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Equipment Qualification of Long-lived Self Powered Neutron Detector

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1. Introduction

KHNP CRI has developed the Long-lived In-Core Instrument (LLICI) Assembly that based on vanadium emitter instead of the existing rhodium emitter based detector. LLICI has the life time of ten(10) years. LLICI consists of 5 vanadium SPND (self-powered neutron detector) and 2 CET(Core Exit Thermocouple). Because CET is a nuclear Class 1E, LLICI must be qualified to verify its performance during normal and accident conditions. The qualification test was conducted in accordance with the qualification test program that recommended as a practice of the IEEE-323 and IEEE-344. It has been demonstrated that the class 1E function of LLICI is not impaired as a result of the environmental conditions and during and after seismic excitation.

2. Qualification Test Program

The qualification test program consists of several tests that were performed in accordance with the applicable standards and specifications listed in references. This qualification was performed onto a representative mock-up. LLICI assembly is composed of 5 vanadium detectors, 1 type K positive wire MI cable, 1 type K negative wire MI cable and 1 background cable as shown in figure 1.

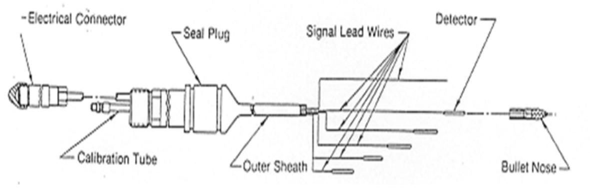

Fig. 1 ICI drawing

The qualification program was conducted as following sequence as a general procedures; Leak test, radiation aging, thermal ageing, pressure/temperature cycling, seismic and combined LOCA/MSLB exposure test. At every test, functional tests of measuring the Insulation Resistance, Dielectric Test, Line Resistance of thermocouple and Type K thermocouple calibration are conducted before and after tests. Insulation Resistance values for a pair of connectors shall be controlled.
Insulation resistance shall be higher than 1E+11 ohm at room temperature. Dielectric test, maximum current shall be lower than 10 mA. Values of Thermocouple line resistance shall be continuous. Calibration of type K thermocouple points are 21.1℃, 121℃, 277℃, 371℃, 538℃, 899℃ and 1,260℃.

3. EQ Test results

3.1 Leak Test

The objective of this test is to demonstrate that test connector can withstand water submergence under 30 ft and also withstand pressure test of LOCA test with margin. The test connector was externally pressurized in water under 5.0 bar during four (4) hours. Test was performed onto a dedicated test bench as shown in Fig. 2. There was no evidence of defect during this test.

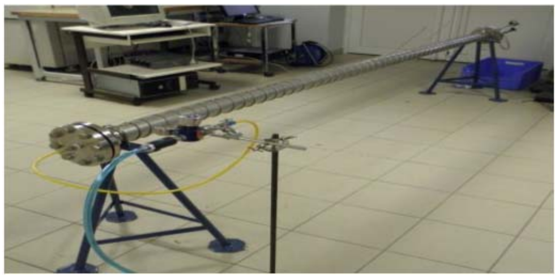

Fig. 2 Leak Test Bench

3.2 Radiation Aging Test

The objective of this test is to demonstrate the capability of LLICI to withstand radiation effect due to normal, accident and post-accident conditions. LLICI will suffer a normal ten (10)-year integrated radiation dose completed with accidental radiation dose. The sources were arranged to have homogeneous dose and a minimum dose rate of 5 kGy/h onto the mock-up.
Radiation aging test shall be done with a minimum dose of 2.6MGy. Radiation test was performed with a dose rate of 5.3 kGy/h and duration of 493 hours that total dose was 2.6 MGy.

3.3 Thermal Aging Test

The objective of this test is to demonstrate the capability of LLICI to withstand thermal effect due to ten (10) years of service in normal conditions. The mock-up was exposed to temperature which simulates ten(10) year service life resulting from exposure to the temperature 49℃ in service. The components of the mock-up were aged in accordance with a time-temperature relationship projected by application of the Arrhenius law. From the given material data, the aging was performed based on the conservative 0.98 eV activation energy constant. The test aged at 108℃ +3/0 ℃ during 377 hours.

$$Dt = Dv \times e^{\frac{Ea}{K}\times\left(\frac{1}{T2}-\frac{1}{T1}\right)} \quad (1)$$

Where T1 = environmental temperature (K)
T2 = test temperature (K)
Dv= life time (Hr), Ea = activation energy(eV)
K = Bolzman constant = 0.8614E-4 eV/K

3.4 Pressure/Temperature cycling Test

The objective of this test is to demonstrate that test connector in mock-up can withstand water-combined pressure/temperature cycling test. The mockup was exposed to pressure and temperature test under such conditions; pressure 0 to 4.85 bar, temperature 20℃ to 121℃. Test conditions were maintained for a minimum of 10 minutes.

3.5 Seismic Test

The objective of this test is to demonstrate the capability of LLICI to withstand seismic effect could appear during seismic event. In order to also be representative of the operating conditions, seismic test was performed with mock-up installed in seal housing. The seal housing was installed inside the seismic table through a rigid mechanical support. Test mock-up should continue to function during the seismic test. Therefore, during this test, signal delivered by mock-up and reference thermocouple were recorded. Seismic test conditions were controlled by several sensors. Table accelerations in each axis were measured simultaneously as well as accelerations of the mechanical support and the seal housing on which the matter shall be used to generate the test response spectra(TRS). TRS were compared with RRS(Required Response Spectra). TRS were compared with RRS including 10% margin and TRS envelopes the RRS as required. Test was performed using a bi-axial seismic simulator, the statistically independent input motions were used simultaneously in both excitation directions.

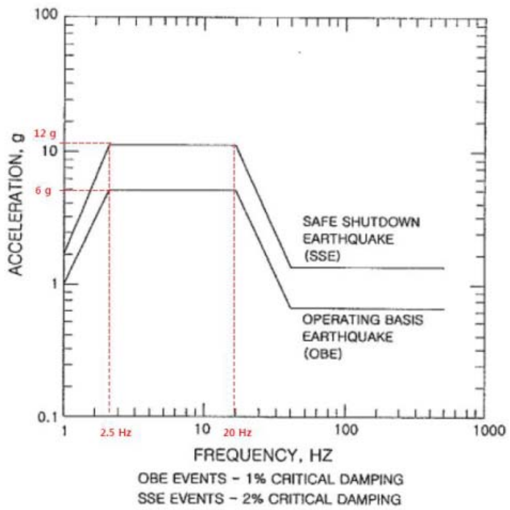

Fig. 3 Required Response Spectra(RRS)

3.6 Combined LOCA/MSLB Test

The objective of this test is to demonstrate the capability of LLICI to withstand high temperature, high pressure and chemical conditions that could appear during LOCA and MSLB event. During the test, the mock-up was subject to environmental conditions simulating the accident conditions within the accident test profile with margin. For MSLB test, thermal aging was simulated by accelerated aging according to the Arrhenius Model. With margin according to IEEE 323 and IEEE 344 standard, +15˚F for temperature, +10% for pressure.

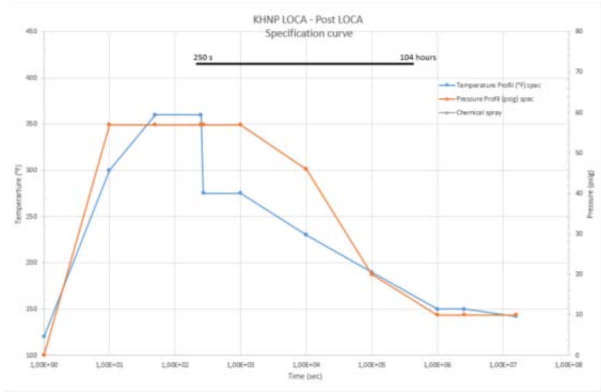

Fig. 4 LOCA/MSLB Curve

4. Conclusion

Equipment qualification for LLICI was successfully conducted through several tests that mainly consist of leak test, radiation aging, thermal aging, pressure/temperature cycling, and combined LOCA/MSLB exposure. Therefore, the mock-up of LLICI was successfully aged to a 10-year operating life condition. The LLICI was found to be fully operational after the aging test, seismic and LOCA/MSLB test. Two (2) assemblies of LLICI will be installed as lead test ICI into OPR1000

Reference

[1] IEEE 323(2003), "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations"
[2] IEEE 344(2004), "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations"
[3] IEEE 3833(2003), "IEEE Standard for Qualifying Class 1E Electric Cables and Field Splices for Nuclear Power Generating Stations"
[4] ASME(1995) section III, Nuclear power plant component, Class 1,2&3
[5] 10CFR50.49, "Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants"