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Preliminary Study on the Effects of Temperature, Radiation, and Humidity on Monitoring Sensors for HLW Repository

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ABSTRACT

Handling highly radioactive waste requires disposal systems known as high-level radioactive waste disposal systems. These systems are crucial for ensuring safety and efficiency, with monitoring sensors playing a key role. In this study, we conducted a preliminary experiment to understand how temperature, radiation, and humidity affect the lifespan of monitoring sensors. This study conducted experiments targeting the accelerometer sensor, which is the most widely used across various fields among monitoring sensors. The goal is to understand how these combined stress factors influence sensor lifespan, aiding in designing a lifespan prediction model. Results show that radiation, combined with temperature, significantly shortens sensor lifespan, supporting the feasibility of accelerated life testing. However, no failures occurred under combined temperature, humidity, and radiation stress, indicating challenges in simultaneous testing. Future research will focus on extreme conditions to better assess humidity's impact. These findings will help develop a reliable sensor lifespan prediction model for HLW repositories.

1. INTRODUCTION

The high-level radioactive waste (HLW) disposal system is designed with multiple

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barriers to prevent the release of radioactive materials. These systems are constructed 500 to 1000 meters underground to ensure safety from human living areas. Given the system's ultra-long expected lifespan, structural degradation and cracking are likely to occur over time, which could lead to severe accidents, such as nuclear waste leakage. This makes structural health monitoring essential.
The HLW disposal system operates under unique environmental conditions, including high heat from nuclear fuel, the swelling pressure of buffer materials, and the influx of groundwater. This restricted access to the structure makes removing or replacing the monitoring sensors impossible once they are installed. Therefore, accurately quantifying sensor lifespan and installing sensors with appropriate durability is crucial.
Sensor lifespan can be predicted through reliability assurance testing, with accelerated life testing being commonly used under harsh conditions to shorten the testing time. Before conducting these tests, we performed a preliminary experiment to understand how combined stress factors such as temperature, humidity, and radiation affect the monitoring sensors.

2. EXPERIMENT

2.1. Experiment Set-up

Figure 1 illustrates the experiment setup. The accelerometers used were PCB PIEZOTRONICS, which are commonly employed in industrial applications. Table 1 details the specifications of the piezoelectric sensors used in the experiment.

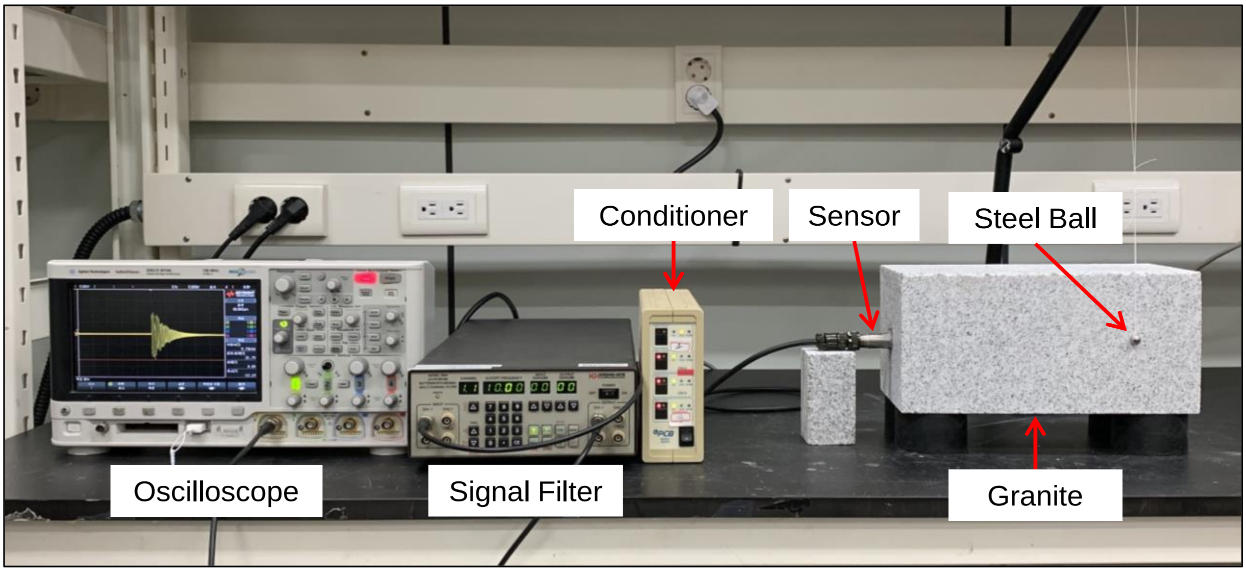


Fig. 1 Accelerometer Signal Collection Experiment Setup

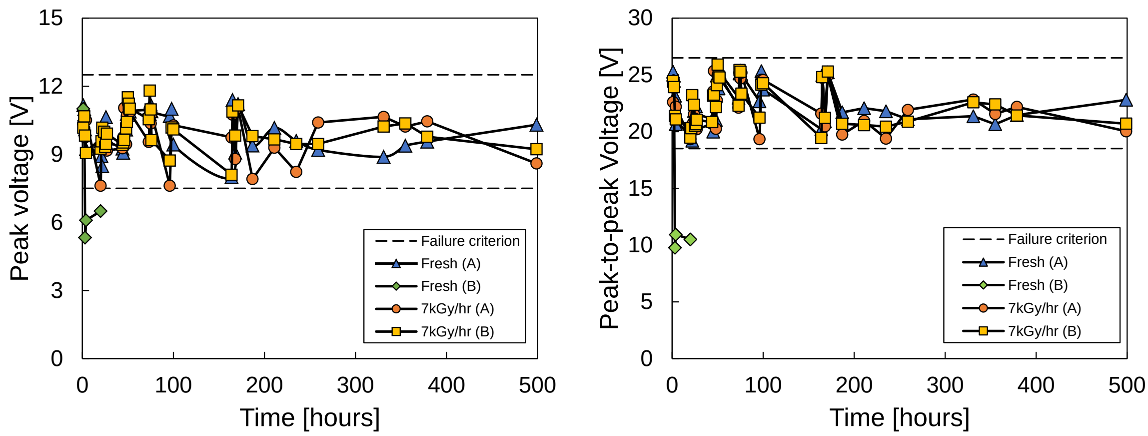
Table. 1 Specification of piezoelectric sensor

Sensitivity [mV/g]	100 (±10%)
Measurement range [g]	± 50
Frequency range [Hz]	0.5~10,000
Resonant frequency [kHz]	25
Temperature [℃]	-54~121

2.2. Experiment Procedure

The study assessed the impact of temperature, humidity, and radiation on sensor durability by comparing the performance of four sensors—two exposed to 7 kGy/hr radiation and two not exposed. The experiment was conducted in a humidity chamber with a temperature of 90°C and relative humidity at 95%. Over a 500-hour period, sensor failure was monitored by calculating Peak and Peak-to-Peak values. The sensors were removed from the oven at specific intervals to measure their signals. The sensors were attached to granite, and a steel ball connected to a string was dropped from a consistent height to impart a constant impact on the granite specimen. The signal was amplified tenfold using a signal conditioner and filtered with a 10 kHz low-pass filter to remove noise for a more accurate reading. Finally, the signal sensitivity was normalized and calibrated to 100 mV/g for data analysis.

3. RESULTS



(a) Peak value (b) Peak-to-peak value

Fig. 2 Failure time with peak and peak-to-peak voltage

To assess the effects of combined stress factors such as temperature, humidity, and radiation on monitoring sensors, two sensors exposed to radiation at a rate of 7 kGy/hr were used, along with two non-exposed sensors for comparison, making a total of four sensors. The experiment was conducted in a temperature and humidity chamber set at 90°C and 95% relative humidity. Over a 500-hour period, the effects of the combined stress factors on the monitoring sensors were evaluated by calculating Peak and Peak-to-Peak values to observe sensor failures. Despite being exposed to radiation at 7 kGy/hr, a temperature of 90°C, and 95% relative humidity, no failures were observed. However, one of the non-exposed sensors failed after 3 hours due to a signal change, which was determined to be a fault inherent to the sensor itself.

4. CONCLUSION

Through this study, we confirmed that radiation exposure under combined conditions of temperature and radiation significantly impacts sensor lifespan, leading to the conclusion that accelerated life testing for these stress factors is feasible. However, in the combined stress experiment involving temperature, humidity, and radiation, no failures occurred over 500 hours, suggesting that conducting accelerated life testing with all three factors simultaneously may be challenging. Therefore, to accurately assess the impact of humidity, additional experiments will be conducted under extreme conditions such as submersion and high pressure. The results of this study will serve as essential foundational data for designing sensor lifespan prediction models in environments with combined stress factors.

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