Risk-Based Approach for Determining Shutdown of Operating Nuclear Power Plants in an Earthquake

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1. Introduction

On September 12, 2016, a magnitude 5.8 earthquake occurred about 27 km from the Wolsong nuclear power plant (NPP) in Gyeongju. This earthquake caused all nuclear power units operating at the site to be shut down.

For the 2016 Gyeongju earthquake, the peak ground acceleration (PGA) of the free-field ground motion was 0.0832 g, and the acceleration response spectral value at frequency 7.1 Hz was 0.3330 g in Wolsong units 2, 3, and 4. Since the Wolsong NPP was designed to 0.2 g, which is a safe shutdown earthquake (SSE) level, and the operating basis earthquake (OBE) level is 0.1 g, the PGA value of the ground motions was lower than that of the OBE ground motion. However, because the spectral acceleration value was higher than 0.285 g, which is the OBE spectral acceleration value, four units were manually shut down in accordance with Korean regulatory guidelines [1].

Current guidelines for determining the shutdown of an operating NPP in an earthquake event are based on key earthquake parameters such as PGA and response spectra. Since these parameters are not directly related to the safety of NPPs, the current guidelines may be conservative for some earthquake events. Equipment can be slightly damaged by an earthquake, but the impact of the damage on plant safety can be ignored.

This paper describes a risk-based approach in determining plant shutdown for an earthquake event.

2. Current Shutdown Criteria

Shutdown of an operating NPP is determined based on the OBE exceedance criterion or observed damage to its structures, systems, and components (SSCs).

The determination of whether the OBE has been exceeded should be conducted by a comparison of the ground and structure motion parameters with the OBE exceedance criterion. According to current guidelines, the OBE shall be considered to have been exceeded if the following hold [2]:

- PGA Check: For the free-field ground motion at the site, check whether any one of three PGA values of the three components (two horizontal and one vertical) has exceeded the OBE peak horizontal ground acceleration for the site.
- Response Spectrum Check: The OBE response spectrum is exceeded if any one of the three components of the 5 percent of critical damping response spectra generated using the free-field ground motion is larger than the following:
  - The corresponding design response spectral acceleration (OBE spectrum if used in the design, otherwise 1/3 of the SSE spectrum) or 0.2g, whichever is greater, for frequencies between 2 and 10 Hz, or
  - The corresponding design response spectral velocity (OBE spectrum if used in the design, otherwise 1/3 of the SSE spectrum) or a spectral velocity of 6 in/s (15.24 cm/s), whichever is greater, for frequencies between 1 and 2 Hz.

When either check exceeds the OBE exceedance criterion, the plant must be manually shut down. Even if the OBE has not been exceeded, when damages are found in plant facilities during an operator's walkdown inspections, the plant should also be shut down by the safe shutdown procedure.

3. Risk-Based Acceptance Guidelines

The U.S. NRC Regulatory Guide 1.174 [3], which shows a risk-informed decision approach on plant-specific changes, provides two sets of acceptance guidelines; one for core damage frequency (CDF) from level 1 PSA (Probabilistic Safety Assessment) and another for large early release frequency (LERF) from level 2 PSA. This paper discusses only CDF criteria because LERF analysis is not performed. Figure 1 shows the acceptance guidelines for CDF-based risk metrics. The guidelines are summarized as follows:

- If the application clearly shows a decrease in CDF, the change has satisfied the relevant principle of risk-informed regulation with respect to CDF. The region associated with such a change is not explicitly indicated in Fig. 1 because the figure uses a logarithmic scale.
- When the calculated increase in CDF (ΔCDF) < 10^{-6} /Reactor Year (RY) (Region III), this is 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), this is acceptable only if the total CDF < 10^{-4} / RY.
- When ΔCDF > 10^{-5}/ RY (Region I), this is normally not allowed.

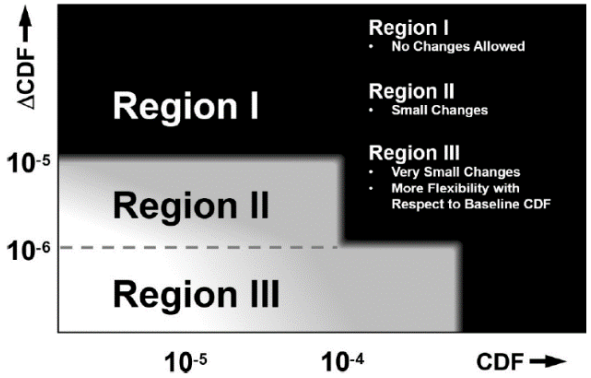

Fig. 1. Acceptance guidelines for core damage frequency. [3]

4. Risk-Based Shutdown Procedure

In a risk-based shutdown approach, plant shutdown is determined by increased risk (ΔCDF) due to damage to safety-related (SR) SSCs in the event of an earthquake. In fact, the SR SSCs designed to withstand a SSE are hardly damaged by OBE ground motion. Nevertheless, current guidelines require the reactor to be shut down when the peak acceleration or response spectrum of ground motions recorded at the plant site exceeds the OBE criteria. Current shutdown criteria are conservative.

Current plant shutdown criteria are based on seismic parameters, while risk-based procedures are based on the impact of earthquakes on plant risk.

Figure 2 shows the risk-based reactor shutdown procedure proposed in this paper. When an earthquake is detected at the plant site, operators must immediately investigate the plant's condition and analyze the ground motion recorded at the site to determine whether a reactor shutdown is necessary. At the same time, operators must perform walkdown inspections to collect damage data from preselected SSCs [2]. Earthquake and damage levels are estimated based on ground motion analysis and walkdown inspection results. Structural and mechanical engineers then evaluate the residual capacity of the safety-related SSCs based on earthquake ground motion and damage levels. If the estimated residual capacity is above the acceptable capacity, the fragility parameters for the damaged SSCs should be determined. On the contrary, if the estimated residual capacity is less than the acceptable capacity, the reactor must be shut down manually. New CDF and ΔCDF are obtained as a result of seismic PSA performed using modified fragility parameters. Finally, risk-based acceptance guidelines determine whether the reactor will shut down or continue operating.

5. Conclusions

A risk-based plant shutdown procedure was proposed for an earthquake event. The risk-based approach shows staff and operators how an earthquake can affect plant safety. Quantified information can be used to determine whether or not to shut down the reactors. The application

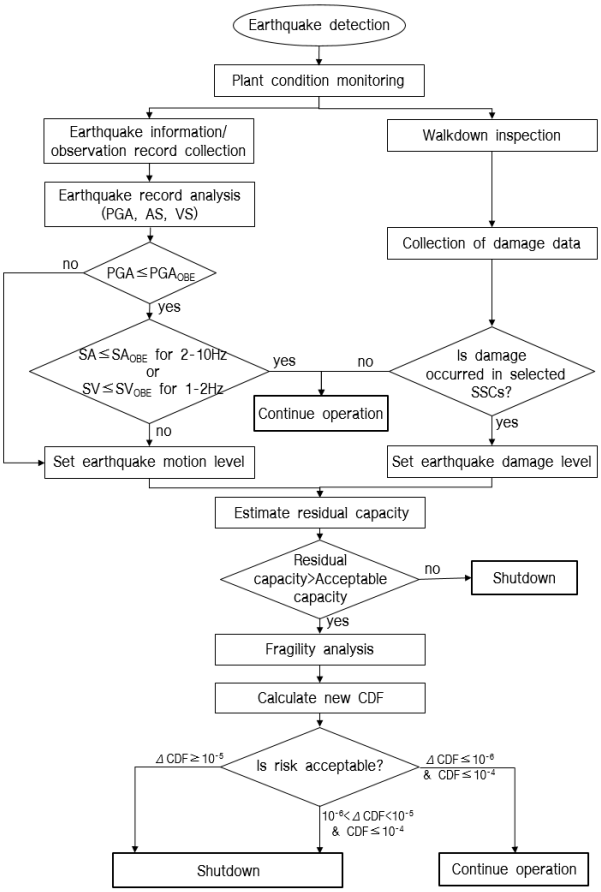

Fig. 2. Risk-based reactor shutdown procedure.

of a risk-based approach to NPPs requires guidelines to define earthquake levels and damage levels, and requires techniques to assess SSC damage caused by earthquakes and to estimate their remaining performance.

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