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Seismic Considerations in the Replacement of RPS Safety Parameter Indicators

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1. Introduction

HANARO is a research reactor located in Daejeon, South Korea. It stands for "High-flux Advanced Neutron Application Reactor" and serves a variety of purposes, including basic and applied research in material science, biotechnology, and environmental science, as well as the production of radioactive isotopes for medical and industrial applications [1]. Since achieving initial criticality in 1995, many of HANARO’s original instrumentation and control systems have become outdated. As a result, these systems are currently being replaced with modern alternatives. Among them, instrumentation and control components associated with safety-related parameters must adhere to seismic regulatory requirements to ensure continued operational integrity.

This paper explores replacement options for pressure, flow, and temperature indicators used to monitor safety-related parameters. Additionally, it analyzes their compliance with seismic regulatory standards and outlines a structured approach for seismic testing.

2. Seismic Compliance and System Upgrade

In this section, we introduce the selected replacement product, review the seismic analysis of the existing Reactor Protection System (RPS) report, and provide a detailed seismic qualification procedure for the replacement product.

2.1 Need for Replacement and System Overview

The Reactor Protection System (RPS) of HANARO is designed to automatically shut down the reactor when predefined safety limits are exceeded, thereby preventing nuclear fuel damage and mitigating the risk of radiation exposure to personnel and the surrounding environment. It also plays a crucial role in safeguarding reactor integrity by maintaining essential safety functions across various environmental conditions, including seismic events. To ensure operational reliability and compliance with safety standards, all instrumentation and control components within the RPS must meet Seismic Class 1 requirements. This classification guarantees that even under the extreme conditions of a design basis accident, the system can maintain its safety shutdown function, thereby upholding the highest levels of quality, reliability, and structural integrity.

Among the instruments utilized in HANARO, the indicators for reactor outlet temperature, coolant flow rate, and primary cooling system pressure were originally supplied by the overseas manufacturer DIXSON. Since the initial operation of HANARO, these components have not been replaced. As they reached the end of their design life, replacement became necessary; however, all models had been discontinued, requiring the selection of suitable alternatives. The replacement process focused on key factors such as ensuring long-term maintenance feasibility, prioritizing domestically manufactured products to improve supply chain stability, and meeting stringent safety and seismic classification standards. These considerations were crucial in maintaining the reliability, regulatory compliance, and operational integrity of the updated instrumentation.

2.2 Review of Seismic Report

The three types of indicators were installed inside the RPS cabinet and subjected to seismic testing. The seismic qualification test was performed on the entire RPS system at an elevation of 85.55 ft, which corresponds to the installation height of the RPS. Accelerometers were strategically placed at key locations to capture seismic responses during the test.

Figure 1 illustrates the front layout of the RPS, showing the placement of installed devices and the positions of accelerometers used in the seismic test [2]. The three types of indicators were installed at positions 4, 5, 6, and 7, and for equipment replacement purposes, the accelerometers at these locations were used to derive the Required Response Spectrum (RRS) of the newly installed indicators based on the In-structure Experimental Response Spectrum (IERS). When IERS data was unavailable at a given location, conservative values from adjacent positions—specifically 4X, 5Y, and 7Z—were selected to ensure a robust evaluation.

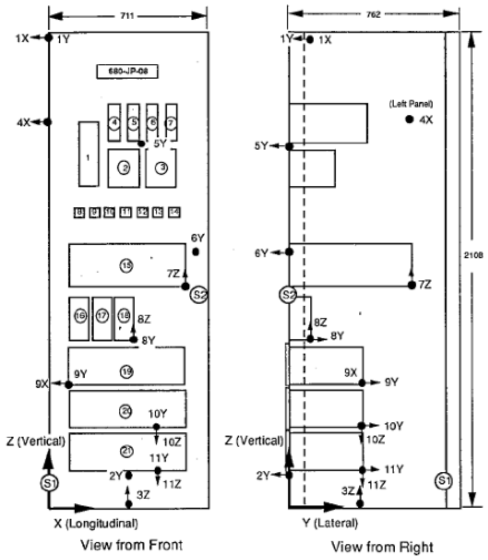

Figure 1 Equipment Arrangement & measuring points of RPS

To verify functional performance during the seismic test, the output voltage of the indicators was continuously monitored to assess whether they maintained operational stability under seismic conditions. The resonance search test was conducted within the 1~50 Hz frequency range using a sine sweep excitation at 0.1g acceleration, allowing the dynamic characteristics of the RPS to be analyzed.

The seismic test applied damping values of 2% for OBE (Operating Basis Earthquake) and 5% for SSE (Safe Shutdown Earthquake), in accordance with Regulatory Guide 1.61. A 6-degree-of-freedom Random Multi-Frequency (RMF) test was performed, confirming that the Test Response Spectrum (TRS) fully encompassed the RRS in all cases such as Figure 2 [2]. Additionally, the cross-correlation function was verified to be below 0.3, ensuring that the seismic excitation was appropriately applied throughout the test.

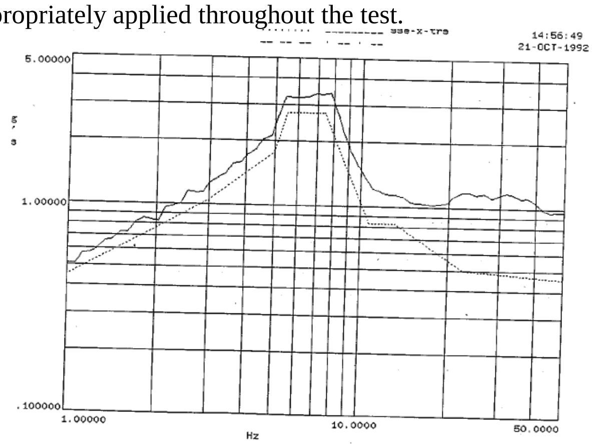

Figure 2 Result of Resonance Search test Y-dir [2]

2.3 Seismic Standards and Testing Approach

The HANARO indicators to be replaced are manufactured by Woojin Co., Ltd illustrated Figure 3. These microprocessor-based digital instruments provide operators with accurate real-time operational data through high-luminance bar graphs and digital numerical indicators [3].

Figure 3 External View of New Indicators [3]

They receive electrical signals ranging from 4~20 mA or 0~10 V from transmitters or process controllers, which are then converted into digital values through A/D processing and scaled into corresponding engineering units. Additionally, these indicators offer over-range and under-range status information, ensuring enhanced operational awareness and system reliability.

The seismic qualification of these indicators must comply with IEEE Std 344-1987, which establishes the seismic qualification requirements for electrical and mechanical equipment in nuclear power plants. This standard ensures that safety-related equipment maintains structural integrity and operational functionality under seismic excitation, preventing failures that could compromise reactor safety.

To verify compliance, these indicators must undergo seismic testing and analytical evaluation based on the interpretation of existing seismic qualification reports, as illustrated in Figure 4 [3].

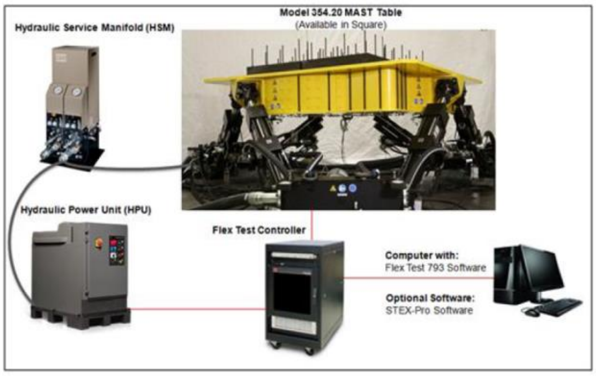

Figure 4 Configuration of Seismic Test [3]

Typically, seismic tests for nuclear power plants are conducted at the cabinet level, where prototype cabinets are subjected to qualification tests, and corresponding reports are issued. However, in this case, only the indicator modules within the cabinet are being replaced. Therefore, instead of full-scale cabinet testing, an analytical approach utilizing existing test data is required. The seismic assessment must demonstrate that the module-level testing does not adversely impact the previously validated seismic performance of the cabinet. This approach ensures compliance with seismic regulatory requirements while maintaining the integrity of prior qualification results.

Furthermore, the applied seismic test parameters, including frequency response characteristics, spectral amplitudes, and damping factors, must align with regulatory RRS. The damping factors applied for qualification are 2% for OBE and 3% for SSE. Ensuring the seismic robustness of the replacement indicators is essential for maintaining the overall structural integrity of the RPS and preventing potential vulnerabilities within the system.

To further assess seismic performance, a resonance search test and random multi-frequency vibration tests are planned. The resonance search test, conducted before the OBE test and after the SSE test, applies low-amplitude sine wave excitation (approximately 0.2 g) within the frequency range of 1 Hz to 100 Hz, using a sweep rate of 2 octaves per minute. While not mandatory, this test helps evaluate dynamic characteristics and structural integrity by comparing pre- and post-seismic responses.

The RMF vibration tests involve three-axis simultaneous excitation, with five repetitions under OBE conditions and one under SSE conditions, lasting a total of 30 seconds, including 20 seconds of strong motion. These tests validate the system's response under realistic seismic conditions, ensuring compliance with designated damping factors and spectral amplitudes. The TRS is defined with damping factors of 2% for OBE and 3% for SSE, applied at 1/6 octave intervals for frequency analysis. The TRS is evaluated against the RRS to confirm resonance behavior, ensuring that resonance occurs at or above 5 Hz or, if absent, is captured at a minimum of 3.5 Hz.

Functional monitoring is conducted throughout the seismic tests to continuously track the indicators' performance. Analog signals are digitized and recorded for post-test verification, allowing for comprehensive data analysis to confirm operational stability under seismic loading conditions.

3. Conclusions and Future Work

This study presents a structured approach for replacing obsolete instrumentation and control (I&C) components in nuclear reactors while ensuring seismic compliance. Unlike conventional cabinet-level testing, this research proposes a component-level evaluation to assess its impact on existing seismic qualification reports. This approach enables targeted replacements, reducing the need for full cabinet upgrades while maintaining regulatory compliance and ensuring reactor safety.

Future seismic tests will be conducted to validate the proposed methodology, ensuring compliance with regulatory standards and confirming the feasibility of modular component replacements in nuclear reactor systems. These tests will determine whether the anticipated outcomes align with actual seismic performance, ensuring the feasibility of modular component replacements in nuclear reactor systems.

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