

Considerations for Implementing Earthquake Response Guidelines to Nuclear Power Plants

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1. Introduction

Over the past four decades, operating nuclear power plants (NPPs) have frequently experienced shutdowns from earthquakes exceeding their operating basis earthquake (OBE) or safe shutdown earthquake (SSE) levels. For instance, V.C. Summer in 1978 and 1979, Perry in 1986, Clinton in 1987, and North Anna in 2011 in the US, and Onagawa in 2003 and 2005, Shika in 2007, Kashiwazaki-Kariwa in 2007, and Hamaoka in 2009 in Japan have been shut down due to earthquakes. For the first time in Korea, four units of the Wolsung NPPs have experienced a manual shutdown due to the 2016 Gyeongju earthquake of M5.8 because the peak ground acceleration (PGA) of the ground motions that were recorded at the plant site during the earthquake exceeded the OBE acceleration.

Based on this experience in Korea, the Nuclear Safety and Security Commission (NSSC) has decided to revise an earthquake reporting system. To prepare for a large earthquake, the Commission added immediate reporting, within 30 minutes, to the current two-stage reporting system (i.e., detailed oral reporting after safety measures), and shortened the decision-making time for a manual shutdown from 4 hours to 2 hours. Therefore, current guidelines for a plant response to an earthquake must be implemented for a rapid evaluation and decision-making at the plant site. A direction of implementation is discussed in this paper.

2. Guidelines for Pre-Shutdown Actions

Guidelines for short-term actions after an earthquake include a determination of the immediate effects of an earthquake on an NPP and an evaluation of OBE and SSE exceedance. Shutdown of the plant is determined based on the OBE exceedance criterion or observed damage to its structures, systems, and components (SSCs) by operators and other on-site personnel.

2.1 Immediate Actions

Operators should respond to plant alarms and other immediate effects of the earthquake in accordance with approved plant operating procedures, abnormal operating procedures, emergency operating procedures, and operating technical guidelines. As part of the operator response to the earthquake, the specific control room check should be made as described in Appendix D of KINS/RG-N04.18 [1]. Some of them are as follows:

- Primary coolant and secondary system radiation, temperature, pressure, and flow parameters for changes and excursions coincident with the earthquake. This includes sampling and analysis of primary and secondary coolant.
- Primary coolant loose parts monitoring system for changes in noise levels and signatures.
- Control and/or instrumentation trips/upsets to safety-related and non-safety-related SSCs, and any evidence of equipment and system malfunctions.
- Rotating equipment vibration monitoring sensors for changes.
- Indications of fluid levels in important low-pressure storage tanks.

2.2 Operator Walkdown Inspections

Operators and on-site personnel who are familiar with the pre-earthquake physical condition of plant SSCs should do a walk down and visual inspection to determine the effects of the earthquake on the physical condition of the SSCs. It is recommended that specific guidance for the plant operators be included in the plant-specific response procedure, based on the inspection items as described in Appendix E of KINS/RG-N04.18 [1]. For example,

- Check for leaks in piping systems, especially at flanged or threaded connections and branch lines.
- Check for damage to low-pressure tanks, particularly ground or floor mounted vertical storage tanks.
- Check for damage to switchyard equipment.
- Check the condition of a sampling of equipment anchorages, including deformation or loosening of the anchor bolts, pullout or shear of anchor bolts, rocking, sliding, or misalignment of equipment.
- Check for major cracks or spalling in reinforced concrete structures. Hairline cracks in reinforced concrete structures are not considered significant.

2.3 Determination of OBE Exceedance

The determination of whether the OBE has been exceeded should be conducted by a comparison of the ground/structure motion parameters (i.e., PGA, acceleration response spectra) with the OBE exceedance criterion within two hours following the earthquake [1].

The OBE shall be considered to have been exceeded if the following hold.

- 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.

2.4 Decision on Plant Shutdown

If the OBE exceedance criterion has been fulfilled, the plant should be manually shut down after pre-shutdown inspections. If the OBE has not been exceeded and plant damage is found during the operator walkdowns, the plant should be shut down by the safe shutdown procedure. A manual shutdown of the plant should be done within four hours following the earthquake [1].

The plant should be shut down if the operator walkdown inspections discover damage. The evaluation of the inspections should be completed within eight hours following the earthquake.

If the OBE was not exceeded and the operator walkdown inspections indicate no damage to the NPP, shutdown of the plant is not required.

3. Considerations for Implementation of the Guidelines to the Plants

The determination of whether the plant-specific OBE has been exceeded should be done within two hours and the plant should be manually shut down based on pre-shutdown inspections within four hours following the earthquake. Therefore, for a reliable decision-making in a limited time after an earthquake, it is recommended that the plant-specific abnormal operating procedures be applicable to the plant and provide adequate technical information for operators and on-site personnel.

The following are recommended for a preparation of the plant-specific earthquake response procedures.

- The OBE exceedance criteria at the plant must be established based on the site-specific ground motions. The CAV (Cumulative Absolute Velocity) check can also be considered as the OBE exceedance criterion, as shown in the US NRC Regulatory guide [2] and EPRI technical report [3].
- Operators' immediate actions can be classified based on the earthquake level.
- The operator walkdown procedure can be prepared for efficient inspections.
- The number of items for pre-shutdown inspections can be minimized.
- The vulnerable SSCs can be classified based on the earthquake level.
- Failure modes and the damage level of vulnerable SSCs can be presented based on the earthquake level.
- The remaining seismic capacity for the damaged SSCs can be predicted.
- The correlation factors between the damage level of vulnerable SSCs and the plant safety can be provided.

4. Conclusions

The revised plant response guidelines to an earthquake require a rapid decision-making. The OBE exceedance should be evaluated within two hours and a manual shutdown of the plant should be determined within four hours following an earthquake.

To satisfy these requirements, it is recommended that adequate and plant-specific technical information be provided for operators and on-site personnel to estimate the physical conditions of vulnerable SSCs and determine if a shutdown of the plant is required.

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REFERENCES

- [1] KINS, Pre-earthquake Planning and Immediate Post-earthquake Actions for Nuclear Plant Operator, KINS/RG-N04.18, Rev.2, Korea Institute of Nuclear Safety, Daejeon, 2017. (Korean)
- [2] USNRC Regulatory Guide 1.166, Pre-earthquake Planning and Immediate Nuclear Plant Operator Post-earthquake Actions, U.S. Nuclear Regulatory Commission, Washington, DC, 1997.
- [3] EPRI Report 3002005284, Guidelines for Nuclear Power Plant Response to an Earthquake, Electric Power Research Institute, Palo Alto, CA, 2015.