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Determination of Qualified Life and Post-DBE Aging for the Limitorque Valve Actuators

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1. Introduction

In accordance with regulatory requirement, it is essential to establish an environmental qualification(EQ) for equipment important to safety on nuclear power plants. EQ is a process of providing assurance that safety-related equipment and systems are capable of performing their safety functions in the environments that they must face following a relevant design basis event(DBE). The qualified life is the period of time, prior to the start of a DBE, for which the equipment was demonstrated to meet the design requirements for the specified service conditions. The purpose of this paper is to present that the method of calculation of qualified life and to demonstrate that the Limitorque valve actuators used inside containment on Kori Unit 1 are qualified for forty years of normal service and up to one year DBE/Post-DBE conditions.

2. Methods and Results

2.1 Equipment Identification

The Limitorque valve actuator is a motor driven device that is used to convert rotary motion into linear motion. The Actuators for analysis are SMB series Limitorque valve actuators located inside containment on Kori Unit 1. These actuators are required for up to three days or one year of post-DBE operation depending on their application. For conservatism, one year has been assumed for all actuators in this analysis.

2.2 Environmental Condition

The valve actuators are located in various locations in containment of Kori Unit 1. The DBE environmental parameters for these areas are 286°F, 43 psig and TID 1.2E08 rad[1]. The peak normal service temperature is 140°F(60℃) in the general areas inside of containment.

2.3 Age Sensitive Components

The Limitorque valve actuators are comprised of two major age sensitive components as shown in Table 1 and identified in the Limitorque Report B0058[2].

Table 1. Age Sensitive Components

Age Sensitive Component	Material	Activation Energy(eV)
Motor Insulation	Class RH	1.016
Switch Material	Fiberite	1.78
	Melamine	1.35

2.4 Calculation of Qualified Life

2.4.1. Determination of Activation Energy, Motor Insulation, Class RH

To determine the activation energy (eV), the regression line methodology was used. The regression line is a straight line curve, therefore, any two values could be selected to determine the activation energy. The two values were selected from the Limitorque Test Report B0058[2].

Table 2. Thermal Life of Limitorque RH Moter Insulation

Temperature	Life(hr)
180℃(453 K)	259,324
60℃(333 K)	3,078,799,000

Using the Arrhenius equation in the following form and solving for the activation energy (eV) yields;

$$\Phi = \frac{K \ln t_1 / t_2}{1/T_1 - 1/T_2} = \frac{8.617 \times 10^{-5} \ln 259,324 / 3,078,799,000}{1/453 - 1/333}$$

$$= 1.016 \text{ eV}$$

Where, Φ : Activation energy(eV)
K : Boltzmann's constant(8.617×10^{-5} eV/K)
t1 : Aging time in hours
t2 : Service time in hours
T1 : Aging temperature(K)
T2 : Service temperature(K)

2.4.2. Thermal Aging Analysis for the Switch Materials

The 60℃ ambient is used as the base temperature for this analysis. The switch material would reach its 50 percent property in 3.07E7 hours at 60℃ based on the U.L. information[2]. Dividing forty years by the expected life determines the percent of the life.

Percent of life used at 40 years at 60℃
= 350,400 / 30,700,000 = 1.14%

Forty year life would represent 1.14% of available life at a service temperature of 140°F (60℃). Since degradation is directly proportional to the life, it becomes obvious that degradation would be negligible at an ambient temperature of 60℃ (140°F). Therefore, artificial aging could be disregarded without affecting the results of the qualification. Thus, the analysis presented by Limitorque is considered to be conservative and adequately justifies the exclusion of the switches from thermal aging. The switch materials have a qualified life of 40 years for an ambient temperature as high as 60℃ (140°F).

2.4.3. Thermal Aging Analysis for the Motor Insulation, Class RH

The motors were aged at 180℃ for 100 hours as stated in the Limitorque Test Report 600456[3]. Using a conservative 60℃ ambient as the base temperature, the qualified life for the motor can be calculated using the Arrhenius equation in the following form;

$$QL = t_{age} e^{\frac{\Phi}{K}\left(\frac{1}{T_{ser}} - \frac{1}{T_{age}}\right)} = 100\, e^{\frac{1.016}{8.617\times10^{-5}}\left(\frac{1}{333} - \frac{1}{453}\right)}$$

$$= 1{,}184{,}225 \text{ hr} = 135 \text{ years}$$

The qualified life of these motors is calculated to be greater than 40 years at a normal service temperature of 60℃ (140°F).

2.5 DBE/Post-DBE Evaluation

2.5.1. DBE Evaluation

The plant accident profile for containment, as defined in the Kori Unit 1 EQ Plan is shown in the Table 3. Table 4 summarizes the test profile from the Limitorque Test Report 600456. Figure 1 demonstrates that the Kori Unit 1 containment DBE is enveloped by the Limitorque test profile. The peak temperature was well in excess of 286°F and two transient peaks were applied.

Table 3. Kori Unit 1 Containment Profile

Duration(hr)	2.8E-3	0.275	2.5	21.22	8,736
Temp.(°F)	120	286	250	247.5	166
Pre.(psia)	15.7	57.7	47.7	47.7	24

Table 4. Limitorque Test Profile

Duration(hr)	2.8E-3	0.5	93	624
Temp.(°F)	120	300	250	200
Pre.(psia)	14.7	84.7	44.7	24.7

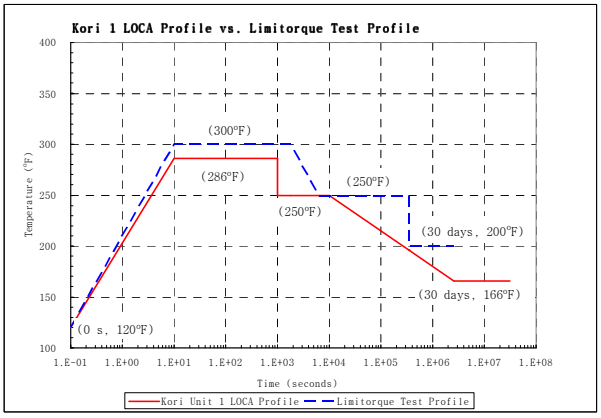

Figure 1. Kori Unit 1 LOCA Profile vs. Limitorque Test Profile.

2.5.2. Post-DBE Evaluation

The Limitorque test profile demonstrates that the thermal degradation experienced by the Limitorque valve actuator during 26 days(624 hours) at 200°F and 69.5 hours at 250°F DBE exposure is equal to or greater than the equivalent thermal degradation which the actuator would experienced during one year of Kori post-DBE operating requirements(166°F). The arrhenius equation was used again to determine the equivalent of thermal service.

$$t_{166} = t_{250} \cdot e^{\frac{\Phi}{K}\left(\frac{1}{T_{166}} - \frac{1}{T_{250}}\right)} = 69.5\, e^{\frac{1.016}{8.617\times10^{-5}}\left(\frac{1}{347.6} - \frac{1}{394.3}\right)}$$

$$= 3{,}853 \text{ hr} = 160.5 \text{ days}$$

And where, test temperature time at 200°F for 624 hours.

$$t_{166} = t_{200} \cdot e^{\frac{\Phi}{K}\left(\frac{1}{T_{166}} - \frac{1}{T_{200}}\right)} = 624\, e^{\frac{1.016}{8.617\times10^{-5}}\left(\frac{1}{347.6} - \frac{1}{366.5}\right)}$$

$$= 3{,}586 \text{ hr} = 149.4 \text{ days}$$

In case of the equipment that have one year mission time, the tested equivalency duration of 7,439 hours(309 days) not exceed the Kori post-DBE requirement of 364 days with 10% margin as required IEEE Standard 323[4]. Therefore, designated life should be calculated.

2.5.2. Post-DBE Evaluation

Cumulative usage factor determines using the arrhenius equation. Cumulative usage factor means exhaustion life at the temperature for the duration of DBE.

Table 5. Cumulative Usage Factor

Temp.(°F)	Duration(hr)	Arrhenius Time	Usage Factor
286	0.28	286.2 hr	9.78E-04
250	2.5	603.0 hr	4.15E-03
166	8,752.2	38,099 hr	2.30E-01
Sum			2.35E-01

As a result of above calculation, cumulative usage factor is 2.35E-01. It means that 23.5% of qualified life is exhausted under the LOCA condition. Using the cumulative usage factor, the designated life for the Limitorque valve actuators can be calculated as follows;

Designated Life = (1-Cumulative Usage Factor) × Arhenius Life at Normal Service Temperature(60℃)

= (1-0.235) × 135 years = 103.3 years

3. Conclusion

Based upon the above evaluation, it is concluded that the SMB series Limitorque valve actuators used inside containment on Kori Unit 1 are qualified for the normal service life of forty years and the postulated DBE/post-DBE conditions up to one year.

REFERENCES

[1] KHNP, "Environmental Qualification Phase Ⅰ of Kori Unit 1," September, 2003.
[2] Limitorque Corporation, Test Report B0058, "Limitorque Valve Actuator Qualification for Nuclear Power Station Service," January 11, 1980.
[3] Limitorque Corporation, Test Report 600456, "Nuclear Power Station Qualification Type Test Report Limitorque Valve Actuator for PWR Service," December 9, 1975.
[4] IEEE Standard 323-1974, "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations," Approved September 4, 1975.