ANACONDA

ANACONDA-CONTINENTAL REPORT NO. 79117

PREPARED FOR

TENNESSEE VALLEY AUTHORITY

ON

L.O.C.A. - 5

IPEC,

MARION, INDIANA

APRIL - 1979

A. INTRODUCTION

A group of electrical cables were subjected to an environmental test program based on the guidelines of IEEE Standards 323-1974 and 383-1974 and the requirements given by Tennessee Valley Authority to determine their suitability for service within the containment of Nuclear Power Generating Stations. This report specifically deals with 21 cables identified as single conductor NSG, low voltage power and control cable.

A portion of the cables were thermally aged as follows: a) 7 days @ 210°C; and b) 28 days @ 210°C; and then subjected to either 20 or 120 megarads of gamma radiation from a cobalt-60 source at an average dose rate of .56 megarads per hour.

Both aged and unaged cables were then subjected to a 16 day exposure of steam and chemical spray which simulated the in-containment environmental conditions resulting from a postulated loss-of-coolant accident (LOCA) and those occuring during the cool down after the LOCA with the cables electrically energized during the LOCA simulation. The temperature/pressure objective of this exposure was as follows:

1) A rapid rise to 280°F (137.7°C) at a steam pressure of 35 psig with a 3-hour dwell at this temperature and pressure.
2) A 3-hour dwell at 240°F (115.5°C)/11 psig.
3) A 4-hour dwell at 215°F (101.6°C)/0-5 psig.
4) A 4-day dwell at 203°F (95°C)/0 psig.
5) A 12-day dwell at 180°F (82.2°C)/0 psig.

The program was conducted by Anaconda Industries, a division of the Anaconda Company, Insulated Products Engineering Center, Marion, Indiana, from the period of October 1978 through April 1979.

B. SPECIMEN DESCRIPTION

Description of the cable specimens and their required energizing potentials and currents are present in Table I:

TABLE I

CABLE SPECIMEN DESCRIPTION & ELECTRICAL LOADING

CABLE SPECIMEN NUMBER	DESCRIPTION	NOMINAL DESIGN DIAMETER	MEASURED OUTSIDE DIAMETER	REQUIRED ELECTRICAL LOADING VAC/AMPS
49.1.1-49.1.3 49.2.1-49.2.3 49.3.1-49.3.3 49.4.1-49.4.3 49.5.1-49.5.3 49.6.1-49.6.3 49.7.1-49.7.3	Low voltage power and control cable, NSG 1/C 12 AWG (7/0305), tinned copper conductor, 45 mil wall of CC-2193, Nuclesil silicone rubber insulation, 6 mil wall of glass braid covering.	.198	.200	480/25

C. TEST PROGRAM

The test program consisted of thermal aging, gamma radiation exposure, simulated LOCA and post accident tests. It was based on the general guidelines of IEEE Standards 383-1974 and 323-1974, which are used for qualification testing of safety-related electrical cables for service within the containment of nuclear power generating stations. A description of the specimen number and its associated thermal aging and radiation is given in Table II.

I - THERMAL AGING

Prior to air oven aging the cables were electrically tested - AC Voltage was applied and insulation resistance was measured. The cables were visually inspected prior to being aged in an air oven. Following mounting on the mandrel (Some of the samples could not be mounted on the mandrel.) the cables were thermally aged as follows:

a) 7 days @ 210°C.

b) 28 days @ 210°C.

II - GAMMA RADIATION EXPOSURE

Most of the cables were mounted on 32 inch diameter mandrels and exposed to gamma radiation from a cobalt-60 source to an accumulated air-equivalent dose of 20 or 120 Mrad at an average dose rate of .56 Mrad per hour. (Some of the samples could not be mounted on the mandrels and were exposed to gamma radiation in the form of coils.) The radiation dose is based on guidelines expressed by the Tennessee Valley Authority and IEEE Standards 323 and 383 and is intended to encompass the radiation dose received during normal operation (2×10^7 rads) plus the dose received during one typical LOCA exposure described by Tennessee Valley Authority (1×10^8 rads). The combined dose was 1.2×10^8 rads.

Following the radiation exposure, the cables were re-inspected.

III - STEAM/CHEMICAL SPRAY EXPOSURE WITH ELECTRICAL LOADING

The 13 cable specimens mounted on the 32 inch diameter mandrels were moved into a 40 inch diameter test vessel (autoclave). The other 8 cable specimens were installed in the test vessel (autoclave) in the form of coils. The cables were spliced to single conductors in the test vessel and the single conductors were passed to the outside of the test vessel through metal tubes sealed with epoxy potting compound. The ends of these "connecting" cables were attached to the electrical energizing circuits. The required electrical energizing levels are provided in Table I. The loading arrangements are shown in Figures 2 and 3. Approximately 20 ft. of each test cable was contained within the test vessel.

Following a set of IR measurements while the chamber was brought to stabilization temperature (120°F) with a continuous water spray, the cables were energized and exposed to a steam/chemical - spray environment for 16 days in accordance with the profile illustrated in Figure 1. After the cooldown period which followed the end of the LOCA profile, the IR of the samples was remeasured and the specimens reinspected after removal from the test chamber. A view of the cables after LOCA is provided in Figures 4 and 5.

IV - MANDREL BEND TEST

At the conclusion of the steam/chemical-spray exposure described earlier, all of the cables were cut from the splices, removed from the mandrel and straightened. The central portion of each sample was coiled around a mandrel having a diameter of approximately 40 times the cable outer diameter. The cable was then visually inspected for evidence of cracks or other breaks in the insulation. The coiled samples were then immersed in tap water at room temperature for one hour and their IR measured.

V - HIGH POTENTIAL-WITHSTAND TEST

After the mandrel bend and IR test, the coiled samples were subjected to a 5-minute application of high voltage.

The conductor of the single conductor cables was connected to the energized lead of the high-potential test set with the ground lead of the test set connected to the water tank by means of a copper wire immersed in the water tank.

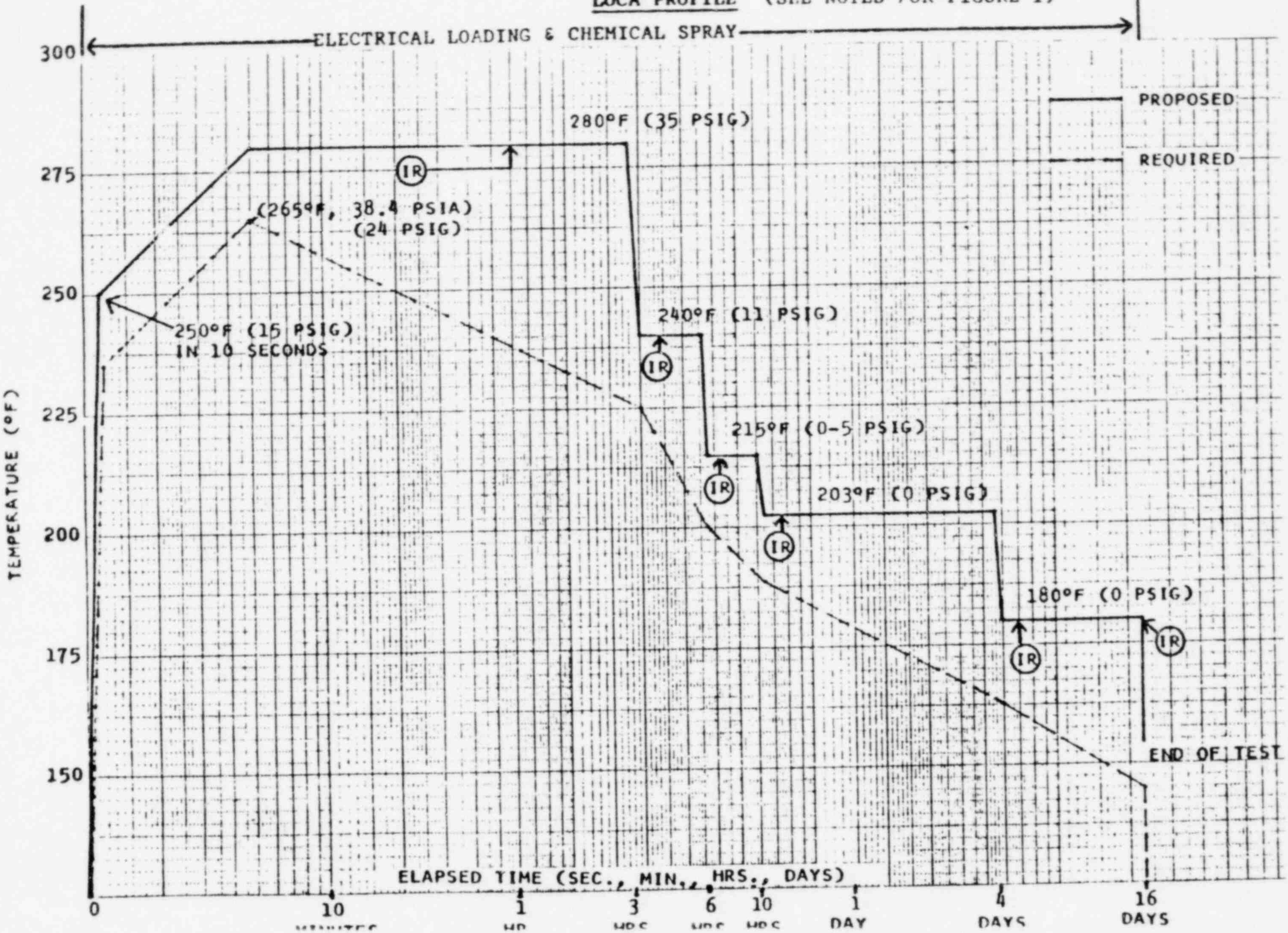
TABLE II

THERMAL AGING AND RADIATION EXPOSURE

SPECIMEN NUMBER	THERMAL AGING	RADIATION	COMMENTS
49.1.1-49.1.3	None	None	All samples in coils
49.2.1-49.2.3	None	2.0×10^7 Rads	
49.3.1-49.3.3	None	1.2×10^8 Rads	49.3.2 & 49.3.3 are in coils
49.4.1-49.4.3	168 Hrs. @ 210°C	2.0×10^7 Rads	
49.5.1-49.5.3	168 Hrs. @ 210°C	1.2×10^8 Rads	49.5.2 & 49.5.3 are in coils
49.6.1-49.6.3	672 Hrs. @ 210°C	2.0×10^7 Rads	
49.7.1-49.7.3	672 Hrs. @ 210°C	1.2×10^8 Rads	49.7.3 is in coil form

FIGURE I

LOCA PROFILE (SEE NOTES FOR FIGURE 1)



NOTES TO FIGURE I

(1) Actual temperature rise through first 10 seconds, 180°F. Time to 250°F was 48 seconds. For the balance of the profile, the temperature was maintained at +2 to 3°F during the test with the equivalent rise in pressure (~2 psig) above 212°F.

(2) Electrical loading was interrupted for short periods to permit IR measurements.

(3) Chemical solution was sprayed radially from the center of the mandrels for the entire test at a rate of approximately 0.15 (Gal/Min.)/FT^2 (6.1 (liters/min.)/M^2) at the cable location.

The chemical solution was composed of: 2000 parts per million boron as H_3BO_3.

(4) The pH of the chemical solution was 8.2.
The pH of the steam condensate was 8.0.
The pH of the chemical solution was maintained between 8.0-8.2 during the test.

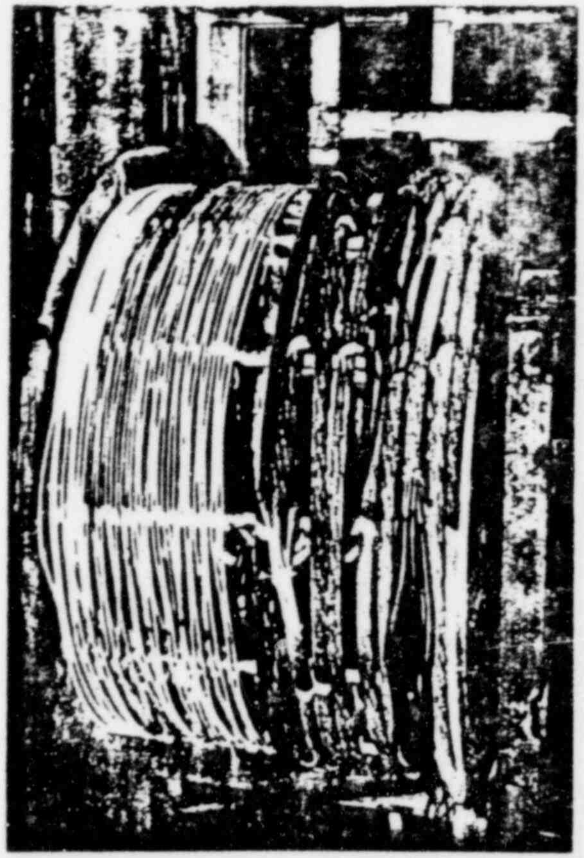


FIGURE 2

View of cables and mandrel prior to LOCA exposure (20 Mrads).

(Some cables shown in this view are not discussed in this report.)

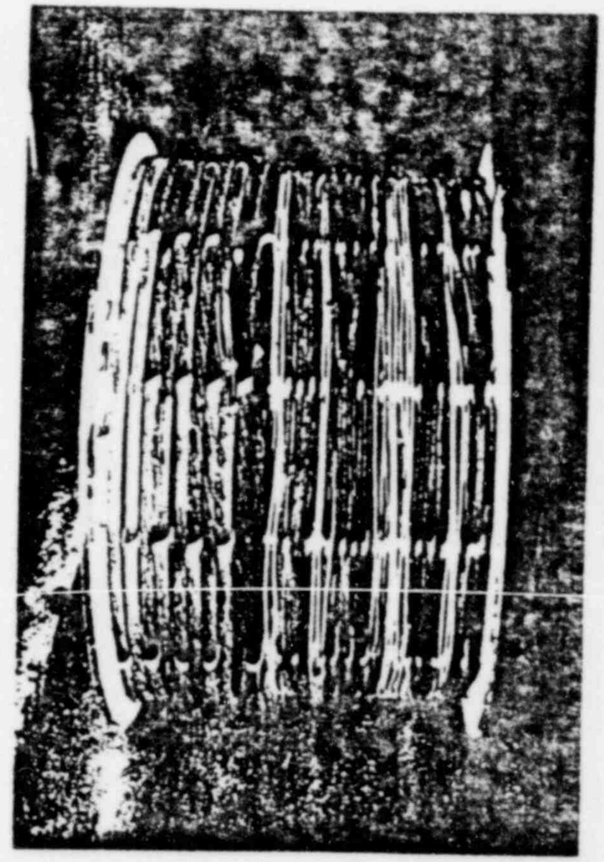


FIGURE 3

View of cables and mandrel prior to LOCA exposure (120 Mrads).

(Some cables shown in this view are not discussed in this report.)

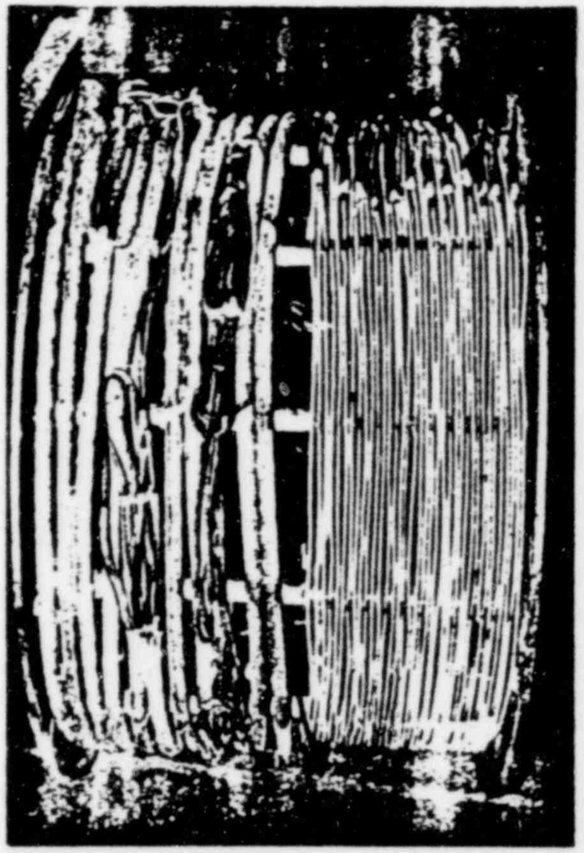


FIGURE 4

View of cables and mandrel after LOCA exposure (20 Mrads).

(Some cables shown in this view are not discussed in this report.)

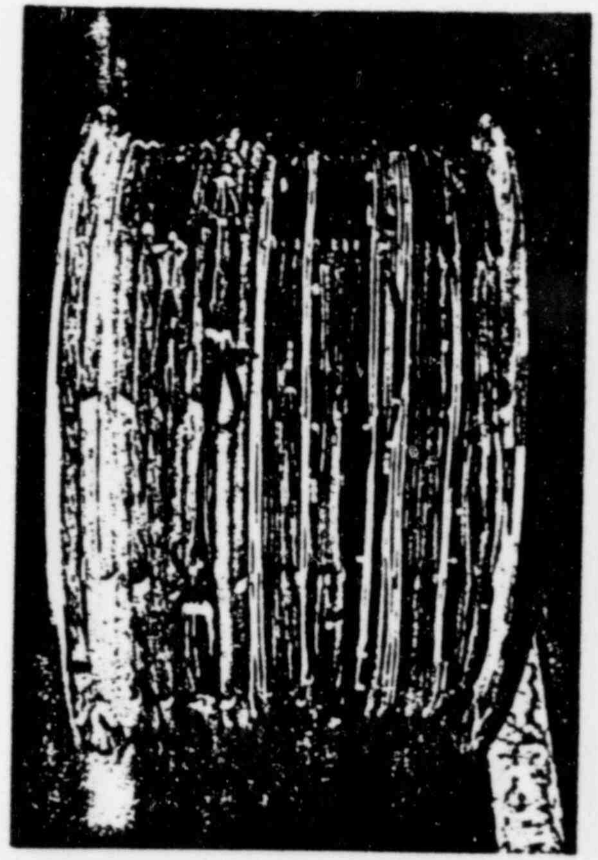


FIGURE 5

View of cables and mandrel after LOCA exposure (120 Mrads).

(Some cables shown in this view are not discussed in this report.)

FIGURE 5

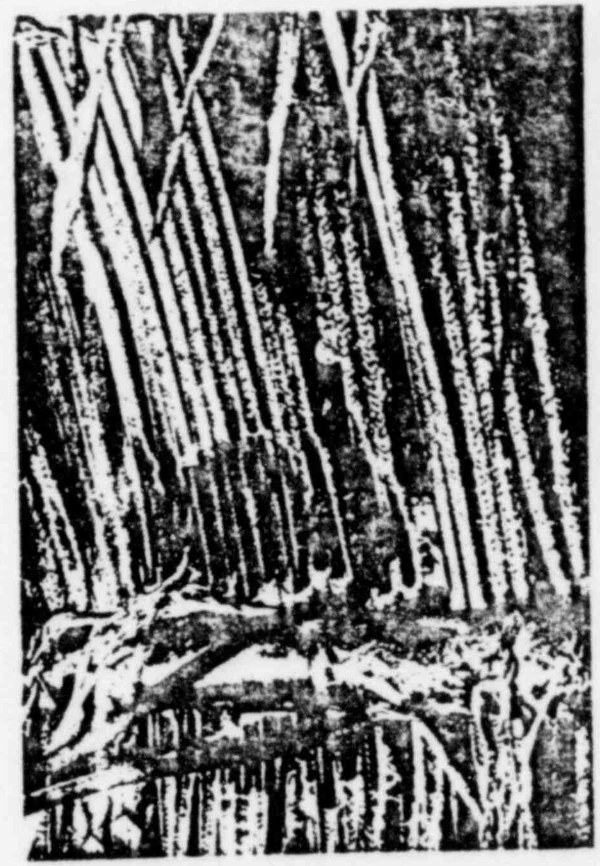


FIGURE 6 (From inside mandrel)

View of cables on mandrel showing area in which cable 49.3.1 failed. Note condition of glass braid from direct impingement of chemical spray.

D. TEST RESULTS

I - THERMAL AGING

The cable samples were aged as follows: 28 days @ 210°C; and 7 days @ 210°C prior to gamma radiation exposure.

Visual inspection of the cables after thermal aging revealed little effect except that some of the cables were slightly discolored over the glass coverings and exhibited increased stiffness.

II - GAMMA RADIATION EXPOSURE

The certification for the 20 Mrad and 120 Mrad radiation exposure with information on the dose rate, temperature and dosimetry is included in Appendix A. There was no visual change in the cables as a result of the gamma radiation exposure.

III - STEAM/CHEMICAL-SPRAY EXPOSURE - INSULATION RESISTANCE MEASUREMENTS

The LOCA, Steam/Chemical-Spray Exposure was provided in accordance with the profile outlined in Figure 1.

The chemical spray was initiated prior to steam exposure and the required saturated steam temperature/pressure dwells were provided for 16 days. Fresh solution (pH = 8.2) from a storage tank was sprayed onto the cables for the first 24 hours of the test after which the solution was changed daily by alternating from one holding tank to another with fresh solution made up each day.

The results of the IR measurements are included in Table III. The IR sequence is shown in Figure 1.

IV - ELECTRICAL LOADING

All cables, except 49.2.1 which was noted as being damaged upon return from Isomedix, held their electrical loading throughout the 16 day LOCA test. Power was removed to permit IR measurement.

V - VISUAL INSPECTION FOLLOWING STEAM/CHEMICAL-SPRAY EXPOSURE

From a visual inspection of the cables following the steam/chemical-spray exposure, after the mandrels and cables were removed from the test vessel, it appeared that the cables were in good condition, but had chemical deposits over most of their lengths. In addition some of the cables had portions of braid removed during the steam/chemical-spray exposure.

VI - BEND AND HIGH POTENTIAL WITHSTAND TESTS

The results of the bend, IR and high potential withstand tests are summarized in Table IV.

TABLE III

INSULATION RESISTANCE SUMMARY (B)(C)(D) (ALL READINGS ARE IN OHMS)

ELAPSED TIME OR EVENT	TEMP.	PSIG	49.1.1	49.1.2	49.1.3	(A) 49.2.1	49.2.2	49.2.3	49.3.1	49.3.2	49.3.3	49.4.1
PRE-IRRADIATION	31°F	----	3.2×10^{8} OHMS FOR 850' LENGTH OR 1.36×10^{11} OHMS FOR 20 FOOT LENGTH →									
PRE-LOCA	68°F	0	1.36×10^{11}	1.16×10^{11}	1.36×10^{11}	---------	1.25×10^{11}	1.72×10^{11}	4.65×10^{11}	5.26×10^{11}	5.68×10^{11}	2.13×10^{11}
FIRST PLATEAU	280°F	35	1.0×10^{8}	6.0×10^{7}	1.03×10^{8}	--------	1.46×10^{8}	1.51×10^{8}	1.35×10^{8}	1.88×10^{8}	1.74×10^{8}	1.98×10^{8}
SECOND PLATEAU	240°F	11	2.58×10^{8}	1.72×10^{8}	2.69×10^{8}	--------	3.76×10^{8}	3.82×10^{8}	4.17×10^{8}	5.51×10^{8}	5.25×10^{8}	5.5×10^{8}
THIRD PLATEAU	215°F	0-5	4.9×10^{8}	2.2×10^{8}	5.23×10^{8}	--------	7.4×10^{8}	7.45×10^{8}	9.75×10^{8}	1.23×10^{9}	1.19×10^{9}	1.14×10^{9}
FOURTH PLATEAU	203°F	0	6.0×10^{8}	2.15×10^{8}	6.03×10^{8}	--------	8.05×10^{8}	7.7×10^{8}	1.03×10^{9}	1.32×10^{9}	1.24×10^{9}	1.21×10^{9}
FIFTH PLATEAU	180°F	0	1.21×10^{9}	1.13×10^{9}	1.17×10^{9}	--------	8.9×10^{8}	8.85×10^{8}	1.12×10^{9}	1.35×10^{9}	1.26×10^{9}	1.42×10^{9}
POST - LOCA	180°F	----	1.86×10^{9}	1.88×10^{9}	1.03×10^{9}	--------	1.25×10^{9}	1.24×10^{9}	7.5×10^{8}	8.0×10^{8}	7.8×10^{8}	1.76×10^{9}

ELAPSED TIME OR EVENT	49.4.2	49.4.3	49.5.1	49.5.2	49.5.3	49.6.1	49.6.2	49.6.3	49.7.1	49.7.2	49.7.3
PRE-IRRADIATION	→										
PRE-LOCA	2.17×10^{11}	2.21×10^{11}	5.48×10^{11}	5.03×10^{11}	6.38×10^{11}	2.48×10^{11}	2.42×10^{11}	2.44×10^{11}	4.42×10^{11}	4.38×10^{11}	5.1×10^{11}
FIRST PLATEAU	1.88×10^{8}	1.99×10^{8}	1.33×10^{8}	1.65×10^{8}	1.1×10^{8}	1.83×10^{8}	1.86×10^{8}	1.77×10^{8}	1.28×10^{8}	1.32×10^{8}	1.63×10^{8}
SECOND PLATEAU	5.1×10^{8}	5.7×10^{8}	4.16×10^{8}	4.90×10^{8}	1.99×10^{8}	5.1×10^{8}	5.3×10^{8}	5.16×10^{8}	3.84×10^{7}	3.97×10^{8}	4.05×10^{8}
THIRD PLATEAU	1.07×10^{9}	1.26×10^{9}	3.0×10^{8}	1.07×10^{9}	2.3×10^{7}	1.08×10^{9}	1.14×10^{9}	1.1×10^{9}	4.0×10^{7}	1.4×10^{7}	7.0×10^{7}
FOURTH PLATEAU	1.1×10^{9}	1.31×10^{9}	5.0×10^{7}	1.09×10^{9}	2.2×10^{8}	1.1×10^{9}	1.12×10^{9}	1.1×10^{9}	3.45×10^{7}	7.5×10^{7}	1.86×10^{7}
FIFTH PLATEAU	1.33×10^{9}	1.52×10^{9}	3.09×10^{7}	4.35×10^{7}	5.65×10^{7}	1.27×10^{9}	1.36×10^{9}	3.8×10^{8}	9.0×10^{7}	2.55×10^{7}	2.15×10^{7}
POST - LOCA	1.64×10^{9}	1.84×10^{8}	8.5×10^{8}	9.6×10^{7}	4.6×10^{7}	1.50×10^{9}	1.52×10^{9}	8.3×10^{7}	1.2×10^{7}	3.6×10^{8}	2.75×10^{8}

NOTES

(A) SAMPLE NOTED AS BEING DAMAGED UPON RETURN FROM ISOMEDIX.

(B) MEASUREMENTS WERE MADE AFTER THE CABLE WAS HELD AT 500 VDC FOR ONE MINUTE.

(C) MEASUREMENTS WERE MADE BETWEEN CONDUCTOR AND GROUND.

(D) CABLES WERE ENERGIZED AT RATED VOLTAGE, EXCEPT WHEN THE IR MEASUREMENTS WERE MADE.

TABLE IV

SUMMARY OF MANDREL BEND, IR AND HIGH POTENTIAL WITHSTAND TESTS

SAMPLE NUMBER	THERMAL AGING HRS./°F	RADIATION MRADS	POST MANDREL BEND IR OHMS	HI-POT WITHSTAND TEST	POST HI-POT IR OHMS @ 68°F	REMARKS*
49.1.1	Unaged	-----	3.7×10^{11}	Pass	2.55×10^{11}	
49.1.2	Unaged	-----	2.9×10^{11}	Pass	2.15×10^{11}	
49.1.3	Unaged	-----	3.35×10^{11}	Pass	2.40×10^{11}	
49.2.1	Unaged	20	-----------	----	-----------	Damaged in transit.
49.2.2	Unaged	20	5.3×10^{11}	Pass	2.25×10^{11}	
49.2.3	Unaged	20	2.0×10^{9}	Pass	1.85×10^{11}	
49.3.1	Unaged	120	2.0×10^{9}	Fail	-----------	⑥ ⑦ ⑧
49.3.2	Unaged	120	9.2×10^{11}	Pass	4.0×10^{11}	
49.3.3	Unaged	120	7.2×10^{11}	Pass	2.05×10^{11}	
49.4.1	168/210	20	6.7×10^{11}	Pass	4.1×10^{11}	
49.4.2	168/210	20	5.65×10^{11}	Pass	3.55×10^{11}	
49.4.3	168/210	20	6.6×10^{11}	Pass	4.40×10^{11}	
49.5.1	168/210	120	2.35×10^{11}	Fail	-----------	Failed at 3.0 KV(AC), ⑥
49.5.2	168/210	120	7.4×10^{10}	Fail	-----------	Failed at 3.0 KV(AC), ⑥
49.5.3	168/210	120	1.3×10^{10}	Fail	-----------	⑥ ⑦
49.6.1	672/210	20	4.75×10^{11}	Pass	3.1×10^{11}	
49.6.2	672/210	20	4.25×10^{11}	Pass	2.9×10^{11}	
49.6.3	672/210	20	1.17×10^{9}	Pass	5.8×10^{8}	
49.7.1	672/210	120	8.0×10^{9}	Fail	-----------	⑥
49.7.2	672/210	120	1.2×10^{9}	Fail	-----------	⑥
49.7.3	672/210	120	2.5×10^{9}	Fail	-----------	⑥

* Numbers in circles refer to notes on the following page.

NOTES (1), (2), (3), (4) and (5) apply to all samples unless otherwise noted.

NOTES TO TABLE IV

(1) The Ratio of mandrel for bending to the cable diameter - 8.0 inches to .200 inches or 40:1.

(2) The voltage applied to each cable was 500 volts DC for 1-minute for the IR measurements and 3600 volts AC for the Hi-Pot test for 5-minutes, unless otherwise noted. The rate of rise was approximately 1000 volts per second.

(3) Voltage was applied conductor to ground (water).

(4) There was approximately 8 turns of cable on the mandrel for each specimen. Each turn is approximately 25 inches.

(5) All cables had chemical deposits on their surfaces.

(6) The first calibrated point on the electrostatic voltmeter was 3.0 KV. Therefore the data is shown as simply "Failed" if less than 3.0 KV or the recorded value if 3.0 KV or higher.

(7) For information on additional post-LOCA testing, refer to Appendix B.

(8) Specimen 49.3.1 was the only one of the (3) 49.3 series which was on the mandrel (See Table II) and in an area exposed directly to the spray nozzle (See FIGURES 5 and 6). For this reason, and by analysis, it is felt that specimens 49.3.2 and 3 are more indicative of the expected behavior.

E. CERTIFICATION

The undersigned certify that this is a true and accurate account of the tests conducted and the results obtained.

John Helwig, Jr.

John Helwig
Chemist, IPEC

D O Bostrom

D. O. Bostrom
Product Engineering Manager
Anaconda-Continental W & C

APPROVED:

Paul S. Cardello

P. S. Cardello
Chief Engineer
Anaconda-Continental W & C

APPENDIX A

CERTIFICATION

FOR

RADIATION

ISOMEDIX

February 22, 1979

Mr. John Helwig
Anaconda Company
Wire & Cable Division
East 8th Street
Marion, Indiana 46952

Dear Mr. Helwig:

This will summarize parameters pertinent to the irradiation of a mandrel wrapped with LOCA cable samples, as per your Purchase Order MA37015-W dated January 11, 1979 requesting exposure to 20 megarads.

The mandrel was placed in a Cobalt-60 gamma field in an upright position which paralleled the long axis of the radiation source. The mandrel was exposed at each of 4 quadrants as marked with a number at its top. By integrating the dose rate at any point on the mandrel during its 4 position exposure, an average dose rate was obtained which, when multiplied by the total exposure time, yields total dose.

Each of the 4 quadrants were exposed for 9 hours at an average dose rate of .56 megarads per hour, yielding a total dose of 20.16 megarads.

Dosimetry was performed using an Atomic Energy of Canada, Ltd. (AECL), Red Perspex system with Type BC-2 readout. Calibration of the Perspex is made by AECL using Ceric dosimetry traceable to the U.S. National Bureau of Standards. Isomedix regularly cross-calibrates its AECL system with an inhouse Harwell Perspex system, and makes semi-annual calibrations directly with NBS, using the NBS Radiochromic Dye system. A copy of the dosimetry correlation report is available upon request.

Irradiation was conducted in air at ambient temperature and pressure. Radiant heat from the source heated the samples somewhat, but the temperature did not exceed 85°F, as indicated by previous measurements on an oil solution in the same relative position.

Irradiation was initiated on February 8, 1979 and completed on February 14, 1979.

Very truly yours,

Louis Castaldi

Louis Castaldi
Ass't. General Manager

LC:at

ISOMEDIX

February 22, 1979

Mr. John Helwig
Anaconda Company
Wire & Cable Division
East 8th Street
Marion, Indiana 46952

Dear Mr. Helwig:

This will summarize parameters pertinent to the irradiation of a mandrel wrapped with LOCA cable samples as per your Purchase Order MA-37015-W dated January 11, 1979 requesting exposure to 120 megarads.

The mandrel was placed in a Cobalt-60 gamma field in an upright position which paralleled the long axis of the radiation source. The mandrel was exposed at each of 4 quadrants as marked with a number at its top. By integrating the dose rate at any point on the mandrel during its 4 position exposure, an average dose rate was obtained which, when multiplied by the total exposure time, yields total dose.

Each of the 4 quadrants of the mandrel were exposed for 53.7 hours at an average dose rate of .56 megarads per hour, yielding a total dose of 120.28 megarads.

Dosimetry was performed using an Atomic Energy of Canada, Ltd. (AECL), Red Perspex system with Type BC-2 readout. Calibration of the Perspex is made by AECL using Ceric dosimetry traceable to the U.S. National Bureau of Standards. Isomedix regularly cross-calibrates its AECL system with an inhouse Harwell Perspex system, and makes semi-annual calibrations directly with NBS, using the NBS Radiochromic Dye system. A copy of the dosimetry correlation report is available upon request.

Irradiation was conducted in air at ambient temperatures and pressure. Radiant heat from the source heated the samples somewhat, but the temperature did not exceed 85°F, as indicated by previous measurements on an oil solution in the same relative position.

Irradiation was initiated on February 2, 1979 and completed on February 19, 1979.

Very truly yours,

Louis Castaldi

Louis Castaldi
Ass't. General Manager

LC:at

ISOMEDIX

February 22, 1979

Mr. John Helwig
Anaconda Company
Wire & Cable Division
East 8th Street
Marion, Indiana 46952

Dear Mr. Helwig:

This will summarize parameters pertinent to the irradiation of 10 coils wire samples as per your Purchase Order MA37759-W dated 2/15/79.

The 10 coil samples were placed in a Cobalt-60 gamma field such that they received a total dose of 120.28 megarads at a rate of .56 megarad/hour for 214.8 hours. The 10 coils were processed with the 120 megarad mandrel.

Dosimetry was performed using an Atomic Energy of Canada, Ltd. (AECL), Red Perspex system with Type BC-2 readout. Calibration of the Perspex is made by AECL using Ceric dosimetry traceable to the U.S. National Bureau of Standards. Isomedix regularly cross-calibrates its AECL system with an inhouse Harwell Perspex system, and makes semi-annual calibrations directly with NBS, using the NBS Radiochromic Dye system. A copy of the dosimetry correlation report is available upon request.

Irradiation was conducted in air at ambient temperature and pressure. Radiant heat from the source heated the samples somewhat, but the temperature did not exceed 85°F, as indicated by previous measurements on an oil solution in the same relative position.

Irradiation was initiated on February 2, 1979 and completed on February 19, 1979.

Very truly yours,

Louis Castaldi

Louis Castaldi
Ass't. General Manager

LC:at

Isomedix Inc. • 25 Eastmans Road, Parsippany, New Jersey 07054 • (201) 887-2666

APPENDIX B

ADDITIONAL

POST-LOCA TESTING

I - INTRODUCTION

After the completion of the original work, on April 26, 1979, two of the cable specimens were further evaluated.

II - POST-LOCA PROGRAM

The cable specimens 49.3.1 and 49.5.3 were immersed again in water, impressed with AC voltage and current and the electrical faults located. The faults were removed and the balance of the specimen retested after immersion in tap water at room temperature for one hour. The test run was as follows:

(a) IR @ 500 volts DC.

(b) Hi-Pot @ 660 volts AC for 5-minutes.

(c) If (b) passes, then Hi-Pot of 1200 volts AC for 5-minutes.

(d) If (c) passes, then Hi-Pot of 1800 volts AC for 5-minutes.

(e) If (d) passes, then Hi-Pot of 3600 volts AC for 5-minutes.

III - POST-LOCA TEST RESULTS

A) Specimen 49.3.1 was noted as having one fault, approximately 40 inches from one end. The short piece was removed and the balance (about 6 wraps) retested in accordance with Part II. See Table B-1 for results.

B) Specimen 49.5.3 was noted as having two faults, one approximately 6 inches from one end and the other approximately in the center of the sample. The sample was cut in half at the center fault, and the shorter fault removed. Both pieces, 49.5.3a and 49.5.3b (about 3-1/2 wraps each) were then retested in accordance with Part II. See Table B-1 for results.

TABLE B-1

SUMMARY OF ADDITIONAL POST-LOCA TESTING

SPECIMEN NUMBER	IR AFTER FAULT REMOVAL OHMS	660 VOLTS AC 5-MINUTES	1200 VOLTS AC 5-MINUTES	1800 VOLTS AC 5-MINUTES	3600 VOLTS AC 5-MINUTES
49.3.1	1.28×10^{10}	Pass	Pass	Pass	Fail (1)
49.5.3a	6.4×10^{11}	Pass	Pass	Pass	Pass
49.5.3b	3.85×10^{11}	Pass	Pass	Pass	Pass

(1) Sample failed when voltage reached 3600 volts AC.

APPENDIX C

ANALYSIS

ANALYSIS - METHOD 1

Elongation is properly regarded as the most critical dependent variable in the evaluation and performance of elastomeric cable insulation systems that are further cross-linked by radiation. The independent variables of prime concern in this study are:

(a) Thermal pre-aging (time and temperature).

(b) Radiation level.

(c) L.O.C.A. (steam/spray cycle).

Since the LOCA steam/spray cycle was fixed and applied to all test specimens it's effect is considered a constant.

Data from a previous study, completed 2Q, 78, on dumbbells cut from ASTM slabs, established the relationship between radiation exposure and elongation (FIG. I) - and between thermal aging and elongation (FIG. II). We therefore can analyze the relationship between the independent variables of radiation exposure and thermal aging.

Anaconda-Continental Report NO. 79117 shows that under conditions of pre-aging for 7 days at 210C, 120 MR plus the steam/spray cycle the test specimens at rated voltage and current operated without problems. After the post LOCA 40X bend all specimens passed a 500 VDC insulation resistance (IR) test, and came within a few hundred volts of passing the severe 80 volt per mil dielectric test. These tests also show that under conditions identical to those above, except with a radiation exposure of 20 MR, the test specimens passed the 80 volt per mil post-LOCA bend and dielectric test. It can also be noted that IEEE-383-74 considers the post-LOCA bend/dielectric test an indication of margin - not necessarily of required in-service performance. Of course, cable procured under the contracts in question, was made some time before the issuance of IEEE-383.

It must now be determined, by analysis, that value of retained elongation (with margin) that is required after a given thermal aging cycle, to pass a given set of normal plus LOCA environmental conditions.

Refer to FIG. I, Plots A, A', AE and AE' (the same data except A and AE uses an expanded elongation scale). AE and AE' is an extrapolation of data between the 0 radiation value (original value of elongation) and the 50 MR value obtained in the "slab study". The expected value of elongation at 20 MR would lie in the shaded area bounded by AE', AX' and the X axis. The line AE' therefore represents the most conservative possibility in this analysis. The 20 MR value of elongation lying on AE' would be 220 percent (i.e. the maximum value of elongation that may be retained).

Let's now assume that as much as 220 percent retained elongation, after an unspecified thermal aging, is required to pass a given level of radiation, LOCA (steam/spray cycle) and the post-LOCA bend/dielectric test.

FIG. II, point 1 is the 210C, 120 MR intercept and point 2 is the intercept between 220 percent elongation and the thermal aging temperature (for 7 days) that is expected to yield 220 percent elongation - that temperature is 175C.

FIG. III, plot A is an Arrhenius plot of time to reach a final value of 50 percent elongation. Plot B is a parallel line drawn through the 7 day (168 Hr.), 175C intercept. 7 days at 175C is more severe than the pre-aging cycle normally used to qualify <u>organic</u> (such as EPR) based polymer insulations (plot C is a typical example). If the assumption of a straight line characteristic parallel to the original Arrhenius plot is made, plot B intercepts the 40 year line at approximately 110C.

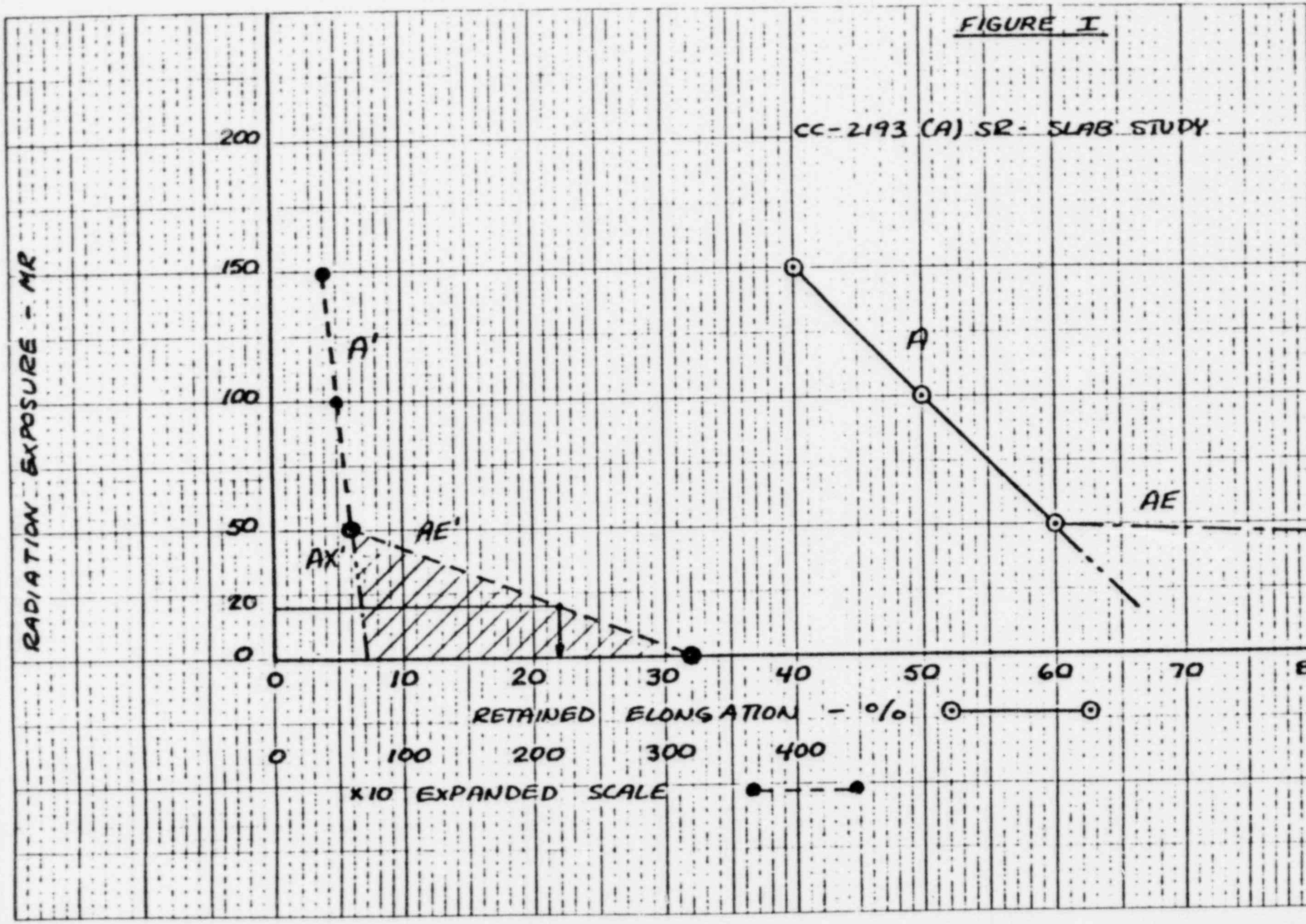


FIGURE I
CC-2193 (A) SR- SLAB STUDY
RADIATION EXPOSURE - MR
200
150
100
50
20
0
A'
AE'
AX'
A
AE
0
10
20
30
40
50
60
70
80
RETAINED ELONGATION - %
0
100
200
300
400
X10 EXPANDED SCALE

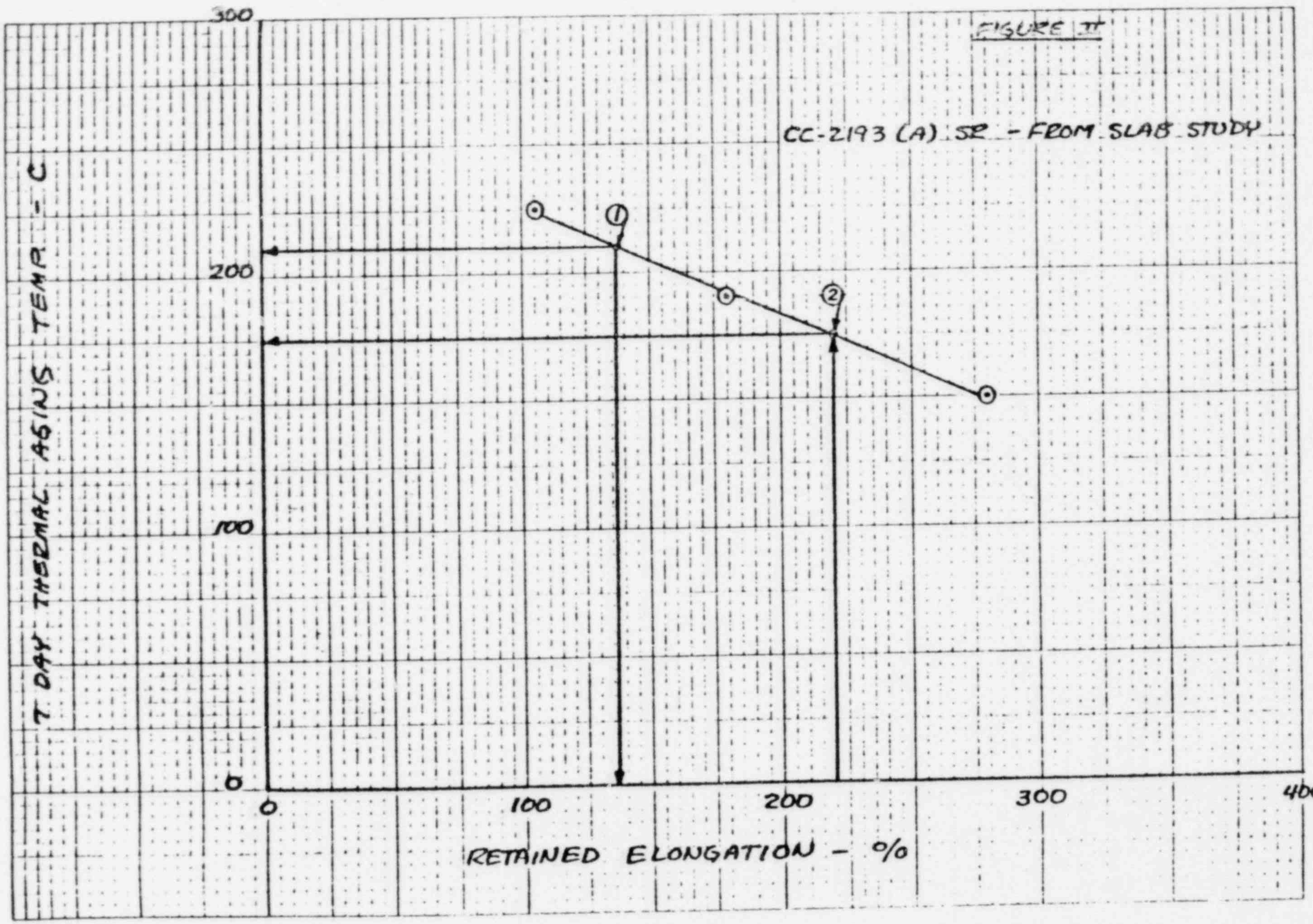


FIGURE II
CC-2193 (A) SR - FROM SLAB STUDY
7 DAY THERMAL AGING TEMP. - C
300
200
100
0
0
100
200
300
400
RETAINED ELONGATION - %
1
2

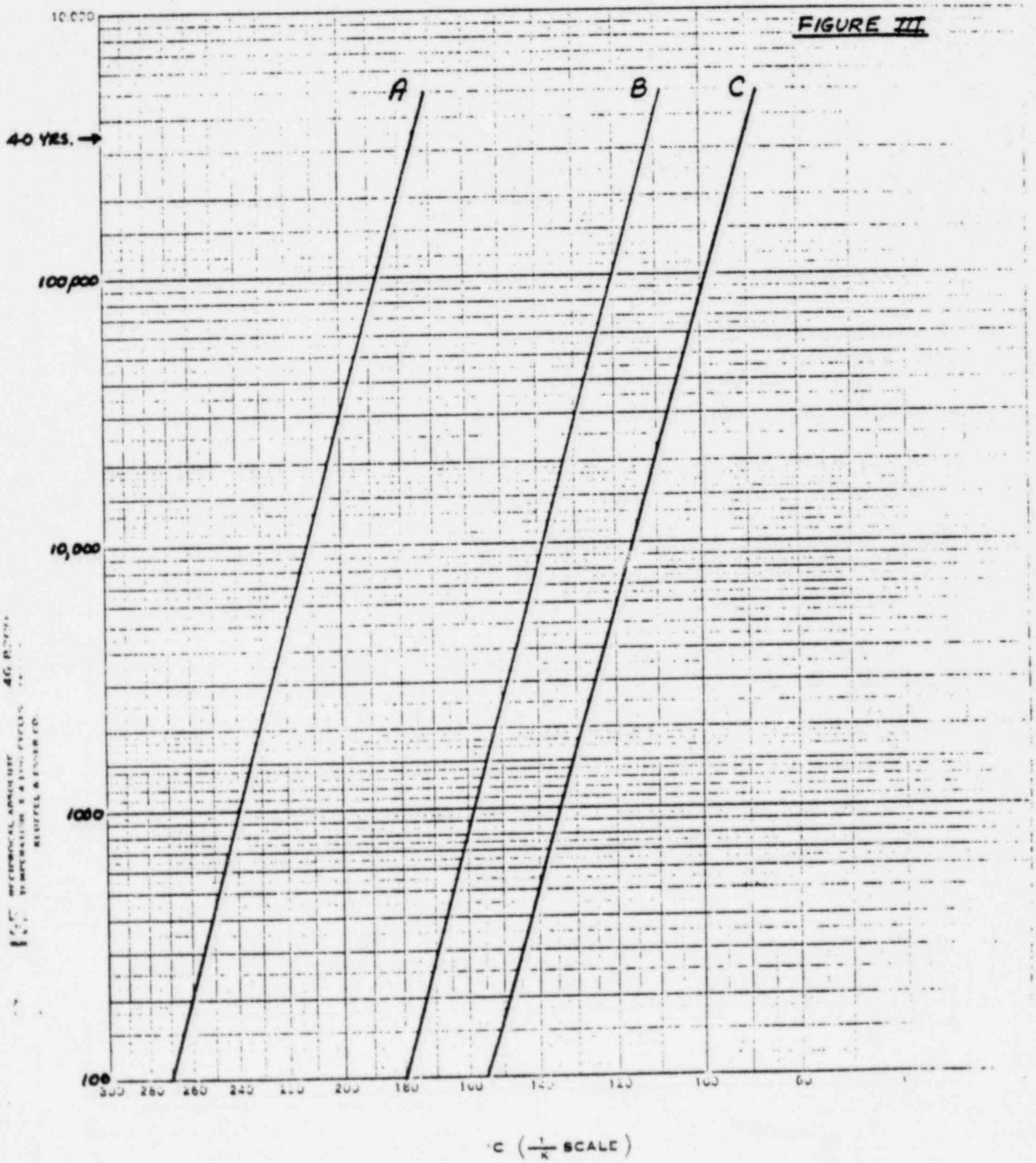


FIGURE III.
A
B
C
40 YRS. →
100,000
10,000
1000
100
300
280
260
240
200
180
160
120
100
°C (1/K SCALE)

ANALYSIS - METHOD 2

Using the "Rule of Thumb" which states that a chemical reaction rate (such as oxidation-reduction) will double for each rise of 10C; noting that the "standard" Arrhenius Plot for silicone rubber approximates this characteristic; and also considering that the 210C aging temperature appears to be a threshold value, it can be shown that:

Aging Temperature	Safety Factor
210	0
200	1-2
190	2-4
180	4-8
170	8-16

This analysis supports the conservative nature of the 175C aging temperature derived at in Analysis - Method 1, and suggests that a 190C aging cycle is well within the capabilities of the material under study.

ANALYSIS - 3

HIGH TEMPERATURE CABLE

A few items were designated for service at temperatures above the norm. of 50C. TVA was supplied our CC-2193 silicone rubber which had an additional heat resistant system (Anaconda-Continental designation HRSR. FIG. IV shows an Arrhenius comparison between a general purpose silicone rubber and the same compound employing the HRSR technology. This data suggests an additional 25+ degree thermal capability for these materials.

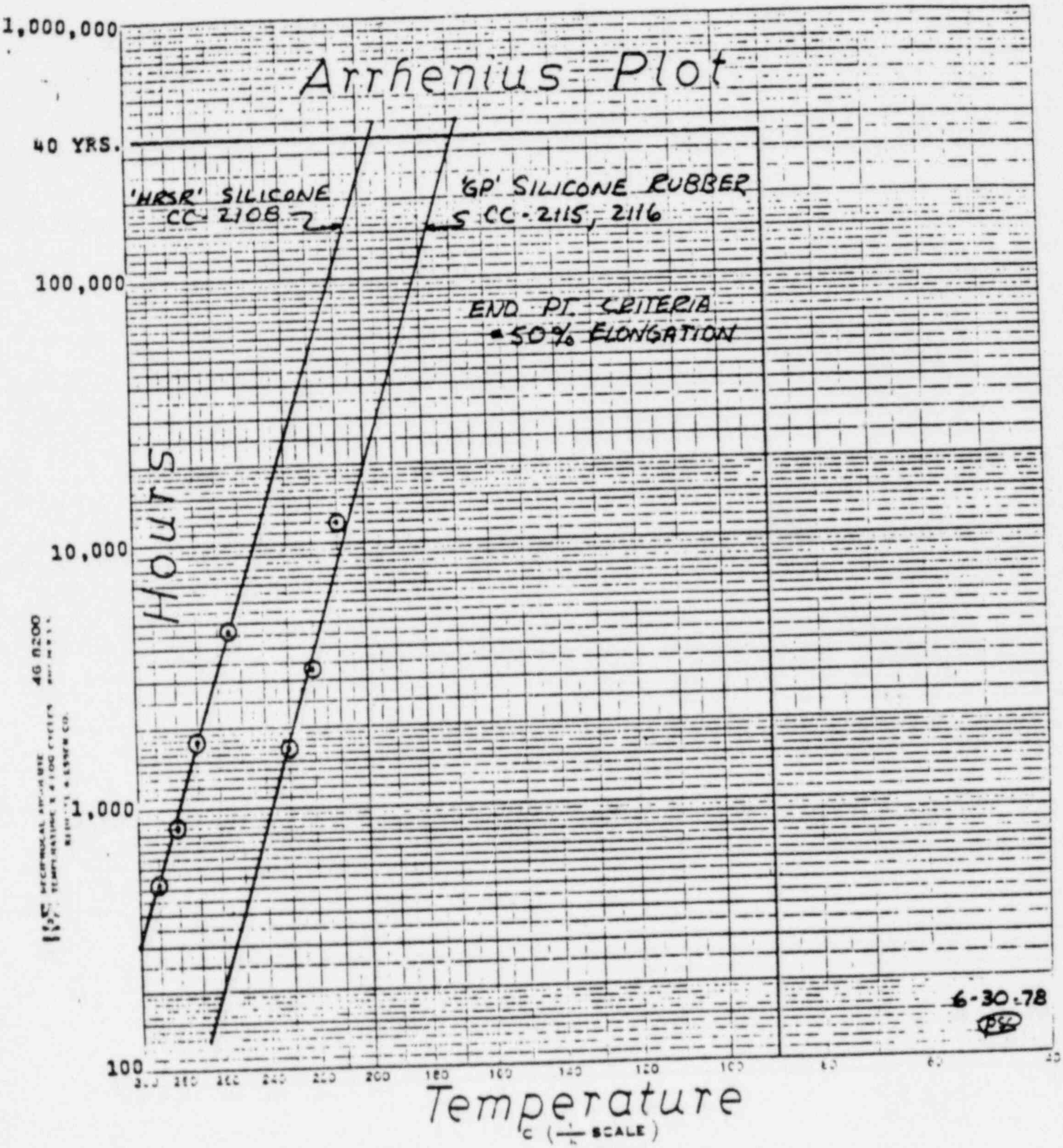
Referring to FIG. V, if we again assume straight line Arrhenius plots, the thermal only (no radiation or steam/spray cycle) extrapolation (to 40 years) is 175C for standard CC-2193 (plot A), and around 200C for CC-2193, HRSR (plot B).

Based on Analysis - Methods 1 and 2, plots C and D define the area bounded by two linear extrapolations from 7 day aging temperatures of 175C and 190C. Point 1 is the average of these plots at 40 years or about 115C. An HRSR material could be expected to intercept the 40 year line in the range of 130C to 145C (plot E). This is not unreasonable since this plot crosses the 7 day line at 210C which was the "threshold value" for non-HRSR material.

If the radiation exposure is limited to 20 MR and no LOCA capability is required (the pressurizer heater application?) the intercept would move up to at least 150C. (Report 79117 showed that all single conductor specimens survived the entire test program when aged 28 days at 210C (point 2) and subsequently exposed to 20 MR plus the steam/spray cycle.) See plot F.

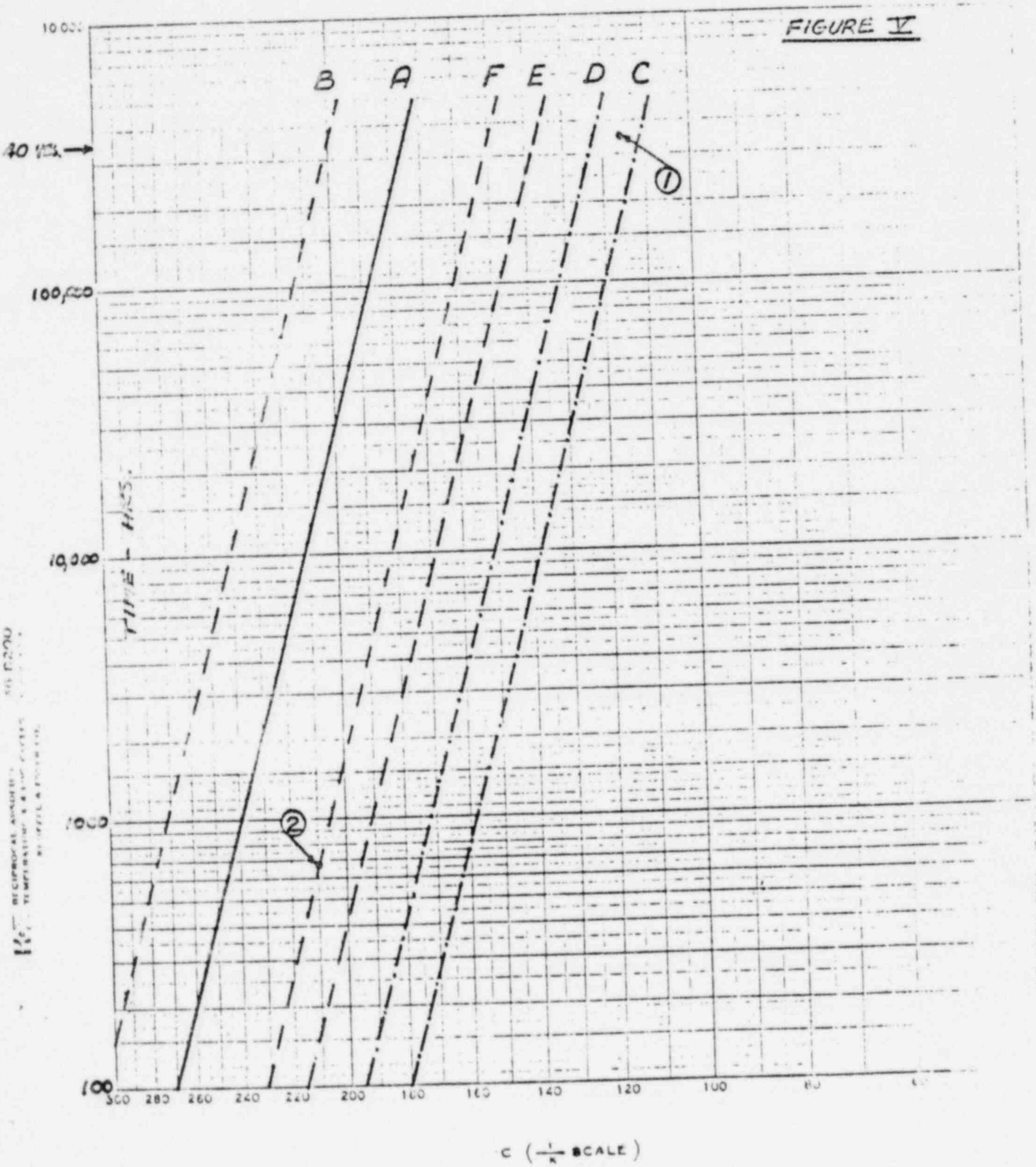
Eliminating the steam/spray cycle and allowing for intermittent service would indicate a correspondingly higher temperature index.

FIGURE IV



Arrhenius Plot
1,000,000
40 YRS.
100,000
10,000
1,000
100
'HRSR' SILICONE
CC-2108
'GP' SILICONE RUBBER
CC-2115, 2116
END PT. CRITERIA
• 50% ELONGATION
Hours
200
180
160
140
120
100
Temperature
C (1/K SCALE)
6-30-78

FIGURE V



B
A
F
E
D
C
40 YRS.
①
②
100,000
10,000
1000
100
TIME - HRS.
300
280
260
240
220
200
180
160
140
120
100
80
C (1/K SCALE)

ANALYSIS - 4

CONCLUSIONS

Based on the analyses used in Methods 1 and 2, it has been shown that linear extrapolations of lines drawn parallel to the previously determined Arrhenius plot, and intercepting the 7 day (168 Hour) line at 175 and 190C define the operating envelope of the cable system under study and intercept the "40 year" line at approximately 110 and 120C (refer to FIG. V, plots C and D). These plots include the effects of a 175 to 190C thermal aging cycle, an exposure to 120 MR, the steam/spray cycle plus the IEEE-383-74 post-LOCA bend/dielectric test.

In like fashion, Analysis - 3 indicates a "40 year" intercept of between 130 and 150C and a 20,000 hour intercept (a standard wire and cable benchmark - approx. 2.3 years of continuous conductor operating temperatures) of between 160 and 175C, depending on the limitations put on the independent variables.

The additional margin accruable to what we believe are conservative analysis techniques, test steam/spray cycle higher than postulated and that built into the IEEE-383 post-LOCA bend/dielectric test - especially the high level of the dielectric test should also be considered.