Determination of Degradation Acceptance Criteria for Structures and Passive Components in Nuclear Power Plants

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1. Introduction

The rate of age-related degradation of structures and passive components (SPCs) in nuclear power plants (NPPs) is not significantly large, but increases as the plants get older. Since the degradation of the SPCs always increases the risk of NPPs, in light of long-term operation, it is necessary to determine acceptable levels of degradation for effective inspection and maintenance.

In contrast to degraded active components, degraded SPCs may not impose an immediate threat to plant safety during normal operation. However, it can be a dramatic safety threat during the low probability of high consequence events, such as large earthquakes.

This paper presents a procedure for a determination of degradation acceptance criteria (DAC) for SPCs in NPPs, based on the potentially increased seismic risk to the plant owing to a degradation of SPCs.

2. Aging-Related Degradation Occurrences

The average number of degradation occurrence records (DORs) per plant increases as the plant gets older, with a slightly higher rate for older plants as shown in Fig. 1 [1], which is plotted using information obtained from Licensing Event Reports (LERs) of the US NPPs.

By the two trend lines in Fig. 1, the older plants (LER 1999-2007) appear to have about 3-times greater average DORs than younger plants (LER 1985-1997). This observation shows that the degradation of SPCs may be more significant in older plants for maintaining the plant safety.

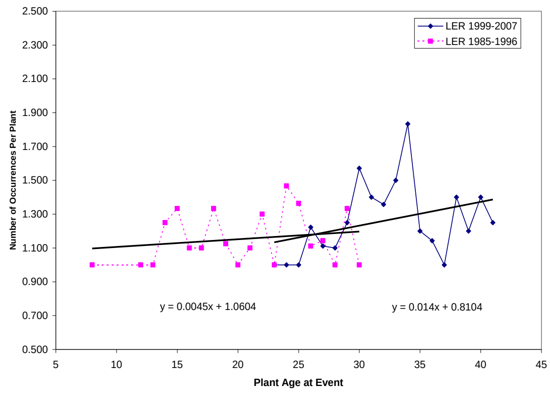

Fig. 1. Average degradation occurrences with plant age at event frequency [1]

3. Acceptance Guidelines

U.S. NRC Regulatory Guide 1.174 [2], which shows a risk-informed decision approach on plant-specific changes, provides two sets of acceptance guidelines for core damage frequency (CDF) and large early release frequency (LERF), respectively.

3.1 Acceptance Guidelines for Core Damage Frequency

Fig. 2 shows the acceptance guideline for CDF-based risk-metrics. Guidelines applicable to the DAC are summarized as follows:

- When ΔCDF < 10^{-6}/reactor year (RY) (Region III), acceptable regardless of whether there is a calculation of the total CDF. However, if there is an indication that the CDF may be considerably higher than 10^{-4}/RY, the focus should be on finding ways to decrease rather than increase it.
- When 10^{-6} < ΔCDF < 10^{-5}/RY (Region II), acceptable only if the total CDF < 10^{-4} /RY.
- When ΔCDF > 10^{-5}/RY (Region I), normally not allowed.

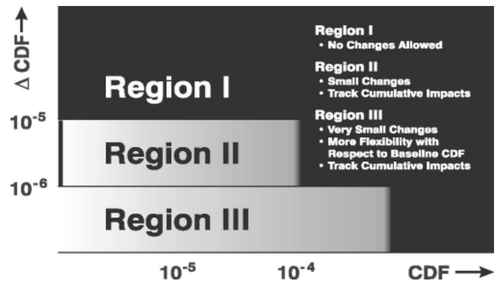

Fig. 2. Acceptance guidelines for core damage frequency [2]

3.2 Acceptance Guidelines for Large Early Release Frequency

Fig. 3 shows the acceptance guideline for LERF-based risk-metrics. Guidelines applicable to the DAC are summarized as follows:

- When ΔLERF < 10^{-7}/RY (Region III), acceptable regardless of whether there is a calculation of the total LERF. However, if there is an indication that the LERF may be considerably higher than 10^{-5}/ RY, the focus should be on finding ways to decrease rather than increase it.
- When 10^{-7} < ΔLERF < 10^{-6}/RY (Region II), acceptable only if the total LERF < 10^{-5} /RY.
- When ΔLERF > 10^{-6}/RY (Region I), normally not allowed.

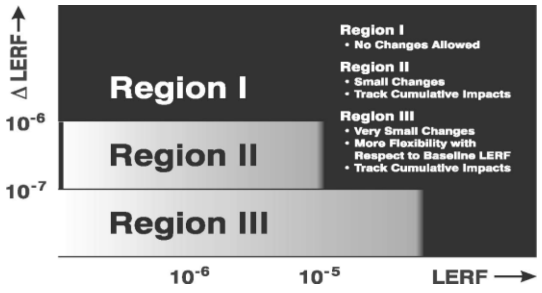

Fig. 3. Acceptance guidelines for large early release frequency [2]

4. Degradation Acceptance Criteria

For simplicity in the development of DAC for SPCs, only $\Delta CDF_{cr} = 10^{-6}$/RY is used in this study [3].

4.1 Development of Three-Tier DAC

The relationships between the levels of degradations, fragility estimates, and CDF estimates are often smooth enough up to the ΔCDF_{cr}, so that a fragility analysis and PSA can be performed conveniently in two steps avoiding the iterations, and the determination of DAC corresponding to the ΔCDF_{cr} can be obtained through proper interpolation. Therefore, a fundamental procedure for the development of the DAC for an SPC includes three major steps:

(1) Develop a range of fragility values of the subject SPC that various levels of degradation can potentially result in.
(2) Perform PSAs of the plant using these fragility values to obtain a range of corresponding CDFs.
(3) Interpolate the fragility-CDF curve using $\Delta CDF_{cr} = 10^{-6}$/RY to determine the critical fragility capacity, F_{cr}.

4.2 DAC Application to Condensate Storage Tank

Three basic degradation scenarios are considered for a Condensate Storage Tank (CST): (a) corrosion in stainless tank shell, (b) corrosion in anchor bolts, and (c) cracking of the reinforced concrete foundation. Fig. 4 can be obtained through a full-scope PSA using fragility values for the three degradation cases.

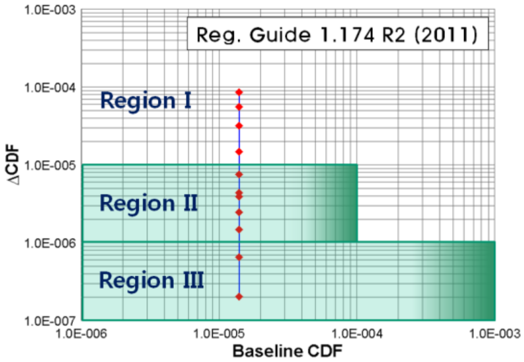

Fig. 4. ΔCDF and risk acceptance guidelines

Fig. 5 summarizes the relationship between the three-tier DAC and ΔCDF_{cr} for the CST [3]. Tier 1 DAC_{HCLPF} was determined by the dominant failure mode (sliding) [4]. Tier 2 DAC_D was developed for the three individual degradation scenarios. Tier 3 DAC_T was defined for the three individual degradation scenarios and the cases of correlated degradation scenarios.

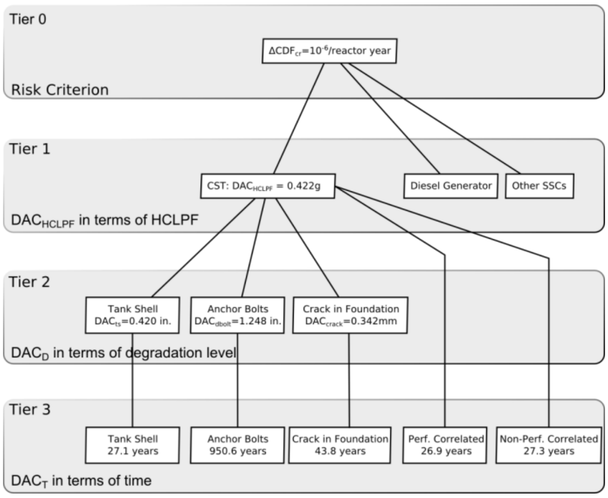

Fig. 5. Summary of DAC for age-related degradation of CST [3]

5. Conclusions

A simple procedure to determine DAC for NPPs was developed based on the U.S. NRC RG 1.174 using $\Delta CDF_{cr} = 10^{-6}$/RY. The proposed procedure can be effectively used for the aging management of old NPPs.

The current practice of PSA may not have sufficient emphasis on representing the degradation status. The PSA model used to calculate the CDFs should represent adequately the as-degraded plant condition. Also, a proper consideration of multiple degraded components in a plant should be explored in the future.

REFERENCES

[1] I.K. Choi, Y.S. Choun, M.K. Kim, J. Nie, J.I. Braverman, C.H. Hofmayer, Identification and Assessment of Aging-Related Degradation Occurrences in Nuclear Power Plants, Nuclear Engineering and Technology, Vol.44, No.3, pp.297-310, 2012.

[2] Regulatory Guide 1.174, An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis, Revision 2, Nuclear Regulatory Commission, Washington, DC.. 2011.

[3] J. Nie, J.I. Braverman, C.H. Hofmayer, Y.S. Choun, D. Hahm, I.K. Choi, A Procedure for Determination of Degradation Acceptance Criteria for Structures and Passive Components in Nuclear Power Plants, BNL-96775-2012, KAERI/TR-4422/2011, 2012.

[4] Y.S. Choun, M.K. Kim, I.K. Choi, J. Nie, J.I. Braverman, C.H. Hofmayer, The Seismic Fragility Analysis of a Condensate Storage Tank with Age-Related Degradation, Transactions of the Korean Nuclear Society Spring Meeting, pp.783-784, 2011, Taebaek, Korea.