Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

The method to Certify Performance of Long-Lived In-Core Instrumentation

Roh Kyung-ho, Cha Kyoon-ho, Moon Sang-rae
KHNP, 1312, Yuseong-daero, Yuseong-Gu, Daejeon, Korea, 305-343 (rohkyungho@khnp.co.kr)
Corresponding author: rohkyungho@khnp.co.kr

1. Introduction

ICI (In-Core Instrumentation) is used measuring the neutron flux of core and is located at the center of nuclear fuel. Rh ICI used in OPR1000 generates the relatively large signal but its lifetime is below 6 years.

Rh ICI consists of 5 detectors which is a type of SPND (Self Powered Neutron Detector), a couple of thermo-couple, one background wire and several fillers. The short lifetime of Rh detector causes increase of procurement price and space shortage of spent fuel pool. Also, it makes operators be exposed by more radiations.

KHNP (Korea Hydro & Nuclear Power Co., Ltd.) CRI (Central Research Institute) is developing the LLICI (Long-Lived In-Core Instrumentation) based on vanadium to solve these problems.

LLICI is the detector which is a type of SPND based on Vanadium and has the lifetime of about 10 years.

Figure1 shows the cross section of LLICI and Rh ICI.

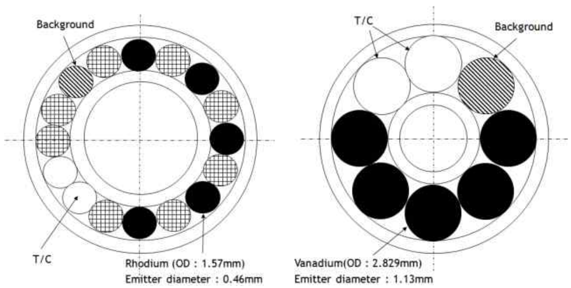

Figure1. Cross section of Rh ICI (left) and LLICI (right)

Rh ICI's lifetime is about 6 years but LLICI's lifetime is about 10 years. Therefore, LLICI should be certified through EQ (Equipment Qualification) for the lifetime of 10 years.

This paper describes how to perform EQ of LLICI.

2. Requirements to certify design lifetime

2.1 Design of Structure, Component, Equipment and System

According to Hanul unit 3, 4 FSAR (Final Safety Analysis Report) chapter 3.1.2.10, reactor coolant pressure boundary shall be designed, fabricated erected and tested so as to have an extremely low probability of abnormal leakage of rapidly propagating failure and of gross rupture. Also, reactor coolant pressure boundary is designed to accommodate the system pressures and temperatures attained under all expected modes of plant operation including all anticipated transients and to maintain the stresses within applicable limits.

2.2 Mechanical Systems and Components

Design transients to perform fatigue analysis for ASME Code Class 1 components are described in the chapter 3.9.1.1 of Hanul unit 3, 4 FSAR. Pressure and temperature fluctuations resulting from the normal, upset, emergency and faulted transients are computed by means of computer simulations. The purpose of the analysis is to demonstrate that fatigue failure will not occur when the components are subjected to typical dynamic events that may occur at the power plant for plant design lifetime (40 years in case of OPR1000).

2.3 Seismic Qualification Testing of Safety-related Mechanical Equipment

LLICI is the safety-related equipment because of including the thermocouple. According to chapter 3.9.2.2.2.1 of Hanul unit 3, 4 FSAR, the ability of equipment to perform its seismic Category I functions during and after an earthquake is demonstrated by tests and/or analysis.

2.4 Seismic and Dynamic Qualification of Mechanical and Electrical Equipment

According to chapter 3.10.3.3 of Hanul unit 3, 4 FSAR, the seismic and dynamic testing of BOP mechanical and electrical equipment is performed in its proper sequence as indicated in IEEE 323-1974. For most safety-related mechanical and electrical equipment, the seismic and dynamic qualification is preceded by inspection, operation under normal and abnormal conditions and thermal aging where design basis event radiation may be included.

3. Performance certification of LLICI

3.1 Environmental and Seismic qualification

The EQ and seismic tests shall be performed using Mock-up which is shortest length LLICI between 2 to 4 meters. The details of test for qualification of LLICI are like below table1;

Tests	Particular specification/acceptance criteria
Functional test	Visual inspection Insulation resistance ≥ $10^{11}\Omega$ under 100VDC at ambient temperature
Thermal Ageing	Qualification by test Specification: 10 years/49℃

(Connector & Epoxy resin seal)	Based on Arrhenius equation Test condition; - Temp. : 130℃ - Duration : 418hours - Activation energy : 0.75ev - Acceleration factor : 210 - Ventilating oven to ensure a sufficient oxygen transfer
Thermal Ageing (LLICI Structure)	Qualification by analysis - Specification: 10 years - Design Temp: 398℃ - Design pressure : 2500psia
Radiation (outside the pressure boundary)	Qualification by test - Normal condition: $4{\cdot}10^5$Gy - Accident conditions: $2{\cdot}10^6$Gy - Total: $2.6{\cdot}10^6$Gy
Seismic	Qualification by test - Seismic conditions (Figure2.)
Accident condition	Qualification by analysis - Temp. Profile (Figure3.) - Pres. Profile (Figure4.)

Table1. Qualification matrix

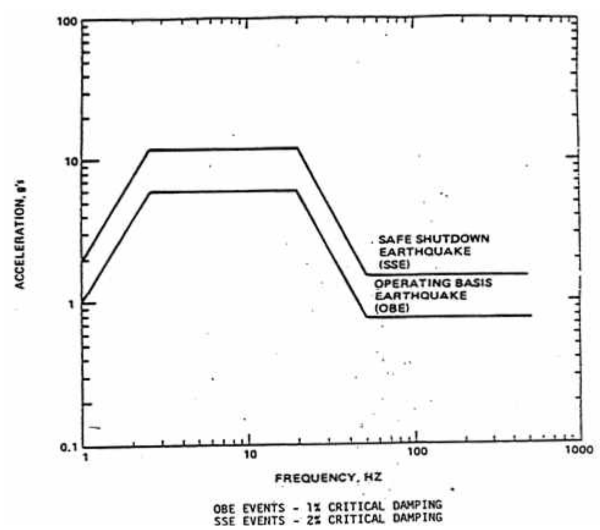

Figure2. Seismic Condition

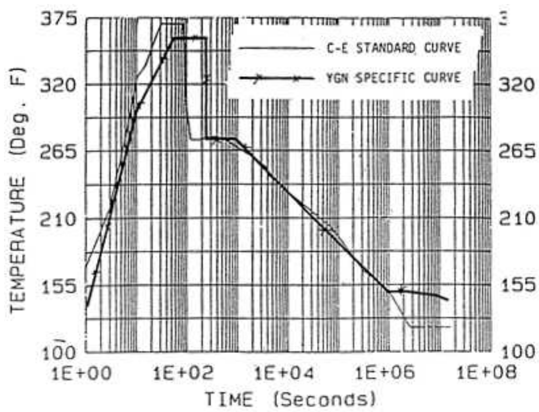

Figure3. Accident Temperature Profile

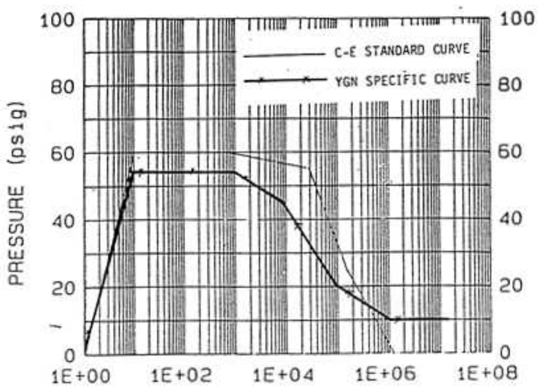

Figure4. Accident Pressure Profile

Above tests shall be performed according to LLICI Technical Specification suggested by KHNP.

3.2 Operating condition for fatigue analysis

Because the lifetime of LLICI is 10 years, fatigue analysis for 10 years shall be performed. Transient operation conditions for fatigue analysis are as below;

3.2.1 Operating Fluctuations

The reactor coolant temperature will increase and decrease approximately 10℉ in one minute. At the same time, the coolant pressure may vary at a maximum of 100psi. These variations will occur a maximum of 250,000 times during the lifetime of the LLICI assembly.

3.2.2 Transient Condition Incidental to Tests of Other Items

During the design lifetime of the LLICI assembly, the coolant system including the instrument assembly seal plug, may be cycled from ambient pressure to 2500psia up to a maximum of 93 times.

3.2.3 Operational Transient Conditions

Transient Conditions	Number of occurrences
1. Plant heat-up	125
2. Plant Cool-down	125
3. Turbine power ramp change of +5%/minute	500
4. Turbine power ramp change of -5%/minute	500
5. Plant leak test	50
6. Reactor trip	25
7. Loss of reactor coolant flow	5
8. Loss of load	5
9. Loss of secondary pressure	1

Table2. Number of occurrences for transients conditions

Above values are calculated based on number of occurrences described in the FSAR of Hanul unit 3, 4. That is, the number of occurrences described in the FSAR is operational transient conditions to demonstrate that fatigue failure will not occur when the components are subjected to typical dynamic events that may occur at the power plant for plant design lifetime (40 years in case of OPR1000). So, fatigue analysis of LLICI shall be performed only for one over four of occurrences described in the FSAR.

4. Conclusion and Future Work

The short lifetime of OPR1000′s Rh ICI and long cycle operation strategy cause increase of procurement price, space shortage of spent fuel pool and more radiation exposed to operators. KHNP (Korea Hydro & Nuclear Power Co., Ltd.) CRI (Central Research Institute) is developing the LLICI (Long-Lived In-Core Instrumentation) to solve these problems. LLICI needs to be certified according to FSAR and IEEE in side of performance because it is ICI which has new design. In order to certify the lifetime (10years) of LLICI, EQ, Seismic Qualification and fatigue analysis shall be performed.

Additionally, KHNP is planning to make LLICI deplete for 10 years to demonstrate the result of fatigue analysis

Reference

1. Hanul unit 3, 4 FSAR, Dec. 1998.
2. Attachment 18.2 of 13-S-A12NJ03-N-0003, Technical Specification for Long-Lived In-Core Instrument Assemblies, May. 2014.
3. NT4636D009, LLICI Assembly for demonstration test by THERMOCOAX, Sep. 2014.