PDHonline Course E185 (1 PDH)

Environmental Qualification of Safety Related Electrical Equipment

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Environmental Qualification of Safety Related Electrical Equipment

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A. Course Description

Environmental Qualification of Safety Related Electrical Equipment

This one hour course is an introduction to the subject of environmental qualification of electrical equipment for nuclear reactors. Critical components necessary to safely shut down a reactor following an accident must be assured to function in the harsh conditions that will be present. This course describes the basics of environmental qualification testing, the history of the topic and how the laws governing environmental qualification evolved. The industry standard for testing, IEEE 323, is explained along with the Federal requirements. A short quiz follows the end of the course.

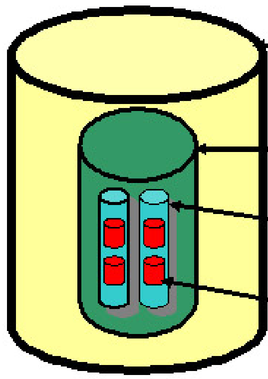
B. Performance Objectives

Upon completion of this course the student will have an understanding of the following concepts associated with the environmental qualification of safety related electrical equipment for nuclear power plants.

1. What is Environmental Qualification (EQ)?
2. The history of the Environmental Qualification rule-making
3. 10 CFR 50.49 the Federal Requirements
4. IEEE 323 "IEEE Standard for Qualifying Class 1 Equipment for Nuclear Power Plants"
5. What the industry learned from EQ.

C. Introduction

Commercial nuclear power plants were designed in the United States with a design philosophy of defense in depth. Part of that defense is to house the nuclear reactor in a containment building which is built of steel and concrete several feet thick.



Defense in Depth via Four Barriers

In the unlikely event of a significant accident in a nuclear power plant (such as a large pipe break in the reactor coolant system), a harsh environment of steam, radiation, high temperatures, high pressures and chemicals will be released into the containment building. Essential equipment necessary to mitigate the effects of this accident must be able to survive the harsh environment long enough to perform their intended safety function. The rigorous demonstration of the ability to do this is the subject of environmental qualification.

D. Body

Part 1 What is Environmental Qualification (EQ)?

All commercial nuclear power reactors (reactors operated by public utilities to produce electricity) in the United States have several things in common regardless of the reactor type or manufacturer. In order to protect the health and safety of the public the reactors are housed in steel and concrete containment structures which serve as a barrier against the release of radiation. Inside these containment structures are reactors and reactor coolant piping systems which contain thousands of gallons of water at very high temperatures and pressures. A Pressurized Water Reactor (PWR) will operate with the reactor coolant at around 575 degrees F and at an operating pressure in the range of 2200 psig.

Containment buildings are designed with redundant isolations valves for all of the piping penetrations into and outside of the containment structure. In the unlikely event of a major pipe break or reactor vessel rupture, the containment building is rapidly sealed shut by closing these isolation valves. In the sealed containment building, the reactor coolant being ejected from the failed system flashes to steam and creates a very rapid temperature and pressure surge in the building. This, when combined with high levels of radiation and in some plants chemical sprays (automatic systems which attempt to mitigate the accident), creates an extremely harsh environment. This accident scenario is known as the Loss of Coolant Accident or LOCA. Electrical components which are required to function after the accident in order to safely shut down the reactor must survive this environment long enough to perform their task. A rigorous demonstration of this ability is called environmental qualification.

Although the Loss of Coolant Accident is usually the most severe, all accidents have to be analyzed to determine the parameters for qualification of safety related electrical equipment. One such accident may be flooding in parts of the plant. The equipment necessary to function to mitigate the effects of the flood must be assured to operate during the flooding conditions. Other accidents may only create high pressure steam jets which may impinge upon safety related equipment. The plant is designed and licensed from its conception to handle these different design basis events.

Part 2 The history of the Environmental Qualification rule-making.

The nuclear power plants in the United States were built and operated by public utility companies. The Federal Government issued licenses to operate these plants after an extensive review of volumes of safety analysis reports. During the early days of nuclear power this governance was performed by the Atomic Energy Commission and in the early 1970s the Nuclear Regulatory Commission was formed to oversee commercial nuclear power.

The principle of design for nuclear power plants was and still is **defense in depth**. Layers and layers of defense were put in place to assure the safety of the public. Some of the elements of the defense in depth philosophy are:

- **Redundant Safety Systems –** The systems necessary to support the safe shutdown of the nuclear reactor were designed with redundant and diverse backup systems. Only the highest quality materials went into the building of these systems.

- **Automatic Reactor Protection Systems** – These systems monitored critical parameters of the reactor system and automatically initiate shutdown of the reactor when the parameter limits are exceeded.

- **Radiation Containment Barriers** – Four physical barriers are designed to prevent radiation from escaping and reaching the public.

- Fuel Design – the nuclear fuel is composed of ceramic pellets which contain most of the radioactive material within the fuel pellet.
- Fuel Rods – the nuclear fuel pellets are placed in metal tubes that are welded shut to prevent the release of any material.
- Reactor piping system – the reactor and the piping associated with the reactor system is composed of very thick steel alloys and is a sealed system.
- Containment Building – the reactor is housed in a steel and concrete building several feet thick. These buildings can withstand the force of hurricanes and the impact of airplanes.

Part of the design requirement regulations are found in Appendix A to 10 CFR Part 50. This appendix contained the General Design Criteria (GDC) which applied to all plants who sought an operating license. **Criterion 4 *Environmental and dynamic design effects design basis*** provides the criteria: "Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions with normal operation, maintenance, testing, and postulated accidents, including loss of coolant accidents." There was limited guidance regarding what the utility had to do to meet or demonstrate meeting Criterion 4. One of the early guidance documents came from an industry group, The Institute of Electrical and Electronic Engineers (IEEE). In 1971, IEEE published IEEE Standard 323-1971 "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations." This document was revised and reissued in 1974. The regulatory guidance document was NRC Regulatory Guide 1.89 *Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants,* first published in November 1974 and later revised in February 1982. These two documents were the standards for qualifying safety related electrical during the 1970's.

In 1969, the Union of Concerned Scientists (USC) was born out of a movement at the Massachusetts Institute of Technology, where an ad hoc group of faculty and students joined together to protest what they perceived as misuse of science and technology. The UCS petitioned the Nuclear Regulatory Commission (NRC) in the mid-1970s regarding the laboratory test failures of safety related electrical equipment some utilities had experienced. As a result, on May 31, 1978, the NRC issued Circular 78-08 *ENVIRONMENTAL QUALIFICATION OF SAFETY -RELATED ELECTRICAL EQUIPMENT AT NUCLEAR POWER PLANTS*. The intent of this document was to highlight to all nuclear plants the important lessons learned from environmental qualification deficiencies reported by individual power plants. This circular noted that the utilities should review their program for qualification of equipment and look at all components in the program. This circular required **no written response.**

Following the issuance of Circular 78-08 the NRC conducted inspections at several utilities and found little progress was being made upon the requested information. As a result, on February 8, 1979 the NRC issued Bulletin 79-01. This bulletin essentially ordered the utilities to provide a written submittal containing the information requested in Circular 78-08 within 120 days.

Another set of events occurred ultimately affecting the requirements for environmental qualification of electrical equipment at all the plants in the country. The Three Mile Island nuclear plant is located near Harrisburg, Pennsylvania. At 4 a.m. on March 28, 1979, the unthinkable happened at the Unit 2 reactor. Following a malfunction of several components, the reactor core experienced a partial meltdown. This serious accident eventually brought about new regulations concerning many aspects of the design and operation of nuclear power plants.

Lessons learned from Three Mile Island included the discovery that several critical components failed during the accident due to the harsh environment. The failure of sensors in the containment building denied the control room operators critical information about what was happening with the reactor systems. On January 14, 1980 the NRC issued Bulletin 79-01B requesting a re-submittal of the information previously requested by 79-01 and Circular 78-08. This version of the Bulletin provided very specific details for what was required to be submitted. Bulletin 79-01B required a Master List be developed that listed all safety related electrical equipment. Each component on the Master List was to be evaluated against the guidelines provided in Enclosure 4, "Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment."

The NRC held a meeting in Bethesda, Maryland in July of 1980 to explain the requirements of this Bulletin and to discuss the codification of these requirements into a new law. The author, along with 1200 other participants, met with the NRC for four days to discuss and understand what was expected of each reactor operator. Following this meeting the NRC issued Supplement 2 and then 3 to 79-01B answering many of the questions raised by the industry. Several years of hard work by many engineers and scientists were required to address all of the NRC's concerns and issues. A final rule (Federal Law) on Environmental Qualification was issued in 10 CFR 50.49 of the Code of Federal Regulations.

The Electric Power Research Institute (EPRI) formed a Utility Advisory Group on Environmental Qualification in the late 1970's to address some of the research which would be necessary to demonstrate qualification for some of these components. The author was a member of this group for several years representing a public utility. This group performed a valuable information exchange in the days before email and the internet allowing utilities to share test data, successes and failures.

During the same time frame, the NRC issued another set of requirements based upon lessons learned from the accident at Three Mile Island. One of these new regulations was Regulatory Guide 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident." This document addressed specific instrumentation used in the control room which needed to be upgraded. The upgrades included higher quality power sources, diversity of the instrument signal, and the environmental qualification of the sensing element. When the rule for Environmental Qualification was issued in the Code of Federal Regulations in 10 CFR 50.49, Paragraph (b)(3) included certain post-accident monitoring equipment, and references the reader to Regulatory Guide 1.97 for determination of the affected equipment.

Although minor changes were made to the rule over the next twenty years, the majority of effort was performed between 1979 and 1984.

Part 3 10 CFR 50.49 the Federal Requirements

The full text of the Environmental Qualification rule can be found at the NRC website in the electronic reading room. This course is only going to address the scope of the rule and the requirements for testing of equipment.

Scope of the Rule: The first requirement in the rule is found in paragraph (a) and it requires each license holder (nuclear power plant) to establish a program for qualifying the electrical equipment defined in paragraph (b) of the rule. Paragraph (b) defines three groups of equipment *important to safety*:

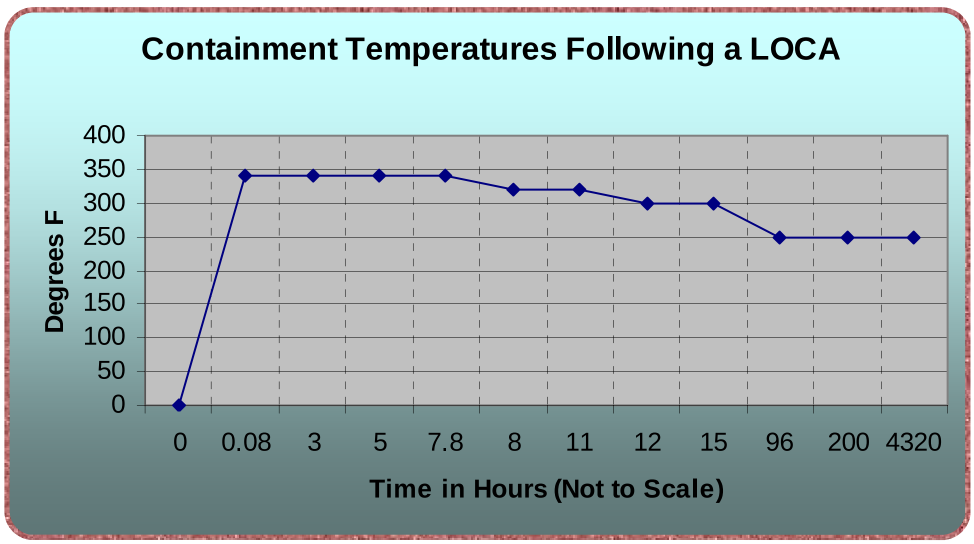
(1) Safety-related electrical equipment
(2) Non-safety related equipment whose failure during accident conditions could prevent a safety-related piece of equipment from performing its safety function.
(3) Certain post-accident monitoring equipment.

The rule defines Safety-related electric equipment as equipment which must survive design basis events to ensure: the integrity of the reactor coolant pressure boundary, the ability to shut down the reactor and keep it in safe shutdown mode, and the mitigation of offsite radiation exposures.

Design basis events are the conditions of normal operation, including anticipated operational occurrences, design basis accidents, external events, and natural phenomena. These events are defined in each plant's Final Safety Analysis Report (FSAR) which gets approved by the NRC prior to the plant receiving an operating license.

Requirements for Qualification: The requirements for qualification are addressed in part (e) of the rule and provide the basis for the qualification program which must include:

(1) *Temperature and pressure*. Time-dependent pressure and temperature has to be established for the location of the electric equipment important to safety.



This must be for the most severe design basis accident which this equipment is required to remain functional both during and after.

(2) *Humidity*. Humidity effects during the design basis accidents must be taken into consideration.

(3) *Chemical effects*. The composition of chemicals used must be the most severe postulated

(4) *Radiation*. The radiation dose for components must be based upon the total dose received during the years of normal operation over the life of the component plus the radiation received during and after the accident.

(5) *Aging*. Equipment that is qualified by testing must be conditioned prior to the test to simulate the years in service prior to an accident. This may be done by using actually aged components or by artificially aging the

component. If artificial preconditioning is not practical for the full intended service life, shorter service lives can be established.

(6) *Submergence* (if subject to being submerged). Equipment must be qualified to the submergence depth anticipated or moved above the flood plain.

(7) *Synergistic effects*. Synergistic effects occur when the combined effect of more than one input creates a more severe response than the sum of the individual inputs alone. If synergistic effects are believed to have a significant effect on equipment qualification, they must be considered.

(8) *Margins*. To account for uncertainty in test or analysis, margins must be applied in the analysis or test. This also provides assurance that variations in manufacturing processes do not negate the qualification.

Part 4 IEEE 323 "IEEE Standard for Qualifying Class 1 Equipment for Nuclear Power Plants"

As previously discussed, IEEE Standard 323 has been the principal document defining how to qualify a device to a harsh environment. The standard describes five methods of qualification which are:

- Type Testing – which is the testing of actual equipment using simulated accident conditions
- Operating Experience – relies upon documented operating histories of equipment
- Qualification by Analysis – utilizes mathematical models to demonstrate qualification
- Combined Qualification – uses a combination of type testing, operating experience and analysis
- On-going Qualification – uses installed test samples which will be tested or analyzed at a future date

The first method of type testing became the industry standard for qualifying equipment in the early days of environmental qualification. This will be the qualification method discussed in this course. (As the industry matured and large data bases of type testing information became available, qualification by analysis became a more frequently used form of qualification.)

Type Testing – Type testing involves simulation of accident environments upon components that are near the end of their installed life. For instance, if a piece of cable is expected to operate for forty years (the license duration for a nuclear plant), you must postulate that the design basis event occurs in the last year of life. As there were no specimens of cable that had operated for forty years in a radiation environment similar to the normal operating conditions, an alternative approach was necessary. This approach involves artificially aging a new component by first exposing the component to a radiation dose equivalent to the expected normal lifetime dose and then artificially aging the component by baking it in an oven at elevated temperatures.

LOCA AUTOCLAVE
TEST CHAMBER

The specimens are then placed in a steam autoclave and are exposed to the temperatures, pressures, humidity, and chemical sprays that are present in the design basis event. All the while, the components operating characteristics are monitored for failure.

The following are the requirements for type testing found in IEEE 323:

- **Test Plan** – A formal test plan is required that addresses the following information: description of the equipment being tested, the mounting and connection requirements, the service conditions to be simulated, the procedure for simulating the aging of the component, the performance and environmental variables to be measured, requirements of the test equipment, test specimen failure descriptions and documentation requirements

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- **Mounting** – Equipment for the test must be mounted as it will be mounted in the power plant. This is particularly important for valve motor operators that can have several different orientations in the power plant.

- **Connections** – The test specimen must be connected in a manner that simulates the installed condition: i.e. conduit fittings, wiring, terminations, piping, tubing, etc.

- **Monitoring** – The test specimen must be monitored by calibrated equipment that is capable of detecting meaningful changes in the components critical variables such as insulation resistance, impedance, etc. IEEE 323 provides several detailed categories of measured variables to consider.

- **Margin** – Margin is the difference between the test conditions and the expected accident conditions for which the device is being qualified.

Test Sequence: IEEE also prescribes a definite sequence for the testing as it is as follows:

1. Inspection of the equipment for defects
2. Operation of the equipment under normal environmental conditions to baseline performance variables.
3. Operation of the equipment under normal environmental conditions at the extreme limits of the electrical characteristics.
4. The aging of the equipment including radiation dose if required.
5. Subjection of the aged equipment to whatever vibration tests required.
6. Operation of the aged equipment while the component is subjected to the simulated accident environment.
7. Operation of the equipment in a simulated post-accident environment.

This concludes the overview of IEEE 323. In actual practice, type testing was very expensive and time consuming. In the mid-1970s there were few facilities in the United States equipped to perform these tests. Within a few years several qualification facilities were established to perform type-testing for the utility industry. Today, a large database of type-test reports exists that utilities share with each other. This makes the life of an Environmental Qualification Engineer a lot easier today.

Part 5 What the industry learned from EQ.

The electric utility industry spent millions of dollars developing and maintaining their Environmental Qualification programs. Equipment was replaced and new procedures put in place for the maintenance of qualified equipment. The following is just a sample of what was learned in the process of establishing environmentally qualified equipment for Class 1E applications:

- Terminal Blocks – terminal blocks were found to be inadequate for most LOCA environments.

They were replaced with crimped splice connectors which were in turned covered with a qualified heat shrink sleeve and sealing compound.

- Splices – always known as a potential weak link in an electrical circuit, it was found that properly installed splices using materials and configurations that had been environmentally qualified were as good as the cable itself and a necessary tool for disconnecting and reconnecting components in the plant.

- Valve Motor Operators – the motor operators, limit switches, torque switches, grease relief valves found in certain motor operated valves (MOV)were found to be inadequate for certain LOCA applications. The sub-components of the MOVs had to be upgraded with replacement parts of different design and material properties in order to qualify the whole valve operator.

- Limit Switches – Certain brands of limit switches were found to be inadequate for LOCA applications and applications where high energy line breaks could occur (limit switches on main steam line application valves).

- Pressure Transmitters – certain brand pressure transmitters were found to be prone to failure in the harsh conditions of LOCA tests. EPRI led an industry project to successfully qualify a specific manufacturer's transmitter.

- Normally Energized DC Relays – these relays were found to have less than expected qualified life due to the heat generated by the constant energized state. It was found easier to simply replace all these relays on a more frequent basis than to try and predict a true qualified life.

This is just a short list of some of the changes in equipment selection that came about as a result of the Environmental Qualification programs in the nuclear industry. Beyond the obvious benefits of having qualified Class 1E electrical equipment, the industry learned a great deal about working together to solve problems bigger than any individual plant can handle. Plants made their environmental qualification results available to other utilities saving their fellow utilities hundreds of thousands of dollars in costs to perform type testing.

Glossary of Terms

- Class 1E – A classification of electrical equipment and systems that are essential for the safe shutdown of the reactor, isolation of the containment structure, maintaining safe shutdown conditions (decay heat removal), and preventing significant radiation release to the environment.
- Design Basis Events – Postulated events or accidents that are addressed in the FSAR for a nuclear plant.
- EPRI – the Electric Power Research Institute – a technical industry group funded by member electric utility companies. EPRI performs research on new technology for the electric industry.
- General Design Criteria (GDC) – those design requirements in the code of Federal Regulations that apply to all nuclear plants.
- HELB – High Energy Line Break – the rupture of a pipe which contains fluid containing high thermal energy (temperature, pressure, or both).
- IEEE - Institute of Electrical and Electronic Engineers.
- Installed Life – the interval from the time a device is installed until it is remove from service
- FSAR - Final Safety Analysis Report – a multi-volume safety analysis of a nuclear power plant which must be approved by the NRC before the plant can operate.

- Limit Switch – an electrical switch which activates when an established position is reached by a mechanical object.
- LOCA – Loss of Coolant Accident – An accident scenario in which the coolant circulating through the reactor is lost through a break in the system.
- MOV – Motor Operated Valve – a valve which has an electric motor actuator, along with position limit switches, all enclosed in a metal housing, attached to the valve.
- Qualified Life – the interval for which a component can be shown to have satisfactory performance for a given set of environmental conditions.
- Synergistic effects – effects that result when the combined effect of more than one input creates a more severe response than the some of the individual inputs alone.
- Type-testing – Tests made on components to verify adequacy of design.
- UCS – Union of Concerned Scientists

E. Conclusions

The accident at Three Mile Island in 1978 changed the course of the nuclear power industry in the United States. This serious accident brought about numerous new regulations that have led to a much higher degree of safety in the operation of these plants, as evidenced by the operating records of the United States plants in the twenty-five years since the accident. Although regulatory interest was already present in the NRC on the subject of Environmental Qualification of Safety Related Electrical Equipment, the winds of change from the accident at Three Mile Island gave this area of nuclear safety the added focus it needed. Another of the lessons learned from the Three Mile Island accident is that the operators in the control room should let the emergency systems perform their automatic functions to the maximum extent possible during and after an accident. Intervention by the operator should generally only occur when an automatic system fails to perform its function. In this unlikely event at a nuclear plant today, the plant operators can be assured that the safety related electrical equipment will perform its intended function, allowing for the prompt mitigation of the event.