PDHonline Course E396 (3 PDH)

Environmental Qualification of Safety Related Electrical Equipment

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Environmental Qualification of Safety Related Electrical Equipment for Nuclear Power Plants

Gary W Castleberry PE PMP

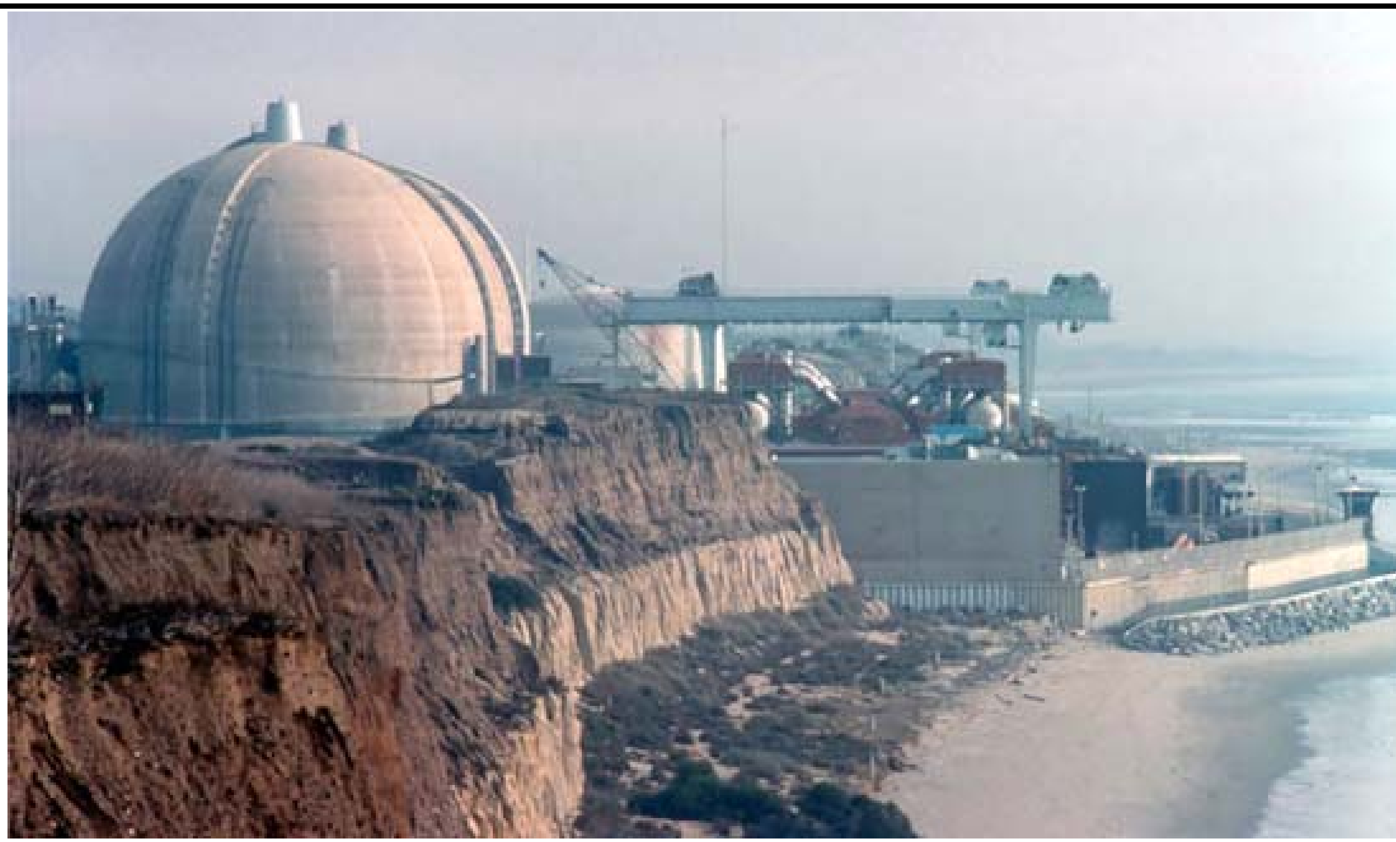
Learning Modules

1. What is Environmental Qualification (EQ)
2. History of EQ
3. Federal Regulation 10CFR50.49
4. IEEE 323
5. What the Industry Has Learned

Module 1
What is Environmental Qualification?

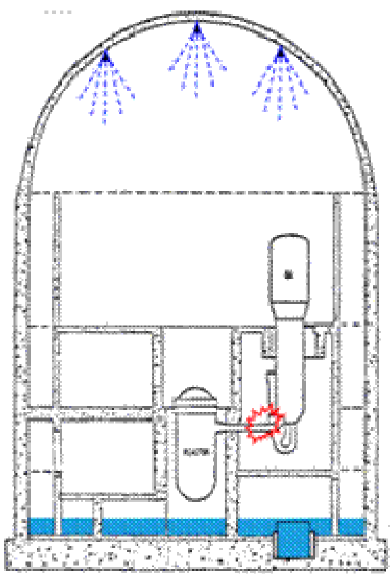
- To protect the health and safety of the public all commercial nuclear reactors are housed in steel and reinforced concrete containment buildings (CB)
- Inside the CB is the reactor and steam generators containing water at high temperatures and pressures
- Also inside the CB are electrical components critical to the safe shutdown of the nuclear reactor
- These components are classified as Class 1E

What is Environmental Qualification?



Typical Containment Building for a Nuclear Power Plant

What is Environmental Qualification?



- All piping penetrations to the CB must have redundant isolation valves
- In the unlikely event of a pipe break in the CB, a large amount of steam and energy is released inside the CB
- This accident would subject the Class 1E components to elevated temperatures, pressures, radiation and possible submergence

What is Environmental Qualification?

- To ensure the Class 1E components can function during and after the accident they must be qualified to this harsh environment
- Many industry standards have been developed to describe the preferred methods for testing and qualifying these components
- To understand where these programs are today, one must understand the history of Environmental Qualification (EQ)

Module 2
History of Environmental Qualification in the USA Nuclear Industry

- In the US nuclear power plants are built and operated by public utility companies
- The Federal Government issued licenses to operate after extensive reviews of volumes of safety analysis reports
- This governance was initially performed by the Atomic Energy Commission
- In the early 1970s the Nuclear Regulatory Commission (NRC) was formed to oversee commercial nuclear power

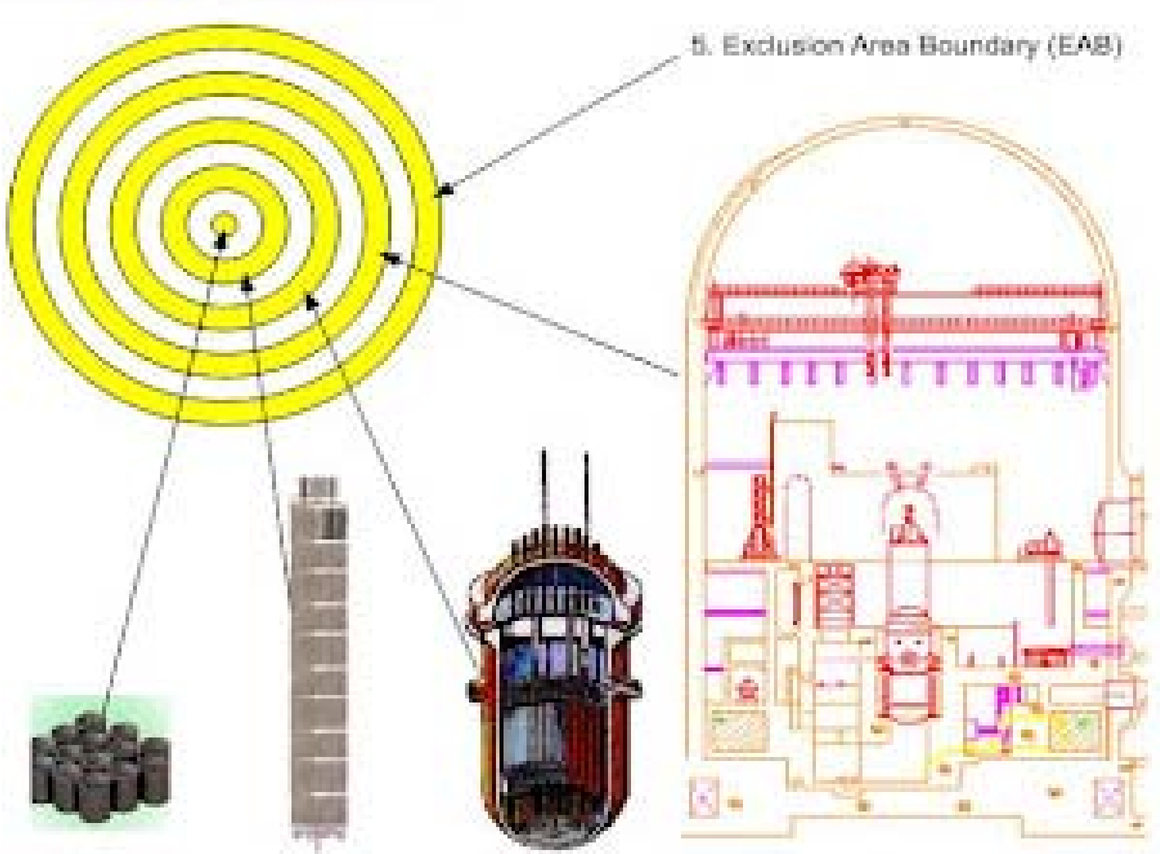
History of Environmental Qualification in the USA Nuclear Industry

- The regulations governing nuclear power are found in Part 50 of Title 10 of the Code of Federal Regulations
- Appendix A to 10 CFR 50 is the General Design Criteria (GDC) which provide the “must do” design aspects of a nuclear power plant
- Their purpose is to inculcate the principle of defense in depth

History of Environmental Qualification in the USA Nuclear Industry

- Elements of Defense in Depth
  - Redundant and Diverse Safety Systems necessary for the safe shutdown of the nuclear reactor
  - Automatic Reactor Protection Systems that shut down the reactor when critical parameter limits are exceeded
  - Radiation Containment Barriers
    - Fuel Rods
    - Reactor piping system
    - Containment Building

History of Environmental Qualification in the USA Nuclear Industry



Physical barriers between reactor core and the environment

History of Environmental Qualification in the USA Nuclear Industry

- Criterion 4 of the GDC requires:
  - "Structures, systems, and components important to safety shall be designed to accommodate the effects of and be compatible with the environmental conditions with normal operation, maintenance, testing and postulated accidents, including loss of coolant accidents."
  - There was little guidance early on in how to meet this requirement

History of Environmental Qualification in the USA Nuclear Industry

- In 1969, the Union of Concerned Scientists (USC) was created
  – Formed by an ad hoc group of faculty and students at the Massachusetts Institute of Technology
  – Wanted to protest what they perceived as the misuse of science and technology
- In the mid 1970s the USC petitioned the NRC regarding the test failures of some safety related components some utilities had experienced

History of Environmental Qualification in the USA Nuclear Industry

- As a result of the USC petition, on May 31, 1978 the NRC issued Circular 78-08 "Environmental Qualification of Safety Related Electrical Equipment at Nuclear Power Plants"
- The intent was to highlight the lessons learned from these test failures
- The utilities were instructed to review their EQ programs
- **No written response** was required

History of Environmental Qualification in the USA Nuclear Industry

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

History of Environmental Qualification in the USA Nuclear Industry

- At 4 a.m. on March 28, 1979 the accident at Three Mile Island occurred resulting in a core melt event

- Lessons learned was that several critical components failed during the accident due to the harsh accident environment
- Failure of sensors denied control room operators critical information during the event

History of Environmental Qualification in the USA Nuclear Industry

- On January 14, 1980 the NRC issued Bulletin 79-01B requesting a re-submittal of the information previously requested in 79-01
- Required the development of a Master Equipment List of EQ components
- 79-01B included Enclosure 4 ”Guidelines for Evaluation Environmental Qualification of Class 1E Electrical Equipment in Operating Reactors”

History of Environmental Qualification in the USA Nuclear Industry

- NRC held four days of industry meetings in July 1980 to discuss the requirements of 79-01B and the future codification of EQ
- Following this meeting the NRC issued Supplement 2 and 3 to 79-01B to answer the questions raised by the industry in the July meeting
- EPRI formed a Utility Advisory Group on EQ to address research required to qualify some components

History of Environmental Qualification in the USA Nuclear Industry

- Following the accident at TMI the NRC issued many new regulations based upon lessons learned
- In December 1980 Regulatory Guide 1.97 "Instrumentation for Light-Water Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident" was issued by the NRC

History of Environmental Qualification in the USA Nuclear Industry

- Regulatory Guide 1.97 addressed specific instrumentation used in the control room which needed to be upgraded
- Upgrades included higher quality power sources, diversity of the instrument signal, and the **environmental qualification of the sensor element**
- When the rule for EQ was issued in 10CFR50.49, paragraph (b)(3) included the equipment from Regulatory Guide 1.97

Module 3
Federal Regulations 10CFR50.49

- The rule for EQ is found in the code of federal regulations 10CFR50.49
- Requires each licensee to establish a program for EQ
- Paragraph (b) defines the three groups of equipment **important to safety**
  - **Safety related electrical equipment**
  - **Non-safety related equipment whose failure could impact a safety related component**
  - **Certain post-accident monitoring equipment**

Important to Safety

Important to safety is an important concept

It encompasses more than just safety related

That is why it is repeated here

- **Safety related electrical equipment**
- **Non-safety related equipment whose failure could impact a safety related component**
- **Certain post-accident monitoring equipment**

Environmental Qualification Program

- 10 CFR50.49 defines safety related 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
  - The mitigation of offsite radiation exposures

Environmental Qualification Program

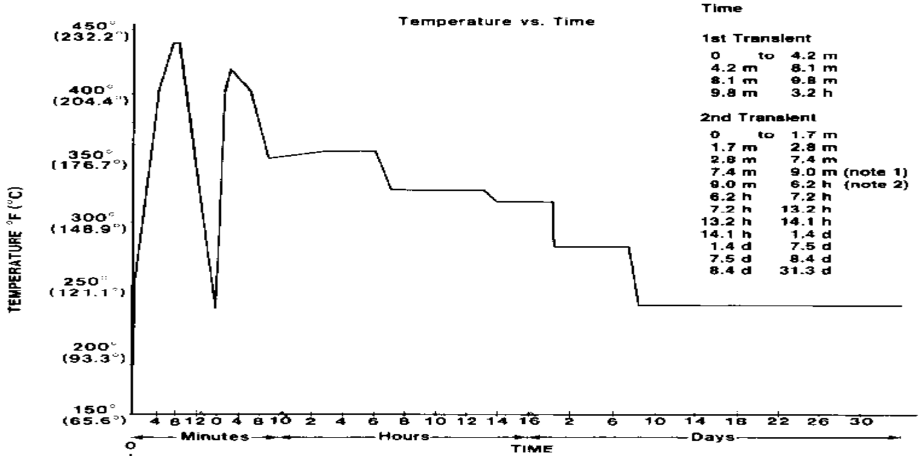
- Design Basis Events
  - Normal operation
  - Anticipated operational occurrences
  - Design basis accidents
  - External events
  - Natural phenomena
- Examples: Loss of coolant accident, high energy line break, flooding

Environmental Qualification Program

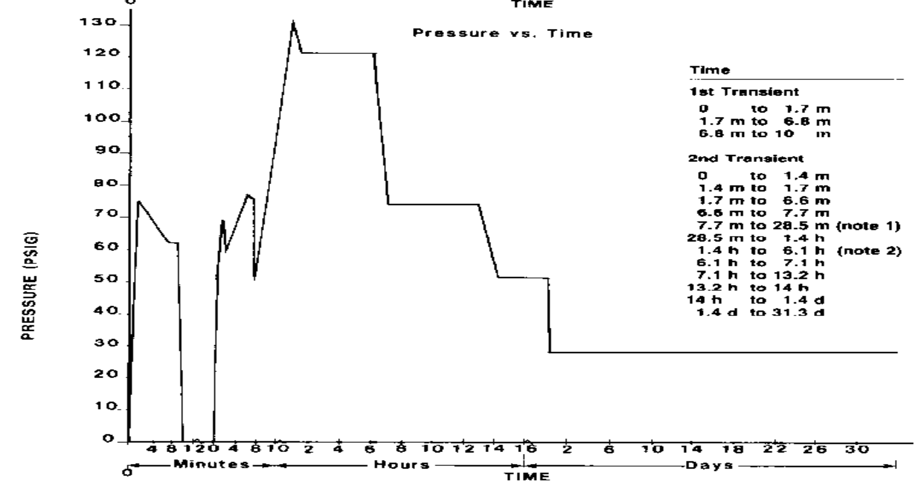
Environmental Qualification Program

- The requirements for qualification are addressed in part (e) of the rule and include:
  - (1) Temperature and pressure. Time dependent pressure and temperature for the location of the equipment important to safety
  - (2) Humidity. Humidity effects during the design basis accidents must be taken into consideration
  - (3) Chemical effects. The composition of chemicals exposure must be the most severe postulated

Environmental Qualification Program



Time		Temperature (°F)	Temperature (°C)
1st Transient			
0	to 4.2 m	191 to 400	88 to 204
4.2 m	8.1 m	442	228
8.1 m	9.8 m	400	204
9.8 m	3.2 h	255	124
2nd Transient			
0	to 1.7 m	230 to 400	110 to 204
1.7 m	2.8 m	420	216
2.8 m	7.4 m	400	204
7.4 m	9.0 m (note 1)	350	177
9.0 m	6.2 h (note 2)	355	179
6.2 h	7.2 h	325	163
7.2 h	13.2 h	325	163
13.2 h	14.1 h	307	153
14.1 h	1.4 d	307	153
1.4 d	7.5 d	280	138
7.5 d	8.4 d	232	111
8.4 d	31.3 d	232	111



Time	Pressure (psig)
1st Transient	
0 to 1.7 m	75
1.7 m to 6.8 m	62
6.8 m to 10 m	0
2nd Transient	
0 to 1.4 m	69
1.4 m to 1.7 m	59
1.7 m to 6.6 m	77
6.6 m to 7.7 m	50
7.7 m to 28.5 m (note 1)	132
28.5 m to 1.4 h	120
1.4 h to 6.1 h (note 2)	120
6.1 h to 7.1 h	74
7.1 h to 13.2 h	74
13.2 h to 14 h	51
14 h to 1.4 d	51
1.4 d to 31.3 d	28

Typical LOCA Temperature and Pressure Curves for Qualification

Environmental Qualification Program

- Requirements continued
  - (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.

Environmental Qualification Program

- Requirements continued
  - (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 some 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.

EQ Program Documentation Requirements from 10CFR50.49

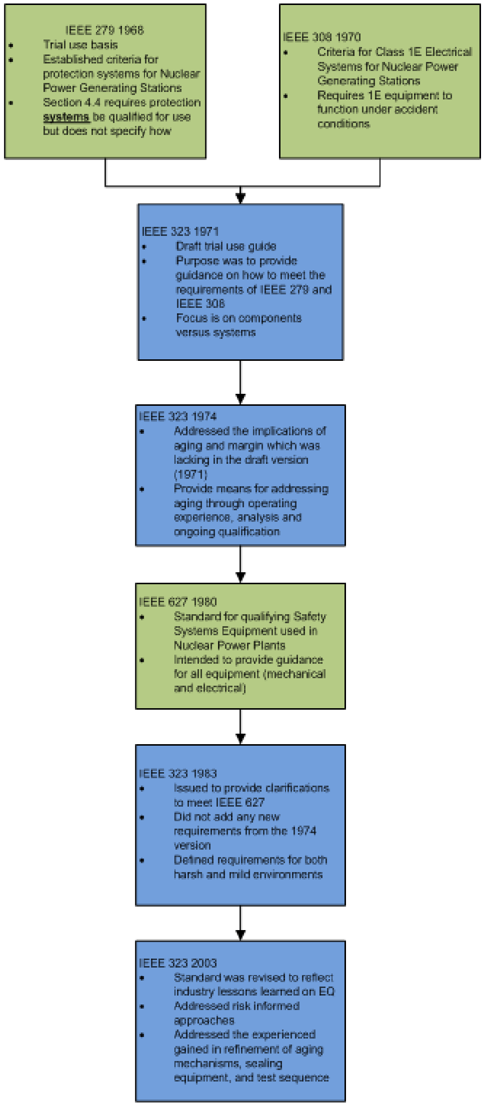
Part (d) of 10CFR50.49 states: "The applicant or licensee shall prepare a list of electric equipment important to safety covered by this section. In addition, the applicant or licensee shall include the information in paragraphs (d)(1), (2), and (3) of this section for this electric equipment important to safety in a qualification file.

The applicant or licensee shall keep the list and information in the file current and retain the file in auditable form for the entire period during which the covered item is installed in the nuclear power plant or is stored for future use to permit verification that each item of electric equipment is important to safely meet the requirements of paragraph (j) of this section.

- (1) The performance specifications under conditions existing during and following design basis accidents.
- (2) The voltage, frequency, load, and other electrical characteristics for which the performance specified in accordance with paragraph (d)(1) of this section can be ensured.
- (3) The environmental conditions, including temperature, pressure, humidity, radiation, chemicals, and submergence at the location where the equipment must perform as specified in accordance with paragraphs (d)(1) and (2) of this section."

Module 4 IEEE 323

History and Evolution of IEEE 323



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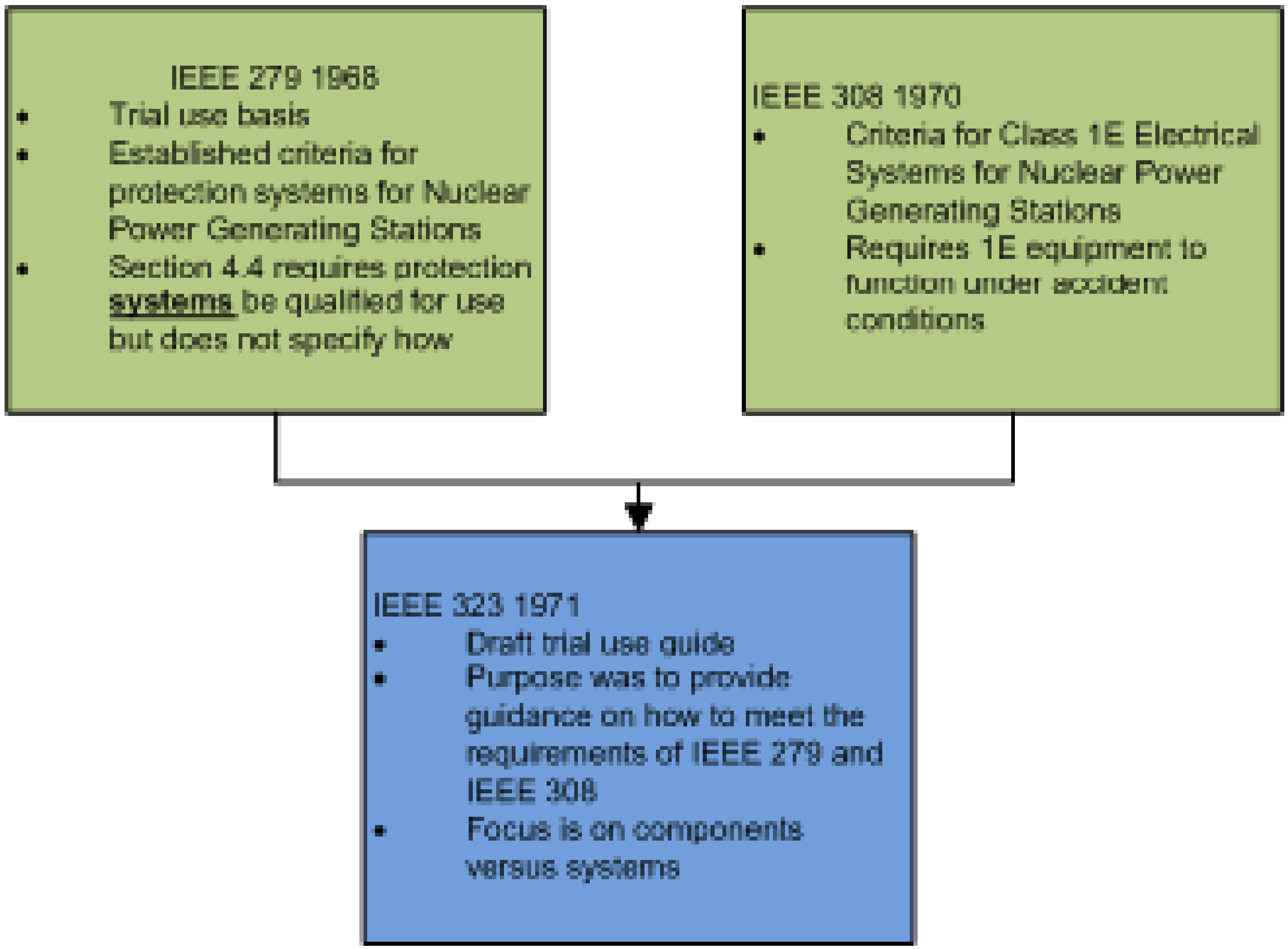
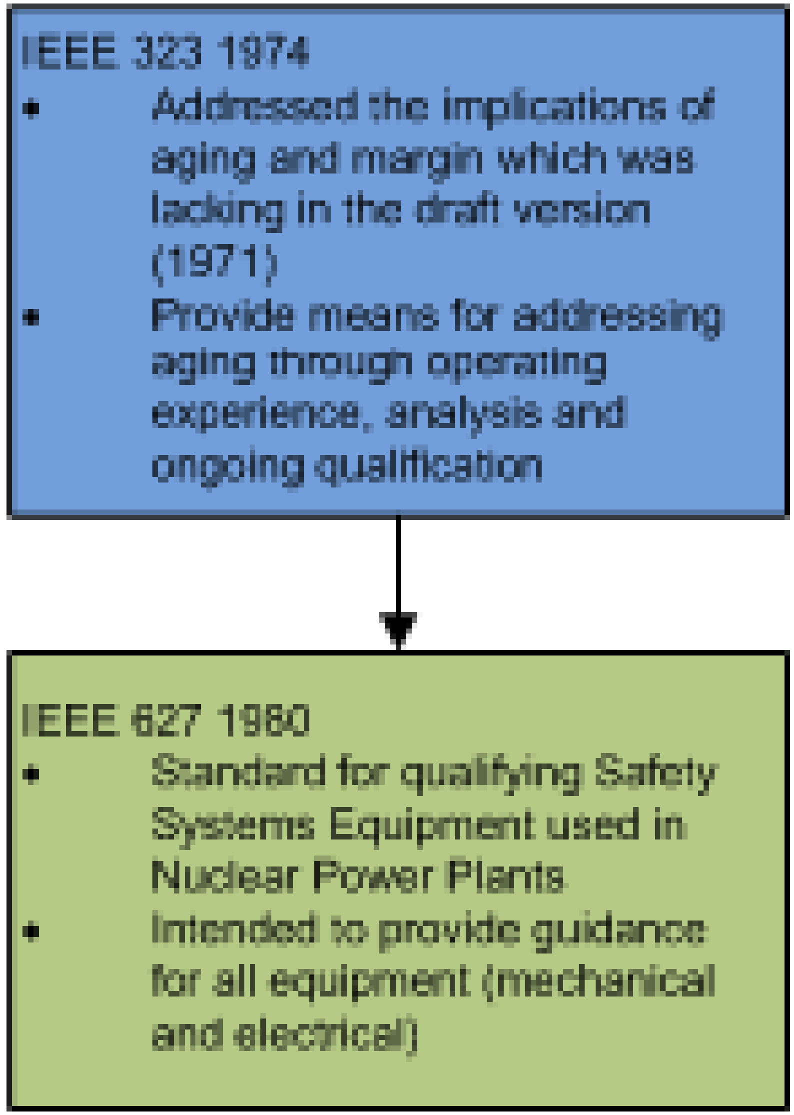
IEEE 323


IEEE 279 1968
• Trial use basis
• Established criteria for protection systems for Nuclear Power Generating Stations
• Section 4.4 requires protection systems be qualified for use but does not specify how
IEEE 308 1970
• Criteria for Class 1E Electrical Systems for Nuclear Power Generating Stations
• Requires 1E equipment to function under accident conditions
IEEE 323 1971
• Draft trial use guide
• Purpose was to provide guidance on how to meet the requirements of IEEE 279 and IEEE 308
• Focus is on components versus systems

IEEE 323


IEEE 323 1974
• Addressed the implications of aging and margin which was lacking in the draft version (1971)
• Provide means for addressing aging through operating experience, analysis and ongoing qualification
IEEE 627 1980
• Standard for qualifying Safety Systems Equipment used in Nuclear Power Plants
• Intended to provide guidance for all equipment (mechanical and electrical)

IEEE 323

IEEE 323 1983

- Issued to provide clarifications to meet IEEE 627
- Did not add any new requirements from the 1974 version
- Defined requirements for both harsh and mild environments

↓

IEEE 323 2003

- Standard was revised to reflect industry lessons learned on EQ
- Addressed risk informed approaches
- Addressed the experienced gained in refinement of aging mechanisms, sealing equipment, and test sequence

IEEE 323

- Common Mode Failure
  - A mechanism by which a single design basis event can cause redundant equipment to be inoperable
- Common Cause Failure is an event in which
  - Components fail within a selected time such that success of the PRA mission would be uncertain
  - Component failures result from a single shared cause and coupling mechanism
  - A component failure or fault occurs within the established component boundary
  - Two or more components fail or are degraded, including failures during demand, in-service testing, or deficiencies that would have resulted in a failure if a demand signal had been received

IEEE 323

- definition of qualification is "generation and maintenance of evidence to ensure that the equipment will operate on demand to meet system performance requirements."
- Environmental qualification is verification and validation that a design adequately accommodates the effects of, and is compatible with, the environmental conditions associated with the normal, abnormal, and accident conditions that the equipment or system might encounter

IEEE 323

- IEEE Standard 323 has been the principal document defining how to qualify a device to a harsh environment via one of five methods:
  - 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

IEEE 323

- Type Testing is the most widely used means of qualification where components are
  - First exposed to the radiation dose equivalent of the expected lifetime dose
  - Next artificially aged by baking in an oven at elevated temperatures
  - Finally placed in a steam autoclave and are exposed to the temperatures, pressures, humidity, and chemical sprays present in the Design Basis Event

IEEE 323

LOCA
Test
Autoclave

IEEE 323

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 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
- documentation requirements

IEEE 323

Type Testing Requirements continued

- **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.

IEEE 323

Type Testing Requirements continued

- **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.

IEEE 323

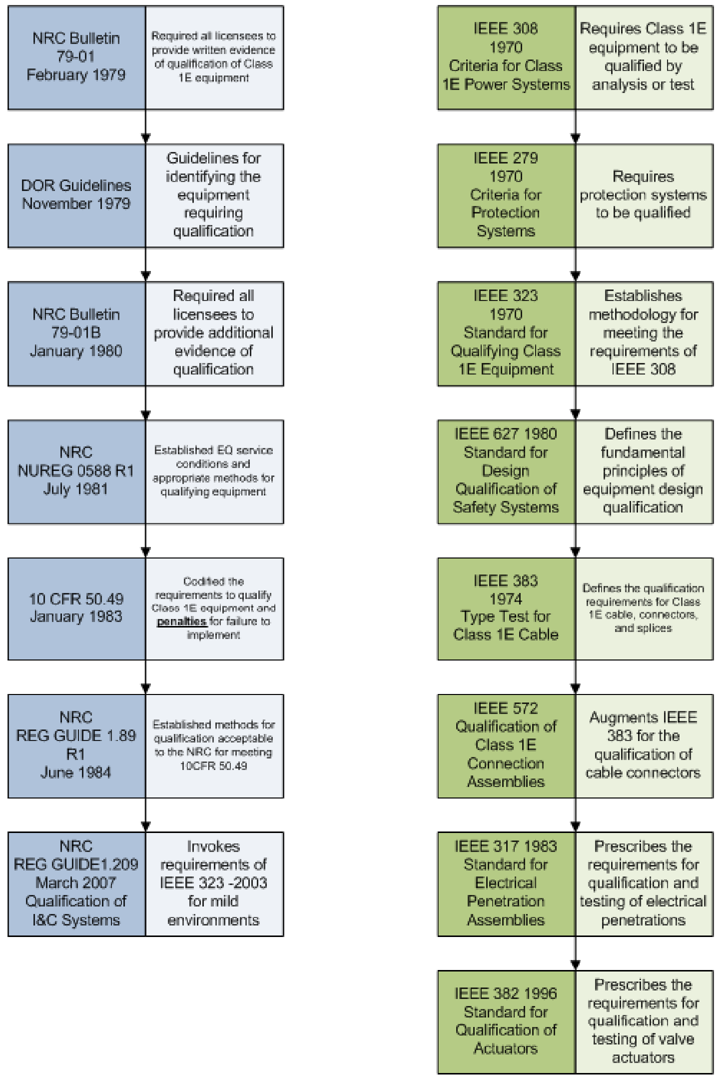
Test Sequence: IEEE also prescribes a definite sequence for the testing as it is as follows:

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

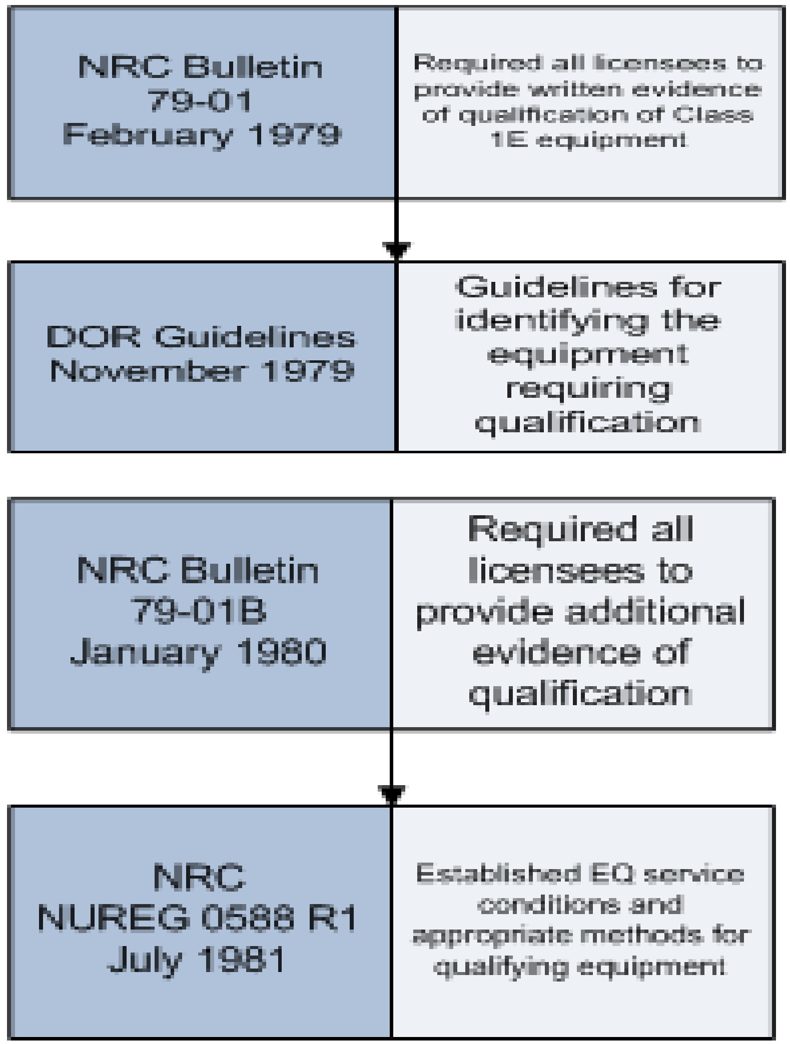
IEEE 323

- This concludes the overview of IEEE 323
- Type testing is very expensive and time consuming
- Today a large database exists of type test reports that utilities share with each other
- There are many standards that augment IEEE 323 and are shown on the next few slides

Evolution of Criteria and Laws Governing the Environmental Qualification of Class 1E Electrical Equipment



Regulations and Standards Associated with EQ



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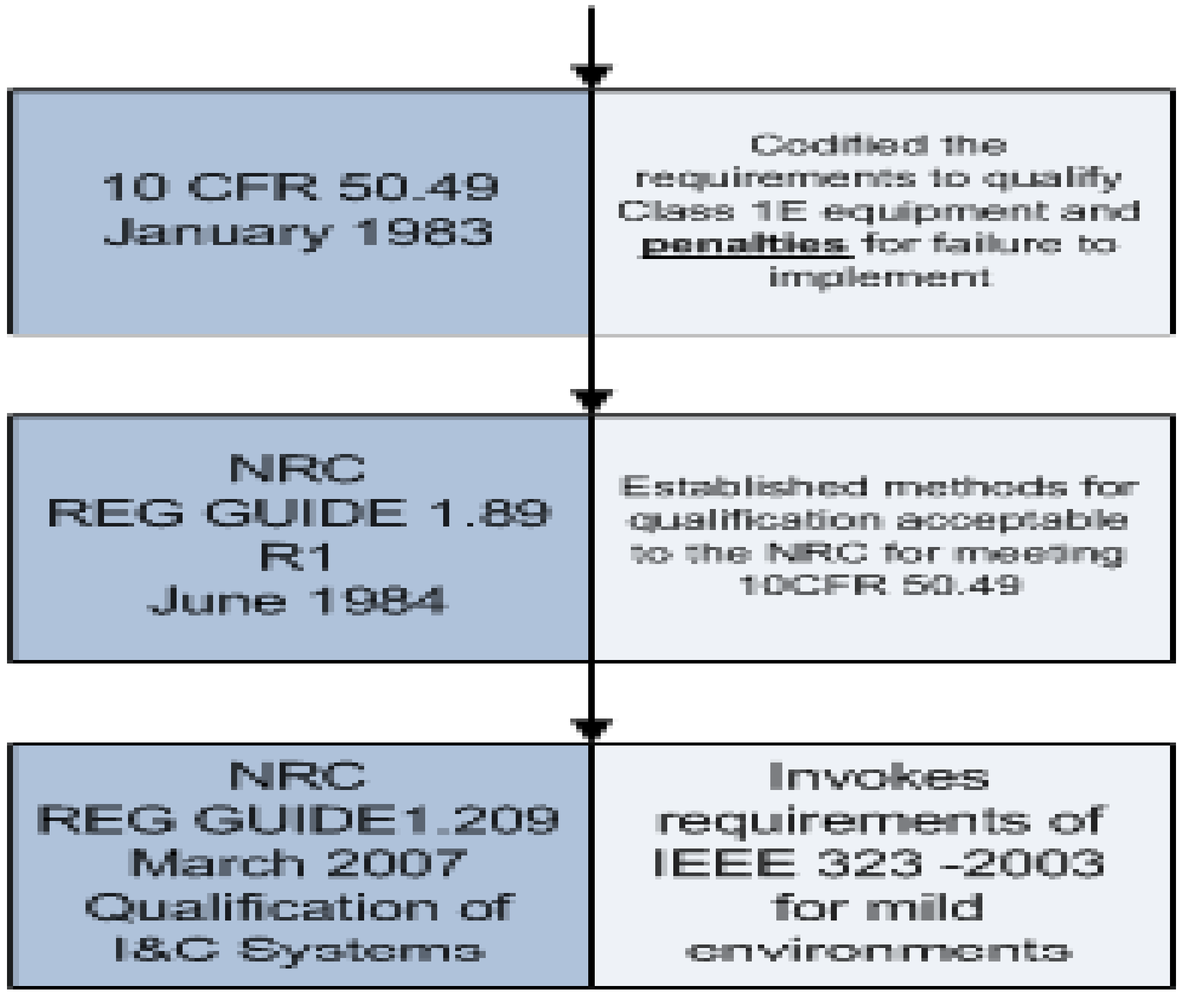
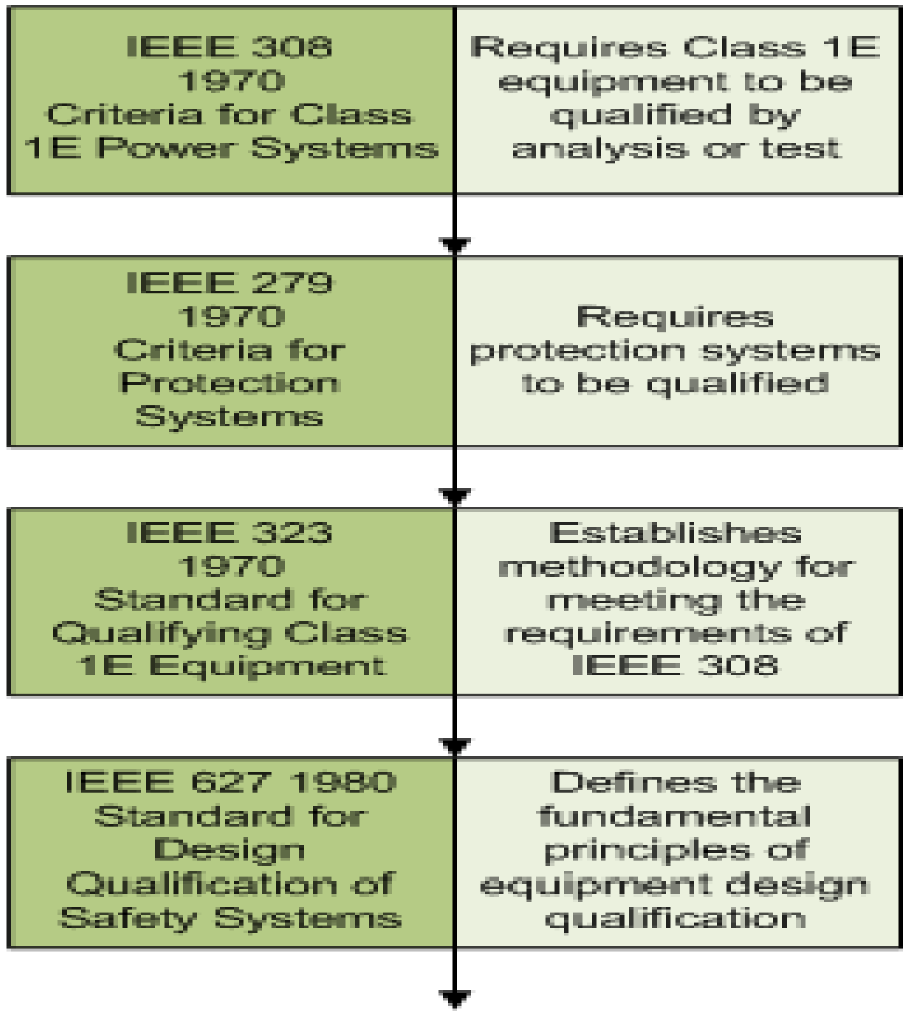
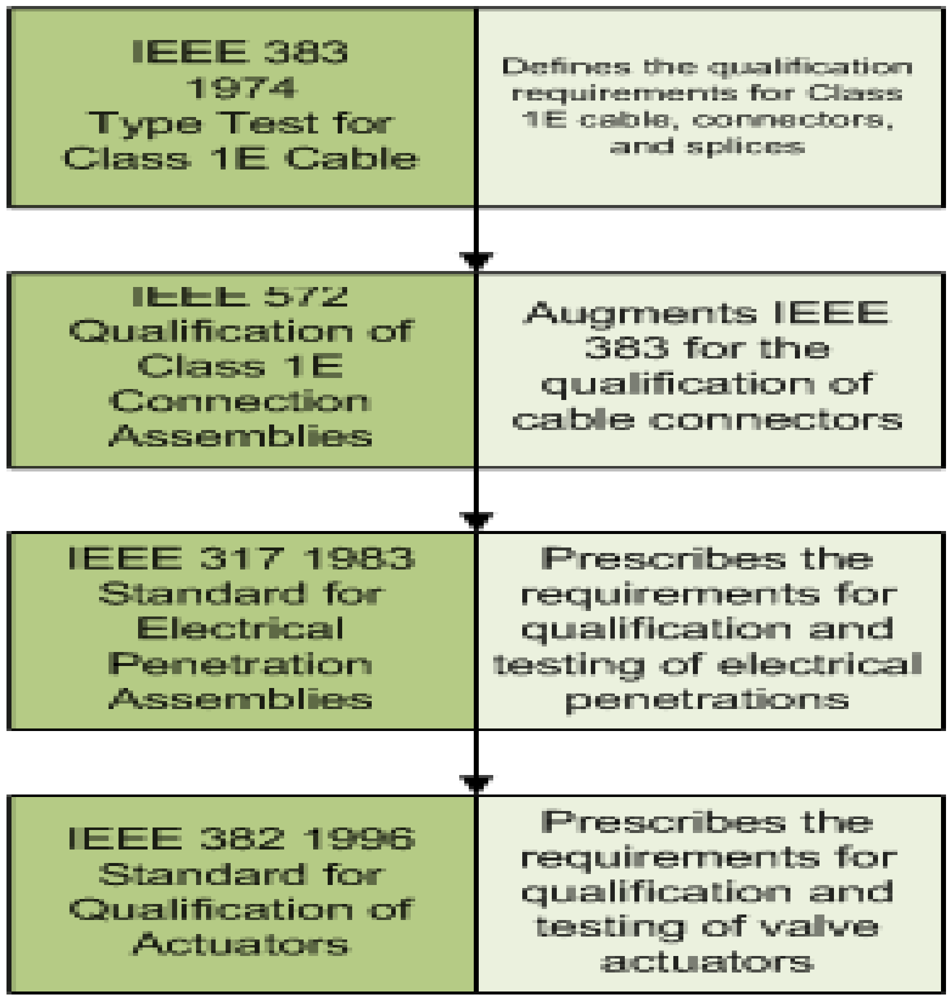
Regulations and Standards Associated with EQ



Regulations and Standards Associated with EQ

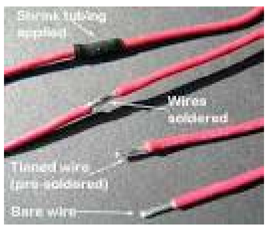


Regulations and Standards Associated with EQ



Module 5
Some of the Lessons Learned in EQ

– 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.

Some of the Lessons Learned in EQ

– 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.

Environmental Qualification

- **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.

Environmental Qualification

- **Conclusions** continued
  - 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.

Environmental Qualification

- **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

Environmental Qualification

- **Glossary of Terms**
  - 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
-

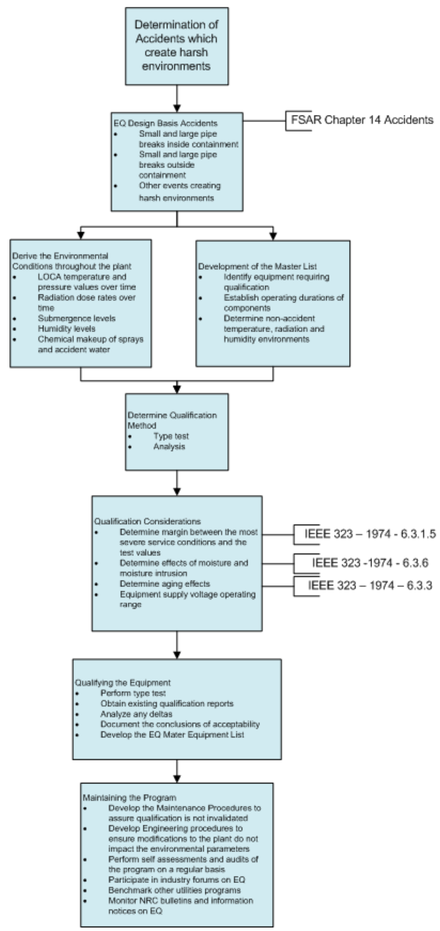
Developing the Environmental Qualification Program

How an EQ Program should be structured for continued success

Developing the Environmental Qualification Program

- The regulations tell you what you must do and have in the EQ Program but they….
  - do not tell you how to set up a program
  - do not tell you how to keep it robust
  - do not tell you how to prevent your equipment from becoming un-qualified
- The following process chart shows the fundamental parts of establishing a program and keeping it healthy

Developing the Environmental Qualification Program



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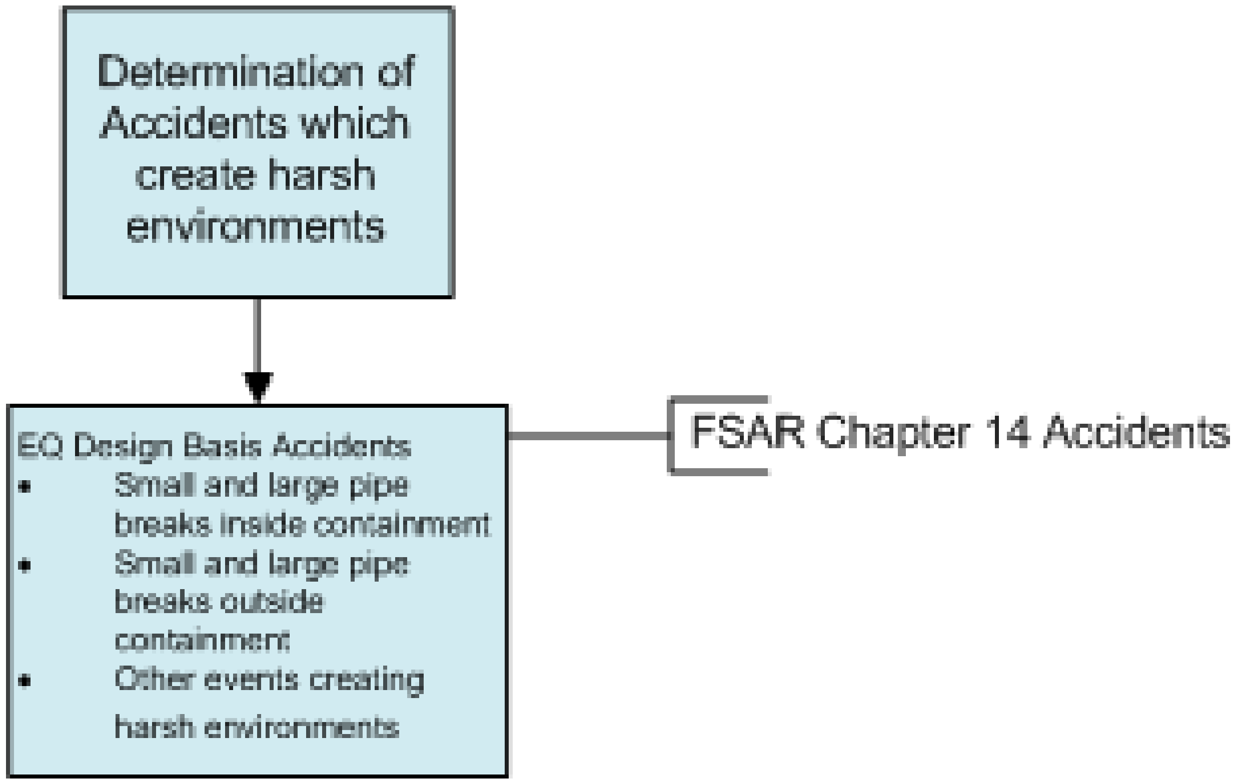
Developing the Environmental Qualification Program



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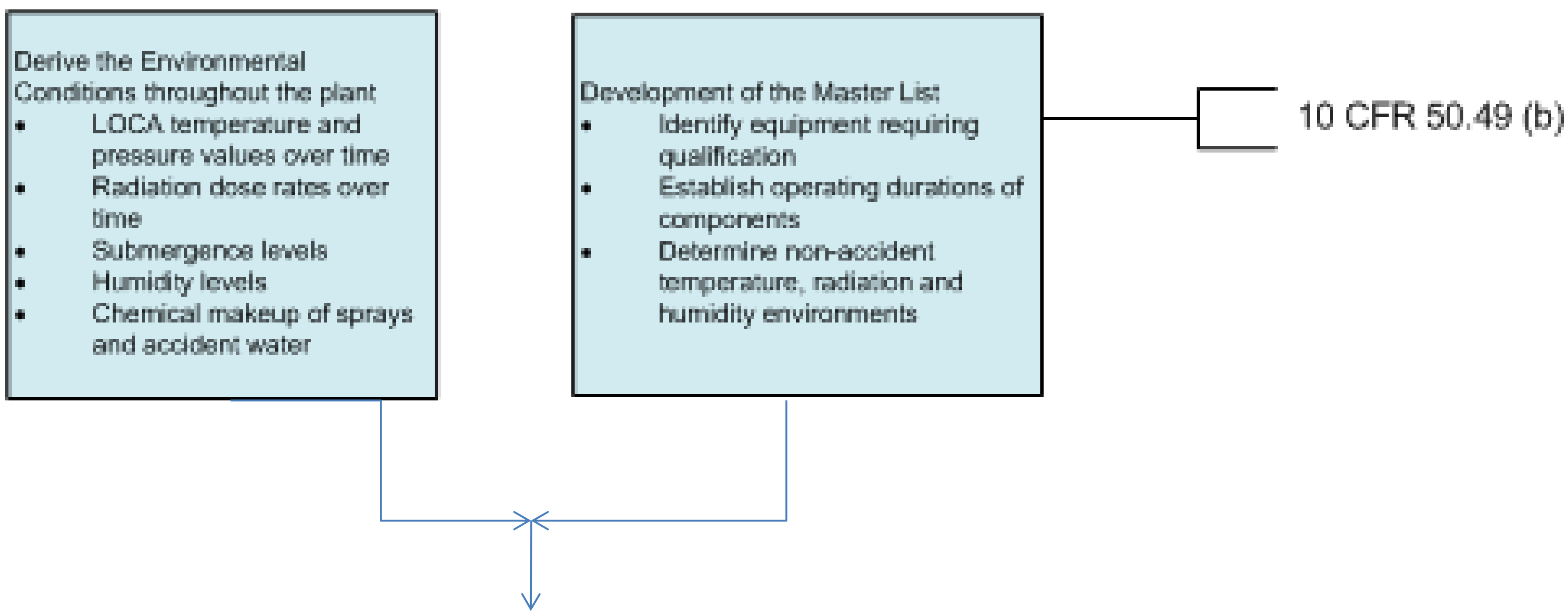
Developing the Environmental Qualification Program



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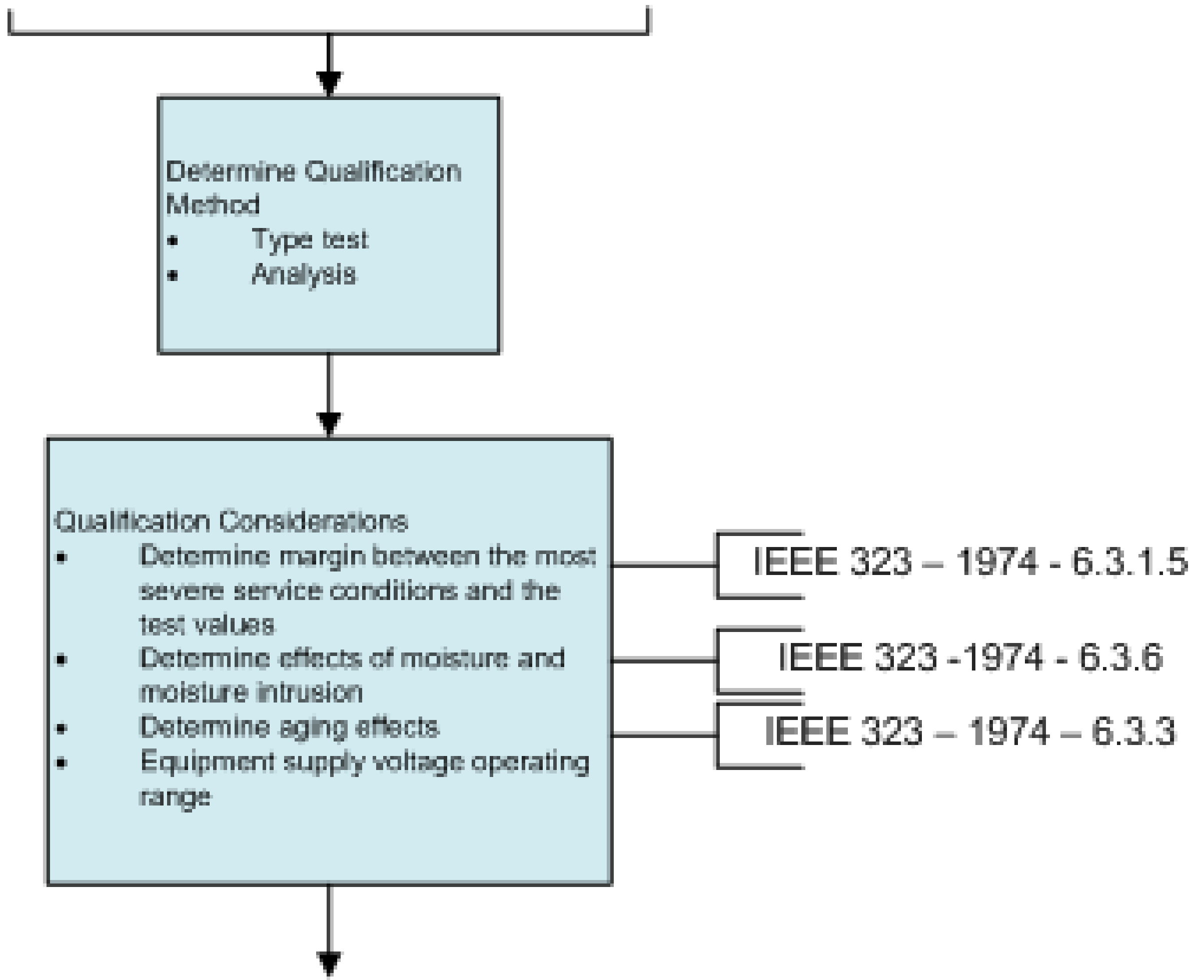
Developing the Environmental Qualification Program



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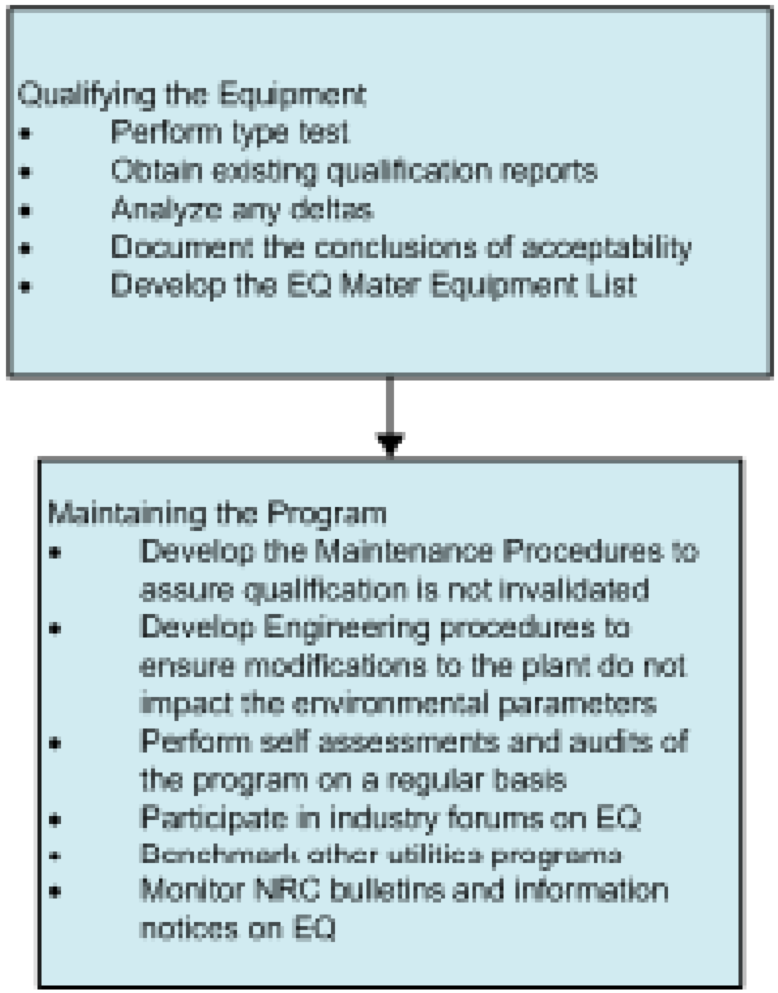
Developing the Environmental Qualification Program



Developing the Environmental Qualification Program

A healthy and robust EQ program requires active participation from many parts of the organization

- » EQ Group – creating and maintaining the Master EQ List, identifying qualified equipment
- » Engineering – Assure future modifications to the plant minimize impacts to the EQ accident parameters
- » Maintenance – Assure maintenance activities do not invalidate qualification
- » Management – Demonstrating full support for the program, recognizing the importance to nuclear safety