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The Effects of Activation Energy and Reference Temperature on the Qualified Life of Safety-related Equipment

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Abstract. In this paper, the effects of some variable factors on qualified life of safety related equipment in nuclear power plant are investigated analytically. In order to predict an accurate equivalent time during the design basis events (DBE), a loss of coolant accident (LOCA) profile of Shin-Kori unit 1&2 which are based on the OPR-1000 is applied to theoretic analysis. The Arrhenius equation and Romberg's method are used to confirm the equivalent time. Based on the results, the reference temperature does not affect the qualified life, while the activation energy is a key parameter. The results are shown to be used for predicting the accurate qualified life for the equipment qualification test and analysis in the nuclear industry.

Keywords: Environment qualification, Equivalent time, Activation energy,

1 Introduction

At the end of 2016, there are 450 nuclear power reactors in operation and 60 nuclear power reactors are under construction all over the world [1]. To operate the nuclear power plant safely and produce electricity stability, equipment qualification which consists of environmental qualification, seismic qualification, and electromagnetic compatibility is performed. The objective of environmental qualification in nuclear power plant is to demonstrate the safety function of equipment under the service condition such as temperature, pressure, humidity, and radiation, etc [2]. The test of design bases events (DBE), i.e., loss of coolant accident (LOCA) and main steam line break (MSLB), is one of the important processes in environmental qualification. The both domestic and international equipment manufacturer perform the DBE test and validate the result by comparing test condition with LOCA profile of nuclear power plant to supply their equipment.

The objective of the present study is to determine the effect of activation energy and reference temperature on equivalent time of environment qualification. In particular, the Arrhenius equation and Romberg's method are used to evaluate the equivalent time of each profile. The LOCA profile of Shin-kori unit 1&2 is used for the comparison. The equivalent time of DBE test and LOCA profile are suggested according to the variation of activation energy. The results can help to demonstrate

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with reasonable assurance that safety-related equipment for which a qualified life or condition has been established.

2 Mathematical Model

Thermal ageing analysis is one of the representative methodologies to simulate the natural aging condition. Arrhenius equation is generally used to predict the lifetime of equipment in accelerated thermal aging. This methodology can apply to determine the equivalent time in DBE test. The LOCA profile presented in *Figure 1* can be sorted into two parts constant and non-constant temperature region.

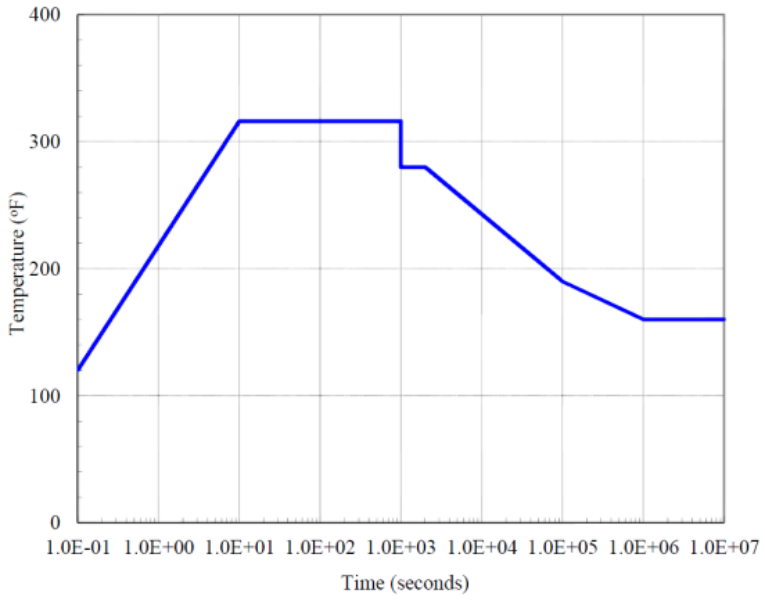


Fig.1. LOCA temperature profile of Shin-kori unit 1&2

2.1 Constant Temperature Region

In constant temperature region, Arrhenius equation is used to calculate equivalent time. Arrhenius equation assumes that a chemical reaction process is controlled by a chemical reaction rate (k), activation energy (E_a), gas constant (R), and temperature (T) [3], as follows:

$$k = \mathrm{A} \times e^{-\frac{E_a}{RT}} \quad \textbf{(1)}$$

The chemical reaction rate at constant temperature region (k_c) is assumed to be the

same value as the reference temperature (k_R), as follows:

$$k_c = k_R \tag{2}$$

Using Eqs. (1)-(2), the equivalent time of constant temperature region (t_{ec}) can be obtained as

$$t_{ec} = t_C e^{\left[\frac{E_a}{R}\left(\frac{1}{T_R}-\frac{1}{T_C}\right)\right]} \tag{3}$$

where t_c, T_R, and T_C are the operating time, reference temperature, and constant temperature, respectively.

2.2 Non-Constant Temperature Regions

The equivalent time of non-constant temperature region (t_{en}) can express as follows:

$$t_{en} = \int_a^b e^{-\frac{E_a}{R}\left[\frac{1}{T_R}-\frac{1}{T(t)}\right]} \tag{4}$$

To solve Eq. (4), a numerical analysis approach by Romberg's method is applied to Arrhenius equation in *Figure 1*, as follows:

$$h_n = \frac{1}{2^n}(b-a) \tag{5}$$

$$R(0,0) = h_1[(a)+f(b)] \tag{6}$$

$$R(\mathrm{n},0) = \frac{1}{2}R(n-1,0) + h_n\sum_{k=1}^{n-1} f[a+(2k-1)h_n] \tag{7}$$

where the function *f* is a temperature variation according to operation time.
Total equivalent time (t_e) of *Figure 1* is obtained by Eqs. (3), (5) – (7) and it can be expressed as follows:

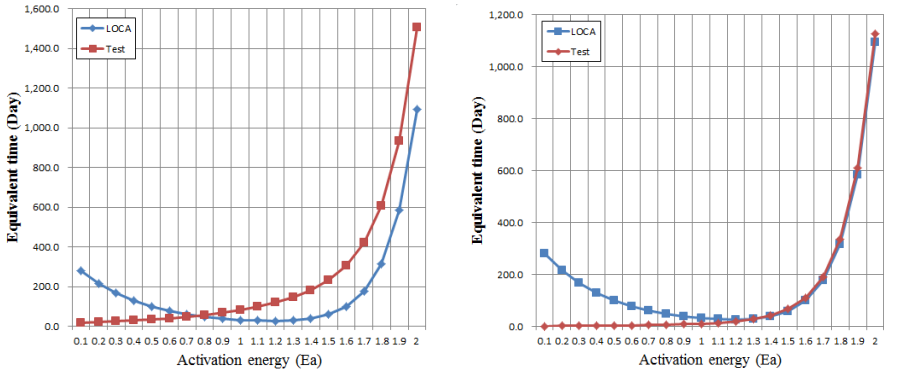
$$t_e = \sum t \times e^{-\frac{E_a}{R}\left[\frac{1}{T_R}-\frac{1}{T(t)}\right]} \tag{8}$$

Margin should be considered in total equivalent time to demonstrate satisfactory performance and normal variation in commercial production and uncertainties in

measurement and test equipment [2]. In this study, to compare the DBE test profile with the LOCA profile of Shin-kori unit 1&2, margin value is set as constant.

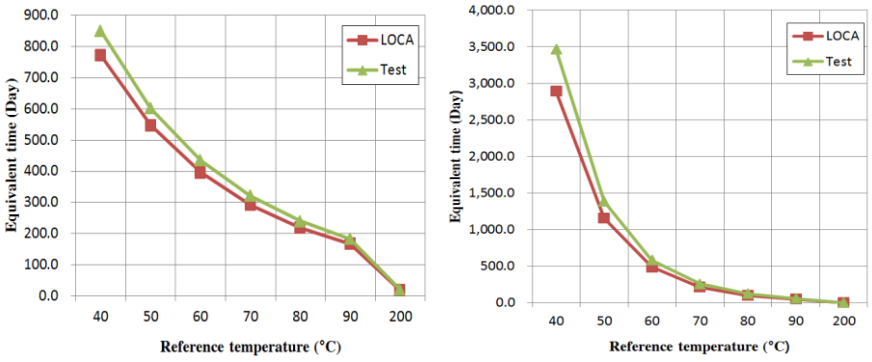
3 Results

Figure 2 shows the variation of equivalent time according to the activation energy. The DBE test profile of *Figure 2* was obtained by using Eqs. (8) with the 19.8% time margin at E_a=0.8 eV. In *Figure 2* (a), there is a big difference of equivalent time between the DBE test profile and LOCA profile as E_a increase or decrease near the 0.8eV. *Figure 2* (b) shows a comparison of equivalent time with the 11.1% time margin at E_a=1.5 eV.



(a)19.8% time margin and E_a=0.8 eV (b) 11.1% time margin and E_a=1.5 eV

Fig. 2. Variation of equivalent time according to activation energy



(a) E_a=0.3 eV (b) E_a=0.8 eV

Fig. 3. Variation of equivalent time according to reference temperature

As the DBE test profile moves to the right in the equivalent time graph, the time difference between DBE test and LOCA profile is decreasing, though the time margin is lower than case (a). It means that there exists a sensitive point on the equivalent time of LOCA profile at which the activation energy and time margin are determined. In other words, these results show how the equivalent time of change with activation energy will vary for LOCA profile. *Figure 3* shows the effect of reference temperature on the equivalent time of DBE test and LOCA profile. Even though reference temperature is changing, the difference of equivalent time between DBE test and LOCA profile is constant.

4 Conclusion

In this study, the effect of activation energy and reference temperature on equivalent time of DBE test and LOCA profile is presented. For this, Arrhenius equation and Romberg's method are used. The results say that the activation energy is a key parameter to obtain the equivalent time on DBE test. In other words, the LOCA profile has its own characteristics on equivalent time according to activation energy. From the results, it provides useful estimation procedure for the environmental qualification at the DBE test.

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