TECHNICAL REPORT
PEI-TR-83-6-8A
June 22, 1983

FINAL REPORT ON THE EVALUATION OF THE QUALIFICATION OF THE MODEL 685.5S REACTOR CONTAINMENT FAN COOLER (RCFC) MOTORS PROVIDED BY WESTINGHOUSE ELECTRIC CORPORATION FOR USE IN THE H.B. ROBINSON STEAM ELECTRIC PLANT-UNIT 2

by
Fredrick L. Roy

Prepared for

CAROLINA POWER AND LIGHT COMPANY
Raleigh, North Carolina

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patel engineers
huntsville, alabama

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PREPARED BY: Fredrick L Roy TWH
Fredrick L. Roy, Program Manager

APPROVED BY: GHBhatia for
Ralph L. Morris, Director

Q.A. REVIEW: M J Kimbrell
M.J. Kimbrell, Director, Product Assurance

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INTRODUCTION AND SUMMARY

This document, designed to assess qualification documentation of Class lE equipment to the H.B. Robinson Steam Electric Plant-Unit 2 (HBR-2) specific requirements, is divided into four (4) sections, as follow:

SECTION I. EQUIPMENT IDENTIFICATION/QUALIFICATION REQUIREMENTS

SECTION II. QUALIFICATION DOCUMENTATION ASSESSMENT

SECTION III. QUALIFICATION JUSTIFICATION ANALYSIS

SECTION IV. CONCLUSIONS

The fan motors assessed are fully qualified to the DOR Guidelines for use in HBR-2 and have a qualified life of 25 years at the motor design temperature.

SECTION I. EQUIPMENT IDENTIFICATION/QUALIFICATION REQUIREMENTS

1. EQUIPMENT DESCRIPTION

System:	HVAC	Component I.D.:	HVH-1,-2,-3,-4
Manufacturer:	Westinghouse	Equipment Type:	Motor, Fan
Serial No.:	N/A	Model No.:	685.5S
Location:	Containment		

Safety-Related Function: Drive containment fan coolers.

2. QUALIFICATION SPECIFICATIONS

a. Applicable Standards

DOR Guidelines:	X
NUREG-0588, Cat. I:	
NUREG-0588, Cat. II:	

b. Normal Service Conditions

Temperature:	120°F for 84% of qualified life 88°F for 16% of qualified life
Pressure:	Atmospheric
Radiation:	1.9×10^{2} rads gamma (air equivalent) TID
Relative Humidity:	20% to 90%
Voltage:	460 VAC
Current:	10 Amperes
Frequency:	60 Hz

d. Design Basis Events

Accident Profile: See Figures 1 and 2.

Source:	MSLB X			
	HELB ___			
	LOCA X			
Operating Time:	3 hours			
Radiation:	3.4×10^6 rads gamma			
Relative Humidity:	100%			
Submergence:	Yes ___	No X		
Chemical Spray:	Yes X	No ___		1.7% H_3BO_3 0.6% NaOH
Mode:	Active X			
	Passive ___			
	Fail-Safe ___			

e. Functional Requirements

Voltage Range:	460 VAC
Current Range:	10 Amperes

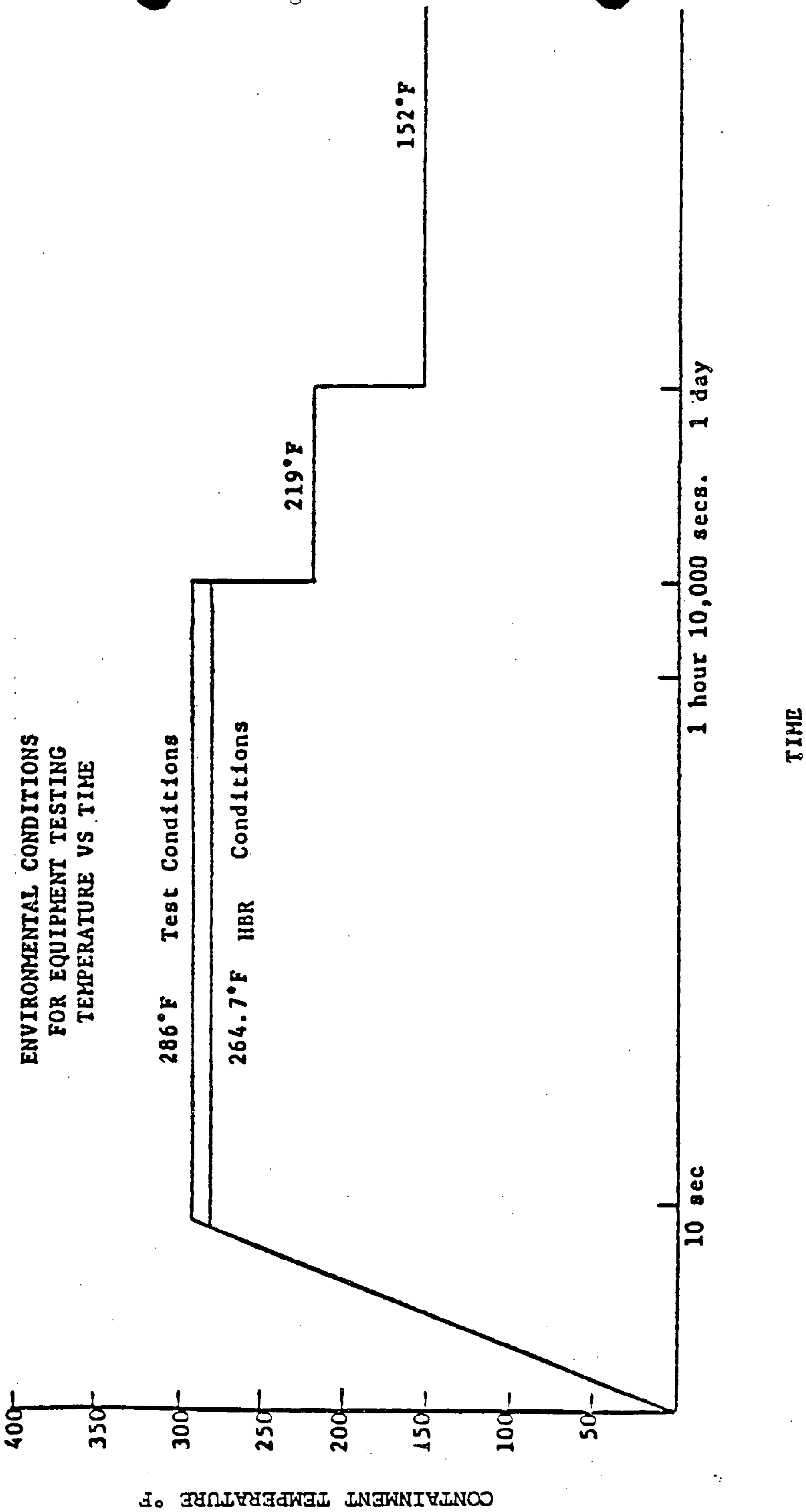

Figure 1. Containment Temperature vs. Time Following LOCA/MSLB

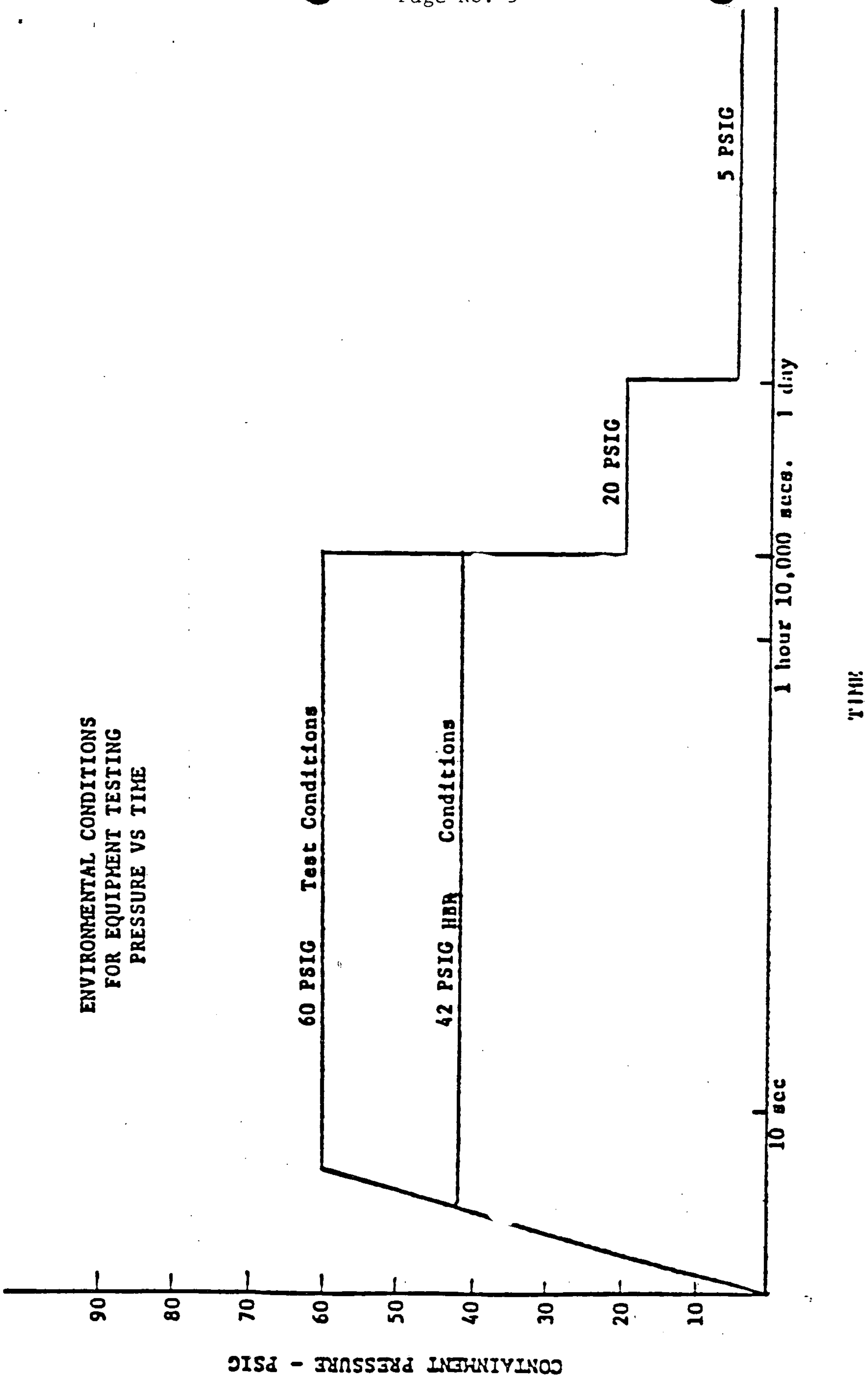

Figure 2. Containment Pressure vs. Time Following LOCA/MSLB

SECTION II. QUALIFICATION ASSESSMENT

1. QUALIFICATION DOCUMENTATION

a. Title: Fan Cooler Motor Unit Test

Report No.: WCAP 7829 Date: April, 1972

Source: Westinghouse Report Provided By Carolina Power and Light Company

2. QUALIFICATION DOCUMENTATION ANALYSIS

a. Design Basis Event Analysis

LOCA Simulation Profile: See Figure 3.

	Yes	No*	N/A
1) Are all peak temperature/pressure and time requirements during the transient phase enveloped?	X		
2) Are all temperature/pressure and time requirements during the post-accident phase enveloped?	X		
3) Are margins as applied consistent with those defined in NUREG-0588, IEEE 323-1974, and/or the DOR Guidelines, as applicable?	X		
4) Are the functional tests as performed adequate to demonstrate that the functional requirements (accuracy, repeatability, insulation resistance, etc.) for the equipment can be met?	X		
5) Was the normal and accident radiation applied prior to and/or simultaneously with the accident simulation? If yes, to what level? $2X10^8$ rads gamma	**		
6) If submergence is a requirement, does the test demonstrate acceptable operation?			X

	Yes	No*	N/A
7) Was the requirement for chemical spray enveloped?	X		
8) Were all known synergisms accounted for in the test sequence?		X	
9) If failures occurred during the test program, are adequate justifications provided in the form of a failure analysis such that the qualification is not negated?			X

b. Normal Service Conditions Analysis

	Yes	No*	N/A
1) Does the aging analysis provided in the supporting documentation provide for a 40-year qualified life at the HBR-2-defined service temperature?		X	
2) Was the aging analysis performed using Arrhenius techniques?		X	
3) Is the aging analysis auditable?		X	
4) Was the radiation requirement accomplished by the radiation test?	X		
5) If any radiation exemptions were utilized, are they auditable?			X
6) Did the equipment perform successfully at the extremes of its normal service conditions (temperature, radiation, pressure, voltage, current, humidity, etc.) as required by IEEE 323-1974 and NUREG-0588?	X		
7) Were the functional tests performed adequate to demonstrate operability parameters as seen in service?	X		
8) Are the acceptance/failure criteria clearly defined?	X		

		Yes	No*	N/A
9)	If failures occurred during the test program, are adequate justifications provided in the form of a failure analysis such that the qualification is not negated?			X
10)	Are all known synergisms accounted for in the test program?	X		

* All questions marked "No" require additional analysis to justify qualification. Section III of this report contains the additional analysis to resolve the qualification deficiencies and justify qualification.

** Radiation tests were performed on a component level. Therefore, the complete motor unit used for other testing was not irradiated prior to DBE testing.

3. CONCLUSIONS AND RECOMMENDATIONS

Reference 1.a fulfills all the requirements of the DOR Guidelines except for those items listed in Paragraph 4 below.

4. OUTSTANDING ITEMS REQUIRING RESOLUTION

- Time-Temperature Effects
- Known Synergisms

Section III of this report contains analyses to address these items.

5. SIMILARITY

The motors qualified in this document are part of a line of motors qualified by Westinghouse through a series of test programs (see Appendix II).

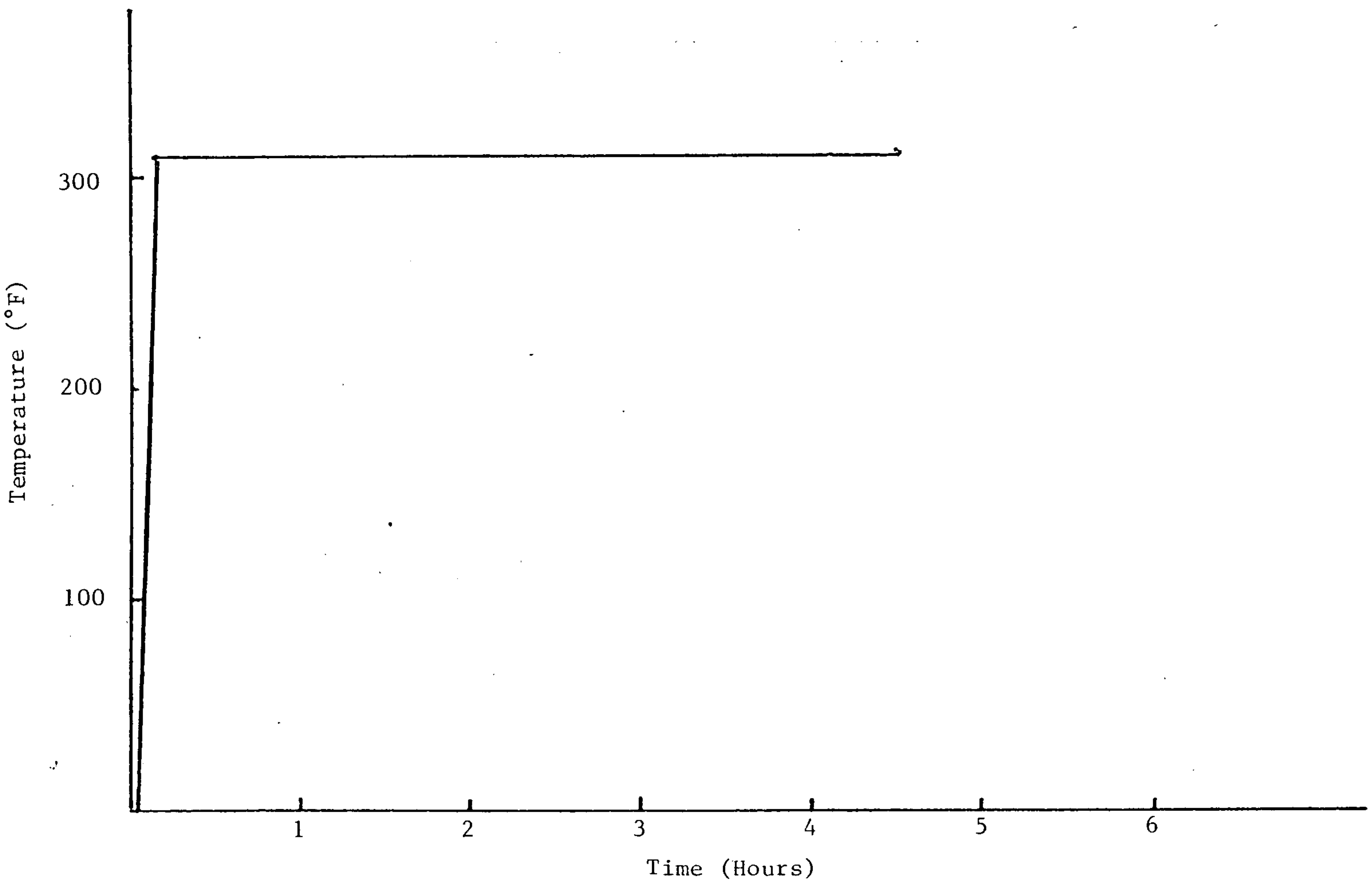

FIGURE 3. TEST PROFILE (GRAPHICAL REPRESENTATION OF DATA FROM TABLE 4 OF APPENDIX I)

SECTION III. QUALIFICATION JUSTIFICATION ANALYSIS

Where qualification parameters are not clearly defined, when new research highlights potential problem areas, or when the plant requirements are not met, analysis must be performed to augment the existing qualification documentation. The intent of this section is to summarize the results of this analysis. From these results, a specific program is recommended, if required, to maintain the qualification status of the Class 1E equipment.

For the fan motors, the following areas were analyzed:

- 1.0 Time-Temperature Effects
- 2.0 Known Synergisms

1.0 TIME-TEMPERATURE EFFECTS

Aging effects on all Class 1E equipment must be considered and included in the qualification program. For time-temperature effects, the present state-of-the-art allows artificial acceleration of these effects associated with organic materials by increasing the temperature. The deterioration due to these effects is judged to be insignificant for metallic materials. Therefore, the aging of the Class 1E equipment will be based on its nonmetallic materials.

For many organic materials, it is known that the degradation process can be defined by a single temperature-dependent reaction that follows the Arrhenius equation (References 1 and 2):

$$k = A \exp(-Ea/k_B T) \qquad (1)$$

where,

k = reaction rate

A = frequency factor

exp = exponent to base e

Ea = activation energy

k_B = Boltzmann's Constant

T = absolute temperature

It is further noted that, for many reactions, the activation energy can be considered to be constant over the applicable temperature range. Equation (1) can be transformed into a form which yields an acceleration factor.

The acceleration factor is defined as t_2/t_1.

The equation is:

$$t_2/t_1 = \exp\left(-(Ea/k_B)(1/T_1 - 1/T_2)\right) \qquad (2)$$

where,

t_1 = accelerated aging time at temperature T_1

t_2 = normal service time at temperature T_2

exp = exponent to base e

Ea = activation energy (eV)

k_B = Boltzmann's Constant (8.617×10^{-5} eV/^{o}K)

T_1 = accelerated aging temperature (^{o}K)

T_2 = normal service temperature (^{o}K)

The transformation of the reaction rate form of the Arrhenius equation to an acceleration form is accomplished as follows:

Life is assumed to be inversely proportional to the chemical reaction rate (References 1 and 2). In terms of life, and after converting to Napierian base logarithm, Equation (1) becomes:

$$\ln(\text{life}) = (Ea/k_B)(1/T) + \text{Constant} \qquad (3)$$

Equation (3) has the algebraic form:

$$y = mx + b \qquad (4)$$

where,

y = ln (life)

x = $1/T$

m = Ea/k_B, constant for single dominant reactions

b = constant

The constants, m and b, can be estimated by fitting experimental data in the form of ln (life) versus 1/T into the above simple linear relationship.

The derivation of an acceleration factor is accomplished by taking the difference between any two points of the linear relationship.

Thus, if we substitute t for life into Equation (3), we obtain:

$$\ln t = (Ea/k_B)(1/T) + \text{Constant} \quad (5)$$

For the set of points (t_1, T_1), Equation (5) becomes:

$$\ln t_1 = (Ea/k_B)(1/T_1) + \text{Constant} \quad (6)$$

For the set of points (t_2, T_2), Equation (5) becomes:

$$\ln t_2 = (Ea/k_B)(1/T_2) + \text{Constant} \quad (7)$$

Subtracting Equation (6) from Equation (7) yields:

$$\ln t_2 - \ln t_1 = (Ea/k_B)(1/T_2) + \text{Constant} - (Ea/k_B)(1/T_1) - \text{Constant} \quad (8)$$

Simplifying and rearranging Equation (8) yields:

$$\ln (t_2/t_1) = -(Ea/k_B)(1/T_1 - 1/T_2) \quad (9)$$

Taking antilogarithm yields:

$$t_2/t_1 = \exp (-(Ea/k_B)(1/T_1 - 1/T_2)) \quad (10)$$

Equation (10) is the same as Equation (2).

The qualified life of the nonmetallics in the equipment is determined by solving Equation (10) for t_2.

$$t_2 = t_1/\exp ((Ea/k_B)(1/T_1 - 1/T_2)) \quad (11)$$

The Containment has two (2) postulated service temperatures during the 40-year service life (see Section I, 2.b., of this report). Therefore, the above equation is modified to:

$$Q.L. = t_1 / \sum_{x=2}^{n+1} P_x \exp((Ea/k_B)(1/T_1 - 1/T_x)) \quad (12)$$

where,

t_1 = aging time

T_1 = aging temperature

T_x = service temperature

P_x = fraction of 40-year life at T_x

exp = exponent to base e

Ea/k_B = activation energy/Boltzmann's Constant

Since, in most cases, it is not practical to independently accelerate the time-temperature effects of each nonmetallic material, a determination is made as to which material has the lowest activation energy. The time-temperature effects are then accelerated based upon the lowest activation energy for conservatism. This assures that the degradation of each age-sensitive component is accelerated to at least the equivalent degradation as that to be encountered during the operating life.

1.1 Specific Analysis of Time-Temperature Effects

The subject equipment was aged prior to the design basis event for 504 hours at 200°C. The nonmetallic materials and their aging mechanisms are the insulation system and lubricant. For the insulation system, using Equation (12):

$$\text{Qualified Life} = t_1 / \sum_{x=2}^{n+1} P_x \exp((Ea/k_B)(1/T_1 - 1/T_x))$$

where,

t_1 = 504 hours

P_x = fraction of 40-year life at T_x

exp = exponent to base e

E_a = 0.99 eV (Reference 6)

k_B = 8.617×10^{-5} (Boltzmann's Constant)

T_1 = $200^{\circ}C$

T_x = service temperature

To account for heat rise associated with the motor operation, the design temperature shall be used. Using the Class A design temperature ($105^{\circ}C$) gives a qualified life of 25 years.

The qualified life of the lubricant is dependent on operating time and speed and is not adequately addressed by the Arrhenius equation. Based on the best available data for a similar grease (Ea = 1.43 - Reference 7), the qualified life at $105^{\circ}C$ is greater than 388 years; however, the manufacturer's recommended maintenance procedures should be followed.

The remaining components of the fan motors, mechanical frame, end bells, shaft, rotor (less windings), and bearings are all metallic in nature and are not subject to any aging due to time-temperature effects, with the exception of the bearings. The subject bearing system is of the rolling ball type. Rolling element bearings are not infinite life devices.

In accordance with AFBMA Standard No. 9, a large group of identical bearings, identically loaded, operated at the same speed, and properly lubricated, will have a failure rate as a function of operating time, not as a function of time-temperature effects. Therefore, a true "qualified life" cannot be established for randomly operated units.

Manufacturers normally recommend that the bearings be treated as a replaceable element by the end user. A maintenance program should be established in accordance with the manufacturer's instruction manual to maintain the bearing and lubrication system qualification.

2.0 KNOWN SYNERGISMS

Two (2) known synergisms were not addressed during the test. They are as follow:

- Radiation prior to thermal aging
- Dose rate effects

An explanation of these known potential synergisms is provided in the following paragraphs.

2.1 Radiation Exposure Prior to Thermal Aging

Testing sponsored by the Nuclear Regulatory Commission (NRC) and reported by Sandia Laboratories (Reference 3) has shown radiation prior to thermal aging to cause some polymers to degrade to a greater extent than when irradiated following thermal aging. The report states that, "The mechanistic postulate is that radiation-cleaved bonds, in the form of radicals, react with oxygen to give degradation products, including peroxides. The peroxides are chemically weak links which are susceptible to thermal cleavage. This thermal peroxide cleavage gives more radicals which, in the presence of oxygen, lead to more degradation and more peroxides. Thermal aging prior to irradiation does not substantially disrupt the polymer's original molecular structure over the normal elevated temperature ranges which, in turn, results in a lesser degree of degradation than may be expected in actual plant applications. Thus, the amplification of the degradation process caused by the thermal peroxide cleavage must be accounted for by performing normal radiation prior to thermal aging.

Subsequent testing by Sandia Laboratories, as reported in SAND 80-2149C (Reference 4), established performing thermal aging after irradiation as the only method in which to account for the strong synergism due to radiation and high temperature found in some polymers. "The joint effect of gamma radiation and elevated temperature was also found to occur when the two environments were applied in a sequential fashion, but <u>only</u> when the experiments were performed in that order--radiation followed by elevated temperature."

2.2 Dose Rate Effects

Testing sponsored by the NRC and reported by Sandia Laboratories (Reference 5) indicates that for some polymers the mechanical damage present for a given total dose is dependent on the dose rate. Testing was performed at $1x10^3$ rads per hour and $1x10^6$ rads per hour. For the polymers tested, it was found that more degradation occurred at the lower dose rate than at $1x10^6$ rads per hour. Specifically, the report states, "Sufficient data has now been accumulated from the low dose rate experiments to indicate that dose rate effects are present for every material which we have studied and must, therefore, be considered before extrapolating high dose rate accelerated simulations to low dose rate ambient conditions."

2.3 Effect on Qualification

The intent of the research documented was to highlight potential aging problem areas between real time and artificially accelerated radiation aging. For Class 1E equipment located in a harsh environment, qualification testing to the postulated normal and accident radiation levels may not degrade the equipment to a level which is indicative of actual degradation experienced in its proposed service life. Surveillance programs or "overtesting" are two (2) methods to account for this effect.

Performing qualification testing at levels in excess of the required level, plus margin, is a common method to account for this synergistic effect. The amount of conservatism normally used is 10%. For the fan motors used at HBR-2, the components were radiation aged to a level 58 times (5,700% above) the requirement. Therefore, it is judged the components were degraded to a level much greater than would be seen in service and no surveillance program would be required.

3.0 REFERENCE AUDITABILITY

In accordance with IEEE 323-1974, the references listed below contain the most applicable data currently available at Patel Engineers and are auditable upon request.

1. "IEEE Guide for the Statistical Analysis of Thermal Life Test Data," IEEE 101-1972, Library Code 102-82.

2. Handbook of Engineering Fundamentals, Wiley, 1975, Library Code 103-82.

3. "A Study of Strong Synergisms in Polymer Degradation," Clough, Gillen, and Salazar, Sandia National Laboratories, SAND 79-092CK, Library Code 104-82.

4. "Radiation - Thermal Degradation of PE and PVC: Mechanism of Synergisms and Dose Rate Effects," R.L. Clough and K.T. Gillen, Sandia National Laboratories, SAND 80-2149C, Library Code 093-82.

5. "Occurrence and Implication of Radiation Dose Rate Effects for Material Aging Studies," K.T. Gillen and R.L. Clough, Sandia National Laboratories, SAND 80-1796C, Library Code 092-82.

6. "Thermalastic Epoxy Insulation for Large AC Motors," Westinghouse Electric Corporation, Application Data 3170, September, 1971, Library Code 283-83.

7. Chevron Teknifax on Chevron SRI Grease, Chevron USA, Inc., G-10, May, 1979, Library Code 157-82A.

SECTION IV. CONCLUSIONS

Based on the comparison of the qualification test documentation to the normal and accident service conditions postulated for Containment, the fan motors are judged to possess a 25-year qualified life at the HBR-2.

This conclusion is based on analyses performed in the following areas:

- Time-Temperature Effects - Based on the lowest activation energy obtained, 0.99 eV, and using the temperatures specified in Paragraph 1.1, Section III, the equipment possesses a qualified life of 25 years.

- Known Synergisms - The test specimen was subjected to radiation after the thermal aging simulation. The two known synergistic effects--radiation prior to thermal aging and dose rate effects--were overcome by a greater than 5,700% margin with a total exposure of 2×10^8 rads gamma, as compared with a requirement of 3.4×10^6 rads gamma.