree of separation, the matter of circuit redundancy, and the effectiveness of various fire extinguishing systems. Studies on cable behav-

ior, and the effect of physical arrangement and separation have been covered in earlier papers. Redundancy and fire extinguishing systems are subjects not relevant to type testing to qualify cables and connections other than to note that the redundancy concept among other things, has made obsolete the requirement of "time to short-circuit".

Cable performance during a tray fire should be postulated as a design basis event, and a method of qualifying cable tray systems had to be developed. The "Philadelphia" Tray Cable Fire Propagation Test, devised in 1965, simulates a fire in a vertical tray, a situation which is more severe than in a horizontal tray. The flame source in the original procedure was crumpled oil-soaked burlap rag. In the following years much effort was expended in trying to eliminate some uncontrollable variables. While a definite burlap folding sequence and oil dipping procedure were developed, the replacement of the oil-soaked burlap with a large ribbon type gas burner together with instrumented control of the air/gas flow resulted in a completely reproducible flame environment. This inadvertently resulted in a more severe test because (a) the gas flame provides a constant heat input for the entire test period whereas the oil-soaked burlap flame reaches a maximum within several minutes and then tapers off until it finally flickers out. Furthermore, (b) the gas flame projects right through the cables thereby completely surrounding them whereas the oil-soaked burlap flame is vertical and in front of the cables so that the majority of the heat reaches about half the circumference. Table V provides the comparative data, as do Tables VI, VII and VIII.

It was agreed by the committees that the only practical clear cut observation than can be made is that of propagation. Failure by this mode is defined as occurring when the fire burns all the way up to the top of the tray, a distance of about 6 feet above the flame source center.

SUMMARY

MOISTURE: In the 1950-57 era with service experience that suggested negative dc potential presented the most severe condition, IPCEA developed a 16 week moisture test procedure based on a continuous water immersion at 50°C while under 600 volts dc. Now more than sixteen years later, new generation insulations can be continuously immersed at 75° or 90°C while under the same dc potential and survive 78 weeks or more. This is at least 5 times longer and at an effective temperature acceleration rate of 6 times greater than anticipated by that IPCEA procedure.

AIR OVEN AGING: Since thermosetting insulations of the 1957 vintage have performed well in early nuclear plants and the ethylene-propylene base and the cross-linked polyethylene insulations take 6-8 times as long to reach 40% loss of elongation as does butyl one of the better dielectrics which has seen at least ten years service, it is safe to predict that these new insulations will

provide a superior thermal aging performance and should achieve the designed life of the plant.

RADIATION AND LOCA: In 1968 the first of many increasingly searching studies were made of the effect of gamma radiation on the electrical and physical properties of 13 different insulations.

By the mid-1970 qualification testing of specimens pre-aged prior to gamma radiation to 3.5 x 10^7 rads followed by a LOCA became necessary for design acceptance. This work was done at FIRL.

Within a year, July 1971, reassessment of design parameters dictated a higher level of radiation exposure, namely 10^8 rads and new BWR LOCA simulation profile for qualification. Again FIRL was called in. The details may, of course, be found in the paper.

In September 1971, a double LOCA simulation for specimens radiated to a total dosage of 2 x 10^8 rads was completed. This simulation is particularly severe because these specimens were loaded to rated current and voltage and tested to the PWR incident profile, and then these same specimens were subjected to a BWR profile by FIRL.

Now a fifth series of cables have been subjected to 2 x 10^8 rads, but simultaneously with life aging and LOCA. This work is also covered by an FIRL report.

CABLE TRAY FLAME TESTS: Redundancy has made obsolete the requirement of "time to short-circuit". This is fortunate indeed because it is not technically feasible to establish a single time requirement for all types and sizes even if someone could identify what period is operationally necessary.

It was agreed the only practical clear cut observation that can be made is that of propagation. Failure by this mode is defined as occurring when the fire burns all the way up to the top of the tray, a distance of about 6 feet above the flame source center if the Standard P383 procedure is followed.

CONCLUSIONS

(1) Based on the type of data presented in this paper, it can be logically shown that Okonite/Okoprene or Okolon and Okoguard insulated cables will survive designed life events in areas of (a) moisture and steam, (b) heat, (c) radiation and LOCA, and (d) fire all with a comfortable margin.

(2) There are constructions whose performance excels in several of these four environments, but only Okonite will do well in all of the situations cited herein.

(3) In view of the time element, long term water immersion data and Arrhenius charts must be handled by certified test reports. The Okonite Company is prepared to do this on our premium station cable designs.

<u>NOTE:</u> All samples used in the tests described in this paper were manufactured by The Okonite Company

ATTACHMENT: T 74 044-4

BY: E. E. McIlveen, V. L. Garrison and G. T. Dobrowolski

LONG TERM 90°C WATER IMMERSION TEST

Sample: 1/C #12 AWG (7X) Coated Copper, .030" Okonite, .015" Okolon

		600V DC-Continuous			600V AC-Continuous		
Time Period	Stress V/mil	PF %	SIC @ 90°C	SIR x 10^3	PF %	SIC @ 90°C	SIR x 10^3
1 day	40	3.14	3.30	1.0	3.16	3.32	0.9
	80	3.19	3.30		3.18	3.32	
7 days	40	1.91	3.30	1.3	1.88	3.34	1.1
	80	1.98	3.30		1.91	3.34	
14 days	40	1.59	3.34	1.6	1.57	3.38	1.4
	80	1.63	3.34		1.60	3.38	
1 month	40	1.40	3.42	1.9	1.26	3.46	1.4
	80	1.45	3.42		1.30	3.46	
2 months	40	1.38	3.53	1.6	1.40	3.56	1.3
	80	1.42	3.53		1.43	3.56	
4 months	40	1.28	3.65	1.6	1.27	3.70	1.3
	80	1.32	3.65		1.30	3.70	
6 months	40	1.24	3.73	2.2	1.20	3.81	1.4
	80	1.31	3.73		1.25	3.81	

			DC	AC
Increase in SIC	1 - 14 days	=	1.2%	1.8%
Increase in SIC	7 - 14 days	=	1.2%	1.2%
Stability Factor,	14 days	=	0.04	0.03
Stability Factor,	6 months	=	0.07	0.05

E. E. McIlvain

Sworn and Subscribed to before me

this 26th day of November 1974

Notary Public of New Jersey

11/26/74

My Commission Expires August 3, 1976

DISCUSSION OF THERMAL AGING/LIFE SIMULATIONS

Arrhenius Plots: The procedures for developing an Arrhenius plot may be found in a recent IEEE paper T 74 044-4 entitled "Class IE Cables for Nuclear Power Generating Stations" by E. E. McIlveen, V. L. Garrison and G. T. Dobrowolski, pages 3 and 4, as well as a discussion of the fallacies and limitations of such a plot.

Designed Life: The attached Fig. 1 contains the same data points as previously published, but the interpretation supporting a 40-year life based on air oven aging has been added to insure proper application. For example, it may be noted that the time spread between our Okonex butyl base insulation and the Okoguard and the Okonite now being offered involves a factor of about 6.7 times. Recognizing that Okonex insulation has been widely used since its introduction in 1946, and that it has been in Peach Bottom Nuclear Plant No. 1 since 1967, a period of seven years, it is logical that the designed life will exceed 40 years (7x6.7 = 46 years).

It might also be noted that in an oven aging test, the entire wall thickness is at the same temperature whereas in actual practice there is a gradient from the maximum temperature at the conductor down to the outside ambient. Actual service is less severe than this simulation.

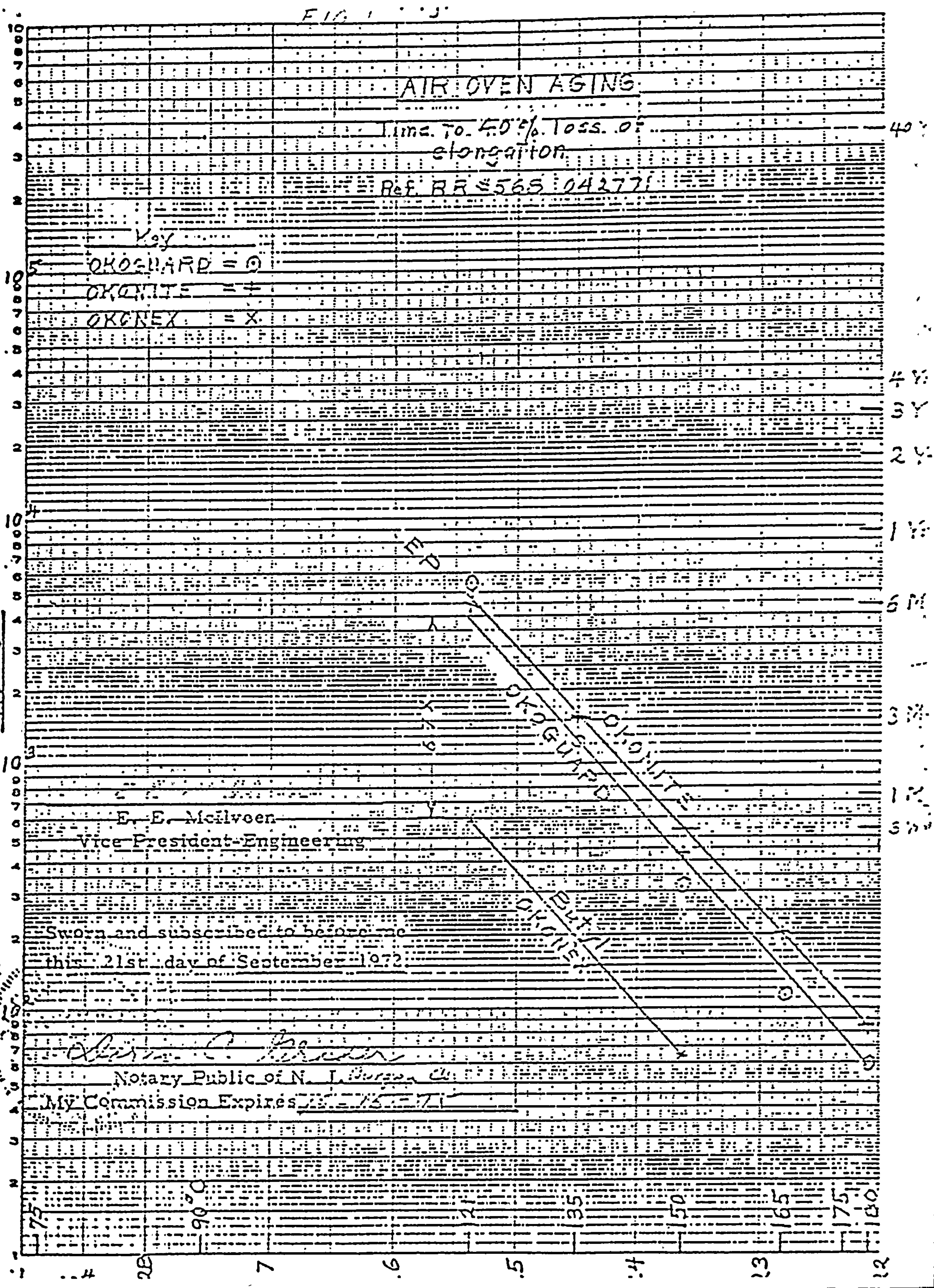
Accelerated Aging: Since the publication of IEEE Std. 383-1974, it has been stated by various engineers that aging for 168 hours at 150°C is significant and infer that it projects to a 40-year life. We have consistently objected to this method of forecasting.

We have used a pre-irradiation aging of 2 weeks at 121°C prior to subjecting the completed cables to another week at 121°C which included 5×10^7 rads of gamma radiation. This more closely simulates service conditions.

It is of interest that IEEE Std. 383-1974, Section 2.3.1 states that a cable that has been manufactured and tested and passed the provisions of one or more of 8 listed industry standards, qualifies for normal lifetime operation. These same standards reference aging at only 121°C for 1 week, UL included.

Another reason for pre-irradiation aging at 121°C was to chose a temperature which would not unduly penalize the outer Neoprene and Hypalon coverings which do not age as well as the higher temperature Okonite EP base insulations. Incidentally, these outer coverings are designed to provide flame resistance to the EP insulated single conductors.

FIG. 1



E. E. McIlvoen
Vice President-Engineering

Sworn and subscribed to before me
this 21st day of September 1972

Notary Public of N. J. Bergen Co.
My Commission Expires [illegible]

10.0 REPORT SUMMARY

Thermal Aging - The Arrhenius technique has been used to demonstrate a qualified life in excess of 50 years.

Radiation - All materials used will readily withstand 1.5 X 10^8 Rads gamma as all tests were carried out at values exceeding 2 X 10^8 Rads.

LOCA - The required LOCA profile having a maximum of 265°F was enveloped by a 340°F temperature profile in the qualification testing performed. Ample margin was demonstrated.

Qualified Life - A qualified life in excess of 50 years from start of plant operation has been demonstrated by test and analysis.