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Tests on Active and Passive elements for Nuclear Applications

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Abstract

Harsh Environment is Produced in Nuclear reactor by Loss of Coolant Accident (LOCA) or Main Steam Line Breaks (MSLB) or pipe breaks in other plant fluid systems. Accidents, such as certain LOCAs, resulting in significant reactor core damage can produce high levels of radiation combined with high temperature, pressure and steam conditions inside primary containment. This will result in Components in various systems subjecting to harsh environmental conditions like high humidity, temperature and radiation during the normal operation as well as during the accident condition such as LOCA / MSLB. Hence, it is essential to ensure reliable operation of active and passive components during the above conditions. To meet these requirements, qualification approval and ageing studies on hardware systems/ components/ materials, is needed. These test results will provide reasonable assurance regarding their survival capability under simulated environment even at the end of specified service life. The Environmental test rigs are used for simulating the Design based Accident (DBA) environment conditions of nuclear power plants. This includes the most severe assumed design basis accident environment of high-energy pipe breakage, such as the large break loss-of-coolant accident (LOCA) with breakage of both ends of main pipe of coolant system inside the containment vessel of nuclear power plants; the main steam line breakage (MSLB) accident inside the containment vessel of nuclear power plants; the main steam line breakage (MSLB) accident areas outside the containment vessel of nuclear power plants.

This paper describes the Environmental test facilities set up at FCRI for conducting the above test as per the relevant standard.

Introduction

Different types of valves of different material and temperature / pressure with size ranging from 10 mm to 900 mm rating are used in the nuclear power plants[1]. The number of valves required for a nuclear power plant may be as high as 16000. Figure 1 shows population of different types of valves used in a nuclear power plant. Gate valves and needle valves contribute to nearly 20 % of population each followed by 17% of globe valves. The process fluid is either

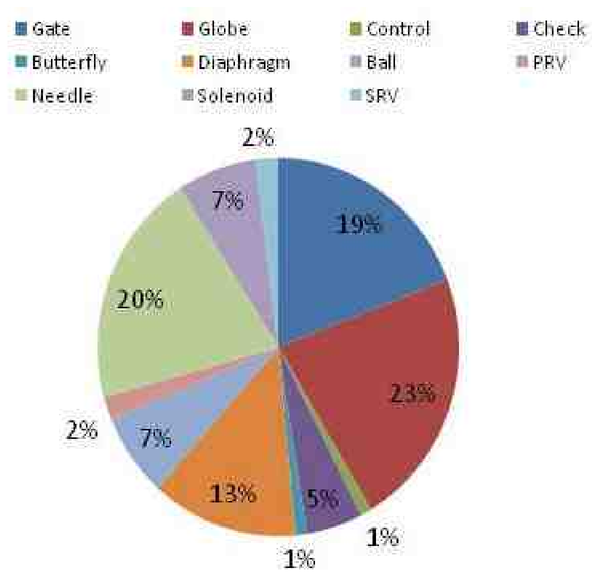

Figure.1 Population of valves for a typical Nuclear plant

heavy water or light water and shall be corrosion resistant. Nuclear valves are designed as per ASME section III Division I B 16.34. Material of construction include carbon steel for low temperature application and low carbon stainless steel with cobalt free, very low Halide and Sulphur.

Tests on valves

The valve assembly will be subjected to a series of tests and analysis as part of proto type approval[2,3,5]. This include

- Actuator qualification as per IEEE382. IEEE 344
- Valve actuator assembly as per ASME QME 1
- Cycle tests for rotary valves
- Valve sealing capability
- Cold and hot cycle operability at service temperature and pressure
- Operability under maximum pipe reaction end loading
- Flow interruption and functional capability
- Adequacy of MOC to survive environmental and aging effects
- Operability during and after loading representative of seismic and vibratory incident for active check valves and relief valves
- Set point and blow down verification for relief valves
- Thermal shock capability

To ensure the above, parent valve will be subjected to tests in the following sequence with pre and post inspection and intermediate inspections after each test.

- Seismic qualification tests for estimating the natural / fundamental frequency followed by seismic qualification tests
- Thermal and radiation aging tests
- Environmental qualification tests (MSLB and LOCA tests)
- Cold and hot cycle tests
- End loading test
- Flow interruption and functional capability test

All these tests are coved in the succeeding sections. The test facilities are designed to test both active and passive elements. During the test, the active elements will be subjected to operation in the severe environment. The passive elements like cables, terminal boxes will be checked for its electrical properties during the test.

Thermal aging test

Thermal aging test is performed as per IEEE 323. Long term thermal aging testing is to monitor degradation of the Test components using qualified test facilities which enable testing for the new, advanced designs. Thermal degradation refers to the change in chemical and physical properties of a material that occur at elevated

Figure.2 Thermal aging test facility

temperatures. Increased temperature accelerates most of the degradation processes. It involves aging the proposed component at three or more elevated temperatures. After each heat cycle, samples are also subjected to a repeated series of environmental exposures, such as cold shock, mechanical stress and humidity

Thermocouples and electronic temperature controllers are used to the test facility to maintain the specified thermal aging temperature. Temperatures are maintained within +1°C of the specified thermal aging temperature. Redundant Controllers are used to prevent overheating of the test samples in the event of a malfunction of the main controller.

The specimen will be kept at 135°C for 57 days. The oven shall have provision for hot air circulation. This test will qualify the test item for normal service condition of 55°C for 40 years of life.

The test item will be subjected to pre and post thermal aging functional tests

Radiation aging test

During this test, sample will be subjected to Gamma Radiation dose of 19 M Rads at a dose rate of 1 M Rads/hr. The test item will be subjected to pre and post radiation aging functional tests

LOCA simulation test

A loss-of-coolant accident (LOCA) is a mode of failure for a nuclear reactor; if not managed effectively, the results of a LOCA could result in reactor core damage. Each nuclear plant's emergency core cooling system (ECCS) exists specifically to deal with a LOCA. If water is present, it may boil, bursting out of its pipes. (For this reason, nuclear power plants are equipped with pressure-operated relief valves and backup supplies of cooling water.). If graphite and air are present, the graphite may catch fire, spreading radioactive contamination. This situation exists only in AGRs, RBMKs, Magnox and weapons-production reactors, which use graphite as a neutron moderator. The fuel and reactor internals may melt; if the melted configuration remains critical, the molten mass will continue to generate heat, possibly melting its way down through the bottom of the reactor. Such an event is called a nuclear meltdown and can have severe consequences. The so-called "China syndrome" would be this process taken to an extreme: the molten mass working its way down through the soil to the water table (and below) - however, current understanding and experience of nuclear fission reactions suggests that the molten mass would become too disrupted to carry on heat generation before descending very far; for example, in the Chernobyl disaster the reactor core melted and core material was found in the basement, too widely dispersed to carry on a chain reaction (but still dangerously radioactive).

Figure.3. Photograph of LOCA test facility

In the LOCA Test, specimen will be subjected to a test profile as below

0 – 110 sec at 123˚C at 0.73 kg/cm^2 pressure

110 – 400 sec at 98˚C at 0.60 kg/cm^2 pressure

400 – 800 sec at 90˚C at 0.46 kg/cm^2 pressure

800 – 1700 sec at 83˚C at 0.31 kg/cm^2 pressure

1700 – 5500 sec at 70˚C at 0.17 kg/cm^2 pressure

Next 48 hours – Moisture laden air at 50˚C

In the above profile, along with steam temperature and water flow, air pressure in the chamber is also required to be controlled for achieving the required profile. Figure 3 shows the photograph a typical LOCA test facility available at FCRI for testing small components.

Figure 4 shows the schematic of LOCA test facility available at FCRI The test item will be subjected to pre and post LOCA functional tests.

Different components like valves, actuators, panel boxes, pressure and temperature sensors, power and instrumentation cables, sealing compounds etc have under gone LOCA test in this facility for NPCIL

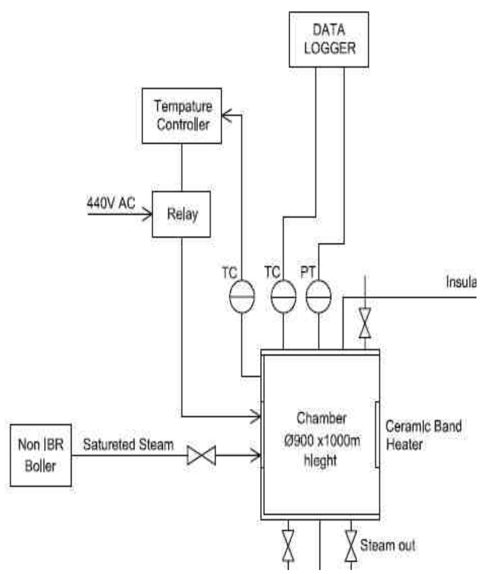

Figure.4. Schematic of LOCA test scheme

MSLB Simulation test

The main steam line break accident **(MSLB)** is initiated by a full size break of one of the main steam line at outlet of one steam generator. The accident is supposed to occur at end of cycle with the core at hot zero power condition. All the control rods are then fully inserted, except for the most reactive one, which is supposed to remain stuck at its position at nominal core operating condition. Pipe breaks in one of the two main circulation loops, the service water system and purification and coolant system as well as steam and feed water line breaks

In MSLB test, specimen will be subjected to a test profile as below

0 – 220 sec at 171˚C at 1.47 kg/cm^2 pressure

220 – 400 sec at 161˚C at 1.41 kg/cm^2 pressure

400 – 800 sec at 128˚C at 1.11 kg/cm^2 pressure

800 – 2200 sec at 108˚C at 0.90 kg/cm^2 pressure

2200 – 11000 sec at 87˚C at 0.40 kg/cm^2 pressure

Next 48 hours – Moisture laden air at 50˚C

In the above profile, along with steam temperature and water flow, air pressure in the chamber is also required to be controlled for achieving the required profile.

Figure 5 shows photograph of a typical MSLB test facility available at FCRI. Figure 6 a typical temperature & pressure maintained during MSLB test of a control valve.

Figure.5. Photograph of MSLB test scheme

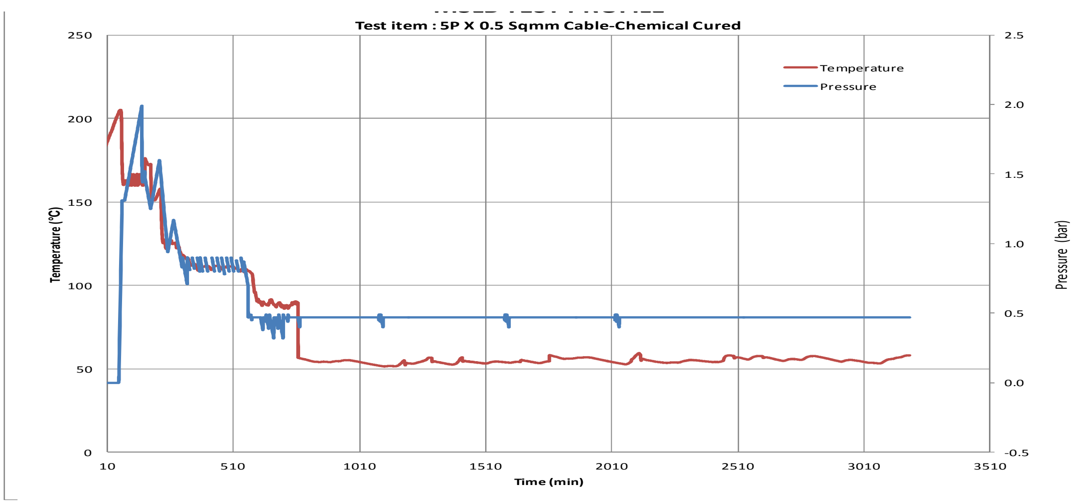

Figure 6 Temperature & Pressure Plot during MSLB test

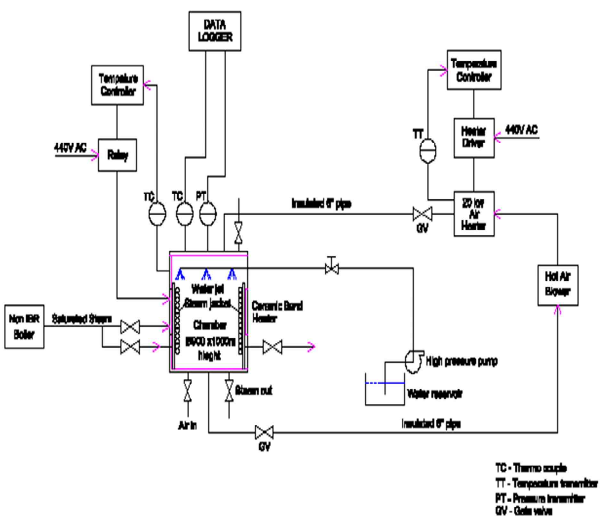

Figure.7. Schematic of MSLB test setup

Figure 7 shows the schematic of MSLB test facility. To meet the sudden temperature changes, this loop is provided with water cooling nozzles, steam and electrical heating and compressed air supply.

The test item will be subjected to pre and post MSLB functional tests.

Hot and Cold cycle tests

During the lifespan of product, encountering different environment conditions may result in failure or damage of product, thereby affecting the reliability of product.

Thermal Cycle Tester is used to thermally cycle products between hot and cold temperatures for accelerated durability tests.

The thermal cycling is achieved by alternating fluid flow from hot and cold sources. During thermal Cycle Testing, precise measurement and control of temperature, flow and pressure of test fluid is required to achieve the required operating profile during the test. Thermal Cycle Tester is designed for continuous, fully automated testing. Each thermal cycle is graphically displayed and monitored to be within specification. Cycles' quality is automatically controlled. During thermal cycling, the test valve will be mechanically cycled to test the life of the valve. The heating and cooling rate can also be controlled. DM water in the subcooled condition is used as test fluid

Alternating temperatures cycling in ambient to 350°C are imposed to the test valve for aging test. The test is a simulation of true conditions. Figure 8 shows a time temperature-pressure profile employed for a typical testing of a nuclear valve.

Figure 9 shows the photograph of the test facility available at FCRI for hot and cold endurance tests of On/OFF and control valves.

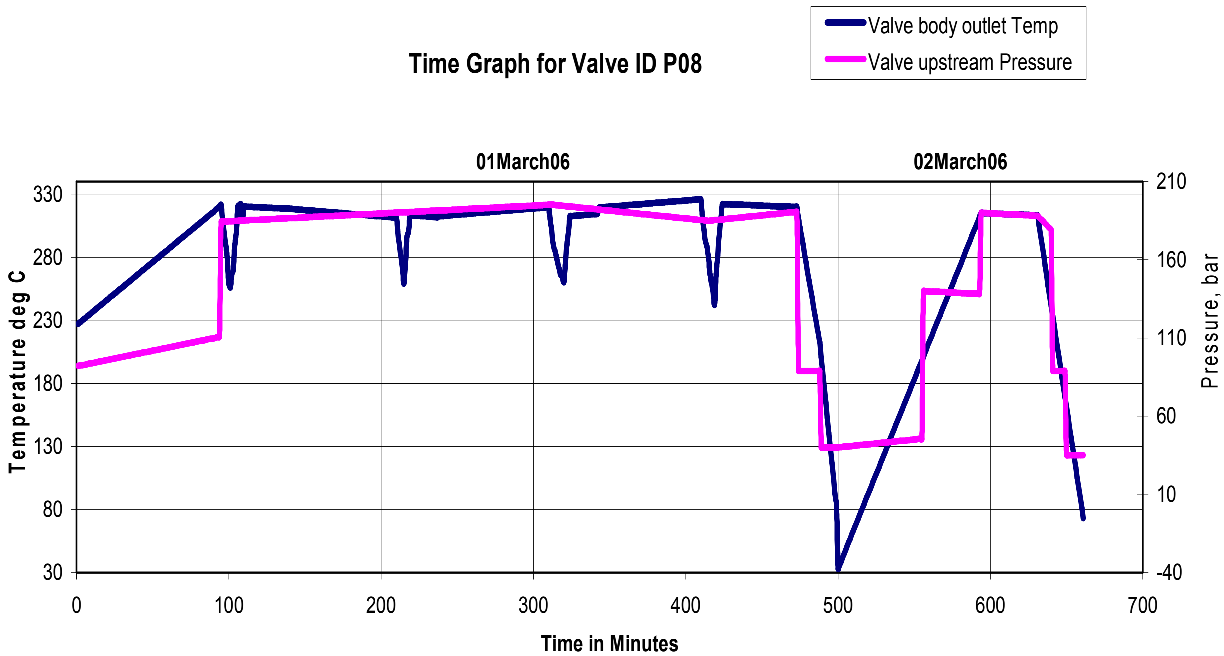

Figure 8 Time – Temperature, Pressure graph during thermal cycling test

The purpose is to impose thermal stresses onto the specimen by accelerating the aging factor, so as to determine whether the specimen will malfunction under the test environment that may damage the system and components, and whether the specimen is correctly designed and manufactured. Based on the test results, the maintenance schedule and operability of critical components of a reactor can be fixed.

Figure.9. Photograph of HOT cycle test facility

Conclusion

All the teste required to be done valve and field instrumentation can be performed at FCRI with the above experimental facilities described above. All the facilities use Demineralized Water as test fluid.

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