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Study for Prognostics of Primary Side Pipe in Nuclear Power Plants

Hyeonmin Kim[a], Jung-Taek Kim[a], Gyunyoung Heo[b*]

[a] *Korea Atomic Energy Research Institute, 989-111 daedekodaero, Yuseong-gu, Daejeon, Korea*
[b] *Department of Nuclear Engineering, Kyung Hee University, 1732 Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do, Korea*

[*] *Corresponding author: gheo@khu.ac.kr*

1. Introduction

In Korea, 25 nuclear power plant (NPPs) units are operating currently, and 3 NPP units are under construction. Among these units, Kori Unit 1 commenced operations in 1978, and after 30 years of operation, which is the unit's design lifetime, its continuous operating was licensed for 10 years in 2008. Moreover, Kori Unit 1 will be closed in 2017. From the status of this NPPs, other NPPs will be evaluated in series for continuous operating in series. Currently, the assessment is based on generic data from an empirical equation and on historical data, which is used for testing the integrity of NPPs.

In the case of OPR-1000, which is the Korea standard NPPs, it has primary side and secondary side to prevent the leakage of radiation sources. The primary side consists of a core, a steam generator, a pump, a pressurizer, and piping. The secondary side consists of a turbine cycle. Specifically, the primary side of the NPPs is weakened under harsh conditions such as high pressure, high temperature, and high radiation. In addition, loss-of-coolant accident (LOCA), which breaks the primary piping, is considered as a major accident, and its occurrence can result in a severe accident [1]. As mentioned previously, most NPPs have been operating in Korea for a long time, and it is predictable that NPPs operating for the same number of years would result in varying extent of aging and degradation. Thus, it is essential to reflect aging as a characteristic of each NPPs, and this is performed through prognostics.

The prognostics can consider each characteristic and estimate the remaining useful lifetime (RUL) by integrating information of conventional reliability and monitoring data. In previous studies, general path model (GPM)/Bayes method that is data based method was used to predict the integrity of steam generator tubes [2]. In this study, particle filter that is physics based method is considered for predicting the integrity of primary piping, and a physics equation for primary piping obtained from PINTIN (Piping INTegrity Inner Flaws) has been developed to determine the failure probabilities of structural components. In addition, this research demonstrates feasibility by offering a new assessment method.

2. Method

In this chapter, assessment for primary side pipe and prognostics algorithm is explained. The target pipe is hot leg of a Pressurized Water Reactor (PWR), therefore, properties of hot leg are referred. In addition, the particle filter which is physics based method of prognostics is used.

2.1 Assessment for primary side pipe

The hot leg in NPPs calls higher temperature pipe that flows heated coolant by core. The material for hot leg is stainless steel and weld joint material is alloy. The stress value for crack propagation and analysis in hot leg was used as below.

$$\sigma_{\min} = \sigma_{DW}(Deadweight) = 14.34MPa$$
$$\sigma_{\max} = \sigma_{N_0} = \sigma_P + \sigma_{DW} + \sigma_{TE} = 340.33MPa$$

The available data on fatigue crack growth in 304 stainless steel was reviewed, including the influence of temperature, environment and mean load effects. Within a scatter band of about one order of magnitude on crack growth rate, it was found that the could be represented by the following equations.

$$\frac{da}{dN} = C\left[\frac{\Delta K}{(1-R)^{1/2}}\right]^m \quad \text{(Eq. 1)}$$

$$C = \ln N(\mu, \sigma^2)$$
$$m = N(\mu, \sigma^2) \quad \text{(Eq. 2)}$$

Where, $\Delta K = K_{\max} - K_{\min}$

$R = K_{\min} / K_{\max}$

The scatter in the data represented by a lognormal value of C with a median of $2.11E-13$ and standard deviation of $5.09E-12$ (where da/dN is meter per cycle per $Pa\sqrt{m}$). The value m represented as 4.

For the weld joint, crack growth rate was represented by the following equation. In addition, experimental parameter represented by a lognormal value C with a median $2.08E-11$, standard deviation $5.09E-10$ and m with a 3.2421.

$$\frac{da}{dN} = C\Delta K^{m} \qquad \text{(Eq. 3)}$$

2.2 Particle Filter

Particle filter is the most widely used in prognostics, particle filter represents posterior distribution of parameter model with finite particle (or sample) and their weights. As Bayesian method, Bayesian method is repetitively performed every time data is measured. Particle filter consists of the following three stages.

1. At the prediction stage, posterior distribution of the previous step is used as prior distribution of the present step. This calculates preliminary posterior distribution at the present point of time through aged deterioration model.
2. The distribution measured at the update stage is calibrated, specifying the weights based on data likelihood measured at the present point of time.
3. At the resample stage, samples are redistributed through the overlapping or removing process of those samples that set the weight.

Figure 1 described that is the data that visualizes the calculating process of particle filter. This shows that the weight is given to the values measured through a few particle options applied into formulas, and that the value on which weight is placed is equivalent to the estimated value at the next stage.

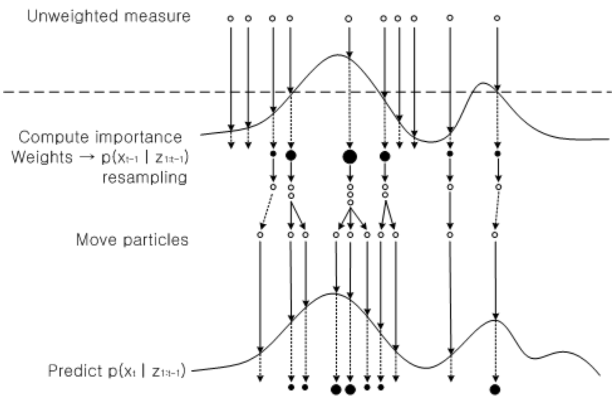

Figure 1. Particle filter visualization

3. Results and Conclusions

As mentioned above, the behavior for stainless steel and alloy were represented as figure 2 and 3.

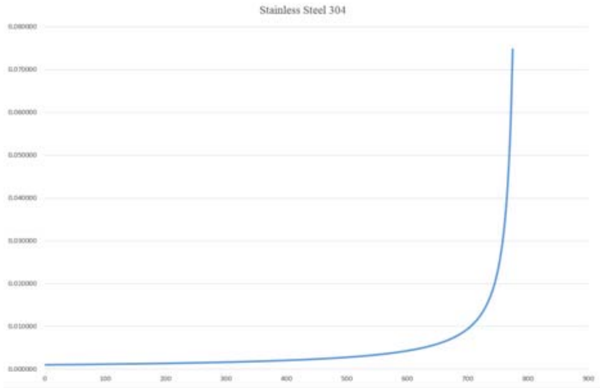

Figure 2. Behavior of Crack growth for hot leg (stainless steel 304)

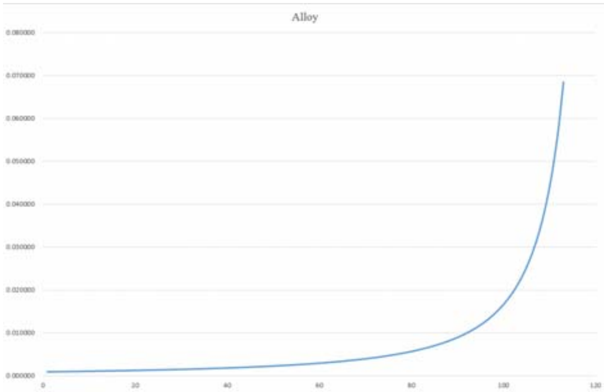

Figure 3. Behavior of Crack growth for hot leg (Alloy; weld joint)

In this paper, prognostic for primary side in NPPs was studied. The prognostics can consider each characteristic and estimate the RUL by integrating information of conventional reliability and monitoring data. In this study, particle filter that is physics based method is considered for predicting the integrity of primary piping, and a physics equation for primary piping obtained from PINTIN has been developed to determine the failure probabilities of structural components. In addition, this research demonstrates feasibility by offering a new assessment method. For the further study, prognostics depending monitoring data will be studied.

REFERENCES

[1] Z. Mohaghegh. et al., Risk-Informed Resolution of Generic Safety Issue 191, ANS PSA 2013 International Topical Meeting on Probailistic Safety Assessment and analysis, 2013.

[2] H. Kim, S.H. Lee, J.S. Park, H. Kim, Y.S, Chang, G. Heo, Reliability data update using condition monitoring and prognostics in probabilistic safety assessment, Nuclear Engineering and Technology, Vol.47, p. 204-211, 2015.