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Status of Long-lived Self Powered Neutron Detector Development in KHNP

Yu Sun Choi*, Sang Rae Moon
KHNP-CRI, 70 Yuseongdaero 1312beon-gil, Yuseong-gu, Daejeon 34101, Korea
**Corresponding author: yschoi5577@khnp.co.kr*

1. Introduction

KHNP CRI has developed the Long-lived In-Core Instrument (LLICI) Assembly that has a 10-years of life -time and is designed to meet the requirement of Seismic Category 1, Electrical Class 1E, Safety Class 1 and Q Class 1[1~6]. The LLICI consists of 5 vanadium SPND (self-powered neutron detector) and 2 CET(Core Exit Thermocouple) and 1 background cable. KHNP CRI is preparing for the SPND depletion test at a Research Reactor and LLICI demonstration test at Nuclear Power Plant(NPP). Before the LLICI actual demonstration test, KHNP CRI has conducted SPND performance test and a series of tests for plant site compatibility in advance.

2. Tests for LLICI

Typically, KHNP In-Core Instrument(ICI) assembly is composed of 5 detectors, 1 background cable, Seal plug and Connector as shown in figure 1.

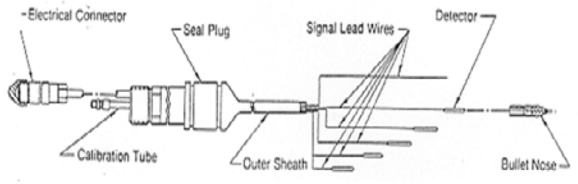


Fig.1 General ICI drawing

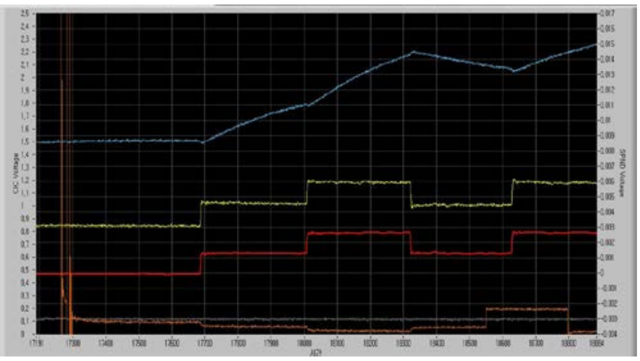
The ICI assembly should meet the requirement of the Seismic Category 1. Seal plug portion of ICI assembly is safety class 1 due to the pressure boundary of primary coolant system. CET portion of the ICI assembly is Electrical Class 1E and Safety Class 3. The equipment qualification for LLICI demonstration test has already been successfully completed[2]. The static and dynamic SPND performance test were conducted to measure the vanadium detector signal range and to analyze the noise effect on data acquisition system(DAS). In order to make LLICI demonstration test more compatible with plant site, two(2) LLICI assemblies are used for pre-tests that consists of the bending test at the factory site and compatibility test at the plant site.

3. Tests Results

3.1 Static and Dynamic SPND Performance Test[Fig2]

The objective of this test is to verify the static and dynamic characteristics of vanadium SPND to finalize the SPND design specification. The following tests are consists of SPND performance test.

- Real circuit noise analysis
- Background Noise Analysis
- Manufacturing Error of SPND
- Feasibility of DAS Improvement
- Characteristics of DAS
- Feasibility of Co SPND
- Comparison of Signal Magnitudes
- Etc.



(Red: reference signal, Yellow: Cobalt signal, Blue: Vanadium signal)

Fig.2 Measurement of SPND signals for Static and Dynamic SPND Performance

As results of SPND test, SPND design was modified to increase diameter of vanadium emitter.

3.2 LLICI Bending Test

The objective of this test is to ensure that integrity of LLICI is maintained even when LLICI is bent more than the maximum curvature during the insertion and withdrawal through ICI guide tube in plant site.

This test is performed by repeating the actual winding and unfolding of actual LLICI on a transfer wheel much smaller than ICI guide tube curvature. Each test was performed by measuring the electrical integrity and total length of the LLICI. As a result of this test, it was confirmed that the electrical integrity of LLICI was maintained even when the actual guide tube curvature worse. Through the X-ray inspection, manufacturing process changes are made to allow to emitter position inspection, which is a requirement of the technical specification of LLICI.

3.3 Plant Site Compatibility Test

The objective of this test is to examine whether LLICI assembly will be compatible with the relevant components before demonstration test at plant site, because LLICI will be the first application to plant demonstration in Korea. The compatibility tests for plant site were performed in the following steps with plant ICI treating tools.

Step1 : Pre-confirmation before plant site test

- Design specification and drawing comparison
- Fuel assembly guide tube applicability

Step 2 : Plant site Tests

- ICI handling tool test
- ICI guide tube insertion and withdrawal test
- ICI cutting test

At the step 1, it was ensured that LLICI outer sheath diameter is compatible with that of existing ICI assembly design of NPP. It was also confirmed that ICI guide tube of NPP has sufficient space and is easy to insert and withdraw.

At the step 2, using the ICI handling and cutting tools that are actually in use at the plant site, it was confirmed that LLICI could be treated by the same tool at plant site. As result of tests, LLICI could be inserted, withdrew and cut by the same tool of NPP.

4. Evaluation of the LLICI loaded Core

The design impact on the loading of two(2) LLICIs was evaluated in view of the nuclear design, thermal hydraulic design, core protection/monitoring design, fuel rod design, fuel assembly design, and safety analysis. The core under evaluation consists of the core with existing forty-three(43) rhodium ICIs and two(2) vanadium ICIs. As a result of the evaluation, it was confirmed that there were no safety related issues on reactor core design caused by the loading the LLICI of OPR1000 core. The reactivity coefficient and peaking factor are also acceptable in the technical specifications.

In case of two(2) vanadium ICI replacement, reactivity and peak pin power difference showed 4pcm and 0.001, respectively that values are negligible.

The uncertainty analysis for core protection system was conducted without two(2) LLICI assemblies are loaded that treated as a failed ICIs. The result of uncertainty analysis showed also the same level of the results for existing NPP.

The heating rate was evaluated for the effects on guide tube by the heat from vanadium detectors. Due to the sufficient flow rate margin in guide tube, LLICI loaded core is acceptable in view of thermal hydraulic design.

5. Summary and Future works

KHNP CRI has completed the Design of LLICI and is preparing for the demonstration test at plant site. Prior to the demonstration test of LLICI at plant site, preliminary test are successfully completed for the compatibility with the plant-related system and insertion, withdrawal, and cutting facilities.

Depletion life-time will be determined through the Research Reactor test and the dynamic compensation constant of Vanadium emitter with the increased diameter will be re-determined.

Two(2) LLICI are currently being manufactured. Actual location of the NPP core is to be determined and safety assessment is planned though the detail core design.

Reference

[1] KHNP CRI, “Technical Specification for Long-lived In-Core Instrument Assemblies”

[2] Y.S. Choi, S.R. Moon, “Equipment Qualification of Long-lived Self Powered Neutron Detector”, Trans. of KNS Spring Meeting, Jeju, May 18-19, 2016

[3] IEEE 323(2003), “IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations”

[4] IEEE 344(2004), “IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations”

[5] IEEE 3833(2003), “IEEE Standard for Qualifying Class 1E Electric Cables and Field Splices for Nuclear Power Generating Stations”

[6] 10CFR50.49, “Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants”