tyco *Electronics Corporation* **Energy Division**

EDR-5332

Analysis of Heat Aging Data to Determine Aging Conditions for –52N Molding Material Nuclear Qualification Testing

NORTH CAROLINA PROFESSIONAL ENGINEER
SEAL
20146
FRANK J. FITZGERALD
30 JAN 2001

Title
Pages: 11

Analysis of Heat Aging Data to Determine Aging Conditions
for –52N Molding Material Nuclear Qualification Testing

Report Number: EDR-5332
Date: 01/03/01

Tested by:

Sheila Roberts Sheila Roberts 1/30/01
Signature: Date:

Howard Evans Howard E Evans 1/30/01
Signature: Date:

Prepared by:

Bridget Gilchrist Bridget Gilchrist 1/30/01
Signature: Date:

Approved by:

Frank Fitzgerald
for Product Management Frank Fitzgerald 1/30/01
Signature: Date:

Approved by:

Kathy Maher
For Technical Kathryn M. Maher 1/31/01
Signature: Date:

Energy Products
8000 Purfoy Road
Fuquay-Varina, NC 27526

TABLE OF CONTENTS

1. OBJECTIVE

To determine the accelerated aging conditions that are to be used for qualifying parts made from "-52N" molding material to the requirements of IEEE 323-1983(1) and IEEE 383-1974(2).

This determination is required as a result of raw material changes made to the "-52" compound. This compound is used to manufacture nuclear molded parts such as end caps and cable breakouts.

2. CONCLUSIONS

Based upon the laboratory analyses conducted for this EDR:

- In order to simulate –52N molded parts that have been in service for 40 years @ 90 degrees C (see introduction), test samples should be aged for 746 hours at 150°C (see Table 3 in this report for alternative times and temperatures).
- The product will retain 30% of its original elongation after 40 years in service at 101°C (11°C above the rated temperature).
- The heat of activation for the –52N molding material is 31.3 kCal/mole

3. INTRODUCTION

The requirements for electric cables, field splices, and other service connections for nuclear power plants are given in IEEE 383-1974. Section 1.3.5.3 of this document states "Type tests for design basis event conditions should consist of subjecting non-aged and aged cables, field splices, and connections to a sequence of environmental extremes which simulate the most severe postulated conditions of a design basis event and specified conditions of installation." Type tests are used primarily to indicate that cables, field splices, and connections can perform under the conditions of a design basis event (abnormal events used in the design to establish performance requirements of the systems and components) demonstrating the equipment’s adequacy to perform its safety functions. Because the design basis event may occur at any time in the station life, the thermal and radiation aging is required in type tests to simulate an accident occurring at end of life. According to IEEE 383-1974, “The basis for establishing time and temperature conditions for aging of samples to simulate their qualified life may be that of Arrhenius plotting or other method of proven validity and applicability for the materials in question." This report presents and analyzes thermal aging results using Arrhenius plots.

It is generally specified that the design life of a nuclear generating station is 40 years and that the majority of the cables used in the plant are rated for a 90°C conductor temperature. Actual conductor operating temperatures typically will be lower than 90°C in use due to lower than "maximum design" ambient temperatures and cable derating practices. It is conservative to assess the aging performance of the –52N molding material at the rated conductor temperature. The cables and splice systems must, therefore, be aged to the equivalent of a 40 year life at 90°C before being subjected to the radiation and design basis event required by the standards. Since un-aged systems must also be tested to the same radiation and design basis event conditions, a cable system passing the tests in both the aged and un-aged condition would be qualified for the design life of the plant.

4. TEST PROCEDURE

Heat aging was performed using standard pelletized, virgin –52N molding material identified as T531, PCN 433379-000, Batch 41775-1, and compounded by Tyco Electronics/Raychem Materials Division – Menlo Park, CA.

1. Fifty (6” x 6”) plaques were compression molded to .080 +/- .005 inches
2. Each plaque was cured in-situ to the specified crosslink density for molded parts
3. Two ASTM D-412 die specimens per plaque were tested per ASTM D-638 for tensile strength, ultimate elongation, tensile stress at 50% elongation, and tensile stress at 100 elongation. The samples were tested on an Instron tester with an initial grip separation of 2 inches and a rate of separation of 2 inches per minute.
4. All data were used in calculating the respective average values for the stress and strain properties. The average value of each property is the “original value” to which the aged samples were later compared.
5. The standard deviations and the average ± 2 standard deviation ranges for each property were calculated.
6. Plaques that had any single observation outside of the ranges described in item #5 were discarded.
7. All remaining plaques were cut into die specimens per ASTM D-412. All specimens were mixed into a single population of samples.
8. Multiple subgroups (n = 5) of randomly selected die specimens were hung vertically in each of four pre-set forced air ovens (136°C, 150°C, 162°C, or 175°C).
9. Subgroups of 5 samples were periodically removed and the tensile strength and ultimate elongation were tested as per item #3 above, and the subgroups’ averages were calculated.
10. The “retention of elongation” was plotted as a function of time at each of the aging temperatures, and is shown in Figure 1.

From these plots the time corresponding to a specific “retention of elongation” can be determined. Times corresponding to specific “retention of elongation” values are shown in Table 1.

The ovens used were calibrated using a 12-point Digi-Sense Scanning Thermocouple Thermometer set up at 9 different zones in the oven chamber. The temperature of each oven was monitored regularly with a single permanently assigned thermocouple. A list of test equipment and calibration information can be found in Appendix A.

5. DETERMINATION OF ACCELERATED AGING CONDITIONS

When the times to reach a selected end point at several temperatures are plotted on a graph with the logarithm of time as the ordinate and the reciprocal of the absolute temperature as the abscissa, it is said to be an Arrhenius plot. The IEEE standards do not state specifically what end point should be selected. For the work described in this report, retention of 30 percent of the original elongation was chosen. This end point provides a wide margin of safety and is a logical end point for a material study. Since the ultimate elongation of this material in its un-aged state is 484 percent, retention of 30 percent of the original value would still give an ultimate elongation value of 145 percent. This is well in excess of the amount of elongation needed for any functional purpose. The times to reach 30 percent retention of elongation at the various temperatures are given in Table 2.

An Arrhenius plot was produced using the times to reach 30 percent retention of elongation on a logarithmic scale and the temperatures as the reciprocal of the absolute temperature in degrees Kelvin (Figure 2). An extrapolation of the data based on linear regression analysis indicates that the material will retain 30 percent of its original elongation after 40 years at 101°C, a temperature 11°C above its required rated temperature. From the slope of the Arrhenius thermal plot, the heat of activation for the thermal oxidation of T531 (-52N) molding compound can be calculated. The heat of activation for T531 compound is 31.3 kCal/mol. To determine appropriate accelerated aging conditions for the purpose of aging specimens for DBE tests, a line may be drawn which passes through the point corresponding to 40 years at 90°C and is parallel to the life curve. Such a line is shown as Curve B of Figure 2. Curve B will have the same heat of activation as the life curve. Any point along Curve B represents a time-temperature combination that may be used to age specimens to simulate end of life conditions for Design Basis Event tests. A few such conditions are given in Table 3. An aging time of 746 hours at 150°C is a practical and valid set of conditions for accelerated aging based on a design life of 40 years at 90°C.

6. TABLES AND GRAPHS

Table 1. Oven Aging Data For –52N Molding Material

Oven Temperature (°C)		Time (hours) to Various Levels of Retained Elongation			
		50%	40%	30%	20%
136		6396	8843	10328	12084
150		1757	2052	2732	3240
162		609	733	868	1032
175		295	350	383	442

Table 2. Time-Temperature Relationship of –52N Molding Material Using 30 Percent Retention Elongation

Temperature (°C)		Time (Hours)
175		383
162		868
150		2732
136		10328

Table 3. Aging Times and Temperatures Required to Satisfy a 40 Year Life at 90°C

Temperature (°C)		Time (Hours)
175		94
162		268
150		746
136		2658

Figure 1. Oven Aging Data

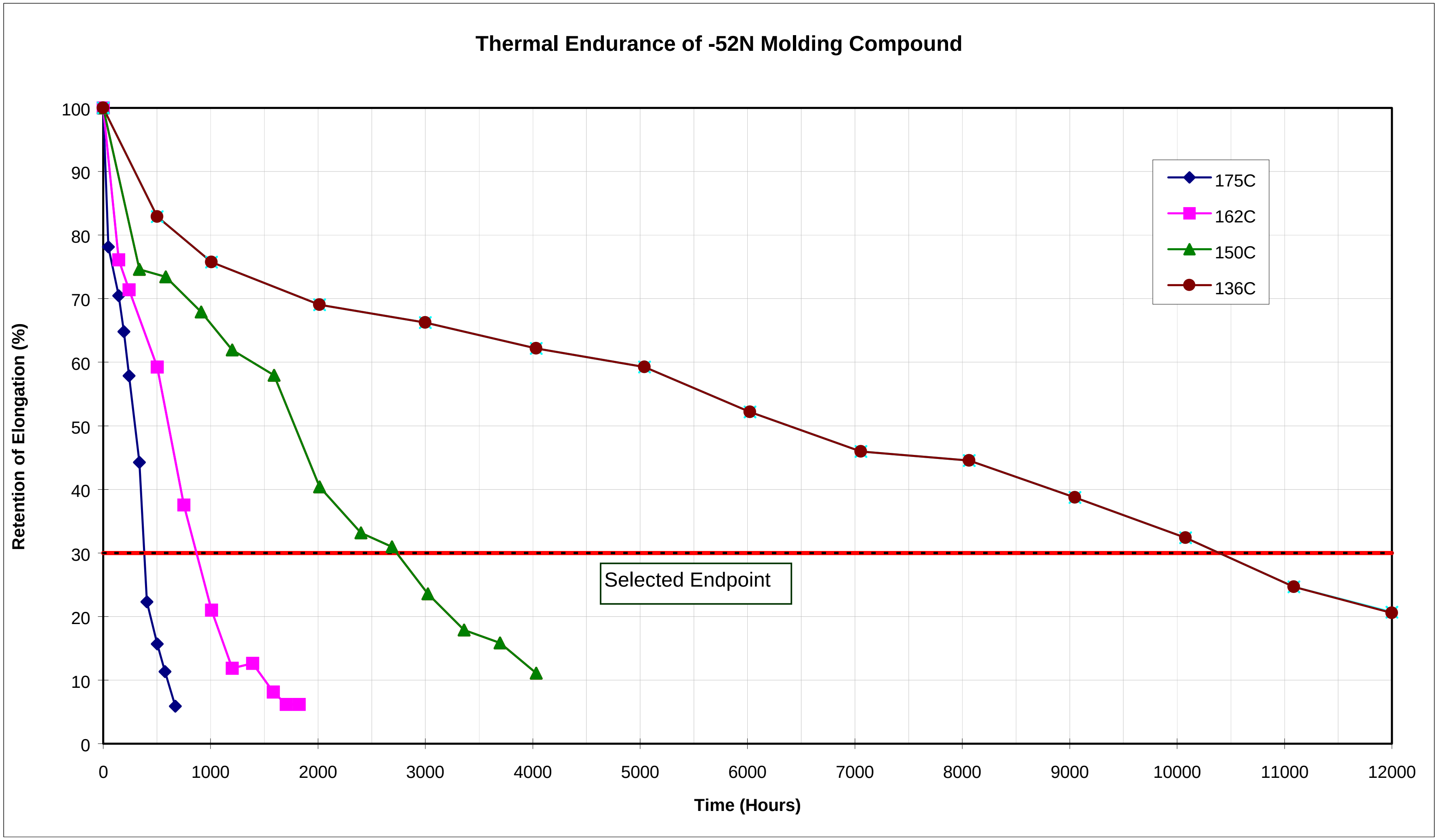
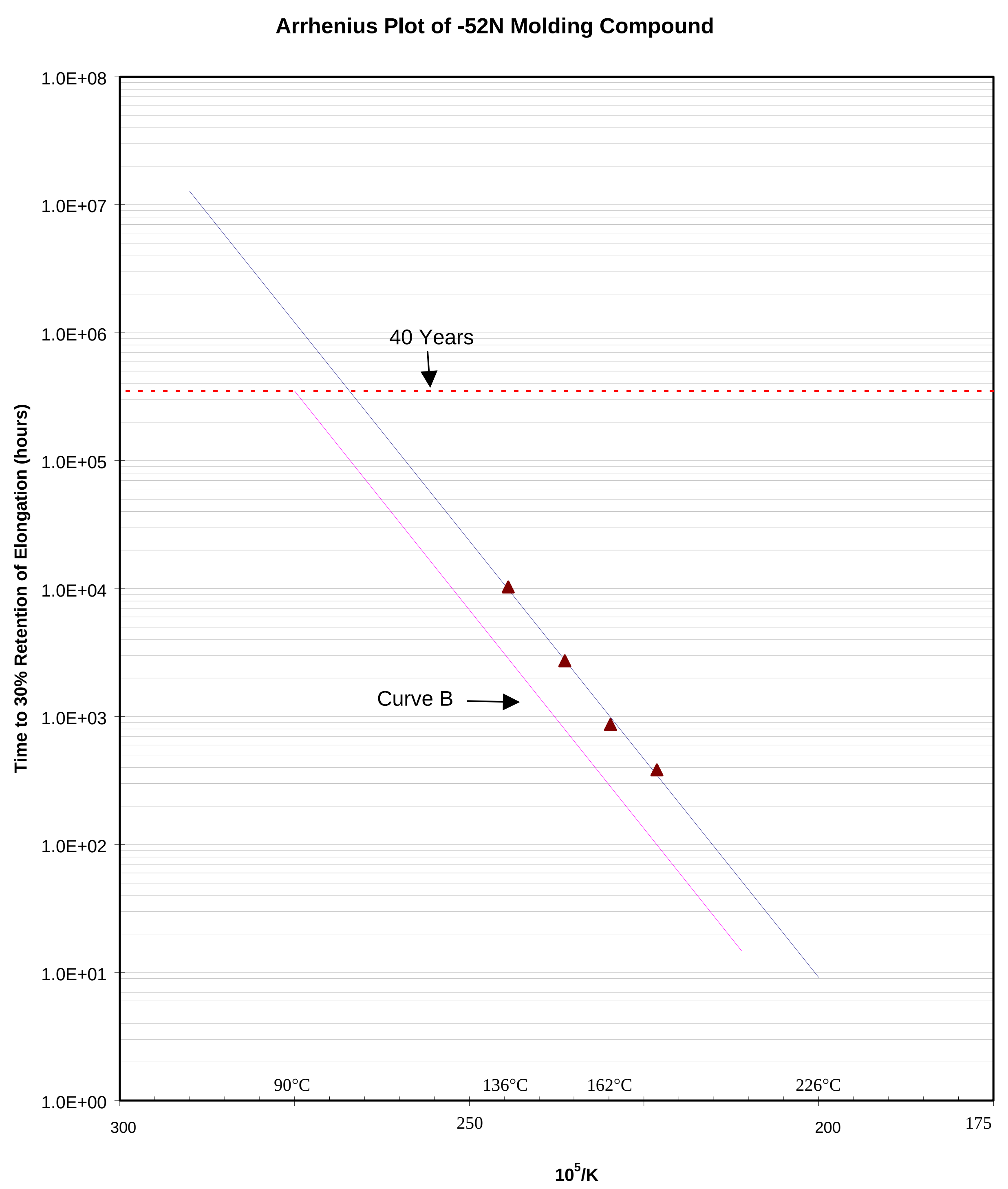


Figure 2. Arrhenius Plot



7. REFERENCES

1) IEEE Standard 383-1974, “IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations.”

2) IEEE Standard 323-1974, “IEEE Standard for Qualifying IE Equipment for Nuclear Power Generating Stations.”

3) EDR-5040, “Analysis of Heat Aging Data On –52 Molding Material To Determine Pre-Aging Conditions For Nuclear Qualification Testing.”

4) Raychem Laboratory Notebook 17192.

5) Raychem Physical Test Laboratory Test Request No. 98087 and 98100.

8. APPENDIX A

LIST OF TEST EQUIPMENT

INSTRUMENT	MFG.	MODEL NO.	RANGE	Calibration ID No.
Oven	Blue M	OV-490-A-3	38-260°C	10068
Oven	Blue M	OV-490-A-3	38-260°C	50577
Oven	Blue M	OV-490-A-3	38-260°C	10053
Oven	Blue M	OV-490-A-3	38-260°C	10065
Digi-Sense Scanning Thermocouple Thermometer	Cole Palmer	92800-10	T-type Thermocouple (-184°C to 371°C)	50556
Tensile Tester	Instron	4206	200 lb Load Cell	50347
Thermocouple Thermometer	Cole Palmer	8528-20	T-type Thermocouple (-250°C to 400°C)	50466
Balance	Mettler	PB3002	0.5g to 3100g	0114
Calipers	Mitutoyo	CD-6	0-6 inches	15006
Calipers	Mitutoyo	CD-6	0-6 inches	50536
Ruler	Lufkin	433cme	0-10 feet	10025