EQUIPMENT QUALIFICATION

Joint ICTP-IAEA Essential Knowledge Workshop on Deterministic Safety Assessment and Engineering Aspects Important to Safety

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EQUIPMENT QUALIFICATION INTRODUCTION

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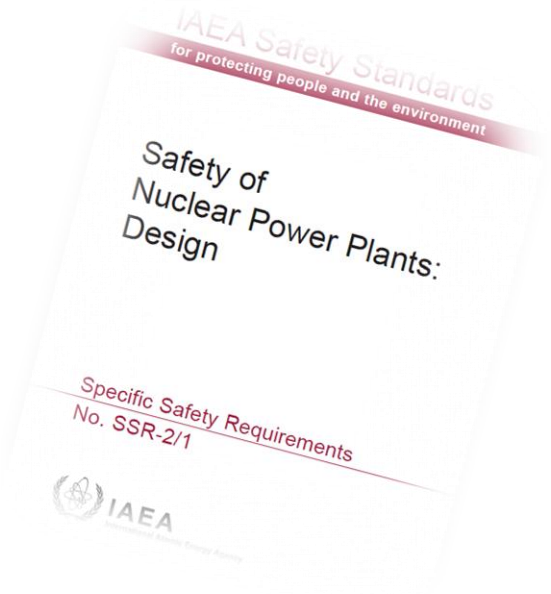
- **10+ years in NPP I&C Engineering** (I&C upgrades, modification, operation support, preventive maintenance plans, cyber security,…)

- **CISSP** (January 2015)
- **IAEA I&C Safety Guide Working Group** (December 2011 – December 2012)
- **Digital I&C Cyber Security Program** (January 2010 – Present)
- **NPP Dukovany Plant Control I&C Systems Refurbishment** (January 2009 – Present)
- **NPP Dukovany Safety I&C Systems Refurbishment** (February 2002 – December 2009)

EQUIPMENT QUALIFICATION INTRODUCTION

SSR 2/1 Requirement 30:

A **qualification program** for items important to safety **shall be implemented** to verify that items important to safety at a nuclear power plant are capable of **performing their intended functions when necessary**, and in the prevailing **environmental conditions**, **throughout their design life**, with due account taken of plant conditions during maintenance and testing.



EQUIPMENT QUALIFICATION INTRODUCTION

Qualification means “generation and maintenance of evidence to ensure that equipment will operate on demand, under specified service conditions, to meet system performance requirements”.

[IAEA Safety Glossary, 2007]

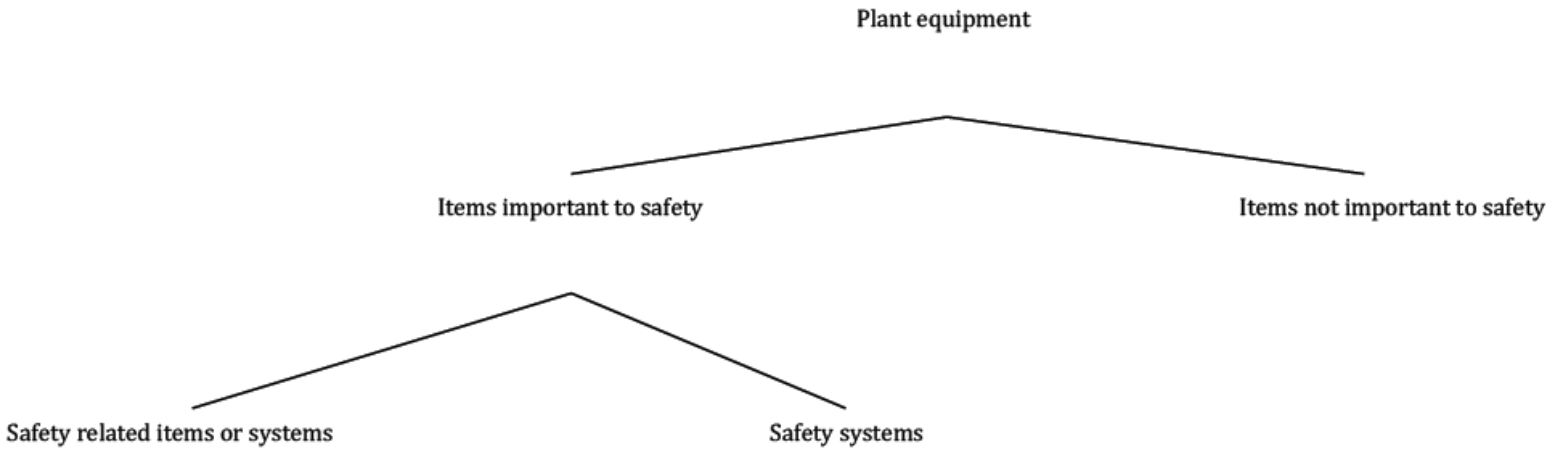
Equipment qualification is a process for ensuring that the systems and equipment important to safety are capable of **performing their safety functions**. This process involves the demonstration of the necessary functionality **under all service conditions** associated with all plant design states.

[IAEA NP-T-3.12]

EQUIPMENT QUALIFICATION CLASSIFICATION

A variety of plant systems, structures, and components are **important to safety** (or safety related) because **they directly or indirectly perform or support the performance of safety functions** (such as reactor shutdown, containment isolation and integrity, reactor cooling and decay heat removal,…)

Safety functions (functional and performance requirements) and **service conditions** must be defined to identify **qualification acceptance criteria**.



EQUIPMENT QUALIFICATION
PLANT SAFETY

Equipment qualification is the verification of equipment design by demonstrating **functional capability under significant operational and environmental stresses**, including those resulting from **design basis events** (accidents).

The qualification process is intended to significantly **reduce or eliminate the probability of common-cause environmental failures**.

In the nuclear power industry, equipment qualification is typically performed on a device-by-device basis.

[EPRI 1021067]

[http://web.ard.de/]

EQUIPMENT QUALIFICATION
PLANT SAFETY

A **common-cause failure** is defined as failure of equipment or systems as a consequence of the same cause. The term is usually used with reference to redundant equipment or systems. Common-cause failures can occur due to design, operational, **environmental**, or human factor **initiators**.

The most common examples of environmentally induced common-cause failures are those occurring as a consequence of earthquakes and postulated accidents, such as steam line breaks. Such events introduce significantly increased stressors to multiple components and have the potential of reducing their functional capability to unacceptable levels.

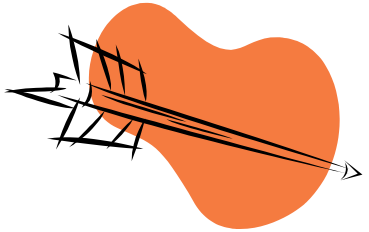
[EPRI 1021067]

EQUIPMENT QUALIFICATION SCOPE

The qualification programs should address all topics affecting the suitability of each system or component for its intended functions, including:

- Suitability and correctness of functions and performance,
- Environmental qualification,
- Qualification for the effects of internal and external hazards, and
- Electromagnetic qualification.

[DS-431, 6.85]



EQUIPMENT QUALIFICATION TERMINOLOGY

Suitability and correctness:

- Systems, and components meet all functional, performance, and reliability requirements. [DS-431]

Service conditions:

- **Environmental conditions**: conditions external to the equipment, such as ambient temperature, radiation, and externally induced vibration.
- **Operational conditions**: conditions internal to the equipment or associated with its physical, electrical, mechanical, or process interfaces.
- **Abnormal conditions**: loss of power supply (station blackout), failure of heating, ventilation, and air conditioning (HVAC) systems, steam or fluid leaks from small process piping or components such as valves, maintenance actions.

[EPRI 1021067]

EQUIPMENT QUALIFICATION TERMINOLOGY

Design basis events (accidents): events creating harsh-environmental conditions and other hazards.

- LOCA: loss-of-coolant accidents
- HELB: High-energy line breaks

Harsh environments are extreme environmental conditions usually produced by pipe break accident (during and following LOCA and HELB design basis accidents inside and outside containment).

Mild environments exist in plant areas not affected significantly by an accident (normal service conditions).

[EPRI 1021067]

EQUIPMENT QUALIFICATION TERMINOLOGY

Environmental stressors: temperature, radiation, pressure, humidity, steam, chemicals, vibration and earthquakes, electromagnetic interference

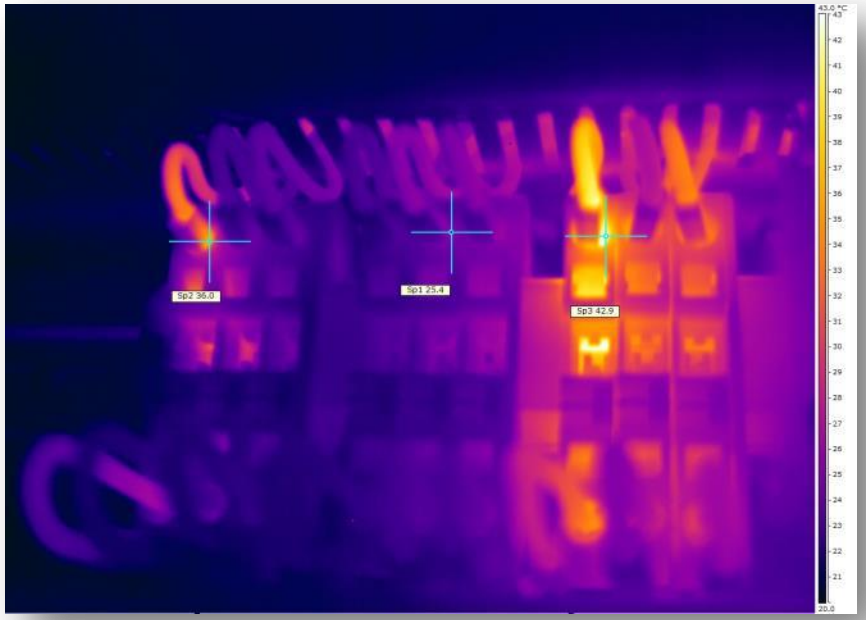
Operational stressors: power supply voltage/frequency, loading, electrical or mechanical cycling, self-heating, process fluid effects, self-induced vibrations

Internal and external hazards: fire, flooding, extreme weather, seismic events, missiles (failure of high speed rotating equipment), falling objects (heavy crane loads, an aircraft impact), pipe whip, electromagnetic interference

[DS-431, NS-G-1.11, EPRI 1021067]

EQUIPMENT QUALIFICATION
MAJOR STRESSORS

Temperature can change material characteristics through gradual chemical and physical processes called thermal aging (binding of moving parts, material cracking and failure, melting,…)



EQUIPMENT QUALIFICATION
MAJOR STRESSORS

Nuclear radiation causes changes in the atomic and molecular structure of materials and associated material degradation through processes such as excitation, ionization,….

Some of the energy absorbed through radiation is converted to heat, creating incremental thermal aging.

Radiative stressors and the increment in thermal stressors caused by radiation are usually low under conditions of normal service, however, the cumulative effect over long periods can be significant.

Radiation affects semiconductor devices (digital I&C systems) through ionization and atomic displacement.

EQUIPMENT QUALIFICATION
MAJOR STRESSORS

Pressure and rapid pressure changes can affect equipment by causing additional forces on parts and components. Excessive differential pressure can cause structural failure of device.

Vibration can cause fatigue and failure in both passive and active components. Vibration results in wear, loosening of parts, cyclic fatigue damage. Vibration stresses may be self-induced during equipment operation or transmitted to the equipment from external sources such as earthquakes.

[http://blog.iqsdirectory.com/plant-facility/you-can-stop-pressure-vessel-failure/]

EQUIPMENT QUALIFICATION
MAJOR STRESSORS

Exposure to high-temperature saturated **steam** combines temperature and humidity effects and can be caused by main steam line break (HELB).

Water spray (humidity) may result either from piping or component leaks, deliberate or inadvertent fire suppression system actuation. Humidity causes corrosion. Corrosion can directly affect performance of metallic components. Electrical terminations and contact surfaces can be degraded by corrosive effects. Humidity can directly degrade organic materials, weakening their physical, mechanical, and electrical properties and distorting their shapes.

EQUIPMENT QUALIFICATION
MAJOR STRESSORS

Interaction with **chemicals** (presence of chemicals in process systems) can lead to material degradation (corrosion). Polymer degradation could release chemicals, such as chlorine.

[FENOC Report, NPP Davis-Besse, 2002]

EQUIPMENT QUALIFICATION
MAJOR STRESSORS

Effects of operational stressors:

- Variations in the applied voltage or frequency can affect equipment performance or the aging characteristics of electrical equipment.
- Loading conditions can include electrical or mechanical stresses.
- Continuous or intermittent operation of equipment can result in electrical or mechanical stresses that cause degradation. Material cyclic fatigue can occur
- Heat rise due to ohmic heating of energized electrical equipment results in higher service temperatures
- Process fluid heating effects can result in service temperatures of equipment that are higher than the local ambient.
- The duty cycle of equipment is related to the amount of time the equipment is energized, operated, or electrically loaded.

[EPRI 1021067]

EQUIPMENT QUALIFICATION
HOW TO DO IT

Equipment qualification should be based on a selection of the following methods:

- Use of engineering and manufacturing processes in compliance with recognized standards;
- Reliability demonstration
- Past experience in similar applications;
- Type tests;
- Testing of supplied equipment;
- Analysis to extrapolate test results or operating experience under relevant conditions;
- Evaluation of manufacturer production processes;
- Inspection of components during manufacture.

It is generally not necessary to apply all of the methods mentioned. The specific combination of methods will depend upon the system or component under consideration. For safety systems, qualification evidence based upon operating experience is normally combined with type testing, and testing of supplied equipment, as well as evaluation of manufacturer production processes, or inspection of components during manufacture.

[DS-431, 6.86, 6.87, 6.90]

EQUIPMENT QUALIFICATION TESTING

Type testing is the preferred qualification method, particularly for **complex equipment** in **harsh environments**. For complex systems (electrical, I&C etc.) type testing is preferred method of qualification (due to the complexity of equipment and wide variety and number of potential failure modes and mechanisms under various environmental conditions).

Type testing includes aging and accident simulation performed on a limited sampling (usually one) of a “type” of equipment.

Typical test approaches:

- simultaneous,
- sequential,
- separate testing.

EQUIPMENT QUALIFICATION TESTING

Possible test sequence:

- Inspection and baseline testing
- Accelerated aging
  - Thermal (dry heat / dump heat / cold)
  - Radiation
  - Operational cycling
- Vibration and seismic simulation
- Radiation accident simulation
- Temperature/pressure/steam accident simulation
- Post accident (long-term) simulation
- Post simulation testing and inspection

The objective of the test sequence is to age the component to an “end of life” condition prior to exposure to the postulated DBE conditions.

[EPRI 1021067]

EQUIPMENT QUALIFICATION
SEISMIC TESTING

All safety-related equipment must be capable of withstanding the **effects of earthquakes** without the loss of its capability to perform safety functions.

Seismic categorization of the plant equipment.

Methods used to demonstrate seismic and dynamic capability:

- Seismic shake-table testing
- Analysis
- Operating experience

[AREVA seismic shake table, us.areva.com]

EQUIPMENT QUALIFICATION
SEISMIC TESTING

Testing

- Single-frequency and multifrequency tests.
- Seismic testing is principally performed on seismic shake tables that simulate the vibratory motions associated with earthquakes.
- Seismic shake tables are designed to simulate vibratory motion in one, two, or three orthogonal axes.

Analysis

- Analysis are usually limited to structural capability and are not able to address complex equipment operability.

Operating experience

- Qualification based on historical earthquake experience data usually on case-by-case basis

[NS-G-1.6, EPRI 1021067]

EQUIPMENT QUALIFICATION
EMC TESTING

EMC testing – Evaluate the impact of electromagnetic interference (EMI) / radio-frequency interference (RFI) on equipment.

Susceptibility tests (Low / high frequency conducted / radiated)

- Conducted: This test verifies the ability of equipment to withstand signals coupled onto input power leads and signal cables.
- Radiated: This test verifies the ability of equipment to withstand radiated magnetic and electric fields.

Surge tests: This test verifies the ability of equipment to withstand high-energy overvoltage conditions on power and interconnection lines due to switching and lightning transients.

Electrically-Fast Transient (EFT) / Burst tests: The purpose of this test is to verify the ability of equipment to withstand repetitive fast transients (bursts) on supply, signal, and control cables due to switching transients created by inductive loads and relay contact bounce.

EQUIPMENT QUALIFICATION
EMC TESTING

Electrostatic Discharge (ESD): This test verifies the ability of equipment to withstand electrostatic discharge, which may occur from personnel coming into contact at human-machine interface points of equipment during normal operation.

Emissions Tests (Low / high frequency, conducted / radiated): The purpose of this test is to limit harmonics emissions on power cables, magnetic field equipment emissions and radiated electric field equipment emissions.

[EPRI 3002000528]

[ABEGU center, http://www.abegu.eu/]

EQUIPMENT QUALIFICATION ANALYSIS

Testing is usually combined with an analysis.

Qualification methods involving some form of analysis:

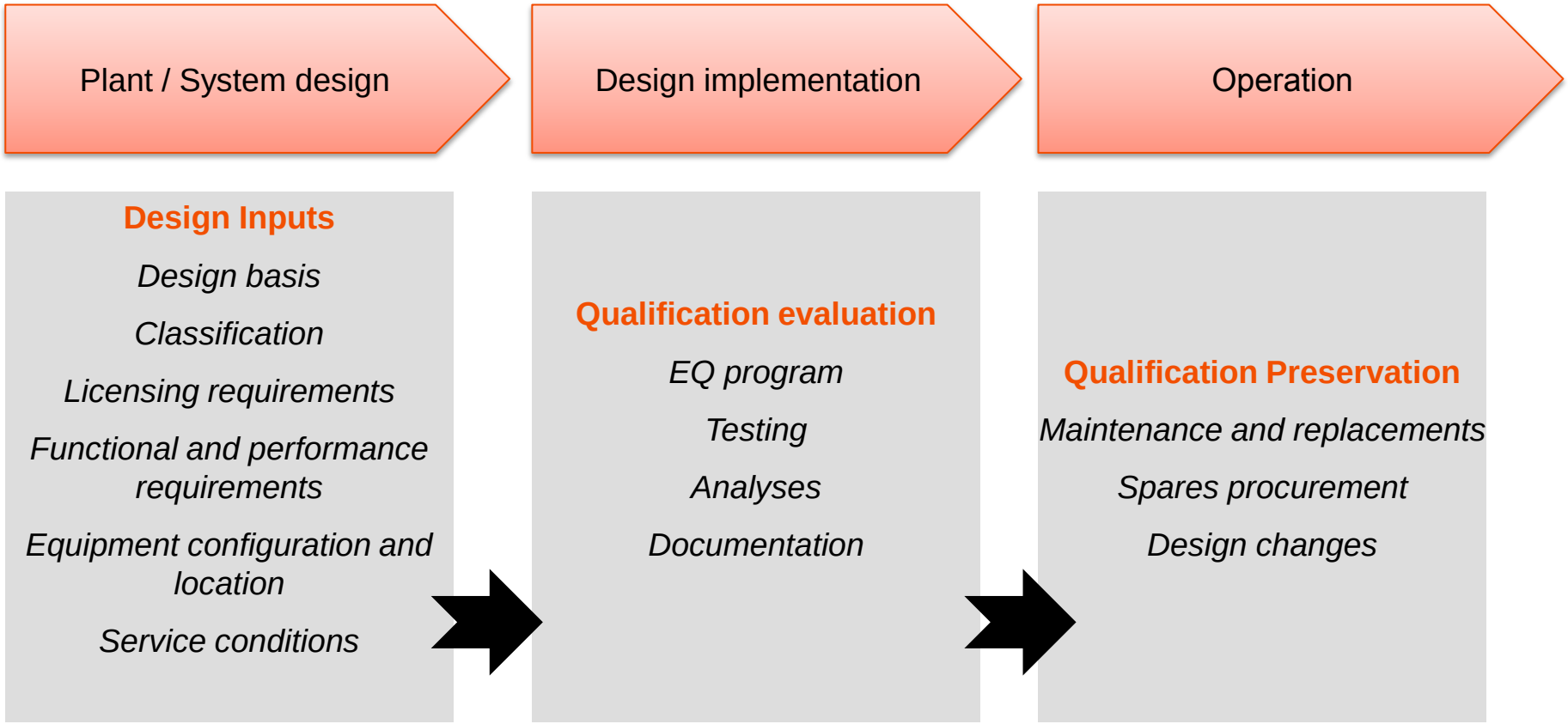
- Testing of an identical item of equipment under **similar conditions** with a supporting analysis
- Testing of a **similar item** of equipment with a supporting analysis
- **Experience** with identical or similar equipment under similar conditions with a supporting analysis
- Analysis in combination with **partial type-test** data that support the analytical assumptions and conclusions

Applicable standards and regulations all recognize experience as a valid method of addressing qualification. However, for harsh-environment equipment, experience has not been effectively used. The principal difficulty arises from the limited data available for equipment that has experienced pipe break environments and/or high-radiation environments.

[EPRI 1021067]

EQUIPMENT QUALIFICATION PROCESS

Qualification as a process



EQUIPMENT QUALIFICATION PROCESS

Equipment and service condition **information critical to qualification** is **defined during initial plant design** and subsequent **design modifications**.

- Design basis (including functional requirement, classification, internal and external hazards)
- EQ-related licensing basis
- Scope of equipment requiring qualification
- Performance requirements and acceptance criteria
- Normal, abnormal, and accident environmental conditions plus power and signal conditions

EQUIPMENT QUALIFICATION PROCESS

Environmental qualification of more **complex equipment** (electrical, I&C,…) is usually achieved using analysis and **testing of individual pieces** of equipment rather than complete systems. Proving that the assembled system is qualified **requires an integrated program** to ensure that system components and their interfaces have been adequately defined and qualified.

Normal and abnormal service conditions must be defined so that they can be appropriately considered for aging simulation during qualification

Accident conditions (LOCA or HELB plus margin) must be defined to allow demonstration of equipment performance under harsh conditions.

Qualification programs can define a single **set of environmental conditions for an entire structure**. Environmental data are then defined for each zone, for normal, abnormal, and accident conditions.

[EPRI 1021067]

EQUIPMENT QUALIFICATION PROCESS

Example of corrosion of the heterogenic weld between nozzle and tube

EQUIPMENT QUALIFICATION PROCESS

The **qualification evaluation** or verification phase is qualification in the narrowest sense; it is when the design related to performance of equipment exposed to plant normal and accident environmental conditions is verified or qualified.

Successful qualification testing typically involves all the following major activities:

- Qualification specification and plan development and approval
- Performance of the test, including data collection
- Test or qualification report preparation, evaluation and approval

[EPRI 1021067]

EQUIPMENT QUALIFICATION PROCESS

Test results / reports often based on testing or analysis to **generic enveloping conditions** and do not always address **plant-specific environmental conditions** or equipment performance requirements.

Additional analyses needed (for example, similarity analyses or qualified life calculations) to demonstrate their specific applicability to the performance of the plant equipment being qualified.

Variations in equipment design, manufacturing, materials, installation configuration, and maintenance practices may **affect qualification conclusions.**

The **evaluation process**, including input information, references, and evaluation results, **must be documented** in an orderly and systematic manner.

EQUIPMENT QUALIFICATION PROCESS

Typical Elements of a Plant-Specific Evaluation

- Qualification Criteria and Standards
- Required Environmental Conditions
- Required Performance and Operational Conditions
- Qualification Test Report Overview
- Similarity of Tested and Installed Equipment
- Configuration Limitations and Requirements
- Acceptance Criteria and Performance Requirements
- Test Sequence
- Aging Simulations and Qualified Life
- Accident Conditions
- Margin and Conservatism
- Test Anomalies
- Maintenance, Surveillance, and Replacement
- Other Information Sources

[EPRI 1021067, Table 7-4]

EQUIPMENT QUALIFICATION PROCESS

Equipment design and **on-site installation** might inadvertently **affect the qualification**. To minimize the potential for these problems plant-specific qualification evaluations and plant engineering must be closely integrated or coordinated.

Both installation drawings and detailed procedures are generally necessary to adequately **define installation criteria and methods**.

Any **changes to the design input** information (e.g. performance requirements, or environmental and operating conditions) used to establish qualification may affect the qualification conclusions.

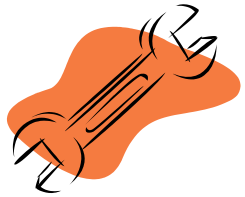
Procedural controls must be in place to ensure that the **qualification impact of plant modification** and design changes is formally addressed.

EQUIPMENT QUALIFICATION PROCESS

Maintenance is a collection of activities intended to ensure continued equipment availability and performance capability.

Maintenance activities are relied upon to ensure that the condition of installed equipment remains bounded by the condition of the test specimens i.e. conditions stay in tested = qualified range.

Some of the **maintenance activities can be essential to maintaining qualification**. These maintenance activities, typically termed EQ-required maintenance, encompass preventive maintenance, inspection/surveillance, periodic testing, and replacement requirements. On the other hand EQ can limit or prohibit certain type of maintenance.



EQUIPMENT QUALIFICATION PROCESS

Spare parts can be used during maintenance.

Spare parts may be not bought from the original equipment manufacturer (OEM). Parts can be procured from other suppliers.

- COTS: commercial off the shelf
- CGI: commercial-grade item

Qualification has to be preserved. Careful consideration must be given to any potential changes affecting qualification, particularly for harsh-environment equipment. Differences in part materials, manufacturer, fabrication methods, special conditioning, and design requirements must be evaluated. In certain applications, the potential differences between batches, lots, or production runs of commercial-grade items must also be considered.

EQUIPMENT QUALIFICATION
COTS

Use of COTS devices might reduce costs and design effort. Furthermore, there may be no nuclear specific device available and use of well-proven commercial product could be more effective or more safe than development of a new item.

COTS devices tend to be more complex, may have unintended functionalities and often become obsolete in a shorter time. They will often have functions that are not needed in the nuclear power plant application. Qualification of a COTS device could be more difficult because commercial development processes may be less transparent and controlled. Often qualification is impossible without cooperation from the vendor. The difficulty with accepting a COTS device may often be with the unavailability of the information to demonstrate quality and reliability.

An important consideration when using COTS devices is the maintenance of their qualification during the plant lifetime.

[DS-431, 2.117-2.119]

EQUIPMENT QUALIFICATION
AGEING

SSR 2/1 Requirement 31: **Ageing management**

The **design life of items** important to safety at a nuclear power plant **shall be determined**. Appropriate margins shall be provided in the design to take due account of relevant mechanisms of ageing, neutron embrittlement and wear out and of the potential for age related degradation, to ensure the **capability** of items important to safety **to perform their necessary safety functions throughout their design life**.

EQUIPMENT QUALIFICATION
AGEING

Structured methodology should be employed and documented.

The methodology should:

- Identity aging **stressors** (from environmental and operational conditions)
- Determine significant **aging mechanisms**
- Use analytical models and/or accelerated aging tests
- Identity methods of addressing aging mechanisms
- Establish a **qualified-life estimate**
- Specify surveillance maintenance and replacement activities

EQUIPMENT QUALIFICATION
AGING

The **aging management** aspects of the **EQ program** are intended to work in combination with other programs to **improve the reliability of plant systems** and equipment.

This is achieved through a combination of preventive maintenance, condition monitoring, environmental monitoring, surveillance testing, post-maintenance testing, and an effective corrective action **program to preclude age-related degradation** or maintenance-preventable functional failures of equipment important to safety.

Such on-going qualification might show that the qualified life of a component is validated or is indicated to be different than the qualified life that was determined through testing, analysis, or experience. **Information from on-going qualification may be used to increase or decrease the qualified life of a component**.

EQUIPMENT QUALIFICATION
QUALITY ASSURANCE

Qualification process should be well **controlled and managed.**

Qualification of installed plant equipment is achieved with a high level of confidence only when the **broad spectrum of activities** affecting the equipment's capability and qualification are correctly performed (design, procurement, production quality control, application engineering, shipping, storage, installation, maintenance, and periodic testing).

A variety of organizations are directly or indirectly involved (manufacturers, suppliers, laboratories, engineering, procurement, installation, maintenance)

EQUIPMENT QUALIFICATION REFERENCES

- [SSR 2/1]: “Safety of Nuclear Power Plants: Design”, IAEA Specific Safety Requirements, 2012
- [IAEA Safety Glossary, 2007]: “IAEA safety glossary : terminology used in nuclear safety and radiation protection”, IAEA, 2007
- [DS-431]: “Design of Instrumentation and Control Systems for Nuclear Power Plants”, IAEA Safety Guide Draft, 2012
- [IAEA NP-T-3.12]: “Core knowledge on instrumentation and control systems in nuclear power plants.”, IAEA Nuclear Energy Series, 2011
- [IAEA NS-G-1.6]: “Seismic Design and Qualification for Nuclear Power Plants”, IAEA Safety Guide, 2003
- [IAEA NS-G-1.7]: “Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants”, IAEA Safety Guide, 2004
- [IAEA NS-G-1.11]: “Protection against Internal Hazards other than Fires and Explosions in the Design of Nuclear Power Plants”, IAEA Safety Guide, 2004
- [IAEA NS-G-1.5]: “External Events Excluding Earthquakes in the Design of Nuclear Power Plants”, IAEA Safety Guide, 2003
- [IAEA NS-G-2.12]: “Ageing Management for Nuclear Power Plants”, IAEA Safety Guide, 2009
- [EPRI 3002000528]: “Guidelines for Electromagnetic Compatibility Testing of Power Plant Equipment”, Revision 4 to TR-102323. EPRI, Palo Alto, CA: 2013. 3002000528
- [EPRI 1021067]: “Plant Support Engineering: Nuclear Power Plant Equipment Qualification Reference Manual”, Revision 1. EPRI, Palo Alto, CA: 2010. 1021067