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No. 3

EQUIPMENT QUALIFICATION IN OPERATIONAL NUCLEAR POWER PLANTS: UPGRADING, PRESERVING AND REVIEWING

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

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FOREWORD

While the task of ensuring a high level of safety of nuclear power plants (NPPs) is a national responsibility, the achievement of excellent safety performance of operational NPPs is also central to the IAEA's programme. The Convention on Nuclear Safety, which entered into force on 24 October 1996, requires all participating countries to review and, where necessary, to upgrade the safety of existing nuclear installations.

A common weakness of NPPs built to earlier standards, particularly of the older ones, is a lack of qualification of equipment important to safety to ensure its capability to perform designated safety functions on demand under postulated service conditions, including harsh accident and post-accident conditions. To assist Member States in assessing the status of equipment qualification (EQ) in operational NPPs and in upgrading it as necessary, the IAEA organized Technical Committee Meetings (TCMs) in 1993 and 1994 to share information on EQ concepts and general process and on the experience in EQ upgrading projects. Topics of preserving EQ during plant service life (i.e. preserving required equipment performance capability and maintaining evidence of this capability) and assessing plant EQ programmes were also discussed.

The information presented at the above TCMs provided the basis for this Safety Report. The report documents current methods and practices relating to upgrading and preserving EQ in operational NPPs and reviewing the effectiveness of plant EQ programmes. The guidance is intended for technical and managerial personnel of NPPs, safety authorities and technical organizations supporting EQ programmes.

The work of all contributors to drafting and review of this document identified at the end of the report is greatly appreciated. In particular, the contributions of P.M. Holzman (USA), S.L. de Boer (Netherlands), and J. Pachner (IAEA), who prepared the report, and P. Castaldo (Canada), S. Kasturi and W. Lynch (USA), K. Thoma (Switzerland) and A. Paziaud (France), who provided material for the report, are acknowledged.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The Convention on Nuclear Safety [1] requires that the design and construction of nuclear installations provide for several reliable levels and methods of protection (defence in depth) against the release of radioactive materials, and that the technologies incorporated in the design and construction of a nuclear installation be proven by experience or qualified by testing or analysis. These protection methods and levels include the following design provisions that aim to prevent the loss of safety functions due to common cause failures of several components, systems or structures employed: physical separation by protective barriers or distance, redundancy linked with diversity, and qualification to withstand damage from expected service conditions [2].

Qualification of equipment important to safety in nuclear power plants (NPPs) ensures its capability to perform designated safety functions on demand under postulated service conditions including harsh accident environment (e.g. loss of coolant (LOCA), high energy line break (HELB) and seismic or other vibration conditions). The IAEA Code on the Safety of Nuclear Power Plants: Design (Ref. [3], p. 43) and the associated Safety Guide on General Design Safety Principles of Nuclear Power Plants (Ref. [4], pp. 28 and 29) present the safety principles and design approaches relating to equipment qualification (EQ). Requirements for implementing EQ in NPPs are prescribed by various international and national standards, codes and guides (e.g. the International Electrotechnical Commission Standard IEC-780 [5]; the IAEA Safety Guide 50-SG-D15 [6], which deals with seismic qualification; the American IEEE Standard IEEE-323 [7]; the American IEEE Standard IEEE-627 [8]; the Regulatory Code 10CFR50.49 [9]; the USNRC Regulatory Guide 1.89 [10]; the French National Codes [11, 12]; and the German KTA Safety Standards [13–16]). The EQ process is described, for example, in Ref. [17]. A comparison of European practices for the qualification of electrical and instrumentation and control (I&C) equipment important to safety is presented in Ref. [18]. Finally, the IAEA Safety Guide on Periodic Safety Review of Operational Nuclear Power Plants [19] identifies EQ as one of the areas of the review and gives a high level review guidance aimed at determining EQ changes needed to maintain NPP safety.

Current EQ efforts are mainly in the areas of upgrading/backfitting EQ in NPPs (particularly the older NPPs) where EQ has not been formally established, preserving EQ throughout the service life of NPPs (including any extended life) and reviewing the effectiveness of EQ programmes in operational NPPs. These are areas of active technical development; however, information on these developments and on the lessons learned is not readily available.

In this context, this Safety Report describes current practices and lessons learned in upgrading, preserving and reviewing EQ in operational NPPs. The report will be of interest to technical and managerial personnel of NPPs, safety authorities and supporting organizations that are concerned with:

— upgrading or backfitting EQ in older plants to current practices;
— preserving EQ during plant service life, i.e. preserving required equipment performance capability and maintaining evidence of this capability;
— reviewing the effectiveness of EQ programmes in NPPs.

1.2. OBJECTIVE

The objective of this Safety Report is to make available information on: EQ concepts and process, effective and practical methods and practices relating to upgrading and preserving EQ, and reviewing the effectiveness of EQ programmes in operational NPPs.

1.3. SCOPE

This report deals with the qualification of electrical, electronic, electromechanical and mechanical equipment for postulated service conditions (‘harsh’ accident environments, normal and abnormal ‘mild’ environments, and seismic conditions). Piping, structures and other passive NPP components are not within the scope of this report because their qualification (safety status) is achieved directly by design, construction, inspection and testing according to applicable codes.

The focus of the report is on upgrading and preserving EQ in operational NPPs and on reviewing/assessing the effectiveness of plant specific EQ programmes. In order to facilitate common understanding, the report also presents information on EQ concepts and EQ process and methods. A glossary of common EQ terms and definitions is provided for use with this report.

References are provided which direct readers to more detailed literature (e.g. regulatory documents, standards, technical and programmatic guidance) in order to keep the report compact and focused.

1.4. STRUCTURE

EQ concepts and the EQ process are presented in Section 2. Section 3 gives an overview of current practices relating to establishing EQ, as well as considerations relating to extending EQ in connection with plant life extension or plant licence renewal. Section 4 describes a common approach to upgrading/backfitting EQ in operational NPPs. Preserving EQ during NPP service life is addressed in Section 5, and finally Section 6 deals with reviewing/assessing the effectiveness of a plant specific EQ programme.

The report includes a glossary of common EQ terms and references directing the reader to more detailed information on specific EQ topics. Annexes provide supplementary information on the impact of licensing assumptions and equipment locations on the scope of a plant specific EQ programme, examples of developing a list of equipment to be qualified and of EQ files and documentation, the evaluation of the licensee’s EQ programme for electrical equipment located in harsh environment, a list of the most significant EQ related components, a checklist for review of licensee EQ documentation files and a physical inspection checklist.

2. CONCEPTS AND PROCESS FOR EQ

Section 2 presents fundamental EQ concepts and describes the EQ process. The Convention on Nuclear Safety (Ref. [1], Article 15) requires NPP designs to provide several reliable levels and methods of protection (defence in depth) to minimize the occurrence of NPP accidents, to mitigate their radiological consequences and to prevent the release of radioactive materials [1]. Fundamental to providing such reliable protection is the need to ensure that safety systems and equipment are capable of performing their safety functions when required during NPP normal operation, transient conditions and postulated accidents.

NPP structures and safety system designs are intended to prevent the loss of safety functions due to component, system or structural failures, particularly those resulting from a common cause (Ref. [2], 4.2.2.4, Dependent Failures). The use of multiple systems or trains which are individually capable of providing required safety functions (redundancy) is one of several methods available to prevent safety function loss. Qualification of equipment is one method of preventing environmentally induced common cause damage to the redundant systems. Other methods include independence, physical separation and protective barriers. Physical protection or separation of safety equipment from the anticipated hazards can minimize common cause failures for service conditions such as fires, explosions, flooding or projectiles ejected owing to failure of rotating or pressurized components.

Qualification is an important design tool whenever safety equipment has to tolerate service conditions that could cause equipment failures. Examples of hazardous environmental conditions which could cause such failures are the radiological and steam conditions associated with pipe breaks, including breaks in the reactor coolant system, and earthquakes. Examples of potentially hazardous process conditions include high velocity two phase flows, high vibration or debris laden process fluids. EQ must demonstrate that equipment designs are capable of functioning under such environmental or operational conditions.

2.1. BASIC CONCEPTS FOR EQ

Reference [3] (Section 12, Design Confirmation) requires:

> "A qualification procedure shall confirm that the equipment is capable of meeting, throughout its operation life, the requirements for performing safety functions while subject to the environmental conditions (e.g. vibration, temperature, pressure, jet impingement, radiation, humidity) existing at the time of need. These environmental conditions shall include the variations expected during normal operation, anticipated operational occurrences and accident conditions."

A report by the International Nuclear Safety Advisory Group (INSAG) [2] states the EQ principle as:

> "Safety components and systems are chosen which are qualified for the environmental conditions that would prevail if they were required to function. The effects of ageing on normal and abnormal functioning are considered in design and qualification."

Several Safety Guides on design [4, 20–24] restate the general principles contained in the code and provide some limited additional guidance. For example, 50-SG-D11 [4], Section 7, Equipment Qualification, restates the general qualification principles contained in the code, references IEC-780 as guidance for the qualification of electrical equipment and states:

> "This (qualification) programme shall include qualification prior to initial equipment installation and subsequent requalification or replacement during the life of the plant as appropriate to demonstrate continuous fulfillment of performance requirements.
>
> The methods of qualification are:
>
> (1) Performance of a type test on equipment representative of that to be supplied;

(2) Performance of an actual test on the supplied equipment;
(3) Application of pertinent past experience in similar applications;
(4) Analysis based on reasonable engineering extrapolation of test data or operating experience under pertinent conditions.

The foregoing methods of qualification shall be used in combination as necessary....”

Assurance that safety equipment will perform when required throughout the equipment’s installed life is provided by EQ and supporting activities ensuring that the qualification conclusions continue to be applied to installed safety equipment. EQ is defined as the generation and maintenance of evidence to ensure that safety equipment will operate on demand to meet safety system performance requirements [5]. The primary role of EQ is verifying that the equipment design is capable of performing its safety functions when required. Other EQ process activities provide confidence that the installed equipment is manufactured, applied, installed, operated, maintained and periodically tested such that EQ exists for the installed life of the NPP equipment.

The universally recognized methods used to establish EQ are testing, analysis, operating experience or an appropriate combination of these three methods. When initial EQ efforts cannot establish qualification for the entire installed duration, additional qualification information and activities, subsequent to installation, need to be developed to extend qualification, or the equipment needs to be replaced. This is termed *ongoing qualification.*

EQ is generally established on a component by component basis. When the components are mechanically and electrically interconnecting as a functional system, the complete system is qualified if the performance functions of the individual devices are properly defined and qualified. These required device functions have to include those critical to other system devices, interfaces and the overall system.

The terms harsh environment, mild environment and seismic event are significant to qualification since qualification practices (methods, regulations, standards, records and other qualification programme details) often vary based on the type and severity of the anticipated service conditions. Qualification practices may also vary on the basis of the equipment’s safety significance, equipment type (i.e. electrical, mechanical or electromechanical) or other considerations (such as size).

2.2. POSTULATED INITIATING EVENTS (PIEs)

EQ should be established for the service conditions, including both normal operation and an appropriate set of PIEs [2-4]. If the plant and its safety equipment can perform required safety functions while exposed to the effects of these PIEs, then it is assumed that other similar but less severe events can also be accommodated. The most severe of the PIEs are termed design basis accidents (DBAs). PIEs include events expected to occur occasionally (e.g., loss of off-site electrical power) and others which ought not to occur but are theoretically possible, such as a large break LOCA.

2.3. SERVICE CONDITIONS

Service conditions are environmental, loading, power and signal conditions expected during normal operation and PIEs. Service conditions are subdivided into environmental conditions and operational conditions.

Environmental conditions typically considered during EQ concern ambient temperature, pressure, humidity/steam, radiation, water/chemical sprays, fluid submergence and seismic vibration.

Operational conditions generally involve process related conditions such as vibration, load cycling, electrical loading parameters (e.g. voltage, frequency, current), electromagnetic interference (EMI), mechanical loads (e.g. thrust or torque) and process fluid conditions (e.g. pressure, temperature, chemistry, cavitation, flow rate).

2.4. AGEING AND QUALIFIED LIFE

Equipment ageing has been recognized as a potential common cause failure mechanism that has to be evaluated as part of the qualification. New equipment may be capable of adequately performing under normal and PIE service conditions. However, after experiencing the potentially degrading effects of prolonged operation, the equipment may be unable to perform adequately when required.

The potential for ageing to contribute to equipment common mode failures is particularly significant during those PIEs when service conditions differ substantially from those occurring during normal operation and periodic testing. In these cases, ageing degradation may go undetected if it does not measurably affect normal operation. Yet, when the more severe PIE service conditions occur, this undetected degradation may prevent adequate performance.

Qualification considers ageing effects by simulating them during tests; evaluating their significance by using analysis or operating experience; and minimizing age related degradation through surveillance, maintenance and periodic replacement of installed equipment or age sensitive parts.

Not all ageing mechanisms need to be formally considered during qualification. Only significant ageing mechanisms must be addressed. An ageing mechanism is significant if it causes degradation during the installed life that progressively and appreciably renders the equipment vulnerable to failure during PIE conditions [7].

Qualified life is the period of time during normal operation when ageing does not prevent satisfactory performance during a subsequent PIE. The equipment's qualified life is defined when qualification is established. Before the end of its qualified life, the equipment has to be replaced, life limiting components renewed or a new, longer qualified life established. Not all Member States require that a qualified life be established. Instead, they rely on ongoing qualification activities (e.g. inspection, surveillance, maintenance and additional qualification testing) to maintain the equipment in a qualified state.

Several organizations, including the IAEA, have initiated activities and published reports, such as Ref. [25], on managing the ageing of NPP components.

2.5. QUALIFICATION MARGIN

Qualification margin is the difference between the specified service conditions at installed equipment locations and the more severe conditions assumed when qualification is established (e.g. for assessing equipment ageing and performance under PIE service conditions). Some amount of margin has to be available to provide confidence that generic qualification conclusions can be confidently applied to the installed equipment. Qualification margin is used to account for normal variations in equipment production, reasonable errors in defining service conditions and satisfactory performance, measurement inaccuracies and other uncertainties. Member State regulations and standards often specify (or recommend) minimum acceptable amounts of qualification margin. Additional margin, often termed conservatism, design margin or a factor of safety, provides increasing confidence in the equipment's capability under PIE conditions.

2.6. RELIABILITY DATA

Current qualification practices do not require statistical or reliability data when establishing EQ. Instead, conservatisms and margins inherent in defining PIE service conditions and required functions are intended to provide reasonable assurance that the installed equipment is capable of performing as required. Qualification tests generally subject only a few equipment items (often only one) to PIE service conditions. Analytical assumptions and operating experience data used during qualification are intended to represent the characteristics of installed equipment. The use of conservative assumptions, margin and QA controls is meant to provide assurance that the installed equipment items will perform similarly.

Although not required, reliability data can be used to establish qualification. Such an EQ approach may be particularly effective when existing operating experience data for a number of similar devices are used to establish EQ for PIE service conditions similar to those normally occurring.

2.7. DOCUMENTATION

Documented evidence of qualification needs to be available in an auditable form for the life of the plant. These records need to be organized in an understandable and traceable manner. The records need to be in a form allowing verification by competent personnel other than those establishing the qualification. The course of reasoning has to show that the result is a consequence of the available assumptions and data.

Records demonstrating that EQ has been established will contain information on the specific equipment items being qualified, the demonstrated safety functions, applicable service conditions, qualification methods, results, limitations, justifications and relevant supporting technical data. EQ standards, such as Ref. [5], require that an EQ file, containing or referencing information relevant to establishing qualification, be maintained. EQ files are typically organized by equipment type and manufacturer.

2.8. QUALITY ASSURANCE

Appropriate quality assurance (QA) measures should apply to activities affecting qualification. These activities include, but are not limited to, equipment design, procurement, qualification, production quality control, application engineering, shipping, storage, installation, maintenance and periodic testing. The various types of organization and personnel performing EQ related activities include equipment manufacturers; material and parts suppliers; testing laboratories; EQ and equipment engineers; safety systems analysts; and equipment installation, operation and maintenance personnel. Errors or omissions when establishing EQ or performing EQ critical activities, particularly equipment installation and maintenance, can negate the considerable cost and resource commitment involved in qualification. Some examples of situations that can create qualification uncertainty, based on Ref. [17], are:

— A testing laboratory’s monitoring instruments are not properly calibrated.
— A manufacturer implements an equipment design change without considering its qualification significance or without informing the user.

- A parts supplier changes a material formulation without notifying the equipment manufacturer.
- An ageing evaluation fails to consider the effect of significant operational vibration.
- Excessively high local temperatures are not evaluated for their significance.
- An equipment installer fails to properly install environmental seals.
- Maintenance personnel fail to report cracking of an embrittled cable that occurred during maintenance.

2.9. TRAINING

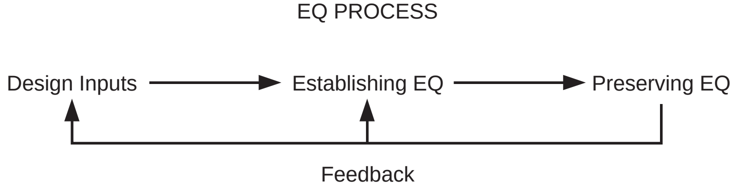
To ensure that EQ related tasks are performed in a consistent, technically acceptable manner, the personnel involved need to possess adequate skills and knowledge. Adequate EQ related knowledge and skills are achieved through an appropriate mix of specialized EQ training, on the job experience/training and technical education. Since EQ is an important but highly specialized subject, the need for EQ training has been recognized as an important part of EQ programmes. Because of the diversity of responsibilities and skills, training needs to be related to job functions.

2.10. EQ PROCESS

The EQ process consists of three phases: Design Input, Establishing Qualification and Preserving Qualification. These three phases and the relationship of activities within each phase are illustrated in Fig. 1.

Design Input phase activities provide important information that is needed before EQ can be established for specific plant applications. These activities determine: (1) the specific NPP equipment applications which require qualification; (2) the equipment performance which has to be verified; and (3) the service conditions (normal and PIE) existing when this performance has to be accomplished. This information is developed by evaluating plant safety analysis, plant and system design criteria, operating and emergency procedures and equipment designs. Additional information on activities and methods that can provide this information is provided in Section 3.

The *Establishing* EQ phase involves all those activities necessary to establish EQ for equipment design, required safety functions and service conditions. The generally recognized qualification methods are test, analysis, operating experience or an appropriate combination of these methods. When qualification is established, EQ critical equipment installation, operation, maintenance, replacement or modification activities, if any, should be identified. If plant modifications are required in order to



Design Inputs

- identify PIEs
- specify service conditions
- determine required safety functions
- develop list of equipment, including functions and mission time

Establishing EQ

- define EQ requirements and criteria
- select qualification method
- establish qualification
- assess ageing effects
- define installation and maintenance requirements
- document qualification results

Preserving EQ

- installation and maintenance control
- replacement control
- modification control
- service condition monitoring
- analysis of degradation and failures
- analysis of experience feedback
- personnel training
- documentation

Upgrading EQ

Upgrading EQ is a special case of establishing EQ that applies to existing equipment in operating plants. Upgrading EQ may also involve establishing or verifying design input information.

FIG. 1. EQ process.

establish EQ they also should be identified. Additional information on activities and methods used to establish qualification is provided in Section 3. Upgrading EQ, as discussed in Section 4, is a special case of Establishing EQ for equipment in an existing NPP.

After EQ is established, a number of NPP activities have to be implemented and controlled so that throughout the NPP lifetime each installed item of equipment reflects the requirements and limitations identified when EQ was established. The *Preserving EQ* phase involves all these activities, including but not limited to:

— equipment installation and maintenance
— replacement equipment and spare parts procurement
— plant and equipment modifications
— monitoring of equipment condition
— monitoring of service conditions
— trending and analysis of equipment degradation and failures
— evaluating other experience feedback and R&D information
— quality assurance
— documentation
— EQ training.

Additional information on the preservation phase and associated activities is provided in Sections 3 and 5.

2.11. QUALIFICATION STANDARDS AND GUIDES

Qualification standards include regulatory requirements and industry standards and guides issued by technical standards writing bodies (e.g. IEC, RCC, IEEE, ASME, KTA). These documents typically contain information and guidance on one or more of the following topics: terms and definitions; defining service conditions; determining equipment scope and functions; qualification principles and methods; qualification procedures; qualification acceptance criteria; equipment modifications; ageing and qualified life; testing sequences, monitoring and data; analytical models and extrapolation; documentation; margin; and technical references.

Regulatory EQ requirements vary among Member States. Regulatory requirements related to qualification can range from broad qualification goals to specific qualification criteria or methods. A broadly framed requirement might state that equipment important to safety has to be capable of performing required functions during the service conditions encountered when these functions are performed. A narrowly framed requirement may state that all electrical safety equipment, located in NPP areas experiencing harsh environments due to LOCA or high energy line break (HELB) events must be qualified by using the type testing provisions of a specific standard (see, e.g., Ref. [5].)

There are two international standards on qualification: IEC-780 (1984) [5] for environmental and IEC-980 (1989) [26] for seismic qualification. Other well known qualification standards, used in some Member States, are IEEE qualification standards (including standards for specific equipment types, e.g. cables, motors, containment electrical penetrations, valve actuators) [27–30], French RCCs [11, 12] and the German KTA rules (e.g. Refs [13–16]).

Qualification guidance is often issued by regulatory bodies, NPP designers, NPP owners or others involved in establishing qualification. These documents provide guidance on acceptable qualification practices, methods and documentation. They serve the important function of being an easily referenced basis for accepted practices. The guides may encourage certain practices and discourage others. They generally recognize that case by case exceptions are permitted when supported by an adequate technical basis. In the USA, regulatory guidance regarding EQ compliance is provided in several documents [10, 31–33]. The Electric Power Research Institute (EPRI) has compiled several decades of EQ experience and guidance in its NPP EQ Reference Manual [17]. The Spanish Nuclear Society, since 1987, has produced qualification application guides (SNE application guides) providing guidance on how to apply and interpret the EQ rules [34, 35]. Excellent summary information on the standards, guides and methods used in several European Member States to qualify electrical and I&C equipment is provided in Ref. [36].

3. ESTABLISHING EQ AND REQUIRED DESIGN INPUT

Section 3 describes the first two phases of the EQ process and provides information on relevant qualification concepts and practices. Phase I — Design Input defines plant specific information that is needed for Phase II — Establishing EQ, which involves activities necessary to confirm qualification of a specific equipment. Upgrading EQ, a special case of Establishing EQ in an operating plant, which may involve verifying or defining certain EQ programme design inputs, is discussed in Section 4. Section 5 contains information and guidance on EQ Process Phase III — Preserving EQ, which maintains EQ throughout the NPP lifetime.

3.1. QUALIFICATION PRACTICES FOR DIFFERENT SERVICE CONDITIONS

The terms harsh environment, mild environment and seismic event are significant to qualification since qualification practices (methods, regulations, standards, records and other qualification programme details) often vary according to the type and severity of the PIE service conditions and whether the equipment is classified as electrical, electromechanical or mechanical.

During PIEs, either environmental conditions, operational conditions or both may differ significantly from those occurring during normal operation. Several types of PIE, involving breaches in the pressure boundary of the reactor coolant system (RCS) LOCA or other high energy NPP systems, produce harsh environmental conditions in certain NPP areas. Equipment may also be exposed to PIE operational conditions that differ significantly from those normally occurring, such as required valve thrust, motor horsepower or process fluid conditions.

NPP areas experiencing significant changes in environmental conditions due to a PIE are called *harsh environment* areas. Harsh environments are produced by an RCS LOCA 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. HELB is the term used to describe pipe breaks in non-RCS systems that can produce high temperature, pressure and steam conditions in various NPP areas. The conditions associated with a HELB occurring inside containment are generally contained within the containment. The conditions resulting from a HELB occurring outside the containment often involve several, but not all, outside containment rooms/areas. These conditions become less severe for rooms/areas further removed from the break location. Since LOCA and HELB environmental conditions are confined to certain plant areas, they do not directly affect all safety equipment.

Mild environment areas are NPP locations which experience the effects of seismic events but whose environmental conditions do not significantly change as a result of a PIE. However, certain equipment in mild areas can experience PIE operational conditions that are significantly different from normal conditions.

Seismic events can produce significant vibration levels that vary in intensity throughout NPP structures and connected equipment. Since seismic vibratory conditions can occur in all plant areas, they potentially affect equipment located in both harsh and mild environment areas.

3.1.1. Harsh environment qualification

Most Member States require a demonstration of EQ for any safety equipment performing safety functions during harsh environmental conditions. This environmental qualification considers any ageing effects that result in degradation that could promote equipment failures during the harsh environment. When PIE service conditions are significantly different from normal, little confidence can be derived from performance during normal operation, pre-operational tests and periodic surveillance tests. As environmental conditions become more severe, material and component characteristics change. Higher temperatures reduce both mechanical strength and electrical characteristics of many materials. When several severe environmental stresses act concurrently (e.g. steam/moisture, temperature and pressure), new failure modes and mechanisms can occur. Installation damage or age related degradation that were insignificant during normal operation can promote failures when environmental conditions become more severe. For example, installation induced or age related cracks in low voltage cables are often undetectable during normal service. If these same cables were exposed to steam, moisture combined with high temperatures could quickly cause electrical shorts and failures.

3.1.2. Mild environment qualification

In some Member States it is believed that formalized environmental qualification programmes should be limited to harsh environment equipment. It is maintained that adequate EQ for mild environments is established on the basis of conservative design practices, proven equipment designs, the results of manufacturing and pre-operational equipment and system tests and appropriate QA controls (during specification, manufacture, installation, testing and operation). Further, continued equipment capability is verified for mild environment equipment by periodic surveillance tests and maintenance practices. Since these measures are elements of normal equipment design and operation, special environmental qualification type tests and special EQ files are not required. Seismic qualification is required for equipment in this mild environment. When operational conditions are significantly different from those occurring during normal operation or surveillance tests, qualification would be required for these more severe conditions.

Such an approach for mild environment equipment can be inferred from Ref. [4], which suggests that a qualification programme should be instituted whenever plant design, equipment application and PIEs preclude the use of equipment with a proven design, and whenever commissioning and operational tests and inspections cannot confirm that the equipment safety functions can be accomplished when required. The US regulatory position for mild environment qualification is typical of this approach. According to Ref. [31], qualification for mild environment applications is established by the design/purchase specifications containing functional requirements and service conditions under normal and abnormal events combined with well supported maintenance/surveillance programmes. The maintenance/surveillance programme includes a good preventive maintenance programme and a periodic review of data and records to ensure that ageing degradation is not adversely affecting equipment capabilities. Engineering judgement is used to modify maintenance/replacement activities on the basis of the periodic reviews.

In other Member States, in addition to the above described approach, the qualification methods are the same for equipment located in harsh and in mild environments. In these Member States, environmental qualification is generally established by type tests or partial testing, with supplemental testing and analysis used to evaluate equipment changes, component capabilities and selected performance functions. France and Germany apply this approach to both electrical and mechanical equipment.

3.1.3. Environmental qualification — Electrical versus mechanical equipment

Virtually all Member States require environmental qualification of electrical equipment, although many limit the formal qualification programme and records to electrical equipment exposed to harsh PIE environments. Member States' practices vary regarding the need for an environmental qualification programme for mechanical equipment.

Some Member States may not require such formal environmental qualification programmes for mechanical equipment but do require some evidence of performance under PIE conditions. In these Member States, ageing and accident service conditions are specifically considered during equipment design, with analysis and limited testing used to verify safety functions during postulated operational conditions. Examples include flow testing of pumps and valve assemblies and selection of non-metallic components with high tolerance to radiation. Selective environmental qualification programmes may be implemented in cases where the failure of non-metallic components of mechanical equipment can prevent the accomplishment of safety functions. Examples of non-metallic mechanical components potentially affecting safety functions and susceptible to ageing and failures induced by harsh environments include, but are not limited to, lubricants, rubber diaphragms in pneumatic valve actuators, plastic and rubber components in pneumatic amplifiers and O rings/seals in containment personnel airlocks. Examples of harsh environmental conditions potentially affecting mechanical equipment are pressurization of confined fluids in certain valve types (e.g. parallel gate) due to external temperature increases and external pressurization effects on pneumatic actuators and regulators.

Other Member States, including France and Germany, require formal qualification programmes for mechanical equipment.

Electrical equipment is more sensitive than mechanical equipment to accident environmental stresses and related significant ageing mechanisms. The following characteristics of mechanical equipment contribute to its greater environmental tolerance [17]:

- Some types of mechanical equipment (e.g. valves and pumps) are designed and exposed to normal process service conditions that are generally more severe than accident environmental conditions.
- Normal operation of mechanical equipment, combined with fabrication, pre-operational and periodic tests, demonstrates performance under these normal service conditions.
- Mechanical equipment is principally fabricated of metallic components that are virtually unaffected by LOCA type environmental conditions (e.g. radiation).
- Mechanical equipment can remain functional after degradation of certain non-metallic components (e.g. seals, gaskets, packing).

As a result, qualification of mechanical equipment is often established by analysis.

3.1.4. Seismic qualification

As for the harsh conditions associated with LOCAs and HELBs, formalized qualification is generally required to establish equipment performance during seismic events. Most Member States require seismic qualification for both electrical and mechanical equipment. Seismic qualification generally includes both structural integrity and operability (functional qualification). When integrity alone is required or operability involves simple mechanisms (e.g. check valves), qualification is often achieved by analysis alone. However, when operability, particularly for relatively complex devices (e.g. electrical switchgear) is required, some testing is considered necessary. Although ageing needs to be considered during seismic qualification, there appear to be few significant ageing mechanisms affecting equipment performance during seismic events. In some cases, prolonged operation or vibration may result in material fatigue that is sufficient to affect integrity or performance during seismic events.

3.2. DESIGN INPUT: PHASE I OF THE EQ PROCESS

During the design input phase of the EQ process, the set of PIEs for which equipment has to be qualified, the NPP equipment items which have to remain functional, the equipment safety functions and operating time, and normal and PIE service conditions are defined.

3.2.1. Identifying PIEs requiring qualification

The PIEs and associated assumptions and evaluation criteria, which are included in the NPP design basis, vary according to a variety of factors including NPP type, age, location and regulatory requirements. Information, either generic to a particular design (e.g. WWER-440/213) or plant specific, needs to be available defining the plant normal, transient and accident states that have to be accommodated by the plant's and the plant systems' design features. The plant states considered in the design basis are often treated differently, depending on their probabilities of occurrence and their consequences.

The scope of qualification efforts can vary significantly on the basis of the assumed set of PIEs, the severity of the PIE service conditions and the equipment requiring qualification. Often, minor changes to some factors such as safety analysis assumptions and equipment locations can reduce the scope of qualification while maintaining acceptable levels of plant safety. Assumptions of the PIE safety analysis potentially affecting qualification complexity include the use of the single failure assumption, crediting non-safety equipment for PIE mitigation and limiting/eliminating certain PIE conditions based on PSA or operating experience. Annex I illustrates the sensitivity of qualification efforts to licensing/safety assumptions and equipment locations.

3.2.2. Specifying service conditions

The PIE service conditions for which qualification is to be established need to be selected so as to provide confidence in equipment performance during expected PIE conditions. Although the practices for defining PIE service conditions vary among Member States, qualification using the assumed service conditions is intended to provide reasonable confidence that safety functions will be accomplished in the event that similar events occur. Regulatory bodies and NPP owners should select conservative, yet realistic, service conditions for the purposes of qualifying equipment. Overly conservative or unrealistic combinations of service conditions can complicate efforts to establish qualification without a commensurate increase in plant safety. A representative combination of environmental and operational conditions is preferred to combining the most limiting conditions, unless the most limiting combination is considered credible by a PSA or is a specific regulatory requirement. Environmental conditions are generally defined by plant area. Operational conditions are generally system specific.

Conservative licensing requirements can result in postulated PIE service conditions that are significantly more severe than those considered credible using PSAs and other refined analysis techniques. In many Member States, guillotine double ended breaks are assumed to produce limiting LOCA conditions. Fracture mechanics analysis (leak before break analysis) of the RCS has demonstrated that such large breaks have an exceedingly low probability of occurrence. Smaller size breaks may be a more appropriate assumption for qualification purposes. Although peak containment temperature and pressure conditions may not change significantly, small break assumptions result in less severe transient conditions, extend the time to core uncovering (if any) and provide additional time to achieve accident mitigation (e.g. core cooling).

The qualification requirements of most Member States do not assume that either a LOCA or a HELB is concurrent or causally linked with a seismic event. Since they are not causally related, environmental and seismic qualification can be separately established. At least one Member State (Canada) requires qualification to assume that a seismic event could occur subsequent to a LOCA.

3.2.2.1. Operational conditions

Operational conditions (loading, power, signal and process system conditions) during a PIE may be significantly different from those occurring during normal operation. The PIE operational conditions used for qualification need to represent specific equipment applications and required safety functions. For example, one motor operated valve (MOV) may be required to close under high velocity two phase flows caused by a pipe break. Other MOV applications may require periodic valve alignment under normal flow conditions.

PIE operational conditions are often more critical than environmental conditions for mechanical equipment. For example, valve disc forces and actuator thrust requirements can increase during isolation of pipe break flows or because of excessive internal pressurization of a confined fluid due to thermal expansion. During LOCA type accidents, certain pumps and strainers may be required to handle debris or high flow conditions not experienced during normal operation or surveillance tests.

3.2.2.2. *Seismic conditions*

For design and qualification purposes, an SL-2 (also called an SSE) earthquake severity is used to define the vibratory limits that have to be tolerated by safety equipment. SL-2 is a level of extreme ground motion that has a very low probability of being exceeded during the plant lifetime. The recommended minimum level is a peak ground acceleration of 0.1 g. A second, less severe, earthquake level, SL-1 (often called an OBE) is used when combining certain event conditions or defining the vibratory levels that should be tolerable without equipment degradation or damage. However, the vibratory motions experienced by NPP equipment will vary on the basis of the filtering, amplification and dampening of intervening structures. In particular, vibratory conditions can be significantly different for devices mounted on piping systems (e.g. valves) and devices directly connected to NPP structures. For more details, see Ref. [6].

3.2.2.3. *Environmental conditions*

The PIEs producing harsh environmental conditions include LOCA and HELB. Other PIEs might also result in harsh accident conditions that may need to be addressed by EQ if they are more severe than LOCA and HELB conditions. These PIEs could include fuel handling accidents, anticipated transients without scram (ATWS), rod ejection accidents and total loss of AC power (station blackout). Other events with the potential for producing harsh environmental conditions, such as internal NPP fires, tornadoes and hurricanes, are not generally considered in EQ since plant designs generally protect a minimum set of essential equipment from these hazards. Even though fire testing has been included in certain cable qualification standards such as IEEE 383-1974 [17], these laboratory tests provide guidance on the relative fire resistance of various cable constructions rather than demonstrating cable performance under hypothesized NPP fire conditions [37].

(a) Steam, temperature and pressure

Inside containment temperature and pressure conditions for LOCAs and steam line breaks are based on computer models of RCS energy/mass releases, containment volume, containment heat sinks, containment spray systems and heat transfer coefficients. Both conservative licensing and best estimate models have been used. In many Member States, containment LOCA conditions for qualification are based on the largest assumed LOCA pipe break. Qualification using these conditions is assumed to demonstrate adequacy for the different conditions resulting from smaller size breaks. In other cases, particularly for in-containment main steam line break (MSLB) conditions, a composite temperature and pressure profile is developed to envelop the conditions from various size breaks.

Owing to the compartmentalized nature of outside containment areas, conditions vary in the areas communicating with the room containing the pipe break. The conditions in areas isolated from the break by continuous structures, or significantly removed from the break, are generally assumed to be unaffected. Many outside containment pipe breaks are terminated by automatic detection and isolation equipment. The relatively small room volumes (compared to the primary containment) and the sensitivity of isolation times to break size can produce widely different temperature and pressure conditions for different break sizes. Conditions can also vary when detection and isolation times change. Factors potentially affecting detection time include the location and response time of sensors. Factors affecting isolation time include the availability of AC power and valve stroke times. Practices vary among Member States and NPP utilities for defining environmental conditions for outside containment breaks. Some use the conditions resulting from the largest size break, others may define a composite profile as describe above. A generic profile may also be used that reasonably represents but does not envelop all the various break size conditions. For example, many outside containment pipe break conditions can be adequately represented by assuming 100°C low pressure steam conditions in the affected areas.

The steam released from the failure of a high pressure steam line contains a significant amount of superheat. These superheated temperatures generally last for only a few seconds or minutes; then they decay quickly to saturation levels. Some Member States require qualification to simulate the total PIE temperature. Other Member States limit EQ temperature requirements to saturation temperatures, recognizing that critical equipment temperatures during the transient superheat period are unlikely to exceed the saturation temperature. For pipe breaks outside the containment, temperature is generally limited to ambient pressure saturated steam conditions.

(b) Radiation

Many Member States require that the LOCA radiation levels used for qualification assume the instantaneous, non-mechanistic release of specified source terms into the containment. In addition to the extremely conservative instantaneous assumption, the release magnitude is often representative of a severe accident and not a mitigated LOCA. Justifications for the use of these very conservative assumptions for qualification are not well documented. The source terms might be based on NPP siting source terms. Justifications might include a defence in depth rationale involving delayed safety system operation, or recognition that qualification to higher radiation levels provides some assurance that equipment might function during certain severe accidents. These assumptions require equipment designed for LOCA mitigation (i.e. prevention of significant core damage) to be qualified for the radiation levels associated with instantaneous core failure (i.e. the safety systems did not adequately mitigate the LOCA event). Some Member States are contemplating changes to such conservative release assumptions. For example, source term research has culminated in proposed changes to release quantity, chemical form and timing for advance reactor designs in the USA [38].

(c) Other harsh conditions

Equipment is generally shielded from the effects of fluid jet impingement, internally generated missiles or pipe whip, instead of qualifying to these conditions. Most NPP designs endeavour to minimize the amount of safety equipment required to function while submerged. The fluid released from inside containment pipe breaks, combined with the fluid supplied by containment sprays and operation of other safety systems, can submerge equipment in the lower containment levels. Safety equipment with required functions located below this flood level needs to be qualified for this submerged condition. Fluid discharges outside the containment generally do not submerge safety equipment because of compartment/room designs, which prevent significant flooding in areas containing safety equipment. Electrical equipment located above flood levels may experience conditions similar to submergence if spraying fluid or condensed steam can penetrate the equipment enclosure. For example, cables routed in closed rigid conduit might be submerged if the conduit system design does not provide adequate pitch and drainage to remove the accumulated water. The conduit system can also channel water into safety equipment that is connected to the conduit without the use of internal water seals and drains.

3.2.2.4. Service conditions during normal operation

Service conditions during normal operation may be used to qualify equipment for mild environment applications or evaluate the effects of in-service ageing degradation.

Qualification for normal service conditions generally involves demonstrating the equipment’s functional capability when experiencing an appropriate combination of service condition extremes (e.g. maximum operating temperature, full load horsepower, rated current capacity). Consideration needs to be given to both high and low operational limits when assessing equipment functionality. For example, certain electronic equipment may not be able to function at temperatures below 0°C, or some electrical contacts may be able to tolerate high voltages and currents but are unable to provide low resistance connections at significantly lower voltage and current conditions.

When service conditions are used to assess ageing effects, it is important that representative, yet conservative, values are defined. If overly conservative (i.e. extreme) values are used, qualification evaluations will overpredict the significance of ageing effects. This can result in shortened qualified life values and unnecessary equipment replacement or renewal. For example, the average temperature in an NPP area may be 25°C with a maximum expected temperature of 40°C. It would be inappropriate to assume the equipment was continually exposed to the maximum temperature.

Normal environmental conditions should be representative of those occurring at the device location. General plant area environmental conditions may not be representative of conditions local to equipment. Ventilation variations and local heat sources are typical of effects that can vary environmental conditions. When equipment items are installed inside other devices or behind panels, the local equipment environment will differ from the general area conditions. Self-heating due to energization of electrical equipment and elevated process temperatures must be identified and considered. Voltage variations can cause significant differences in the temperature rise due to self-heating for most electrical equipment.

Before commercial operation, plant environmental conditions are based on plant and system design calculations. Experience indicates these design based environmental conditions are generally appropriate. In some instances, actual plant values have deviated significantly from these calculated values owing to operational changes (e.g. removal of piping insulation), design changes (e.g. addition or removal of heat sources), installations changes or inappropriate plant design assumptions.

Plants with operating experience can utilize actual plant operating data to define or refine service condition definitions. Actual operational data are preferred to design based values since they more accurately represent plant service conditions. Data should be collected that adequately represent operational and seasonal variations. When significant changes in plant design or operation occur that can affect service conditions, it may be appropriate to reverify these conditions.

3.2.3. Identifying safety functions and equipment requiring qualification

Safety equipment need only be qualified for the normal and PIE service conditions when specific equipment safety functions are required. Formal definitions and classifications of safety equipment and functions vary among Member States. IAEA Safety Guide 50-SG-D1 contains additional information on safety functions and component classifications [39].

According to that Guide, safety functions are accomplished in order:

- to safely shut down the reactor and maintain it in a safe shutdown condition during and after appropriate operational states and accident conditions;
- to remove residual heat from the core after reactor shutdown and during and after appropriate operational states and accident conditions;
- to minimize the potential for the release of radioactive materials and to ensure that any releases are within prescribed limits during and after operational states and within acceptable limits during and after accident conditions.

Member States' practices vary regarding the equipment that has to be qualified for SL-2, SL-1 and other seismic levels. The IAEA states in Ref. [6] that the following equipment should be qualified for SL-2 levels:

- items whose failure could directly or indirectly cause accident conditions;
- items required for shutting down the reactor, monitoring critical parameters, maintaining the reactor in a shutdown condition and removing residual heat over a long period;
- items that are required to prevent radioactive releases or to maintain releases below limits established by the regulatory body for accident conditions.

The IAEA Guide also recommends, as a conservative measure, qualification to SL-2 levels for those items that are designed to mitigate the consequences of design basis accidents, which may be postulated to occur in the primary pressure boundary, despite the fact that the primary pressure boundary is designed to withstand earthquake loads.

Qualification need only demonstrate necessary safety functions for required durations during applicable PIE conditions. Not all safety equipment functions are required for adequate system and plant response during a particular PIE. Different safety functions may also be required for different PIEs. For some items, the safety functions required during normal operation (or for PIEs with normal service conditions) are not required for PIEs with more severe service conditions. Reactor protective functions using neutron monitoring systems might not be required for LOCAs. In this case the neutron monitoring system need not be qualified for LOCA service conditions. The only LOCA function required, for certain normally energized solenoid operated valves (SOVs) located inside containment, may be to isolate, within seconds after LOCA detection, pipelines penetrating containment (i.e. containment isolation function). It is easier to design and qualify the SOV to shift from its energized to its de-energized state at the onset of the LOCA than it is to design and qualify the SOV to cycle periodically throughout the entire LOCA event. For these neutron monitoring and SOV examples, other circuit components (e.g. field cables, connectors, terminations and containment electrical penetration) would not have active electrical safety functions during the LOCA event. LOCA qualification for these components could be limited to demonstrating that the containment electrical penetration will maintain the integrity of its containment pressure boundary. However, some analysis, such as a failure modes and effects analysis (FMEA), would need to demonstrate that credible failures of these circuit components will not cause adverse consequences (e.g. causing the SOV to spuriously re-energize). Even in cases where equipment, such as the SOV, has been generically qualified for operation throughout the LOCA, the special installation and maintenance requirements (conduit and coil enclosure seals) necessary to ensure continued operability during a LOCA may not be needed for applications whose safety functions are immediately performed.

One Member State, which limits environmental qualification to harsh accident environments, suggests developing equipment categories to define the type of qualification being required [10]. Table I identifies the categories for harsh environmental conditions. Only equipment in categories 1 and 2 need be qualified for the harsh conditions. Equipment in categories 3 and 4 either performs its safety functions under non-harsh conditions or has no required PIE safety functions. Similar

TABLE I. EQUIPMENT QUALIFICATION CATEGORIES

Category	Category description
1	Equipment that will experience *harsh environmental* conditions of a PIE during which it has to function for accident mitigation must be qualified to demonstrate operability in the accident environment.
2	Equipment that will experience *harsh environmental* conditions of a PIE during which it need not function for accident mitigation but must not fail in a manner detrimental to safety must be qualified to demonstrate lack of such failures in the accident environment.
3	Equipment that performs its accident mitigation functions before experiencing *harsh environmental* conditions of the PIE and whose subsequent failure in any mode is not detrimental to safety need not be qualified for the accident environment.
4	Equipment that will experience *harsh environmental* conditions of a PIE during which it need not function for accident mitigation and whose subsequent failure in any mode is not detrimental to safety need not be qualified for the accident environment.

categories could be developed to define the qualification need for seismic (SL1 or SL2) and operational conditions by substituting the terms *seismic* or *harsh operational* for the term *harsh environmental*.

Experience indicates that the scope and complexity of the qualification programme, particularly installation and maintenance requirements, can often be minimized by defining required functions for each relevant PIE and equipment application. An equipment application PIE matrix can then be developed which defines the required functions for each item, i.e. a PIE combination. Table II illustrates this matrix concept for two hypothetical containment isolation valves in a cooling water system.

Design basis documents, NPP safety and system analyses and plant equipment lists are used to develop a list of NPP equipment and functions requiring qualification. These sources are useful in identifying final devices (e.g. motor/pump, SOV) and primary sensors (pressure transmitter, resistance temperature detector). Other information sources (drawings, specifications and in-plant inspections) are needed to identify equipment interfaces and other auxiliary circuit devices requiring qualification. For example, an in-containment pressure transmitter circuit may contain field cables interconnecting the transmitter and the containment electrical penetration, field cable connections (e.g. splices or connectors) at both the transmitter and penetration, and a transmitter electrical seal assembly (i.e. conduit seal). All these devices have to be identified and their required functions specified.

TABLE II. EXAMPLE OF AN EQUIPMENT APPLICATION PIE MATRIX

PIE	LOCA		HELB outside containment	
Equipment and location	Functions	Environmental conditions	Functions	Environmental conditions
MOV-1 Outside containment	– Pressure boundary – Containment isolation, immediately close, remain closed	Normal except for accident radiation	– Pressure boundary – No active function required	HELB steam conditions
MOV-2 Inside containment	– Pressure boundary – Containment isolation, immediately close, remain closed	LOCA steam and radiation	– Pressure boundary – No active function required	Normal (for in-containment equipment)

Although safety equipment is the principal focus of qualification, Member States often require some form of qualification for other types of equipment, including non-safety related electrical equipment in harsh environments whose failure under accident conditions would prevent the accomplishment of safety functions by safety equipment. Several Member States require qualification for certain post-accident monitoring (PAM) instrumentation systems. Qualification is also required by some Member States for certain equipment used for beyond-severe accidents. The most common example is equipment, such as hydrogen igniters and recombiners, used to limit the consequences of hydrogen generated inside containment during certain severe accidents. Qualification may also be necessary for specialized parts and materials, such as paints or coatings used inside containment.

Experience indicates that a formalized EQ equipment list should be developed identifying the NPP equipment items included in the qualification programme. The EQ equipment list can be a subset of a more detailed NPP equipment list. The qualified equipment list serves as the primary reference for identifying equipment within the EQ programme. In cases where all plant equipment of a particular design (e.g. coaxial instrument cables) requires qualification, the list need not identify each unique application. However, it should state that all applications of the equipment design are included within the programme. For example, all in-containment cables important to safety may be qualified.

The EQ equipment list is a valuable reference document during the planning and performance of engineering, procurement, installation, operation and maintenance activities. For example, one of two otherwise identical NPP equipment items may require qualification while the other, non-safety related item does not. Without access and reference to an EQ equipment list, it may be difficult for NPP personnel to determine whether qualification and qualification related activities, particularly special installation, maintenance and inspection methods, have to be applied to one or both of these devices.

3.3. ESTABLISHING QUALIFICATION: PHASE II OF THE EQ PROCESS

The establishing qualification programme phase involves those activities where qualification data are compiled, developed, evaluated, accepted and documented in an auditable form that demonstrates, in accordance with applicable qualification criteria, the qualifications of a specific equipment. Qualification is established by using test, analysis, operating experience, or a combination of these methods. When qualification cannot be established for the installed life of the equipment, additional activities, called ongoing qualification, can be implemented. Establishing qualification includes defining EQ critical installation, operation and maintenance activities. This EQ programme phase may also include verifying the that the equipment’s initial installation is in accordance with qualification requirements. Alternatively, verifying appropriate initial installation can also be considered an element of the preservation phase (Phase III). Several considerations associated with establishing qualification are discussed below.

3.3.1. Selecting appropriate qualification methods

Test, analysis, operating experience and combinations of these methods may be applied in a variety of ways to establish qualification. Prescriptive application of these methods based on rigidly defined methodologies, criteria and format of records tends to minimize technical disagreements and provides a consistent methodology. Technically justified but flexible applications may improve cost effectiveness, but opinions on adequacy can differ.

Type testing, as the principal qualification method, is the technically preferred method. Type testing can rarely be applied to equipment without some analysis to address material, design, manufacturing or application differences between the tested and the installed items. Analysis, as the principal method, is less preferred since conclusions can vary on the basis of assumptions, analytical rigour, analysis scope and quality of the supporting data. Often selected items, considered representative of a class or family of devices, are type tested with a similarity analysis used to apply the qualification to the entire class or family of devices. Operating experience is assumed to be of limited applicability because of the absence of documented operating experience information.

Identifying the scope of equipment requiring a formal qualification programme and the qualification methodologies which can be used can be an evolving and iterative process between the regulatory body and NPP utilities, particularly when upgrading is contemplated. The following factors should be considered when determining qualification programme scope and methodologies:

— Age of the NPP
— Licensing basis of the NPP
— System and equipment safety significance
— PIE conditions (harsh, mild, seismic)
— Equipment class (electrical or mechanical)
— Equipment type (e.g. electronic transmitter, motors, valve actuator)
— Equipment age (existing or new)
— Equipment performance functions
— Number of equipment items (per plant or group of plants).

For older NPPs, it is appropriate to permit greater flexibility when establishing qualification for existing equipment since it can be difficult to acquire samples of installed equipment for use as qualification test specimens and cost prohibitive to replace all older equipment with newer designs qualified to more recent standards. Existing equipment in operating plants should have significant successful operating experience, in both NPPs and commercial facilities, that can be used to establish qualification for normal and certain PIE service conditions.

3.3.1.1. Testing

Qualification by type testing refers to a series of tests subjecting equipment test samples to limiting environmental and operational conditions, with appropriate margin, while required performance is verified. Type testing is generally considered the preferred qualification method. It involves a planned test sequence subjecting equipment first to simulated normal operating conditions, including ageing, and then to PIE service conditions. The combined tests are designed to demonstrate required equipment performance, including performance required by supporting features and equipment interfaces.

Type testing is usually performed in accordance with a test plan or specification that contains sufficient details to describe the required test conditions and performance objectives. The test results are documented in a qualification test report which thoroughly describes the test plan, equipment, configurations, results and problems. The test plan and report should be comprehensive and include sufficient information, data and photographs to accurately document the testing. Ideally, selected equipment characteristics, beyond those required to verify specific performance requirements, will be monitored during the testing. Experience indicates that these supplemental data, combined with a detailed test record, are useful in evaluating qualification issues, applications or conditions that arise subsequent to test programme completion.

Partial testing refers to material, component or equipment tests demonstrating functional performance under certain operational conditions or tolerance to selected environmental conditions. Material radiation tests are one example of partial tests used to establish qualification for equipment made from similar materials. Partial testing is often combined with other qualification information (test, analysis or operating experience) to establish qualification. Many of the useful partial test data were originally developed for non-NPP needs. The acceptability of these data should be based on the quality of information provided, its consistency with other data sources and the controls applied during the testing.

3.3.1.2. Analysis

Qualification by analysis generally requires the construction of valid analytical models of the item to be qualified. The models have to address the relevant characteristics, including materials and configuration, of the items being modelled and their known responses to service conditions and other influences. The validity of the model and its applicability to the equipment items must be justified by auditable data based on physical laws, tests or operating experience.

Analysis as the principal environmental qualification method is generally limited to evaluating the effects of a single service condition (e.g. seismic vibration or temperature) on equipment performance. Such an analysis becomes more difficult when several service stresses occur simultaneously. For example, analytically considering the separate effects of moisture (100% humidity), temperature and pressure would not adequately represent the combined effect of these conditions during steam line breaks for most electrical devices. If a device were hermetically sealed, effectively isolating sensitive internals from pressure and humidity effects, then such analyses might be more easily justified.

Seismic analysis is widely used to demonstrate qualification of equipment where testing is impractical, equipment is easily modelled (no secondary structures) and no complex equipment functions are required. Reference [6] provides information on the use of analysis for seismic qualification.

Analysis in combination with partial test data supporting the model assumptions can establish a strong technical basis for qualification. Any analysis has to contain conservatisms that strengthen its applicability and account for uncertainties. Ideally, these conservatisms should be varied, on the basis of the accuracy of the analytical model and the quality of the supporting data.

Analysis is often used to extrapolate existing qualification results to address changes in equipment or material design, performance requirements, installations or factors not fully considered by other qualification information. Analysis is used to justify type testing of a few equipment items to represent an entire equipment family.

3.3.1.3. Operating experience

Operating experience has historically been considered of limited usefulness for qualification to harsh environmental and seismic conditions. The limitation was due to inadequate data and records on equipment performance during such severe service conditions. However, recent efforts have shown that equipment performance in non-NPP facilities during earthquakes can be documented and conservatively applied to establish seismic qualification for NPP equipment [40].

Operating experience can be an important data source establishing qualification for existing equipment during PIE conditions that are similar to normal conditions in operating NPPs. Equipment performance information from NPP pre-operational tests, periodic surveillance tests and continuous operation under normal conditions can be used to establish qualification for equipment exposed to similar service conditions. It some cases, it may be possible to analytically extrapolate these operating experience data to qualify for more severe service conditions. Operating experience from non-NPP facilities can also be used, but it is often difficult to document such performance.

There have been successful efforts in the USA to acquire generic operating experience data for a variety of equipment types during earthquakes. These efforts indicate that, with few exceptions, properly anchored mechanical and electrical equipment used in commercial facilities can withstand the seismic levels typically hypothesized at NPP sites [40]. This seismic experience information is being applied to review the capability of safety equipment in the older NPPs.

3.3.1.4. Qualifying for the limiting 'worst case' application

Where possible, it is recommended that an equipment design be qualified for the most limiting combination of service conditions and functions for all plant applications. Equipment design refers to items in an equipment family with similar materials and operating principles. If qualification is successful for the most limiting conditions and functions it can be easily established for any applications with less severe conditions and functions. For example, a motorized valve actuator (MOV) design could be qualified for periodic cycling operations during seismic and then LOCA type accident conditions. This qualification could then be applied to: (1) MOVs performing a single operation to isolate a HELB during high temperature, short duration HELB conditions; (2) actuators located inside the containment requiring periodic operation during LOCA conditions; (3) any actuators requiring seismic qualification. In cases where qualification for the most limiting combination of service conditions and functions cannot be accomplished because of equipment limitations, qualification can be separately established for application subsets with similar service conditions and functions.

3.3.2. Assessing ageing effects

Significant ageing mechanisms will vary according to device design and normal service conditions. The following service conditions are related to potentially significant ageing mechanisms:

- — Temperature
- — Thermal cycling
- — Radiation
- — Humidity
- — Voltage
- — Vibration
- — Corrosion
- — Erosion
- — Operation (cyclical or continuous).

Most qualification programmes require ageing to be specifically considered when qualification is established for electrical and mechanical equipment located in harsh environments. Experience and research have demonstrated that several significant ageing mechanisms can contribute to failures when electrical equipment containing electronics and non-metallic materials is subsequently exposed to harsh environmental conditions, particularly steam and radiation. Similar ageing mechanisms can exist for the non-metallic parts of mechanical equipment. When qualification is established for harsh environmental conditions by type testing, thermal, radiation and operational cycling (if significant) need to be simulated as part of the type test.

The principal ageing mechanisms for mechanical equipment are wear, corrosion, erosion and fatigue. Wear, corrosion and erosion are difficult to accurately accelerate during type test ageing simulations. For most mechanical equipment these mechanisms can be adequately addressed by (1) considering their significance during equipment design and (2) identifying significant degradation during periodic equipment inspections and surveillance tests. The non-metallic materials used in mechanical equipment (O rings, gaskets, seals and lubricants) are also susceptible to ageing, particularly thermal and radiation induced. If degradation of these non-metallic parts can adversely affect safety functions, these ageing mechanisms need to be evaluated in qualification programmes.

Experience and research suggest that few significant ageing mechanisms exist for most equipment types exposed to seismic events [41–43]. Lead acid storage batteries are one of the few equipment types with a demonstrated correlation between ageing and seismic capability [17]. Fatigue due to excessive operational vibration may also affect seismic resistance. Since there is an apparent lack of significant ageing mechanisms for seismic events, opinions vary on the need to simulate ageing as part of seismic qualification type testing.

During PIEs, the environmental conditions in mild environment areas are not significantly different from those occurring during normal operation. Therefore, ageing effects will be similar during normal operation and these PIEs. For such items, a wide variation in end of life failure times can occur around some average or median life value. The installed life of equipment in mild environments can be divided into two phases: random failures and wearout (end of life). During wearout, age related degradation substantially and progressively increases equipment failure rates. Owing to normal variations in equipment fabrication and NPP service conditions, the times to failure during the wearout phase are statistically distributed for an otherwise identical equipment population. It is not uncommon for a significant percentage of the wearout failures to occur within a time range that is numerically larger (often several times larger) than the median life value [44]. Consequently, it can be difficult to define a useful qualified life value for mild environment equipment without either testing a statistically significant number of equipment items to failure or defining very conservative life values. It may be more appropriate to schedule replacement of life limiting parts and items on the basis of operating experience and evaluation of in-service failures.

Some Member States require significant ageing mechanisms to be formally evaluated for all equipment when qualification is established. Other Member States, as an alternative to formal evaluation and the use of type test ageing simulations, rely on maintenance, surveillance, failure tracking and root cause evaluations to identify the end of life for devices installed in mild environments.

Ageing is addressed in qualification type tests by subjecting aged devices to simulated PIE conditions. Although naturally aged devices could be used, the common practice is to subject new devices to accelerated ageing in special tests. For example, thermal ageing can be accelerated by exposing equipment samples to higher temperatures for relatively short periods of time.

3.3.2.1. Accelerated ageing models

In order for a qualified life value to be based on the accelerated ageing tests, there has to be a reasonably accurate relationship correlating accelerated and normal conditions. Unfortunately, relatively few such ageing correlations exist. The Arrhenius and n–K half-life models are the most widely recognized models for accelerated thermal ageing. However, considerable uncertainty exists when predicting normal ageing with these models. For example, for radiation ageing, the equal dose–equal damage assumption had been made. However, this assumption was shown to be incorrect by research which has demonstrated dose rate effects for most elastomeric materials [45].

The ageing effects of operational cycling are typically simulated in type tests by conservatively estimating the number of cycles occurring during the equipment's lifetime and subjecting test specimens to this total number of cycles using a rapid cycling rate over a short period of time.

It may be possible to accelerate the effects of other ageing mechanisms such as voltage, humidity, vibration, corrosion, erosion, wear and continuous operation, since the degradation rate will increase when the ageing mechanisms are made severe. However, no generally accepted models exist to correlate the accelerated effects with those occurring more slowly during normal operation. For these mechanisms, conservative equipment design practices, combined with periodic tests, inspections and maintenance, can be relied upon to minimize the significance of in-service degradation.

Several Member States, including France and Germany, have adopted a practice of subjecting equipment test specimens to accelerated ageing conditions as part of type tests but do not use these simulations to predict a qualified life. Rather, they use the ageing tests as evidence that equipment in an age degraded state can perform its intended functions during PIEs. Monitoring, inspections, maintenance and replacements are intended to maintain the installed equipment in an acceptable condition. This approach is applied to qualified equipment applications in both harsh and mild environments.

A second approach, practised in the USA and elsewhere, prefers using accelerated ageing tests of thermal, radiation and cyclic ageing effects to define a qualified life for harsh environment electrical equipment. In practice, virtually all the harsh environment qualified life values are based on thermal ageing considerations. Conservative design, monitoring, periodic inspections and maintenance are intended to identify and minimize ageing effects for other potentially significant ageing mechanisms.

Most users of this second approach do not typically require ageing effects to be evaluated for mild environments or seismic events unless there are known significant ageing mechanisms. Ageing for mild environment applications is addressed through conservative design combined with periodic maintenance/inspections, failure

TABLE III. TECHNIQUES TO ADDRESS SIGNIFICANT AGEING MECHANISMS

When equipment is designed
Overdesign equipment rendering ageing mechanism insignificant
Select materials that are highly tolerant to ageing mechanism
Design equipment to protect sensitive components from ageing conditions
When qualification is being established
Analyse ageing significance as part of qualification evaluation
Simulate the ageing degradation during qualification testing
Identify significant mechanisms not amenable to simulation
Identify periodic inspections and maintenance actions for mechanisms not amenable to simulation
During plant operation
Replace and maintain equipment in accordance with qualification guidance
Maintain equipment to minimize significant ageing effects
Implement appropriate inspection, surveillance and condition monitoring
Trend equipment failures and determine if wearout (end of life) is occurring
Monitor service conditions and reduce where possible to control the rate of ageing degradation

trending and timely corrective actions when life limiting conditions are identified [31]. For seismic events there is reliance on the general absence of a seismic ageing correlation and the other practices described above for mild environment equipment.

Limitations of existing accelerated ageing methods have prompted a range of other approaches to address the ageing effects for both harsh and mild environment equipment. Table III, based in part on Ref. [17], lists various techniques.

3.3.3. Defining installation and maintenance requirements

When establishing qualification it is important to determine which installation, operation and maintenance activities are critical to qualification and have to be performed. Experience indicates that these activities may not be properly identified and implemented unless they are specifically identified as requirements in the EQ file or in the NPP drawings, specifications or procedures used by plant operations personnel. The determination of which activities are critical to EQ will depend on qualification data, combined with NPP utility experience and manufacturer installation/maintenance manuals. Not all installation, maintenance or parts replacement practices recommended by the manufacturer need be performed. Service conditions, required functions and operating experience are used to modify and supplement manufacturer information. The basis for variations, particularly those permitting more lenient or less frequent actions, should be well justified and documented. Section 5.3.1 provides some suggested criteria that can be used to evaluate maintenance activities for their EQ significance.

3.3.4. Sources of qualification data

Qualification type tests and associated test reports are generally paid for by equipment manufacturers, NPP designers or utilities. These tests and reports are implemented under appropriate QA programme controls and focus on NPP EQ. Partial tests may be sponsored and controlled similarly; however, many partial tests were originally performed for non-NPP purposes. Material test data, including long term tolerance to service stresses (e.g. temperature and radiation), are often provided by material suppliers or contained in publicly available research reports, conference proceedings or technical papers. For example, CERN (Centre Européen de recherche nucléaire, Geneva) has published numerous reports and articles on the radiation resistance of a wide variety of materials [46–48]. Although the quality controls applied to such non-NPP tests may vary, the data can generally be used for qualification, particularly when similar results were achieved in several different efforts.

Analysis is generally plant or equipment specific and performed by using applicable NPP quality controls. Since analyses are tailored to specific needs, it is difficult to identify specific sources of analysis data.

NPP equipment operating experience data, including pre-operational and periodic surveillance test results, can be developed by using plant operation and maintenance records. Few non-NPP experience data have been compiled in a form useful for qualification. Manufacturers, utilities, regulatory bodies or other industry groups may have sponsored equipment studies for the express purpose of documenting equipment performance in NPP and non-NPP applications. Recent efforts have used such documented survey data to demonstrate seismic adequacy for several generic equipment classes (e.g. pumps, valves, switchgear).

There have been a few efforts to compile summary qualification data on equipment currently used in NPP applications. Information exists in Ref. [49] on material capabilities, summary qualification data for utility specific applications and current manufacturers of some qualified equipment. This information focuses on US NPP applications, but some European information has been added. The European Benchmark Qualification Group is developing a list of equipment types currently qualified for use in the NPPs of group members. The group has also issued a report on European qualification practices for instrumentation and control equipment [36].

Qualification and the broad topic of equipment performance during PIE conditions have been the subject of numerous published articles and research programmes. Most of these efforts have been sponsored by a Member State or NPP owners, but the data generally have a broader use. The Electric Power Research Institute (EPRI) recently issued Ref. [12] to summarize US qualification concepts, methodologies and experience. Several international qualification conferences have been held; see, in particular, Refs [50, 51].

3.3.5. EQ file

When EQ is established under a formal qualification programme, most Member States require the information used to establish qualification to be contained in, or referenced by, an EQ file. In many Member States, each utility is responsible for establishing and maintaining an NPP site specific EQ file. In other states, such as France, an EQ file applicable to various NPPs is maintained in a central location.

The EQ file contents will vary according to the specific methods used to establish qualification. The file records should include:

— relevant details of the qualified equipment;
— qualification (test, analysis and operating experience) data;
— how the qualification data are synthesized to establish qualification;
— similarity between the qualified equipment and installed equipment and spare parts.

To facilitate use and review, it is recommended that each EQ file contain summary information identifying: (1) the qualified equipment, functions and relevant service conditions; (2) overall conclusions and limitations of the qualification (if any); and (3) special activities necessary to preserve qualification for installed equipment (such as critical installation, maintenance and replacement requirements). Annex II describes the EQ file structures of two Member States.

EQ files established and maintained by a utility need not contain manufacturers' evaluations of the qualification impact of minor equipment design, material or manufacturing changes. These manufacturers must be obligated by their QA programmes to evaluate such changes for qualification impact and maintain appropriate documentation. These situations can occur when a manufacturer sponsors qualification type tests, issues a qualification report and then certifies that subsequent equipment (including that with minor changes) is qualified on the basis of the qualification report.

When a utility (or third party) without manufacturer participation pays for the qualification, then it assumes direct responsibility for identifying and evaluating equipment design, material and manufacturing changes. This may be difficult, particularly when commercial (i.e. non-NPP) products are used and the manufacturer is either reluctant or not able to provide information on equipment design, material and manufacturing changes.

4. UPGRADING EQ IN OPERATIONAL NUCLEAR POWER PLANTS

The operational NPPs have primary responsibility for maintaining an acceptable level of nuclear safety. Part of this responsibility is to demonstrate that installed equipment important to safety will perform its safety function on demand. There are NPPs in operation for which EQ has not been adequately established and evidence does not exist that the equipment could perform its safety function when required.

The EQ status of these NPPs can be categorized as follows:

— Plants that have some elements of EQ incorporated (e.g. equipment is seismically qualified, but performance under harsh environmental conditions has not been demonstrated).
— Plants that have few or none of the elements of EQ incorporated (industrial grade equipment has been installed).

For such NPPs an EQ upgrade programme is required.

Most NPPs have been put into service in the last 30 years. Over this time period, events that have stressed the installed equipment have changed our knowledge of equipment performance in harsh environments. As a result, licensing requirements have evolved, new national and international standards have been developed, and weaknesses in the design, operation and performance of installed equipment have been identified.

Many plants have undergone modifications in their physical configuration since they were put into service. These modifications may affect the current EQ state of the plant.

Modifications in the licensing requirements or in the physical configuration of the plant and identified weaknesses of installed equipment are also reasons for an EQ upgrade programme.

An EQ upgrade programme is a process for ensuring the nuclear safety performance of an operational NPP by ensuring that the equipment will perform its safety functions on demand over its installed life during and following a design basis event (DBE). The process for establishing an EQ upgrade programme can be divided into three main phases; development of the programme, implementation of the programme and preservation of EQ.

In developing an EQ upgrade programme, the utility assesses the general EQ status of an NPP in order to establish the need and the scope for an EQ upgrade programme. The results of this review are utilized to identify and define the processes required to achieve EQ, to provide the basis for the justification for interim operation, to produce an initial estimate of resources required, to define priorities, to produce a preliminary schedule and to obtain funding and approval to proceed with implementation of the upgrade programme.

Implementation of the upgrade programme is the adoption of the processes defined. These include: identification of equipment to be qualified, definition of EQ parameters, evaluation of the EQ status of the individual equipment, definition of corrective action plans and priorities, implementation of interim measures and the upgrade of EQ. Documented evidence should be generated during the entire upgrade programme to record how the required EQ status is obtained.

An EQ upgrade programme and its activities will be described in the following sections. In developing and implementing an EQ upgrade programme, consideration needs to be given to the unique needs and limitations of the utility operating the NPP. Regulatory agencies are consulted during this process.

Preservation of EQ ensures that the EQ established is retained for the intended life of the equipment. This is described in detail in Section 5.

4.1. DEVELOPMENT OF THE PROGRAMME

In assessing the need for an EQ upgrade programme in an operational NPP, the current EQ state of the plant has to be reviewed and evaluated. On the basis of the results of this review, the utility has to determine the need for an EQ upgrade programme and the type of programme most suitable for the NPP, and to make a preliminary estimate of the resources and the time required to complete the programme.

The scope of the upgrade programme will depend on the regulatory requirements, the standards adopted, the current EQ status of the NPP, the resources available and the restrictions imposed.

4.1.1. Review of the licensing requirements

In most countries, the NPP operating licence is subject to review and approval by an independent regulatory agency. The licence is granted on the basis that the data submitted demonstrate an adequate level of plant safety. The licence is based on meeting appropriate regulatory limits for radioactive releases for all DBEs. In practice, this requires demonstration that sufficient equipment important to safety is capable of operating under harsh environmental conditions. The DBEs that generate these harsh conditions are typically determined by combinations of deterministic and probabilistic methods acceptable to both regulators and utilities.

During NPP operational life, changes to the licensing requirements may add additional DBEs that could increase the severity of the environment for which the equipment has to be demonstrated to be operational.

The regulatory agencies may also issue directives related to EQ such as:

— new requirements to be retrofitted to operating plants (e.g. the systems for which EQ has to be demonstrated);
— priorities for EQ upgrades and duration of such programmes; and
— acceptable standards for demonstration of EQ.

The utilities need to review the requirements for which the plant was granted an operating licence and any safety or licensing commitments made. The operating licence basis and any directives issued by the regulatory agency determine the DBEs for which EQ was, or needs to be, established and the number and extent of plant modifications required.

The standards applied to create the installed equipment configuration need to be identified and those relevant to EQ should be reviewed. For some older plants, EQ may have been demonstrated mainly by analysis with supporting evidence from steam tests on unaged equipment. At other NPPs, EQ may have been demonstrated mainly by testing of equipment. For other NPPs, EQ standards may not have been available.

The standards that will be applied to demonstrate EQ during implementation of the EQ upgrade programme have to ensure that the current licensing requirements will be met. In Section 2, relevant EQ standards are identified and discussed. These standards need to be reviewed and decisions made as to which ones will be adopted and how they will be applied. In reviewing these national and international standards, it needs to be borne in mind that there are some differences, especially in the area of ageing methodology. Suffice it to say that all referenced standards are suitable for use taking into account the respective national requirements.

4.1.2. Review of the existing EQ status

To review the existing EQ status, it is necessary to define:

— the licensing requirements and commitments;
— the installed configuration;
— the standards that were applied to create the installed configuration;
— the EQ standards that will be applied during the implementation of the EQ upgrade programme.

The existing EQ status is determined by conducting a comparative analysis of the licensing requirements, the installed configuration, equipment data and the requirements listed in the standards. EQ upgrades will be required when the licensing requirements have not been met and EQ cannot be demonstrated to be in accordance with the standards which have to be applied.

Preliminary data on the installed configuration can be obtained by:

— creating a list of the systems important to safety;
— creating a list of the equipment associated with the systems important to safety;
— obtaining data relevant to the EQ status of the equipment.

These lists should be of sufficient detail that the upgrading effort can be estimated.

The following information should be considered when determining the EQ status of the installed equipment:

— Lack of EQ test reports may signify lack of EQ.
— Less severe normal operating environmental conditions may provide longer equipment life.
— More severe normal operating environmental conditions may cause premature failure of equipment.
— Data on the operating experience of the equipment may identify inadequacies affecting EQ.

— The maintenance and operating history may provide an indication of the ageing effects on the materials used in the construction of the equipment as well their performance under abnormal conditions (for example, a flooding event may have demonstrated that equipment sealing is inadequate).
— Walkdowns of the equipment may provide additional data on the current state of the equipment, the degree of ageing and whether the installed configuration accurately reflects the tested or documented configuration.
— The quality of data demonstrating existing EQ.
— The material composition of the equipment may identify materials known to have poor ageing performance.
— Experience with qualification of the same or similar equipment.
— Results from surveillance and inspection programmes.

Some Member States include, in the scope of an EQ upgrade programme, the qualification of active and passive mechanical equipment, as well as protection measures against jet impingement, pipe whip and piping erosion or corrosion. These issues are, in addition to the demonstration of adequate performance of equipment, important to safety under harsh environmental conditions resulting from a DBE. Other Member States have implemented separate programmes for these issues.

4.1.3. Definition of the EQ upgrade programme

4.1.3.1. Scope

In general, EQ has to include performance during normal operation, seismic events and DBEs. The scope of an EQ upgrade programme therefore needs to include review of the applicable DBEs for which EQ has to be demonstrated. The safety requirements define the systems important to safety, the equipment to be qualified and the harsh environments for which the equipment has to be qualified. In developing the scope of an EQ upgrade programme, the following simplifying assumptions may be useful:

— exclusion of equipment consisting of all metallic parts;
— exclusion of EQ for mild environmental conditions.

For these assumptions to be valid in an EQ upgrade programme, it is necessary to demonstrate that, for equipment important to safety, there are no significant ageing mechanisms; and, where there are such mechanisms, that ageing effects will be detected and corrected before equipment failure.

Equipment consisting only of metallic parts, in general, is more robust and does not have a significant ageing mechanism with respect to temperature and radiation conditions [17]. Equipment in mild environments is not affected by the environments resulting from a DBE. Deterioration of the performance of this equipment due to ageing does occur; however, for the majority of equipment this is detectable and timely corrective actions can be taken through preventive maintenance. Where deterioration is not detectable, the equipment is identified and the issue solved outside of the scope of an EQ upgrade programme.

Seismic events also affect equipment in mild environments. Data exist for some equipment, demonstrating that ageing is not a factor in seismic qualification [42]. For equipment for which ageing has an impact on the seismic qualification, the corrective actions are identified by seismic test programmes and operating experience [5].

Thus an EQ upgrade programme focuses on those types of equipment that have been identified as being susceptible to failures resulting from a harsh environment or a combination of harsh environment and ageing degradation. These typically include electrical equipment, instruments, control devices and active mechanical devices that contain materials susceptible to ageing. Upon completion of the EQ upgrade programme, qualification of such equipment will have been demonstrated and a process implemented to retain the qualification for the plant life.

The scope of an EQ upgrade programme is also a factor in the overall costs of the programme. Some programmes deal with seismic qualification and EQ for harsh environments as two independent issues. If the installed equipment has been previously seismically qualified, then EQ can be demonstrated in the majority of cases without having to include seismic testing in EQ tests for the installed equipment.

4.1.3.2. Upgrading options

Potentially, there are a number of options that could be adopted for an EQ upgrade programme. The option chosen will depend on a number of factors such as licensing requirements, resource restrictions and the time required to complete the programme. The upgrade programme formulated at this time may need to be modified later as more information becomes available on the EQ status of the NPP.

One option is to ‘do nothing’. It has to be realized that with this option the nuclear safety of the plant will continue to deteriorate. As equipment ages, the likelihood of it operating as designed during a DBE continues to decrease and it may at some point be incapable of performing its credited safety function. Where EQ did not form part of the equipment design specification, the equipment may not be capable of operating during a DBE, regardless of age.

Another option is to dedicate the initial effort to the collection and generation of input data and the completion of EQ assessments for all identified equipment. This is followed by equipment upgrades which, when completed, result in a step change in nuclear plant safety. The benefits of reduced public risk would appear later in plant life and the time to recover the costs of the upgrades would be shortened because of shorter operating life of the NPP remaining after the EQ upgrade. The overall costs of this option may be lower owing to efficiencies in the process.

In a phased upgrade programme the required EQ upgrades are prioritized to maximize the safety benefits over time. This is achieved by first addressing known EQ deficiencies and, in parallel, collecting and generating input data required for EQ assessments. In this type of programme, additional EQ upgrades are performed once the assessments identify the changes required to establish EQ. Known EQ deficiencies are identified by reviewing the experience of other utilities, past efforts to qualify the same or similar equipment and EQ publications.

Each aspect of an EQ upgrade can define additional options. These include the specific methodology to demonstrate EQ, interim measures, a programme utilizing only testing as proof of qualification, or other possibilities.

4.1.3.3. Organization and resources

Implementation of an EQ upgrade programme may require changes to the existing NPP organizational structure. Typically, this may entail creation of an interim organization to deal with the upgrade programme and the integration of the responsibilities for preservation of EQ into the existing organization while disbanding the interim structure. Alternatively, the responsibilities for EQ can be incorporated into the existing NPP organization without need for creating an interim structure. Whichever approach is adopted, the responsible parts of the organization need to be clearly identified.

There will be organizational issues in an EQ upgrade programme, and their resolution will affect the success of the programme. Success will be more likely if the whole utility organization and not just the organization for EQ accepts that there is a valid problem which needs resolution. Since EQ requires assistance from other parts of the utility organization, co-operation must be established. The maintenance personnel are important contributors to the programme and need to understand their role, the importance of the safety benefits and the value of their contributions. Any delays in obtaining the necessary co-operation will also delay realization of the safety benefits from the programme.

In most organizations, the personnel assigned to EQ do not immediately possess the necessary knowledge to conduct an upgrade programme. Training to establish the requisite skills needs to cover all aspects of an EQ upgrade programme: collection and generation of input data, definition of environmental conditions, performance of EQ assessments, implementation of modifications, special EQ related maintenance, etc.

Once the responsibilities have been identified and assigned, procedures need to be developed to address the tasks of the EQ upgrade programme such as collection and generation of input data and performance of EQ assessments.

4.1.4. Estimate of required resources

Most NPPs have design lives of 30 to 40 years. An EQ upgrade programme results in an improvement in the nuclear safety of the NPP and is the overriding reason for undertaking such a programme. It involves the expenditure of financial resources and more staff to achieve the goals. The upgrade option chosen needs to satisfy the licensing requirements for the NPP and to minimize the overall cost of the upgrade programme.

The utility needs to consider the following factors in minimizing the overall cost of the upgrade programme:

- Longer plant life versus cost of an EQ upgrade;
- Installing new systems to reduce the severity of the potential accident (e.g. addition of structural members to reduce local dynamic effects of pipe whip, increasing the strength of protection walls, addition of quick acting steam valves);
- Installing new systems to mitigate the consequences of DBEs;
- Qualified equipment replacements versus requalification of installed equipment;
- Relocation of equipment;
- Protective measures (e.g. equipment enclosures to reduce environmental effects);
- Duration of the upgrade programme;
- Scope of the EQ upgrade programme;
- Requirements for staff.

Appropriate staffing levels and mix of skills can also reduce the programme cost by early completion of the upgrade programme.

Staffing levels vary from utility to utility. Some utilities extensively employ contractors and a minimum of internal staff, while others utilize larger numbers of internal staff and a lower level of contracted staff. The staffing levels adopted and the ratio of internal to external staff also affect the overall programme cost.

The accuracy of estimated resources and time to complete the programme depends on how many data are available on the current EQ status and the effort involved in upgrading the environmental qualification of the equipment. A need for additional data may require partial implementation of the EQ upgrade programme before the generation of a final total programme cost estimate.

The cost of an upgrade programme may differ from country to country. Depending on the ratio of material to labour costs, some programmes may be more suitable than others. In one case, a programme requiring more staffing resources and a shorter schedule may be adopted whereas in another case a programme with lower staff levels in combination with an extended schedule may also be acceptable. The choice dictates the final costs, the type of upgrade programme and the duration of the upgrade activities.

In the USA the costs of the EQ upgrades undertaken in the last decade (1980s) ranged from US $2 to 26 million per reactor unit. Most of the upgrades were completed within a time span of five years, in the period of 1980 to 1985.

In Canada, EQ upgrades are under way, and the costs are also expected to vary from utility to utility. In one utility the costs are projected to be from US $15 to 60 million per reactor unit, and the time to complete such an upgrade has been projected to be ten years.

4.1.5. Definition of safety based priorities

In defining priorities, the data and conclusions derived from the review of the existing EQ situation need to be reviewed (see Section 4.1.2). This review may have identified significant EQ deficiencies. Priorities will need to be established as it is unlikely that a utility is able to address all EQ deficiencies simultaneously. Where necessary, a ranking of the deficiencies with respect to their importance to plant safety is performed and carried through to the lower levels: the NPP, the unit, the system and the equipment on which to start the upgrade.

For an NPP with multiple units in need of an EQ upgrade, the choice of the lead unit for the EQ upgrade is dictated by considerations unique to the utility. The choice may be governed by age of the unit, completeness or availability of data relevant to EQ, or some other criteria.

The choice on which system EQ upgrading is first performed tends to be somewhat arbitrary. By definition, all systems important to safety are required to function in order to mitigate the consequences of an accident. Therefore, all should be upgraded simultaneously. In practice, one system is chosen as being first, and the remaining systems are upgraded sequentially.

The priorities for EQ may be dictated by consequences of specific events (pipe whip, jet impingement, etc.) and their impact on nuclear safety. The safety impact could be assessed by a probabilistic safety assessment (PSA) to identify the increase in public risk as a result of the postulated events and the resultant harsh environment. For example, pipe break may cause the failure of equipment in redundant channels and systems credited with the mitigation of the pipe whip event. Harsh environment EQ does not provide a safety benefit unless the equipment is also protected from the physical damage resulting from the above events. It could be argued that in this scenario pipe whip should be given first priority. This may specifically be true if the resultant risk to the public is higher than that for the other events.

PSAs are available as tools for setting priorities at the equipment level. Depending on the PSA, an analysis can be performed to identify those components that are major contributors to the increase in core melt frequency. On the basis of the sensitivity analysis of hazards resulting from DBEs (harsh accident conditions and condensing steam generally have the greatest impact), it is possible to identify critical components and concentrate EQ initially on these components. The principles of this approach are described in an IAEA handbook on safety related maintenance [52].

If there is sufficient staff, some aspects of the EQ programme may be done in parallel. Typically, environmental conditions can be defined while equipment lists are being prepared. In addition, where it is desirable to reduce the duration of the programme, some of the EQ assessments may be done in parallel with the collection and generation of the required input data. The choice of equipment on which to perform the assessments should be made in consultation with staff knowledgeable of system operation and equipment locations.

4.1.6. Justification for interim operation

Where significant safety deficiencies are identified, measures are necessary to justify interim operation of the plant until completion of the upgrade programme.

To determine the interim measures needed, an analysis should be performed of the systems important to safety credited with the safety analysis for each DBE. This system analysis concentrates on the safety features of the defence in depth such as redundancy, physical separation, electrical separation and periodic surveillance.

Interim measures may include modifications to existing equipment, changes to operating procedures or increased surveillance. Examples of such measures are:

— installing equipment enclosures to reduce the severity of the environmental conditions;
— modifications ensuring that a system valve remains in a state that would reduce the severity of the harsh environment following a DBE;
— performing more frequent inspections to identify visible signs of deterioration;
— application of techniques for better monitoring of equipment conditions (e.g. condition trending or failure trending).

It is essential that the plant will always be in a safe operating configuration; therefore, the selected interim measures should be prioritized and implemented before the rest of the EQ upgrade programme is implemented.

4.1.7. Agreement on/approval of the upgrade programme

It is beneficial both to the utility and the regulator to review an EQ upgrade programme before its implementation. It provides the regulator with the opportunity to assess the safety benefits as well as the timeliness and the priorities of the EQ upgrades. For the utility, it provides the opportunity to obtain input from the regulator and agreement on what constitutes an acceptable programme. This is also an opportunity to discuss the licensing basis assumptions. The conservatism in these assumptions can be reviewed and, where necessary, agreement can be reached on modifying these assumptions so as to achieve the safety benefits while providing additional flexibility in the upgrade programme.

An analysis of the revenues that would be generated over the remaining life of the plant may conclude that the costs of implementing an EQ upgrade programme may not be recoverable. Thus, it may be concluded that it is more economical to decommission the plant earlier without implementing EQ. Adequate safety in the interim period until decommissioning would still need to be demonstrated. On the other hand, there may be cases where the societal cost of decommissioning the plant early may justify the additional cost of an EQ upgrade programme.

4.1.8. Documentation

The development of the upgrade programme and the justification for interim operation need be documented. The documentation should be organized in an auditable form.

The documentation should describe the EQ assessment process, the criteria used and the results. In addition, corrective action plans should be indicated for EQ deficiencies identified and justification should provided to allow interim operation of the plant while the upgrade programme is implemented.

4.2. IMPLEMENTATION OF THE EQ UPGRADE PROGRAMME

In the preceding section the process for developing an EQ upgrade programme has been described. The implementation of an EQ upgrade programme has the following major steps: identification of equipment to be qualified, definition of EQ parameters, evaluation of the EQ status of the individual equipment, definition of corrective actions, implementation of interim measures and qualification of the selected equipment. These steps will be discussed in this section.

4.2.1. Identification of equipment to be qualified

The preparation of a list of equipment to be qualified is a prerequisite to the start of the formal equipment assessments. This list should be generated and finalized early in the programme in order to achieve timely completion. The activities associated with this task consist of:

(a) Identification of the DBEs for the NPP;
(b) Generation of a list of systems important to safety credited with the safety analysis for each DBE, their function and mission times;
(c) Generation of a list of equipment important to safety associated with these systems;
(d) Generation of a list of equipment important to safety that is exposed to the harsh environment resulting from a DBE.

All systems important to safety credited with the safety analysis for a DBE should to be identified. To generate a list of equipment important to safety, the credited systems are systematically reviewed to identify the equipment necessary for mitigation of the DBE (including all interfacing equipment such as terminations, fuses, breakers, protective equipment enclosures, etc.). A piece of equipment is placed on this list if it is required for operation of the system important to safety during a DBE or if its failure would result in failure of the system to perform its required safety function. This would include equipment in a harsh as well as in a mild environment.

A *hazard analysis* can help identify equipment requiring qualification for service conditions which may cause equipment failures. Figure 2, adapted from Ref. [53], illustrates, in flowchart form, a typical hazard analysis. If the hazard analysis suggests that a safety function can be impaired by DBE [54] service conditions, then compensating actions must ensure that the safety function is achieved.

Qualification of equipment to the hazard conditions is one of several alternatives. The other alternatives are reducing the hazard severity or protecting equipment from the hazard conditions. Actions to reduce the hazard might include analysing, inspecting or replacing portions of a piping system to eliminate consideration of certain pipe breaks. Protecting equipment would include equipment relocation to areas unaffected by the hazard or shielding the equipment from the effects of the hazard. Historically, there has been a preference for hazard reduction or equipment protection in lieu of EQ. However, numerous instances arise where hazard reduction or equipment protection are not technically or economically feasible.

The above information is reviewed to create a list of equipment important to safety that is exposed to the harsh environment resulting from the DBE and required to function under such conditions. This list, the EQ master list (EQML), may also

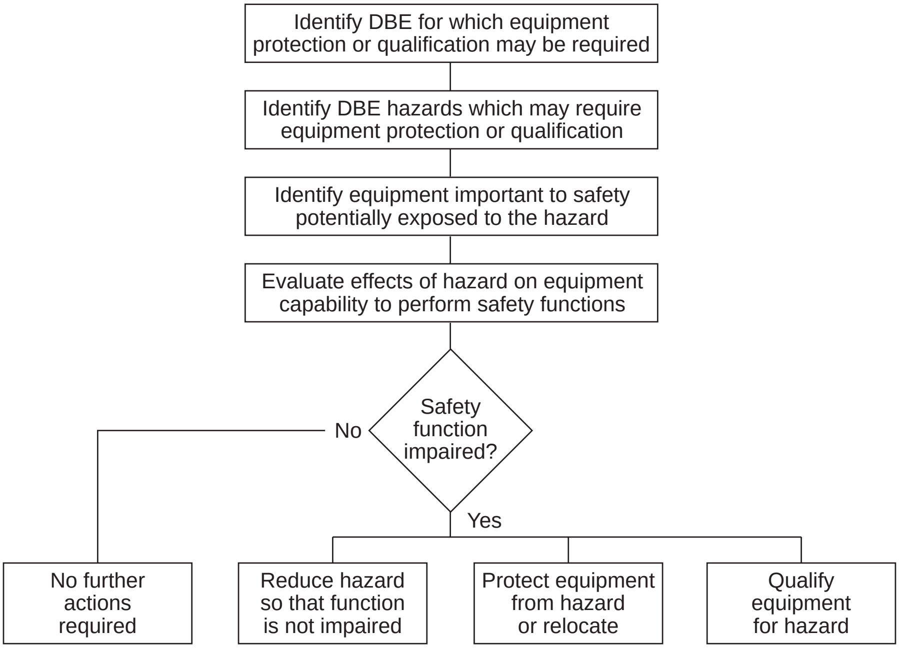


FIG. 2. EQ upgrading application of a hazard analysis flowchart.

include enclosures that provide a barrier to protect the equipment in the harsh environment. This list of equipment and enclosures forms the basis for the EQ assessments. The EQML may be further reduced by conducting a failure mode and effect analysis. This would identify equipment whose failure (due to EQ considerations) would not have an adverse effect on the operation of the safety and safety support systems. The EQ assessments would then be performed on the equipment having adverse failure modes.

The format and content of the EQML vary amongst utilities. However, in many cases this controlled list identifies the scope of equipment requiring harsh environment qualification.

Independent of its form, the EQML serves as a source document for engineering, procurement, operations and maintenance personnel, identifying the scope of equipment that has to meet the EQ requirements. More details about the EQML can be found in the EPRI EQ Reference Manual [17].

4.2.2. Definition of EQ parameters

The EQ parameters include the equipment service conditions and mission times. The service conditions include the environmental conditions and the operational conditions during normal operation and DBEs (see Section 2.3). Principal environmental conditions are temperature, pressure, humidity (moisture and water spray), radiation, water immersion, chemicals (including sprays), vibration and seismic motion. The service conditions and mission times are inputs for the EQ upgrade process (testing, analysis or other methods) which will demonstrate EQ and an acceptable qualified life. The normal operating conditions determine the degree of ageing experienced, and the DBE conditions define the harsh environment in which the aged equipment has to perform its safety function. The less severe the environmental conditions to which the equipment is exposed, the higher is the probability of successful demonstration of EQ.

In determining the consequences of the DBEs, simplifying conservative assumptions are typically made which result in overly severe environmental conditions and long equipment mission times, e.g.:

— Post-accident mission times of long duration (e.g. greater than two weeks) during which equipment must be demonstrated to function without operator intervention.
— High radiation source terms that do not take into account mechanisms which bind the radioactive materials and prevent their release as an aerosol.
— Deterministic events which maximize calculated radioactive releases, but in reality have an extremely low probability of occurrence and low release levels.

Environmental conditions may be shown to be less severe by refining the calculations and by specifying equipment location specific conditions. Additional benefit may be realized by utilizing actually measured environmental data specific to the location of the equipment of interest.

It may be practical first to utilize bounding environmental conditions in assessing the qualification of the equipment. The conditions need to envelop all possible equipment locations and all possible DBEs. The enveloping conditions would demonstrate the potential for qualifying the installed equipment. The equipment that would not be qualified to the bounding conditions would be analysed with environmental data specific to its location or applicable DBE. The expenditure of additional resources would then be concentrated on those items for which maximum benefit could be derived.

4.2.3. Evaluation of EQ status of individual equipment

As part of the evaluation process, available data are collected and evaluated for individual equipment to demonstrate that the equipment can function under harsh environmental or seismic conditions at the end of its installed life, or alternative solutions are formulated.

4.2.3.1. Information to be reviewed

Documents relevant to the EQ status of the installed equipment need to be collected and reviewed. These documents include:

- — safety analysis reports
- — EQ test reports
- — EQ requirements
- — equipment specifications/datasheets
- — detailed equipment parts lists
- — procurement documents
- — installation documents
- — maintenance history records
- — PEER review and audit reports
- — calculations and measurements of environmental conditions (for DBEs as well as for normal operation).

In older plants, the documentation on the installed equipment may not have always been adequately maintained. As a result, changes may have been made to the installed equipment which are not reflected in the documentation. To reduce the qualification effort, it is beneficial first to inspect the equipment and document the installed configuration. Typically, this entails documenting the equipment orientation, interfaces, nameplate details and other relevant details. Photographs of the installed equipment are beneficial in providing visual documentation of the installed configuration. This activity is usually referred to as a 'walkdown'.

4.2.3.2. Environmental qualification of electrical and instrumentation and control equipment

If an EQ test report is available for equipment of interest, the test data are reviewed to ensure that sufficient accelerated ageing has been performed and that the accident conditions are enveloped by the test conditions. Where there are inadequacies in the test data, ageing analysis may be required to demonstrate that there was sufficient ageing performed. Additional analysis may be required to demonstrate that the equipment tested is similar to that installed. For similarity to be justified, it is usually necessary to demonstrate that the 'fit', 'form', 'function', 'materials', 'manufacturing process' and 'manufacturer' are identical.

The results of EQ tests performed on equipment similar to that installed are reviewed to determine whether the equipment can operate during the peak temperature, pressure and humidity levels experienced during a DBE. The installed equipment is then reviewed to determine the constituent non-metallic materials. On the basis of this determination and an analysis to establish the impact of failure of these non-metallic materials, the ageing model (thermal and radiation) is applied to determine a qualified life for these materials.

Operational experience as proof of qualification is also acceptable, but in practice rarely used. It would be necessary to demonstrate that the operational conditions experienced by the equipment are as severe as, if not more severe than, those experienced during a DBE. If this could be demonstrated, it would form an acceptable basis for EQ.

Replacement of equipment should be considered if it is concluded that the installed equipment may not be qualifiable. Replacement of equipment may also be necessary because:

— documentation related to the qualification is not available;
— the manufacturer of the equipment is no longer in business;
— replacement parts are no longer available;
— there are insufficient test data to demonstrate qualification;
— the equipment is near the end of its installed life;
— there is a lack of spare parts;
— it may be more economical to replace the equipment than to continue with the assessment;
— the ageing degradation of the elastomeric materials may reduce the capability of the equipment to function when subjected to a harsh accident environment.

4.2.3.3. Mechanical equipment qualification

Qualification of passive mechanical equipment is dealt with in the appropriate national and international standards such as ASME, AISC and ACI or their equivalents. Qualification is achieved if the requirements of the standards are met. In general, this is demonstrated by analysis of the installed configurations and verifying that the stresses meet the requirements of the standards. Where appropriate, bracing is added to minimize the consequences of pipe whip and jet impingement.

Qualification of active mechanical equipment is addressed by Ref. [55]. This standard defines the requirements for demonstrating qualification of active mechanical equipment.

4.2.3.4. Seismic qualification

Where EQ upgrading includes seismic qualification, an analysis to demonstrate that the structures will support the seismic loading must be performed and the installed equipment seismically qualified by suitable testing or analysis or by comparing data on the installed equipment with those from an experience database.

Current national and international standards address the methodology for seismic qualification of new installations [56]. Upgrading of seismic qualification in operating plants is usually done by using an experience database. The latter is a compilation of the experience of various types of industrial installation during actual earthquakes. This database has been compiled from the experiences during earthquakes in California and Latin American countries. By comparing the experience of similar equipment which has undergone an earthquake and some analysis, recommendations are made for upgrading the installation in order to provide assurance that the equipment will perform its function during an actual earthquake. For more information, the reader can contact the owners of this database [54].

Acceptable methods for evaluation of the seismic qualification of equipment in operating plants are seismic PSA and seismic margin assessment (SMA). The essential features of these methods are the use of earthquake experience data, generic EQ and fragility test data, PSA methods to develop screening guidelines and to apply these guidelines and the use of expert judgement for screening equipment during plant walkdowns. More details of these methods can be obtained from the proceedings of an EPRI/NRC workshop on SMA [57].

4.2.4. Corrective action plan and priorities

If an equipment located in a harsh environment has a qualification deficiency, the following EQ upgrade options are available:

— *Test*
  Simulate the harsh DBE environment and demonstrate that the equipment will function.
— *Analyse*
  Provide evidence by comparison or by calculation that the equipment can be considered qualified.
— *Protect*
  Change the local environment.
— *Relocate*
  Move the equipment to a less harsh environment.
— *Modify*
  Replace parts which are the cause of the equipment’s failure to meet the qualification requirements.
— *Replace*
  Put in a fully qualified equipment.

Where existing equipment has to be requalified, possible ageing degradation of this equipment during its installed life should be taken into account.

In selecting the appropriate option, the utility must ensure that the current licensing requirements are being met and should consider future licensing or design changes for incorporation into the upgrade programme. A change required for EQ may, with some additional expenditure, also improve the operating efficiency of the plant.

Test

Type testing (ageing simulation followed by a test to simulate DBE conditions) of the installed equipment would be the preferred option to evaluate the EQ.

In operational NPPs, however, testing of installed equipment may not be possible for the majority of cases. It would require removal of equipment or the availability of similar equipment from spares stock or from the suppliers. Owing to the age of the NPPs and changes in technology, suppliers may no longer be able to provide equipment similar to that installed nor would the equipment be available from spares stock. Where testing of installed equipment is possible, the following issues should be addressed:

- Determination of the operating and maintenance history in order to establish the additional accelerated ageing required to reach the end of plant life.
- Restrictions, if any, on the operation of the NPP due to removal of the equipment.
- Determination of the root cause when failures occur during testing. The failure may be the result of some unknown event in the equipment history, the process of removal or the process of shipping rather than a weakness in the equipment.

If similar equipment from spares stock or the supplier is to be tested in order to demonstrate EQ, it is necessary to document the equipment storage history (storage environment, operating history if previously installed, maintenance history and possibly other factors) and the basis for similarity to the installed equipment.

Less preferred, but still acceptable in some cases is a steam test of a non-aged item of equipment supplemented by an ageing analysis of the age sensitive materials. Where test results for equipment are not available, it may be necessary, as a minimum, to conduct a steam test on the installed equipment such that the test conditions bound the worst case DBE conditions in terms of temperature, pressure, humidity and pH levels. This method may be acceptable where the ageing analysis identifies the age sensitive materials and defines a changeout frequency which in essence maintains the equipment in the ‘as new state’. The ageing analysis may also demonstrate that the materials in the equipment are essentially non-age-sensitive. In some Member States where EQ upgrades were undertaken, equipment capability in a harsh environment was demonstrated by tests performed on unaged equipment. Acceptable DBE test results and an appropriate demonstration of a suitable qualified life constituted EQ.

Analyse

Qualification by analysis only is the least preferred option and is very difficult to justify without test data to support it. However, this method has been used in some Member States to demonstrate EQ in some older NPPs.

Protect or relocate

Protection of existing equipment from harsh environments would eliminate the need for qualification, but requires qualification of the structures providing the protection and any of the services credited with maintaining a mild environment in the protected area. Relocation of the equipment would serve a similar purpose.

Modify

In the case where specific equipment parts (e.g. seals) are the cause that the equipment cannot be qualified for harsh environmental conditions, replacement of these parts by suitable parts may be considered.

Replace

When the EQ evaluation demonstrates that the equipment is not suitable for the required application, equipment replacement will be necessary.

When the make and type of installed equipment cannot be traced, replacement of this equipment by qualified equipment of known capability may be necessary and more economical.

Installed equipment difficult to qualify can be replaced by a different set of equipment that can provide the same safety function and is readily qualifiable. This kind of replacement may require additional changes, for example new operating practices or plant physical changes.

Priorities

Implementation of the results of the EQ assessments in practice tends to be by equipment type. If deficiencies are noted in one equipment type (e.g. a solenoid valve installed in many systems and having many applications), the necessary changes to the equipment are usually made on all safety systems in which this equipment is installed and for which EQ has to be demonstrated. The safety significance of the equipment failure, the availability of planned outages, the impact of equipment unavailability and the impact of safety system unavailability will dictate the priorities.

The time schedule for the EQ upgrade programme will utilize the scheduled plant maintenance outages and will seek to avoid the use of forced plant outages, which would increase the overall cost of the programme.

4.2.5. Implementation of interim measures

To continue safe operation of the plant during the implementation of the EQ upgrade programme, interim measures may be necessary to make up for the identified EQ deficiencies.

Immediate safety improvement may be realized by correcting known EQ deficiencies as identified by the experience of other utilities. Such improvements typically, would be:

(a) Sealing components against moisture intrusion (e.g. applying conduit seals or sealing conduit ends susceptible to moisture ingress).
(b) Splicing low voltage, low current signal cable termination points in the harsh environment locations. Only those terminations carrying signals supporting the required safety function would be spliced.
(c) Ensuring that other electrical terminations are protected against moisture intrusion either through qualified splices or quick disconnects.
(d) Providing drainage points in junction boxes and conduits.
(e) Replacing components or materials known to fail in a harsh environment.
(f) Replacing unidentifiable or unqualifiable lubricants with standard lubricants qualified for the required applications.

Other interim measures may include temporary changes in operating procedures, preventive maintenance and increased surveillance.

4.2.6. Qualification of the selected equipment

Testing as proof of qualification is recommended when the installed equipment is replaced by new equipment. Currently, the number of manufacturers willing to supply environmentally qualified equipment is decreasing because of the small market and the cost of qualification. Qualification is usually based on tests previously conducted and demonstration of similarity to the equipment currently available for purchase. It should be ensured that the supplier of the equipment has an adequate quality assurance (QA) programme to provide this proof of similarity. When qualification testing is performed by the utility, responsibility for similarity resides with the utility. It has to be ensured that the equipment purchased and installed is similar to that tested. The utility must then provide documentation of similarity for current purchases and future purchases. For all equipment that has been qualified, the QA programme of the NPP has to ensure that plant practices do not alter the installed configuration for which EQ was demonstrated.

Purchase of equipment previously qualified can include the documentation of the tests performed and a certificate of conformance (a declaration by the manufacturer that the equipment being supplied is similar to the equipment in the test report). An evaluation of the test report reveals whether the test conditions envelop the expected plant harsh and service environments.

Seismic events are included in the design basis events for a number of NPPs. As a result, seismic testing is included in the testing standards addressing EQ. When purchasing new equipment and seismic qualification is a requirement, seismic testing should be included in the EQ testing programme.

Qualification may also be achieved by ‘ongoing qualification’. Ongoing qualification involves, in addition to the initial qualification, activities performed subsequent to equipment installation (e.g. condition monitoring, maintenance, analysis of operating experience and testing) to extend the qualification for an additional period of time. Testing in this situation may include the removal and destructive testing of sacrificial samples as well as non-destructive testing. Since accelerated ageing is usually conservative, some utilities use sacrificial samples and monitoring of normal environmental conditions to assess ageing degradation in comparison with accelerated ageing techniques.

EQ may also be demonstrated by analysis in combination with test data. The analysis utilizes test data for similar equipment or materials, a mathematical model for thermal ageing and a model for radiation ageing to determine a qualified life. In most cases, the Arrhenius mathematical model is employed for thermal ageing. A generally acceptable mathematical model for radiation ageing does not currently exist. The radiation damage threshold and 25% of the radiation damage threshold level are commonly used as the exposure limit for a material in radiation analyses.

When the qualification of the selected equipment has been completed some additional effort may be required. Typically, the maintenance requirements identified in the EQ assessment have to be implemented. Once the equipment has been placed into a known EQ configuration, a final walkdown should be conducted and preservation of EQ implemented.

The final walkdown is a verification that the installed configuration reflects the assessed configuration. This is an essential part of EQ which entails:

(a) verifying that the equipment make and type is in agreement with that assessed;

(b) verifying that the equipment is installed as described in the assessment;
(c) verifying that the specific parts for which EQ has been demonstrated have been installed;
(d) verifying that the proper lubricants have been utilized.

To ensure that further deterioration of the EQ status does not occur, ongoing plant modifications should be reviewed for EQ requirements. Where there is an EQ requirement the following may be necessary:

(a) replacement equipment requiring environmental qualification should be purchased in accordance with the latest standards and requirements for EQ (see Section 2);
(b) implementation of a programme to control the procurement, storage and placing into service of EQ spare parts or whole components (see Section 5).

4.2.7. Documentation

The processes and outcome of the EQ upgrade programme must be documented. Control of EQ documents should be similar to that exercised for other plant documents. As a minimum the following should be documented:

— design basis events (DBEs);
— systems important to safety;
— list of equipment to be qualified (EQML), applicable service conditions, mission times and location;
— environmental conditions;
— manufacturer’s documents supporting EQ;
— EQ assessment performed and its results;
— walkdown data confirming that the installed equipment is the assessed equipment;
— maintenance requirements imposed by the EQ assessment;
— operating procedures required to retain EQ;
— material control procedures to retain EQ.

These documents are the basis for controlling the installed configuration and thus the means to preserve the qualification established. The documents may be in paper or electronic format.

Producing these documents, typically, requires a QA plan and procedures for review, approval and issuing of documents. In addition, retention periods of documents should be established. Where databases form part of the documentation process, ownership and change control of the databases should also be established.

5. PRESERVING EQ

Preserving EQ refers to activities to be undertaken to ensure that the established qualified status remains valid. This section discusses the need for preserving EQ, relevant organizational aspects and the important elements of an EQ preservation programme.

5.1. THE NEED FOR PRESERVING EQ

EQ is an ongoing process. Equipment items are qualified for specific applications in specific configurations. Once EQ has been established, it is important to preserve the qualified status of the installed equipment. Configuration management (change control), procedures controlling prescribed activities and operating experience feedback are essential to preserving EQ. Configuration management provides a systematic process to ensure that EQ implications are appropriately considered whenever changes occur to the plant, equipment or operating/maintenance/replacement activities. Changes which affect qualification can take place as a result of new requirements, design modifications, revisions to PIE accident analysis, procurement activities, storage, equipment maintenance and material control. After such changes the EQ status has to be re-established. Procedural control of prescribed activities provides assurance that activities essential to preserving EQ are correctly performed and properly integrated in facility work practices. Operating experience feedback is critical to identifying unanticipated changes in service conditions or equipment performance and, by monitoring of environments and equipment, establishing data to support ongoing qualification of installed equipment.

Examples: Replacement of qualified equipment or parts thereof. If identical materials are not used for replacements, the qualification originally established may be invalidated.

A change such as replacement of the boric acid addition system used in a PWR emergency core cooling system with a passive bagged pentaborate type system. In this case, the qualification of in-containment instruments, cables, etc. will have to be re-evaluated to address the effect of low pH spray water.

The relocation of a qualified equipment item from one location to another. In this case, the qualification of the equipment item will need re-evaluation to ensure that the originally established qualification remains valid for the environments in the new location.

In summary, changes of any type can affect the previously established qualification. Thus a systematic change control process is essential to preserve EQ. It should incorporate measures to assess the impact of all changes and initiate appropriate action where a change affects qualification.

5.2. ORGANIZING FOR THE PRESERVATION OF EQ

Effectively preserving EQ involves many entities internal and external to the NPP organization, as shown in Fig. 3. Preserving qualification during the operational phase of an NPP may require establishing new plant programmes or may affect existing plant programmes. Utilizing modern information technology can be beneficial and should be considered when developing a programme for EQ preservation.

5.2.1. Personnel and organization

The responsibility for an EQ programme may be given to a separate NPP group (EQ unit) within the NPP organization or, as an adjunct function of engineering, to QA and maintenance department staff. Although ultimate responsibility for the EQ programme should reside with a single unit, a number of organizations will participate in the preservation programme. Regardless of how EQ responsibility

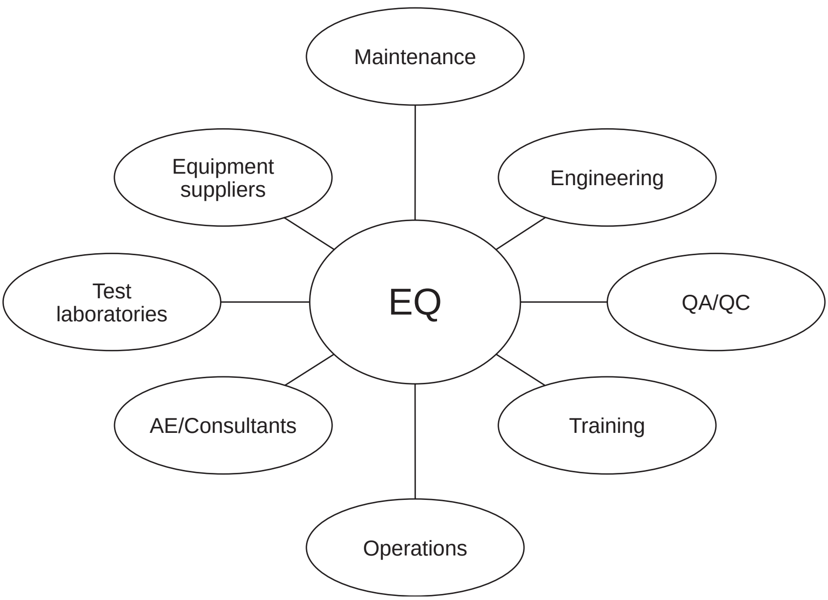


FIG. 3. EQ programme participants.

is assigned within the overall plant organization, strong leadership with EQ knowledge and skills is necessary. The tasks of the organization responsible for preserving EQ will include the following:

- Written procedures that define the EQ preservation programme and the interfaces between the various organizational units involved.
- Co-ordinating EQ activities between the relevant organizational units such as maintenance, operations, replacement parts engineering or design engineering.
- Providing a listing of EQ special maintenance, parts replacement and repair requirements along with associated special requirements for their implementation.
- Acting as an in-house consultant to those working on plant programmes or activities that may impact EQ.
- Performing EQ evaluations and operability assessments.
- Keeping EQ documentation current and accurate.
- Identifying EQ related training needs and providing (or assist in providing) training to those involved in the EQ process.
- Preparing response to EQ related inquiries from the regulatory authority.
- Keeping abreast of EQ technology, operational feedback, standards and practices.

Items to consider when organizing for preserving EQ in an operational NPP include:

- Organizational structure and procedures should promote the integration of EQ activities into mainstream activities such as preventive maintenance, surveillance and failure evaluation.
- Interfaces between organizational groups should be fully identified and controls should be established to ensure effective co-ordination of EQ activities. For example, controls should be established to ensure that EQ maintenance information is conveyed in a timely manner to all plant organizations which need it, and the division of work responsibilities between groups should be clearly defined.
- Information flow and related controls should make use of modern information technology to minimize paper work and the approval process.
- To the extent practical, attention should focus on standardizing maintenance, parts replacement and engineering review activities to simplify the steps and minimize the need for many unique activities.
- Training for personnel involved in the EQ process.
- Configuration management to ensure that the documentation is always consistent with the actual plant installation.

5.2.2. Training

Substantive variations exist in qualification methods, and documentation for various equipment EQ demands knowledge of and attention to many details. Therefore, to ensure that the EQ activities are performed correctly and consistently, and documented in an auditable manner, personnel involved in the EQ process (management, engineering and craft) should be trained.

EQ training should be an integral part of the overall EQ programme since personnel involved in the process should possess the job skills necessary to implement their responsibilities. Such training encompasses on the job, informal and formalized training activities. Particular emphasis is placed on training for personnel establishing qualification or involved in EQ preservation activities. Formalized training and job certification should be considered for critical activities requiring specific skills, such as certain engineering, installation and maintenance activities. Besides being technically sound and comprehensive, such training should:

— be specific to the job, task and procedure to perform the task;
— integrate EQ details in the hands-on maintenance training for each equipment type (e.g. maintenance personnel training on maintaining transmitters will cover applicable EQ related details, DOs and DON'Ts and inspection for degradation);
— cover related responsibilities and their scope;
— be an ongoing activity; and
— extend to both in-house personnel and contract personnel, e.g. temporary personnel who work on-site during outages and major modifications.

Additional information on EQ training can be obtained from EPRI training courses specifically designed for maintaining qualification [58]:

5.3. PRESERVATION ELEMENTS

Factors that can impact the already established EQ include:

— quality of installation and maintenance;
— changes to the design basis or plant installation;
— new information developed from recent qualification tests or research tests that may challenge or modify original assumptions or test/analysis results;
— new EQ requirements;
— feedback on operating and maintenance experiences;

— availability of qualified spare parts;
— obsolescence of equipment.

Therefore, a systematic programme that includes the following key elements is essential to preserving the qualified status of equipment:

— maintenance
— replacement of parts/equipment
— plant modifications
— condition monitoring
— degradation trending and failure analysis
— operating experience feedback and R&D efforts
— quality assurance
— documentation.

The following subsections provide guidance on each of the elements listed above.

5.3.1. Maintenance

After EQ has been established for an NPP, specific maintenance or parts replacement activities may be necessary to maintain the equipment so that it remains in its qualified configuration. These activities are typically called ‘EQ required maintenance’. This maintenance is essential to preserving qualifications of equipment.

In-plant maintenance activities are relied upon to:

— ensure that the installed equipment remains in its qualified condition (e.g. mounting bolts are torqued to the proper values, parts with limited life expectancy are replaced as required),
— provide timely identification of unforeseen ageing mechanisms that may be causing equipment degradation.

Unless justified by engineering evaluation, a minimum set of maintenance activities as prescribed in the establishing EQ phase have to be performed. The following criteria may be used to identify EQ required maintenance activities necessary to preserve qualification [17]:

— Does maintenance involve replacement of components necessary to preserve the qualified configuration (e.g. replace gaskets whenever the equipment is opened)?

- Is maintenance based on limits or values established by the ageing portion of the qualification programme (e.g. replace coils or capacitors on the basis of time and operating temperature)?
- Does maintenance address significant ageing mechanisms not fully simulated by the ageing portion of the qualification programme (e.g. visually inspect relay contacts for pitting or corrosion caused by humidity)?
- Does maintenance address ageing mechanisms that could render the equipment more susceptible to failure in a PIE environment (e.g. periodic cleaning of terminal block's insulating surface)?
- Does maintenance reduce the potential for common mode failures resulting from specific ageing mechanisms (e.g. periodic inspection of motor shafts to check for vibration induced cracking)?
- Does maintenance represent specific actions to address specific ageing mechanisms derived from operational and industry feedback?
- Are there specific installation requirements necessary for qualification (e.g. device orientation, sealing, drains, etc.)?

When establishing EQ required maintenance, consideration also should be given to the following items:

- Is it cost effective to replace the whole equipment item rather than to rebuild it?
- Will replacing the equipment item rather than rebuilding it minimize the potential for human errors and/or minimize radiation exposure to the worker?
- Would it be cost effective to establish common replacement intervals for similar items grouped either by location or service?
- Activities during normal plant operation and/or grouping activities with routine surveillance tests so as to minimize the impact on plant outage durations.
- Reviewing the manufacturer's recommendations and comparing them to plant/industry practices and experience.
- Delineating the actions required to be taken if the EQ required maintenance cannot be performed within the established interval, if applicable.

Maintenance and test procedures should identify EQ required maintenance, detailed instructions for maintenance, any associated precautions and required documentation. Maintenance management information systems should include the capability for tracking these activities. When necessary, special work instructions, independent verification and quality control are included to ensure the quality of work.

Experience indicates that errors during maintenance could invalidate the qualification established. Examples of commonly occurring errors are:

- Incorrectly installed cable splices and equipment terminations;

— Gaskets that seal equipment housing not installed or installed incorrectly;
— Piping insulation installed incorrectly, leading to overheating of pipe mounted sensors such as RTDs;
— Equipment mounting bolts or housing cover bolts missing or incorrectly torqued down.

Training of maintenance personnel should address such maintenance errors, their causes and implications. In particular, they should be trained in proper installation techniques, documentation, equipment specific degradation mechanisms and their manifestations.

Preventive and corrective maintenance is also important. Preventive maintenance, which includes surveillance, inspections, testing, calibration and servicing activities, is performed at pre-established intervals or on the basis of an assessment of the condition of the equipment. Corrective maintenance activities are performed in response to a failure or malfunction, and these failures need to be tracked to identify common cause failure mechanisms. EQ can be affected by any of these types of maintenance activity. Therefore, the procedures of these maintenance activities will reflect sensitivity to EQ related requirements. A well developed preventive maintenance programme can also aid qualification through timely identification of the onset of premature degradation. For example, the procedure for performing corrective maintenance on a transmitter may require that, after the work has been completed, the equipment housing should be installed with a new gasket and torqued to the required values to restore it to its original qualified configuration. This same procedure also needs to include a checklist of items to inspect, such as embrittled wire insulation, cracked terminals and smoky deposits that may provide a clue to the onset of unanticipated degradation mechanisms at work.

It is recommended that a plant maintenance information management system be established to track equipment service history so that vital data (e.g. failure data, parts replacement data, data indicating where commercial grade items are installed) are readily available. This will be particularly useful when addressing premature or recurrent failures, or generic defects or design deficiencies.

5.3.2. Replacement parts/equipment

When a part is replaced in a qualified equipment item, it is necessary to ensure that the original conclusions regarding qualification of this item remain valid. Originally purchased equipment contained parts that were selected, inspected or, in some cases, manufactured to an approved QA programme. This was most likely true even if the manufacturer of the equipment purchased the parts as commercial grade items (CGIs). However, when replacements are purchased later, changes may have been made to their design, materials of construction or manufacturing process.

Obsolescence may dictate substitution of the original part with an equivalent or a specially fabricated part. Therefore, substitute parts have to be identified and critical characteristics evaluated to ensure that they will perform adequately to preserve qualification. Engineering evaluation of replacement equipment/parts should include the following considerations:

- What is the safety class of the item and its basis?
- Will it be procured as a CGI?
- What QA requirements are to be applied to the supplier?
- What documentation is required to demonstrate continued qualification of the parent equipment?
- How is shelf-life assigned and controlled?
- What critical characteristics (i.e. form, fit, function and materials of construction) of the part(s) are important to preserve the capability of the equipment item in which the part is installed to perform its specified functions in PIE environments?
- Have there been any changes in the design, material and manufacturing process and, if so, how will these changes affect the critical characteristics and parent equipment qualification?
- How can the critical characteristics be replaced?
- Where, when and by whom will the critical characteristics be verified?

The Electric Power Research Institute (EPRI) reports on the technical evaluation of replacement items [59] and the utilization of CGIs and other related topics [60] contain additional guidance. Information on 'shelf-life', and how to establish it, may be found in Ref. [61].

5.3.3. Plant modifications

Modifications can involve changes to either the plant configuration, the design basis or both. Design basis modifications can involve changes to licensing commitments, normal and/or PIE service conditions, accident analysis assumptions, system and component operating parameters, system operating configurations and emergency operating procedures. Modifications to the plant configuration can involve relocation, change, addition or deletion of systems, structure or components (e.g. revised electrical circuit configuration, addition of new instrument channels), and equipment performance requirements (e.g. valve opening time, maximum flow output). Before being implemented, all modifications should be evaluated for their EQ impact.

Changes can be temporary or permanent. Temporary changes can also have an impact on EQ. During implementation of a plant modification or when performing certain maintenance activities, it may be necessary to remove or alter the penetration seals of conduit or pipe penetration sleeves in the floor of the wall. Routine alterations may also occur.

Examples of such alterations include changes to piping or valving configurations during plant outages, or the realignment (for extended periods) of equipment room doors or barriers for access control reasons. Such changes are evaluated for potential EQ impact, including changes to original assumptions used in accident analysis.

Modifications that involve only non-safety systems or equipment can also affect EQ. To ensure EQ preservation, these changes should be evaluated for possible impact on the original qualification of affected qualified equipment.

Plant procedures for controlling plant modifications should require the evaluation of changes to assess their impact on EQ. Considerations in such evaluations include the following [17]:

— Does the proposed change affect the scope or location of equipment required to mitigate the consequences of LOCA or pipe break events?
— Does the proposed change affect the required performance levels or duration of operability for the qualified equipment?
— Does the proposed change affect accident (LOCA and other pipe break) mass and energy releases and their spatial distribution within plant areas (e.g. barrier or piping changes, etc.); or the resulting temperature, pressure, steam or flooding conditions experienced by the equipment?
— Does the proposed change affect the radiation source term releases, their distribution within plant areas or systems, or doses experienced by equipment?
— Does the proposed change affect other PIE environmental conditions (spray composition, submergence) or their distribution within plant areas?
— Does the proposed change affect the normal environments (in particular, changes in temperature or radiation levels) of equipment in the scope of the EQ programme?
— Does the proposed change affect the operating conditions or limits for electrical or mechanical systems containing or supporting operation of qualified equipment?

5.3.4. Condition monitoring

Condition monitoring refers to activities performed to assess the functional capability/operational readiness of the equipment. It can be a valuable adjunct to EQ because it can support:

— assessment of in-service ageing effects and remaining equipment capability;
— validation and possible revision of the qualified life, if applicable;

- identification of ageing mechanisms that may not have been adequately addressed during original qualification;
- identification of incipient failures.

Condition monitoring may be implemented wherever additional information on in-service degradation is needed to preserve qualification and when a practical monitoring technology is available. Condition monitoring should be considered when:

- service conditions are suspected to be more severe than previously assumed;
- ageing evaluations contain significant assumptions or uncertainties; or
- known ageing mechanisms cannot be fully evaluated or simulated when qualification is established.

Effective monitoring of ageing degradation requires knowledge of one or more measurable parameters, called *condition indicators*, which indicate the performance or physical state of the component at the time of observation and can be used to assess a component's ability to perform its specified functions during a period following the time of observation [62]. The condition indicators for a given equipment type should be keyed to detecting changes caused by significant ageing mechanisms. An appropriate condition indicator provides a warning of impending function degradation that may not be otherwise apparent. Ideally, monitoring a single condition indicator would be sufficient to determine the component's qualification status. However, for some components more than one indicator may be needed.

To the extent practical, a condition monitoring programme should be established on the basis of a thorough review of the equipment design, application failure modes, service conditions and potential ageing mechanisms.

Examples of existing condition monitoring techniques for specific equipment used at some NPPs are:

- Trending motor performance through current signature analysis. In this technique, the starting and running currents of a motor are trended over a course of time. By comparing the changes in the profile of these variables, the condition of a motor can be assessed.
- Trending the winding temperature of motors. An increasing trend in the winding temperature may be indicative of insulation degradation and/or winding shorts.
- Dielectric testing (e.g. insulation resistance, polarization index) is widely used to gauge the systems conditions.
- Monitoring and analysis of motor operated valve condition indicators (current, torque, etc.) can detect the onset of, and predict, age related degradation.

It would be advantageous to select condition monitoring activities to be performed when normal operational monitoring, calibration, alignment, surveillance or preventive maintenance are conducted. Objective acceptance criteria should be established to determine acceptable and unacceptable equipment conditions. The condition indicators and acceptance criteria should be related to equipment functional capability under normal, abnormal and PIE service conditions. The basis for selecting the indicators and criteria levels requiring remedial or corrective actions should be carefully documented.

A well defined condition monitoring plan can serve as a cost effective means of supporting extended operation of the equipment (i.e. beyond the original expected life or into an extended licence term of the plant, if applicable). Therefore, selection of the equipment parameters to monitor and data to trend schould take into account the long term data needs that can support an ongoing assessment of the remaining service life of equipment.

Although condition monitoring techniques can extend operation of equipment, they may also reveal premature degradation, indicating the presence of unanticipated service stresses and non-conservative assumptions contradicting prior life estimates. In these cases, the service life estimate of equipment should be re-evaluated. Also, the applicable maintenance and surveillance activities should be modified to foster the timely recognition and effective control of the known degradation mechanism(s).

5.3.5. Environmental monitoring

The qualification process typically utilizes conservative design estimates for normal service conditions such as temperature, radiation and operational cycling based on the original plant design calculational estimates. Hence, the qualified life and parts replacement intervals established, if applicable, may also be very restrictive. Monitoring of the actual plant conditions under various operating modes and shutdown, taking into consideration seasonal climatic changes, may provide a basis for re-evaluating and extending the qualified life. In NPPs in some Member States, additional temperature and radiation monitoring instrumentation has been installed in the containment and in some critical outside-containment areas. The data collected from these instruments have been used to refine the qualified life estimates and maintenance and parts replacement intervals. Additional guidance on monitoring plant environments is provided in Ref. [17].

5.3.6. Failure trending and analysis

Monitoring equipment operating and failure history can assist in identifying in-service degradation trends to prevent failure. Performing a failure analysis can assist in identifying potential failure mechanisms and prevent future equipment malfunctions. These conditions can be evaluated to determine whether previous qualification conclusions or installation, maintenance or replacement requirements schould be revised. Additional maintenance, more frequent equipment replacement or refurbishment, and equipment and plant modifications are some of the types of corrective action that may be implemented on the basis of this analysis.

A formal failure trending and analysis programme should be established. In these programmes, a root cause analysis can identify potential common cause failure mechanisms and degraded conditions that could render the equipment vulnerable to a failure, particularly in a harsh environment. Such a programme will contain the following:

- Guidance for the maintenance staff regarding the information to be collected. Failure data are most useful when they are complete with attendant service and operating conditions and service durations. A checklist may be very useful to ensure that data on failures are complete. For additional guidance, see IAEA Safety Series No. 50-P-3 [63].
- Clear and usable criteria established by equipment specialists for determination of whether a failure stems from a random cause or from an ageing related cause.
- Guidance and references to assist in evaluating ageing mechanisms.
- Guidance for the use of the results from failure trend analysis such as conditions that would warrant:
    - replacement of all equipment of a certain type;
    - replacement of a single part of item within an equipment item on all equipment;
    - plant modifications to alter the ambient or operational service conditions, operational procedures or system configuration.

Job specific training for maintenance personnel should include this topic. Setting up failure trending and analysis as a function of an independent entity such as engineering or QA may be beneficial. Supplementing the plant’s own historical data with information from industry databases on equipment failure, such as the Nuclear Plant Reliability Data System (NPRDS) maintained by the Institute of Nuclear Power Operations (INPO) in the USA, may be useful in performing failure analysis.

5.3.7. Operating experience feedback and research and development efforts

The foregoing text on condition monitoring, environmental monitoring and failure trending and analysis provides feedback within a utility or NPP. Operational feedback and research results within the industry will also be elements of preserving equipment qualification.

Exchange of such information among industry participants such as NPP operators, manufacturers, research laboratories and others can help in:

- refining the original qualification conclusions such as life estimates, effects of certain combinations of service and operating conditions, rate of progress of certain previously simulated ageing effects and the presence of unforeseen significant ageing mechanisms;
- estimating time to failure (e.g. mean time between failures) of installed equipment, particularly that with limited access (e.g. harsh environment equipment);
- implementing cost effective solutions to equipment problems and EQ preservation activities; and
- contributing to a better understanding of equipment ageing effects and the underlying causes.

Ideally, all such information should be evaluated. Practically, only information with potentially significant safety or cost implications needs to be considered.

In some cases, operating experience and/or R&D results may raise questions about the validity of the qualification established for installed equipment. After evaluating this information, the equipment's qualification for certain PIEs may be indeterminate. In such cases, justifications for continued operation should be developed and documented, taking into consideration safety significance, the degree of uncertainty and performance capability in a degraded state. Such determinations are often required to be made with partial information and on the basis of engineering judgement. Yet, these evaluations are important to ensuring continued safe operation of the plant.

A comprehensive list of industry and government information sources that can provide information on equipment operation, maintenance and failure experience is given in Annex VII.

Guidelines for the review, analysis and documentation of experience data should be provided. Typical steps for performing such review may include the following:

- Comparing equipment data (i.e. make, model, lot number, layout drawings, manufacturing date, etc.) and service conditions.
- If experience suggests modifying a maintenance technique, determine whether it mitigates the underlying failure mechanism in the specific plant application.
- If experience indicates a new degradation type or mode, determine whether it is applicable in the specific plant application.
- Determining if the diagnostic methods employed or the maintenance procedure needs modification and, if so, how?

— Determining equipment operability (i.e. ability to perform during and after a PIE) if the item involves continued validity of qualification of installed equipment.

5.3.8. Quality assurance

EQ is achieved and preserved with a high degree of confidence only when the broad spectrum of related activities is correctly performed and documented. This is the responsibility of the persons performing the work. The role of the QA function within the organization is to ensure that the work is being performed and documented consistently by using proper procedures and to identify potential trouble spots and programmatic weaknesses. This is achieved by a system of independent reviews, audits, inspections and evaluations of activities that affect work quality. The role of QA in EQ is similar to its role in any other activity or programme involved in a nuclear plant. The IAEA Code on QA [64] and the supporting Safety Guides provide requirements and guidance on QA for NPPs. In order to properly execute the responsibilities for QA, the QA staff should be trained in EQ technology and the plant specific EQ programme and procedures.

QA staff should participate in the selection and approval of the test facility and the equipment vendor, and monitor plant equipment surveillance and maintenance activities. Additional guidance regarding the performance of vendor audits is available in Ref. [65]. QA personnel should perform periodic audits (as a minimum, once in two years) and inspections and surveillance of the EQ programme activities. Such audits and inspections focus on the programmatic and technical aspects of EQ. Member States' experience indicates that using the services of technical experts from within the industry has been of significant value in performing EQ audits and inspections. Section 6 provides additional information on the assessment of EQ programmes.

5.3.9. Documentation

Preservation of EQ involves record keeping and documentation. Documentation should provide information necessary to verify qualification. The documentation should reflect current plant configuration and design basis and should be readily available. This documentation can consist of:

Establishing EQ documents

— EQ master lists
— List of limited life items and replacement intervals
— Maintenance requirements and intervals

— Qualification test plan and test data
— PIE and normal operation performance requirements
— Initial event and normal operation service conditions
— Calculations and analyses (seismic stress evaluation, qualified life, etc.)
— Walkdown verification checklists.

Configuration management history

— Installation details
— Detailed layout and wiring diagrams
— Parts list
— Vendor drawings.

Procedures controlling preservation activities and work practices

— Maintenance procedures
— Failure trending and analysis procedures
— Surveillance and testing procedures
— Equipment and parts procurement procedures.

Activity and equipment history

— Equipment operation, maintenance, parts replacement and failure history
— Equipment operating and service conditions (normal, abnormal, transient, etc.)
— Walkdown verification checklists
— Parts substitution and associated engineering justifications
— Historical data from condition monitoring programmes.

6. ASSESSING EFFECTIVENESS OF THE EQ PROGRAMME

6.1. PURPOSE AND SCOPE OF ASSESSING AN EQ PROGRAMME

The utility as a holder of an NPP operating licence (a licensee) is responsible for the overall plant specific EQ programme whose objective is to provide assurance that equipment important to safety will perform its safety functions when required throughout the life of the plant. The licensee therefore has to ensure that the EQ programme covers all aspects of the EQ process and all related activities which are needed to establish and preserve the qualified status of equipment, regardless of who is responsible for performing them; and that these activities contribute effectively to the achievement of the EQ programme objective. The role of the regulatory body is to verify that the licensee's EQ programme meets the applicable regulatory requirements and standards.

This section provides guidance for conducting periodic audits and reviews and ongoing/routine surveillance and inspections of EQ programme activities designed to assess the effectiveness of an NPP EQ programme and to identify areas for improvement. This guidance is presented in the form of generic checklists, listing aspects or activities of an EQ programme to be reviewed. These checklists may not cover all aspects and activities of a specific EQ programme and should therefore be updated in accordance with current knowledge and practices and checked for consistency with relevant national and international codes and standards.

The primary responsibility for conducting periodic audits and ongoing surveillance of EQ programme activities rests with the licensee. However, the regulatory body also performs, as appropriate, periodic audits and routine surveillance of selected EQ programme elements as part of its safety verification activities.

6.2. PERIODIC AUDITS AND REVIEWS OF EQ PROGRAMME

There are two kinds of periodic audit/review of a plant specific EQ programme: (1) comprehensive audits/reviews covering all aspects and activities of a plant EQ programme which are usually performed when the programme is first established and as a part of a periodic safety review of an NPP (typical period: ten years) or a licence renewal review (e.g. as planned in the USA); (2) focused audits/reviews covering selected aspects and activities of an EQ programme which are conducted more frequently and often in response to incidents suggesting possible weaknesses in specific areas. Both the comprehensive and the focused audits/reviews are usually performed by QA personnel with some training in environmental qualification theories and practices or with the assistance of EQ specialists.

Elements of review for periodic audits/reviews of an EQ programme are presented in three checklists covering activities of the following major performers or suppliers of EQ related services:

— Licensee EQ programme activities
— Activities of suppliers of EQ services
— EQ test facility activities.

These elements of review typically describe documents and/or activities that contribute to the effectiveness of the EQ programme.

Annex IV gives an example of a comprehensive review procedure based on United States Nuclear Regulatory Commission (NRC) Inspection Manual Temporary Instruction 2515/076, ‘Evaluation of Licensee’s Programme for Qualification of Electrical Equipment Located in Harsh Environments’. The NRC used the instruction to perform an initial evaluation of licensee EQ programmes and, as necessary, subsequent focused reviews at individual licensees.

Elements of review: Licensee equipment qualification programme activities

A licensee’s EQ programmes and procedures should be comprehensively reviewed to ensure that all facets are in place and effective. The following programme elements are suggested for review:

1. EQ programme document describing key programme elements and responsibilities necessary to demonstrate qualification of equipment important to safety. The programme document may include procedures for:

   — preparing a list of equipment covered by the plant EQ programme (EQ master list) and for controlling any changes to the list;
   — identifying design basis environmental parameters (normal and accident) to which equipment should be qualified;
   — organization, review and control of qualification documents in an auditable and traceable form;
   — EQ impact assessments relating to plant design and procurement changes including temporary alterations;
   — identification and incorporation of EQ related requirements into plant procedures for equipment procurement, fabrication, QA, storage, transportation, installation, surveillance, maintenance, replacement and training.

2. Methods and criteria utilized in the EQ programme reflect required licensing and design basis.

3. EQ master list is available and up to date.

4. Qualification documentation is available in an auditable and traceable form providing evidence of qualification for each item on the EQ master list, including a system for locating required supporting documentation.

5. EQ supporting documentation is traceable; it includes, but is not necessarily limited to, test and analysis documentation, evaluation of operating experience

and information from feedback programmes, procurement documents, production QA, storage, transportation and installation requirements, and surveillance and maintenance requirements.

6. Verification through physical inspection that:

   (a) installed equipment matches the qualified equipment;
   (b) the equipment is installed correctly (e.g. mounting, connections and conduit seals comply with the qualified configuration documentation); and
   (c) the equipment is in good condition, working order and appropriately protected.

7. Measures required to preserve qualification during equipment's installed life are documented in appropriate plant procedures or instructions (e.g. storage and handling of qualified spare parts, installation, surveillance, maintenance and component replacement requirements) and are implemented.

8. Relevant personnel are familiar with the purpose of EQ, with the measures needed to preserve EQ and with their responsibilities with regard to these measures, and are qualified to perform assigned job functions.

9. A surveillance programme (including testing, inspection and condition monitoring activities) has been established to ascertain that ageing degradation and functional capability of the equipment remain acceptable, and a feedback process is in place to address unanticipated degradation identified during surveillance or maintenance.

10. A programme is in place to analyse failures of qualified equipment and to implement appropriate corrective actions, including revisions of qualification conclusions.

11. A feedback programme is in place to gather and review information relevant to the status of qualified equipment. Such information includes, but is not necessarily limited to, plant operating experience, generic operating experience from other plants, significant event reports, supplier or manufacturer feedback, research and development results, and regulatory notices and advisories.

12. The above elements reflect current design information, including any recent plant and equipment modifications.

It should be noted that certain EQ programme elements (e.g. 7–11) are usually integrated within existing plant maintenance, surveillance, event analysis, feedback of operating experiences and engineering programmes.

Elements of review: Activities of suppliers of equipment qualification services

When an architect–engineering or consulting company, rather than the licensee, is responsible for the generation and maintenance of equipment specific qualification documentation, its QA programme and activities relating to EQ should be periodically reviewed. If the licensee has this responsibility, the applicable elements would be included in the review of its EQ programme activities. The following programme elements are suggested for review:

1. Project and organizational documents describing nuclear power plant specific EQ services. This may include documentation of personnel training and expertise.

2. Control of project input documentation (e.g. EQ specifications, vendor qualification test reports, drawings, correspondence).

3. Procedure for the review and approval of qualification documents, including items such as:

   — Traceability of the documents to the specific plant equipment;
   — Technical review of the qualification test reports to ensure their applicability, completeness, correctness and accuracy;
   — Resolution of test failures and anomalies;
   — Positive statement of qualification;
   — Listing of special EQ related maintenance, parts replacement and installation requirements;
   — Control of analyses, calculations and related computer software.

4. Sample qualification document package(s) to verify implementation of the procedure for review and approval.

5. Verification of computer software used for analysis and evaluation (e.g. finite element analysis used for seismic qualification of control panels, motors). For problem specific software (e.g. motor heat rise evaluation, thermal lag evaluations, Arrhenius thermal life evaluations), the user organization should be able to demonstrate that the software has been validated for the application at hand.

6. Effectiveness of the QA/QC programme of the supplier of EQ services.

Elements of review: Equipment qualification test facility activities

Test facilities should be audited regardless of whether they are independent or manufacturer's facilities. The following programme elements are suggested for review:

1. Effectiveness of the QA/QC programme, including appropriate control of subcontracted services.

2. Procedures for:
   - generating a specific test plan and procedure for each testing activity;
   - proper identification and control of test specimens throughout the test cycle;
   - the control of measurement and testing equipment calibration;
   - witnessing and signing off of test and data collection by QC personnel;
   - recording, evaluating, dispositioning and documenting failures and anomalies which may occur during tests;
   - the control of receipt, storage and handling of test specimens;
   - the preparation, review and approval of test reports;
   - the appropriate training of personnel involved in testing.

3. Documentation verifying that the appropriate personnel are qualified.

4. Actual qualification test reports and supporting documentation.

5. Physical inspection of the test facility for compliance with its own procedures.

6. Acceptance criteria for evaluation of test results.

6.3. ONGOING/ROUTINE SURVEILLANCE AND INSPECTIONS OF EQ PROGRAMME

Ongoing/routine surveillance and inspections of EQ programme focus on relevant plant operation, maintenance, procurement and material control activities. Surveillance and inspections are usually performed by plant QA/QC personnel and, as appropriate, also by site inspectors of the national regulatory authority.

Elements of review: Operation, maintenance, procurement and material control activities

1. Review sample maintenance and surveillance procedures to verify that applicable special maintenance and parts replacement requirements have been incorporated.

2. Review sample maintenance work orders to verify timely performance of special EQ related maintenance requirements and appropriate engineering evaluations for any postponed or missed activities.

3. Review selected maintenance activities to verify that correct tools, materials and procedures are being used to perform the required special EQ maintenance and that the qualified configuration is being preserved.

4. Review equipment surveillance activities to verify timely and correct performance of prescribed tests, inspections and condition monitoring tasks and generation of required records/reports.

5. Verify that failures, abnormal conditions, system modifications and the replacement of component parts have been properly documented in accordance with the facility's procedures.

6. Perform periodic walkdowns of plant equipment and systems to identify any abnormal conditions of qualified equipment such as missing bolts, covers, loose nuts, exposed wiring, damaged flexible conduits or plugged grease fittings.

7. Perform periodic observations of maintenance shops (I&C, electronics, electrical and mechanical) activities to verify that qualified equipment repair is being conducted in accordance with approved procedures and vendor instructions.

8. Review the repair of qualified equipment at the on-site maintenance and/or vendor facilities to verify that proper materials are being used, repair and tests are being conducted in accordance with approved procedures and that the required qualification documentation is being created correctly.

9. Review the implementation of control and tracking of dated materials, including parts, components and subcomponents.

10. Inspect warehouse facilities to verify that storage and in-storage maintenance requirements are being implemented properly.

11. Review the control of documents associated with parts specification and procurement.

12. Review the requirements associated with receipt inspection and their implementation.

13. Review the control of ‘Approved Suppliers’ list.

14. Review sample system equipment and system design changes documentation to verify that EQ requirements have been adequately addressed.

Annex I

EFFECT OF LICENSING ASSUMPTIONS AND EQUIPMENT LOCATIONS ON THE SCOPE OF AN EQ PROGRAMME

The following discussion illustrates the potential qualification impact of certain licensing assumptions and equipment locations. The objective of this discussion is to inform readers that efforts to refine PIE and safety analysis assumptions can reduce the scope of qualification efforts while providing adequate overall safety.

Consider a hypothetical plant with three systems (two safety systems and one non-safety system), each capable of mitigating the effects of a pipe break PIE producing severe environmental conditions in certain plant areas. In this hypothetical NPP, essential equipment in only one of the safety systems (SS1) is located in areas experiencing the severe pipe break conditions. The equipment in the other safety system (SS2) and the non-safety system (NSS) is isolated from the severe conditions by plant structures. Table I–I illustrates how the qualification scope might vary according to of the licensing basis of this hypothesized NPP.

TABLE I–I. VARIATIONS IN THE SCOPE OF EQ ON THE BASIS OF HYPOTHETICAL NPP SAFETY ANALYSIS ASSUMPTIONS

Case number	Random single failure	Credit for non-safety systems	Stress analysis eliminates break assumption	System available before qualification	Qualification scope for severe pipe break conditions
1	No	No	No	SS2	None required
2	Yes	No	No	SS2	SS1 equipment
3	Yes	Yes	No	SS2, NSS	None required
4	Yes	No	Yes	SS1, SS2, NSS	None required

In the first case, no qualification for severe environmental conditions is needed since the NPP safety analysis does not require random single failures to be assumed and only requires equipment in one safety system to remain functional during the PIE. For this case, the SS2 equipment is functional since it is isolated from the break conditions. In the second case, which requires redundant safety system equipment for PIE mitigation, the SS1 equipment which is exposed to the severe conditions has to be qualified. In the third case no qualification for severe conditions is necessary since the NPP safety analysis requires redundancy but credits the operability of the non-safety system. Both the SS2 and NSS equipment are isolated from the severe conditions. In the fourth case, no equipment requires qualification for the severe conditions since a piping system stress analysis (e.g. fracture mechanics) is used to demonstrate that the probability of a pipe break in the specific plant area of concern is vanishingly small and need not be considered. Obviously, modifying the plant design and layout could further alter the scope of equipment requiring qualification. Continuing with this example, we consider the adverse qualification scope impact of locating equipment from both safety systems in areas experiencing the severe pipe break conditions.

Overly conservative or unrealistic PIE assumptions regarding long term equipment operation can also affect the scope of qualification efforts. Some utilities in the USA have established qualification of certain equipment for post-LOCA durations ranging from 30 days to one year. In the USA, current qualification regulations for electrical equipment in harsh environments require equipment to be qualified for the duration of its required accident functions. All NPP owners must determine these durations for their NPP equipment. In contrast, other Member States with similar NPP designs, such as France and Germany, have limited post-LOCA qualification test durations to a few weeks with analysis justifying longer operating times. Such differences in requirements may be due in part to the fact that the most safety significant equipment performance occurs during the first few hours or days of the LOCA. Although establishing qualification for longer post-accident durations can provide added conservatism and safety assurance, the safety significance and the cost effectiveness of this effort are considered by some to be minimal. PSA and operating experience suggest that a variety of operational strategies are available post-accident once the NPP conditions have been stabilized (e.g. the reactor core is subcritical and adequately cooled). Consequently, demonstration of extremely long term operation of most equipment through qualification may not be necessary.

Annex II

EXAMPLES FOR DEVELOPING A LIST OF EQUIPMENT TO BE QUALIFIED

1. DEVELOPING A QUALIFIED EQUIPMENT LIST (FRANCE)

In order to identify all plant equipment requiring qualification, the following activities have to be completed:

1. Define overall NPP safety objectives for normal, abnormal and PIE operating conditions;
2. Establish a list of elementary functions which are required to achieve the safety objectives;
3. Establish the list of equipment required to achieve the elementary functions. This is the equipment which must be qualified.

The elementary functions, such as precision Reactor Coolant System (RCS) temperature measurement, safety injection flow or, on-site electric power (diesel

TABLE II–I. EQUIPMENT ITEMS THAT MUST BE QUALIFIED FOR THE RCS PRESSURE MEASUREMENT FUNCTION

Equipment items requiring qualification	Type of qualification[a]
RCS pressure sensor located inside containment	K1 (harsh)
Electric connector located inside containment	K1 (harsh)
Instrumentation cable located inside containment	K1 (harsh)
Containment electrical penetration	K1 (harsh)
Instrumentation cable located outside containment	K3 (mild)
Low level signal amplifier located outside containment	K3 (mild)
Control room monitor desk	K3 (mild)
Control room indicator	K3 (mild)

[a] Three types of qualification are defined by RCC code:

K1 Equipment installed inside the containment that is required to perform its functions under normal, accident and post-accident ambient conditions, as well as under seismic loadings.

K2 Equipment installed inside the containment that is required to perform its functions under normal ambient conditions and under seismic loadings.

K3 Equipment installed outside the containment that is required to perform its functions under normal operating conditions as well as under seismic loadings.

generator set), can be established by analysing the plant operating procedures that are intended to ensure the achievement of the overall NPP safety objectives.

The list of equipment requiring qualification can only be developed by carefully determining the entire chain of equipment and equipment performance needed for each elementary function. This equipment chain can include electrical, electromechanical and mechanical equipment. An example is given in Table II–I.

For each equipment item being qualified, the qualified equipment list must include the following information:

— Industrial references
— Qualification file references
— Type of qualification obtained
— Equipment safety classification
— Safety requirement file identifier.

The equipment list must be carefully updated to reflect changes in safety objectives, required elementary functions, plant design and operation.

2. DEVELOPING A QUALIFIED EQUIPMENT LIST (USA)

The following description applies to efforts to comply with one regulation in the USA, 10 CFR 50.49, that is specific to environmental qualification of electrical equipment.

Environmental qualification is required for all electrical equipment exposed to harsh accident conditions (i.e. conditions that are substantially different from those occurring during normal operation and anticipated operational occurrences) and needed to mitigate the accident producing the harsh conditions. These design basis accidents (DBAs) and associated environmental conditions are identified in each NPP's safety analysis. Generally, these accidents are limited to LOCA and HELB type accidents. Equipment is generally protected from, rather than qualified to, the flooding effects of moderate energy line breaks, jet impingement and whipping effects of HELBs and the damaging effects of fires.

Equipment requiring qualification can be grouped into the following three categories:

— Safety related equipment with required accident mitigation functions;
— Non-safety-related equipment whose failure could prevent the accomplishment of required safety functions;
— Certain post-accident monitoring instrumentation.

In the USA the term ‘safety related’ means equipment or systems relied on to ensure[1]:

— the integrity of the reactor coolant pressure boundary;
— the capability to shut down the reactor and maintain it in a safe shutdown condition;
— the capability to prevent or mitigate the consequences of accidents that could result in significant off-site radiation exposures.

Safety related systems include protection systems, actuation systems and safety system support features. The list of equipment requiring environmental qualification can be developed in several ways. A typical process used to define this equipment includes the following steps:

1. The safety functions and systems required to mitigate accidents producing harsh environments are identified.

2. Within these systems, the actuated devices (motors) and sensors with required functions are tabulated along with their functions and the required duration of equipment operation.

3. Mechanical and electrical drawings are reviewed to identify support features (e.g. electric power distribution equipment, diesel generators, component cooling water) and equipment required by these systems and equipment.

4. Electrical circuit diagrams are reviewed to identify other electrical devices, located in the harsh environment, with necessary active or passive functions. Such devices may include cables, connectors, relays and containment electrical penetrations.

5. Review of electrical drawings to determine whether failure of non-safety equipment located in the harsh environment and not electrically isolated from safety equipment may prevent the accomplishment of safety functions.

6. NPP operating procedures are reviewed to identify any other equipment with required functions that may not have been identified during the document reviews.

[1] This term is synonymous to the IAEA term ‘safety system’ (or ‘safety equipment’).

7. Equipment specifications and procurement documents are reviewed to identify the manufacturer, model and other identification information for the selected equipment.

8. For operating plants, documented equipment inspections (called walk-downs) are performed to verify that the equipment identification information (e.g. manufacturer, model number) is correct and to determine whether additional circuit equipment not identified on NPP drawings is located in the harsh environment. Examples of this type of equipment include jumper wires and connections installed by NPP personnel during equipment installation or repair.

This information is tabulated, along with other information relevant to qualification, in a list often called the EQ master list (EQML). Typical EQML information for each equipment item includes:

— equipment identification number
— equipment type (MOV, cable, motor)
— equipment manufacturer
— equipment model number
— qualification category[2]
— plant location
— required operating time
— EQ file number.

[2] In the USA, different qualification criteria are applied on the basis of plant age and type of equipment. Replacement equipment and all equipment in the newer plants must meet the most recent criteria.

Annex III

EXAMPLES OF EQ FILES AND DOCUMENTATION

1. QUALIFICATION DOCUMENTATION (FRANCE)

Various documents are developed and updated in order to ensure that qualification is correctly established and preserved. The principal qualification documents are:

- Equipment procurement technical specification
- Identification file
- Qualification file
- Reference file
- Installation specifications
- Maintenance procedures.

Except for the reference file, the utility is responsible for retaining and updating these documents throughout the equipment's operating period. Each of these documents is described below.

Equipment procurement technical specification

The equipment procurement technical specification is the reference document used to order the equipment. Depending on the type of equipment, this specification may be retained by the utility or the equipment manufacturer. For large equipment, such as a reactor coolant system pump, it is often retained by the manufacturer.

Identification file

The identification file (or manufacturer's data file) describes the materials of construction and relevant operational characteristics of the equipment being qualified. The file, originally developed by the manufacturer, is retained by the utility qualification department. The file describes important materials, parts, design and fabrication information for the equipment being qualified. The information is presented in sufficient detail to support qualification and establish similarity between this equipment and the equipment that is subsequently procured and installed in the NPP.

Qualification file

The qualification file contains detailed information which comprehensively describes the data used to establish qualification. It is this file that demonstrates that the installed NPP equipment is qualified, including equipment modifications and changes to qualification requirements and standards. The file is retained by the utility organization responsible for qualification. The qualification file contains the following types of document:

— Procurement specification for the tested equipment
— Qualification test specification
— Test reports from each laboratory including incident reports and official (regulatory body) appraisals
— Qualification analysis reports
— Qualification synthesis report
— Technical information (if any) sent to the regulatory body.

The synthesis report integrates the information in the various technical reports, compares the results with qualification requirements and describes how qualification is achieved.

Reference file

This extensive file, identified and managed by the manufacturer, contains the information necessary to control the manufacturing process. If the utility terminates its contract with the manufacturer, arrangements should be made for continued maintenance of the reference file. The file is maintained by the manufacturer to guarantee that confidential information is not disclosed. It must be accessible to the utility and allows strict and accurate management of all modifications.

The reference file (1) provides evidence that all equipment manufactured subsequent to establishing qualification is identical to the qualified equipment; (2) records design and manufacturing modifications made to the equipment; and (3) justifies that the modifications do not adversely affect qualification or interchangeability of equipment or parts thereof.

The reference file is organized as follows:

1. The list of applicable documents (LAD) identifies the various file documents along with their issue and revision dates. Utilities retain a current version of the LAD.
2. A modification list identifies each product modification and the product or fabrication batch after which they become applicable.

3. Model designation and, if necessary, other model version data, along with equipment and subassembly codes sufficiently precise to identify the model, model series (for modifications) and fabrication versions.
4. Principal characteristics of importance to qualification.
5. Manufacturing plans.
6. Equipment lists.
7. Procurement specifications.
8. Documents specifying manufacturing processes.
9. Characteristics of the machines used during manufacturing.
10. Manufacturing procedures and instructions.
11. Manufacturing control and test specifications.
12. Manufacturing and control data sheets.
13. List of suppliers and subcontractors.

All equipment modifications are documented in the reference file. The following information is provided for each modification:

— Modification description;
— List of reference file documents revised owing to the modification;
— Classification of the modification as 'major' or 'minor' along with appropriate justification based on the modification's effect on qualification or interchangeability;
— Modification applicability (e.g. affected parts and equipment, possibly retroactively)
— Date of applicability.

Major modifications require prior utility approval based on technical justification material provided as a report by the manufacturer. The report includes a detailed description of the modification and a technical analysis demonstrating that the modification complies with qualification and interchangeability requirements. Modifications are classified as 'major' if they are (1) liable to affect qualification or interchangeability, or (2) cost prohibitive or excessively time consuming when reconfiguring the equipment to its pre-modification state.

Minor modifications are the responsibility of the manufacturer, and prior utility approval is not required. A data sheet describing the modification is provided to the utility for all minor modifications. The utility may cancel or delay the modification if it is considered that it ought to have been classified as a major modification.

Installation specifications

An installation specification, specific to each type of equipment, ensures that NPP equipment is correctly installed (e.g. earthquake resistant mounting, ventilation features) to properly operate during normal and PIE conditions. The specification is prepared by the manufacturer and is updated and controlled by the utility.

Maintenance procedures

Maintenance procedures describe (1) inspections used to establish correct operation and general equipment condition; (2) maintenance precautions; and (3) the periodic intervals between specific maintenance actions. Maintenance procedures exist for the installed lifetime of the equipment. They are initially prepared by both the manufacturer and the utility. Subsequent procedure revisions are issued by the utility base on operating experience feedback.

2. QUALIFICATION DOCUMENTATION (USA)

Regulatory body requirements specify that documents associated with establishing environmental qualification for electrical equipment in harsh environments have to be retained in or referenced by an EQ file. An EQ file is typically developed for each equipment ‘family’ (same manufacturer and similar model numbers). The file is developed and maintained for the installed life of the equipment by the NPP utility. Since there are no regulatory requirements specifying the file format or specific contents, file organization varies among utilities. However, a representative EQ file contains the following sections:

1. Review/approval cover sheet
2. Table of contents
3. List of applicable plant equipment items
4. Data establishing similarity between installed and qualified equipment
6. Qualification evaluation checklists and plant specific analyses
7. Qualification reports, analyses and evaluations
8. Equipment installation requirements
9. Equipment maintenance, surveillance and replacement requirements
10. Analysis of relevant NRC and operational feedback data
11. Other documents.

The section on *data establishing similarity between installed and qualified equipment* can include procurement specifications, manufacturer’s certifications or similar information. The section may also contain required installed configuration and walkdown data. These data are particularly important when qualification is being established or upgraded after equipment installation, or when existing records are insufficient to accurately define the installed equipment.

Most equipment is supplied by manufacturers under a nuclear, approved QA programme with EQ certified to qualification reports owed by the manufacturer. These manufacturers certify that the equipment is qualified by these qualification reports to the specified service conditions and functions. The manufacturers must retain, for utility audit, information demonstrating that the procured equipment is sufficiently similar to the originally qualified equipment. If the procured equipment is not identical, then the manufacturer has to develop additional analysis or test data demonstrating that qualification is achieved. This additional information can either be retained by the manufacturer, provided as supplemental qualification data to the utility or integrated into a qualification report revision. When the qualification report is utility sponsored, it is the utility's responsibility to demonstrate that subsequently procured equipment is sufficiently similar to the originally qualified equipment.

The section on *qualification evaluation checklists and plant specific analysis* describes how the referenced qualification tests, analyses and experience data are integrated to demonstrate qualification. This plant specific analysis, by evaluating normal operating conditions and qualification data, also defines the equipment's qualified life. The checklists are used to systematically evaluate the available data against criteria applicable to the qualification category being used. In the USA, different qualification criteria are applied based on plant age and type of equipment. Replacement equipment and all equipment in the newer plants has to meet the most recent criteria.

The sections on *equipment installation requirements* and *equipment maintenance, surveillance and replacement requirements* identify specific requirements that are considered critical to establishing and preserving qualification for the installed equipment. The information in these sections is provided to NPP plant operating and maintenance organizations for integration in equipment installation, operation, maintenance and replacement procedures.

NPP equipment installation, operation, maintenance and replacement drawings and procedures must reference or contain qualification requirements and limitations. Plant modification and maintenance records are used to demonstrate that qualification requirements were properly implemented.

Equipment failures and operating experience data are evaluated for qualification significance. The data are provided by the NPP to utility engineering personnel in those cases where existing qualification conclusions may need to be re-evaluated.

Annex IV

EVALUATION OF A LICENSEE'S EQ PROGRAMME FOR ELECTRICAL EQUIPMENT LOCATED IN A HARSH ENVIRONMENT

The following information for evaluating the programmatic and technical aspects of an EQ programme is principally based on inspection instructions developed by the US NRC in the 1980s for compliance inspections of environmental qualification programmes for electrical equipment located in harsh environments. The US NRC guidance is contained in the NRC Inspection Manual, Temporary Instruction 2515/076, Evaluation of Licensee's Program for Qualification of Electrical Equipment Located in Harsh Environments. The inspections were performed to determine licence compliance with a new EQ regulation [9] requiring upgrading of environmental qualification in operating NPPs.

1. PURPOSE

To provide guidance: (1) for the inspection of licensee environmental qualification programmes for safety grade electrical equipment located in harsh environments as required by revised regulatory qualification requirements; and (2) for determining that licensee commitments for resolution of outstanding qualification issues identified in prior licensee or regulatory evaluations are being properly implemented.

2. OBJECTIVES

— To review the licensee's implementation of a programme for meeting regulatory requirements and licensee commitments related to environmental qualification.
— To review the licensee's implementation of prior commitments regarding environmental qualification corrective action.
— To review the licensee's implementation of a programme for maintaining the qualified status of equipment during the life of the plant.
— To perform a physical inspection of equipment to determine that the installations agree with licensee commitments and qualification requirements.

3. BACKGROUND

In response to regulatory requirements to upgrade environmental qualification, licensees have submitted EQ documentation to the regulatory agency. This documentation was reviewed by the regulatory staff, and evaluation reports were issued listing the qualification deficiencies in the documentation. Subsequent meetings were held with the licensees to establish commitments for corrective action.

4. RESPONSIBILITIES

A team may be assigned to perform this inspection with the following members as a minimum:

a. *Team leade*r — A regulatory staff inspector to lead discussion with licensee, to conduct entrance and exit interviews, to co-ordinate team activities and participate in the inspection effort. (May also perform roles b, c or d below.)

b. Tec*hnical specia*list — Knowledgeable about the application and operation of electrical power and control equipment requiring EQ.

c. *Quality assurance specialist* — Knowledgeable of quality assurance requirements for procurement, maintenance and testing of electrical equipment requiring EQ.

d. *Equipment qualification specialis*t — Knowledgeable of EQ testing and analysis requirements and requirements for documenting qualification results.

5. INSPECTION REQUIREMENTS

5.1. Pre-inspection tasks

The following tasks need to be accomplished before the site inspection:

a. D*ocument review*

Inspectors obtain and review copies of the plant specific documents listed at the end of this Annex.

b. *Sample selection*

The inspection will include evaluation of qualification documentation and visual inspection of 10 to 15 equipment items. Selection of the devices to be evaluated is important because multiple concerns need to be addressed by the inspection.

The sample list should be ranked in importance, with the most critical devices first. The list of devices schould contain as many different equipment types as possible and should be developed with the following concerns in mind:

1. If prior licensee submittals or regulatory evaluations classified the current qualification into various categories (e.g. qualification fully established, not fully qualified, to be replaced with qualified equipment, additional qualification testing planned), select several items from different categories.
2. Outstanding regulatory or industry issuances related to qualified equipment problems should be considered.
3. Plant specific EQ related problems previously reported to the regulatory agency.
4. Access to the equipment during the walkdown inspection should be considered.
5. Equipment which the licensee has added to, or deleted from, the list of devices requiring qualification since issuance of item 9 of the attached list of documents considered.
6. Equipment that has changed from one category to another (e.g. from qualification not established to qualified) since issuance of item 9 should be considered.
7. Special attention should be given to devices listed in item 9 for which no documentation was submitted for review.
8. Equipment that has been installed as a replacement for non-qualified equipment should be included.
9. At least one piece of equipment whose qualification is based on a significant amount of analysis or partial test data should be included.
10. The list of samples should cover a variety of equipment types including transmitters, valve operators, solenoid operated valves, cables, limit switches, motors, terminal blocks and containment penetrations when possible.
11. Probabilistic risk analysis (PRA) of the sensitivity of hypothetical severe accident damage to component failure should be considered. Annex V lists the most significant EQ related components identified in one PRA study in order of decreasing significance.
12. Partial review of certain files should be considered to address, more rapidly, the treatment of specific concerns such as those cited under 2 and 3 above.

Some modification of the sample list during the inspection may be desirable or necessary.

c. *Team member assignments*

The responsibility for the main segments of the inspection (see Section 5.2) should be divided among the team members before the inspection. The segments may be performed in parallel; however, comparison and correlation of information discovered during the inspection are necessary. For example, maintenance requirements described in qualification documentation should be compared with maintenance procedures, and equipment descriptions in the qualification documents should be compared with the installed equipment.

d. *Licensee contact*

Approximately three weeks before the inspection, the following items need to be reviewed with the licensee:

1. The scope of a detailed inspection.
2. Documents to be made available for the inspection: See References.
3. Advance copies of procedures: item 12.
4. Licensee presentation in the entrance meeting covering:
   (a) organization chart with EQ applicability
   (b) overview of EQ programme
   (c) overview of EQ documentation file organization
5. Advance arrangements for plant walkdown to avoid unnecessary delays.
6. Other logistics matters as appropriate.

5.2. Inspection tasks

a. *Entrance meeting*

During the entrance meeting at the start of the inspection, the team leader will describe the scope of the inspection and identify the list of the samples selected, including identification of walkdown samples. The logistics of the inspection will be discussed. The licensee's presentation to describe its organization, EQ programme and the status of programme implementation should be made.

b. *Procedural and programmatic inspection*

1. Review the licensee's procedures to determine that a programme has been implemented to identify and document the plant equipment items requiring environmental qualification for harsh environmental conditions in accordance with regulatory requirements.
2. Review EQ programme documentation to determine that the licensee has implemented procedures for review and approval of EQ documentation and for establishing EQ.

3. Review selected maintenance and/or surveillance procedures to determine that EQ requirements have been incorporated.
4. Determine that the procedures for procurement of replacement and spare equipment address EQ requirements and require qualification of the equipment to be established before its use in the plant. Review selected procurement documents to determine that EQ upgrading requirements have been incorporated. If regulations require replacement equipment to be qualified to a higher level than existing equipment, determine that the higher level of qualification is required by procurement documents.
5. Determine that the procedures for control of plant modifications include evaluations of the effect of the modification on qualified equipment (e.g. the modification requires equipment that is qualified or the modification affects the environment of qualified equipment). Review selected modification packages and related documents such as work requests to determine that EQ requirements have been incorporated.
6. Determine by interviewing licensee personnel performing work involving qualified equipment that they are aware of EQ requirements and procedures. Determine that personnel performing review and approval of qualification documentation have appropriate training or experience.
7. Determine that the licensee has established and implemented a mechanism for addressing regulatory, manufacturer or nuclear industry problem notifications relating to equipment requiring qualification.
8. Review licensee QA/QC audit records for evidence of conformance to procedure requirements.

c. *Documentation file inspection*

1. Review the completeness of the licensee's list of equipment requiring qualification by determining that the list includes equipment identified and relied on in emergency procedures for accident mitigation and equipment used as accident monitoring instrumentation. Compare items 9 and 10. Review the changes made to the EQ list and determine that they have been made in accordance with established procedures.
2. Review the qualification files for the samples selected in Subsection 5.1b to determine if they contain the qualification specification for the equipment, adequate documentation of the qualification of the equipment and an indication that the documentation has been reviewed and approved and the equipment determined to be qualified for its application. The review will be general in nature to determine whether the important qualification requirements have been addressed. A checklist that can be used as a guide for these reviews is contained in Annex VI. Not every checklist item has to be reviewed for each file; the

comments column can be marked N/A for items not reviewed. In-depth review of one qualification package is addressed in Subsection 5.2c.5 below.

3. Review the documentation files to determine that the licensee has demonstrated that the qualified devices are the same as, or have been proven to be adequately similar to, the devices requiring qualification (i.e. the installed equipment).
4. For the selected samples, determine that the commitments for corrective action stated in Ref. 7 have been fulfilled or appropriate action is being taken.
5. Determine if the licensee's procedures for review and approval of qualification documentation have been implemented through review of the documentation file for a new device installed as part of a plant modification or for a piece of replacement equipment.

   This evaluation may entail an in-depth review of the adequacy of the qualification documentation in addition to the evaluation of the licensee's review and approval process. The check sheet provided in Annex VI should be completed for the in-depth review of one component file.
6. Obtain the equipment descriptions, model and serial numbers and equipment identification numbers for use in the physical inspection. Determine any special requirements for device orientation, connections, housing seals, etc., dictated by the EQ documentation. (Annex VII contains a generic checklist for standard pieces of equipment.)

d. *Physical inspection*

1. At the beginning of the inspection, discuss the accessibility of the devices to be inspected with the licensee. Modify the list as appropriate.
2. Through use of the equipment checklists contained in Annex VII, determine if the installed equipment is the same as that described in the licensee's documentation and if the equipment appears to be properly installed and maintained. The team member reviewing the documentation for a component should also perform the physical inspection, if possible. Physical inspection of the equipment by the entire team is desirable.
3. Determine if the equipment surrounding the device being inspected may fail in a manner that could prevent the device from performing its safety function. Any condition that could adversely affect the safety function of equipment being inspected needs to be noted for discussion with the licensee.

6. REPORTING REQUIREMENTS

The team leader is responsible for the timely assembly and generation of the inspection report. The results of the inspection will be documented in a standard inspection report. A copy of the report will be retained by the regulatory agency and a copy forwarded to the licensee.

LIST OF DOCUMENTS

1. Regulations defining requirements for environmental qualification of equipment.
2. Regulatory guidance documents describing recommended or acceptable methods of complying with the agency's environmental qualification requirements.
3. Accepted international or national standards defining qualification methods, criteria and documentation requirements.
4. Prior technical and programmatic evaluations of licensee's environmental qualification documents and programme, including identification of specific deficiencies.
5. Prior regulatory safety evaluation reports pertaining to the licensee's environmental qualification programme, including identification of specific deficiencies.
6. Licensee's commitments for corrective actions for deficiencies identified in prior qualification evaluations.
7. Regulatory guidance on the scope of accident monitoring instrumentation, including those items requiring environmental qualification.
8. Technical guidance documents prepared to assist regulatory personnel in evaluations of licence environmental qualification programmes.
9. Licensee's previously submitted qualification information, including summary qualification data and identification lists of equipment requiring environmental qualification.
10. Licensee's current qualification information, including summary qualification data and identification lists of equipment requiring environmental qualification.
11. Generic and licensee specific communications defining licensee obligations, commitments and schedule for compliance with upgraded EQ requirements.
12. Licensee's procedures applicable to EQ (EQ programme, procurement of qualified equipment, maintenance of qualified equipment and modifications to plant that could affect qualified equipment).
13. Licensee's current qualification documentation and/or files.
14. Applicable equipment installation, operation, maintenance and replacement procedures and documents.

Annex V

MOST SIGNIFICANT COMPONENTS RELATED TO EQ

PWR component sensitivities, PRA study

Component	*System*
Solenoid valves for control valves	Auxiliary feedwater
Motor operators for valves	Auxiliary feedwater
Pump motors	Auxiliary feedwater
Motor operators for valves	High pressure ECC
Motor operators for valves	Service water
Pump motors	Service water
Motor operators for valves	Low pressure ECC
Pump motors	High pressure ECC
Pump motors	Low pressure ECC

BWR component sensitivities, PRA study

Component	*System*
Motor operators for valves	Low pressure ECC
Motor operators for valves	Service water
Pump motors	Service water
Motor operators for valves	High pressure ECC
Pump motors	Low pressure ECC
Pump motors	High pressure ECC

Annex VI

CHECKLIST FOR REVIEW OF LICENSEE EQ DOCUMENTATION FILES

This checklist is provided to assist a reviewer in performing an evaluation of the adequacy of environmental qualification documentation for a piece of equipment. Such a review is intended to determine the adequacy of qualification for the device and the overall qualification review and approval process. As time permits, complete reviews will be performed for a few devices, and selective reviews, using some of the checklist elements, may be performed for other devices. Mark ‘N/A’ in the comments column for any items that are not applicable or not reviewed.

Plant name:______________________ Reviewer name:________________________

Equipment:____

Documents/files reviewed:____

Applicable EQ requirements:____

EQ issue	Yes	No	Comments
1. Stated conclusion that the equipment is qualified for the intended applications			
2. Full description of the equipment			
3. Adequate similarity between installed and qualified devices			
4. Allowed mounting methods and orientations			
5. Interfaces — conduit, housing seals, etc.			
6. Per EQ requirements, a qualified life has been established with appropriate technical justification and testing			
7. Per EQ requirements, type tests were performed sequentially on the same test specimens			

8. Type test sequence conforms to requirements or is otherwise adequately justified			
9. Performance/acceptance criteria (operating time, accuracy, etc.) appropriately defined and achieved			
10. Radiation qualification covers both normal and accident conditions			
11. PIE environment simulation meets plant requirements Steam exposure Humidity Temperature Pressure			
12. Chemical or water spray simulation performed if required			
13. Submergence simulation performed if required			
14. Qualification margins established per EQ requirement			
15. Relevant type test anomalies evaluated and resolved			
16. Periodic maintenance, surveillance and replacement activities defined			
17. Relevant regulatory or industry notifications evaluated and resolved			
18. Referenced data and documents identified and either attached or readily retrievable			

Annex VII

PHYSICAL INSPECTION CHECKLIST

The following checklist can be used for the physical inspection of environmentally qualified equipment. Before the physical inspection, the ‘Condition or attribute’ fields should be completed on the basis of information contained in the EQ documents. During the physical inspection, the installed conditions should be compared with the documented conditions. Agreement between the installed and

Configuration information per EQ documents			Installation agrees with documents
Condition or attribute	Yes	No	Comments
1. Plant location (bldg., room, elevation):			
2. Manufacturer:			
3. Nameplate data: Model No.: Other data:			
4. Mounting description:			
5. Orientation:			
6. Electrical connections (type, seal, etc.):			
7. Process connections:			
8. General condition:			
9. Expected ambient temperatures:			
10. Other expected normal conditions:			
11. Obvious damage or degradation			
12. Surrounding area clean and dry			
General comments on physical condition:			

documented information should be marked in the ‘Yes’ column. Discrepancies should be marked in the ‘No’ column, and a description of the disagreement placed in the ‘Comments’ column. Space is provided for general comments at the bottom of the checklist. This generic checklist can be used for most electrical devices; the checklist can also be tailored to specific equipment types (e.g. motors, cables, solenoid valves) by adding other fields.

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LIST OF ABBREVIATIONS

AC	Alternating current
ASME	American Society of Mechanical Engineers
ATWS	Anticipated transient without scram
CERN	European Organization for Nuclear Research
CEC	Commission of the European Communities
CGI	Commercial grade item
DBA	Design basis accident
DBE	Design basis event
EPRI	Electric Power Research Institute
EQ	Equipment qualification
EQDB	Equipment qualification databank
EQML	Equipment qualification master list
FMEA	Failure modes and effects analysis
HELB	High energy line break
I&C	Instrumentation and control
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
INPO	Institute of Nuclear Plant Operations
LOCA	Loss of coolant accident
LWR	Light water reactor
MOV	Motor operated valve
MSLB	Main steam line break
NPP	Nuclear power plant
NPRDS	Nuclear plant reliability data system
OBE	Operating basis earthquake
PAM	Post-accident monitoring
PIE	Postulated initiating event
PRA	Probabilistic risk assessment
PSA	Probabilistic safety assessment
PWR	Pressurized water reactor
QA	Quality assurance
QC	Quality control
QEL	Qualified equipment list
R&D	Research and development
RCS	Reactor coolant system
RTD	Resistance temperature detector
SMA	Seismic margin assessment
SOV	Solenoid operated valve
SSC	System, structure or component
SSE	Safe shutdown earthquake
US NRC	United States Nuclear Regulatory Commission

GLOSSARY

Most of the following definitions are adopted from IAEA NUSS publications and from EPRI Common Ageing Terminology. They are included here for the purposes of the present publication.

EQUIPMENT QUALIFICATION RELATED TERMS

accelerated ageing. Artificial ageing in which the simulation of natural ageing approximates, in a short time, the ageing effects of longer term service conditions.

artificial ageing. Simulation of natural ageing effects on SSC by application of stressors representing plant preservice and service conditions, but perhaps different in intensity, duration and manner of application.

ageing (noun). General process in which the characteristics of an SSC gradually change with time or use.

ageing mechanism. Specific process that gradually changes characteristics of an SSC with time or use (examples: curing, wear, fatigue, creep, erosion, microbiological fouling, corrosion, embrittlement and chemical or biological reactions.)

Arrhenius ageing model. Mathematical model for thermal degradation of material that assumes that the degradation rate over some limited temperature range depends inversely and exponentially on the reciprocal of the absolute temperature and a constant called activation energy.

certificate of conformance. Written statement, signed by a qualified party, certifying that the items or services comply with specific requirements.

commercial grade item. An item which is used in applications other than the nuclear industry, is not subject to design specifications unique to the nuclear industry and can be purchased on the basis of a published specification such as a vendor catalogue or brochure.

condition indicator. Characteristic that can be observed, measured or trended to infer or directly indicate the current and future ability of an SSC to function within acceptance criteria.

condition monitoring. Observation, measurement or trending of condition or functional indicators with respect to some independent parameter (usually time or cycles) to indicate the current and future ability of equipment to function within acceptance criteria.

design input phase. Initial phase of the EQ process when normal and PIE service conditions, required equipment and the necessary equipment functions to be qualified are defined.

electrical equipment. General category of equipment which includes electronic equipment (such as instrumentation transmitters), electromechanical equipment (such as solenoid operated valves) and other types of electrical equipment (such as cables, terminations and transformers).

equipment qualification. Generation and maintenance of evidence to ensure that the equipment will operate on demand to meet system performance requirements.

equipment application analysis. Process of mathematical or other logical reasoning that leads from stated premises to the conclusion concerning specific capabilities of equipment and its adequacy for a particular application.

environmental conditions. Ambient physical states surrounding a system, structure or component (examples: temperature, radiation and humidity in containment during normal operation or accidents).

establishing qualification phase. Second phase of the EQ process during which qualification data are developed and evaluated, demonstrating that an equipment design is qualified for the applicable service conditions and required functions. During this phase, equipment specific requirements for equipment installation and for preserving qualification are also established and equipment is installed. The results of these activities are documented in an EQ file.

equipment qualification process. As used in this document, a process consisting of the following three phases: design input phase, establishing qualification phase and preserving qualification phase.

equipment qualification programme. Programme that formalizes the equipment qualification process for specific equipment (or a plant). Such a programme typically requires the development of (an) EQ file(s) and records providing evidence that the equipment will operate on demand to meet systems performance requirements.

equipment qualification file. A file, not necessarily at the plant site, containing records demonstrating that qualification has been established for a type of equipment. The file contents describe, but are not necessarily limited to, relevant details of the qualified equipment, the similarity between the qualified equipment and installed equipment/parts, qualification data, and how the data are synthesized to establish qualification.

equipment family. Group of devices within a range of sizes with similar design principles, materials, manufacturing processes, limiting stresses, operating principles and design margins.

harsh environment. Environmental conditions in an NPP location which significantly change as a result of a PIE.

installed life. Period from installation to removal of an SSC.

mild environment. Environmental conditions in an NPP location which do not significantly change as a result of PIEs, except for a seismic event.

N °C half-life model. Model for thermal degradation of material that assumes, over some limited temperature range, that life is reduced by half (degradation rate doubles) for every N °C increase in material temperature. N is typically in the range of 8 to 12.

ongoing qualification. Activities performed subsequent to EQ, including condition monitoring, maintenance and analysis of operating experience, to extend qualification for an additional period of time.

preserving qualification phase. Final phase of the EQ process which includes those activities (such as maintenance, monitoring and replacement) needed to preserve qualification of installed equipment throughout the NPP lifetime.

qualified life. Period of time for which satisfactory performance can be verified for a specified set of service conditions.

qualification margin. Difference between the most severe specified service conditions of the plant and the conditions used in qualification to account for normal variations in productions of equipment and reasonable errors in defining satisfactory performance.

service conditions. Environmental, loading, power and signal conditions expected as a result of normal operating requirements, expected extremes (abnormal) in operating requirements and postulated conditions, appropriate for the design basis events of the station.

significant ageing mechanism. Ageing mechanism causing degradation during the equipment's installed life that progressively and appreciably renders the equipment vulnerable to failure during PIE conditions.

traceability. Information or records demonstrating that installed equipment is identical or sufficiently similar to the equipment type that was qualified.

type testing. Tests made on samples of equipment to verify adequacy of design and manufacturing processes.

walkdown. Examination of installed equipment to identify (a) for qualified, equipment differences from the qualified configuration (e.g. abnormal conditions such as missing or loose bolts and covers, exposed wiring or damaged flexible conduits); and (b) for unqualified equipment, its orientation, interfaces, elastomeric materials and nameplate details.

GENERAL NUCLEAR SAFETY RELATED TERMS

acceptance criterion. Specified limit of a functional or condition indicator used to assess the ability of an SSC to perform its design function.

accident (or accident state). State defined under accident conditions or severe accidents.

accident conditions. Deviations from operational states in which the releases of radioactive materials are kept to acceptable limits by appropriate design features. These deviations do not include severe accidents. (A deviation may be a major fuel failure, a loss of coolant accident (LOCA), etc.)

active component. A component whose functioning depends on an external input such as actuation, mechanical movement or supply of power, and which therefore influences the system processes in an active manner. (Examples: pumps, fans, relays and transistors.)

anticipated operational occurrences. Operational processes deviating from normal operation which are expected to occur once or several times during the operating life of the plant and which, in view of appropriate design provisions, do not cause any significant damage to items important to safety nor lead to accident conditions. (Examples: loss of normal electric power and faults such as a turbine trip, malfunction of individual items of a normally running plant, failure to function of individual items of control equipment, loss of power to main coolant pump.)

characteristic. Property or attribute of an SSC. (Examples: shape, dimension, weight, condition indicator, functional indicator, performance, or mechanical, chemical or electrical property).

common cause failure. Failure of a number of devices or components to perform their functions as a result of a single specific event or cause.

component. Discrete item, several of which are used to assemble a system.

configuration management. Integrated management programme that establishes consistency among design requirements, physical configuration and facility documentation and maintains this consistency throughout the life of the facility.

design basis accidents. Accident conditions against which the nuclear power plant is designed according to established design criteria.

design inputs. Criteria, parameters, bases or other requirements upon which the detailed final design is based.

failure. Occurrence where an SSC is unable to function within acceptance criteria.

failure modes and effects analysis. Systematic process for determining and documenting potential failure modes and their effects on systems, structures and components.

item. General term covering materials, parts, components, systems or structures including computer software.

items important to safety. Items which comprise:

(1) structures, systems and components whose malfunction or failure could lead to undue radiation exposure of the site personnel or members of the public;
(2) structures, systems and components which prevent anticipated operational occurrences from leading to accident conditions; and
(3) features which are provided to mitigate the consequences of malfunction or failure of structures, systems or components.

maintenance. Aggregate of direct and supporting actions that detect, preclude or mitigate degradation of a functioning SSC, or restore the design functions of a failed SSC to an acceptable level.

operational conditions. Influences on a system, structure or component from the performance of design functions (operation of a system or component and loading of a structure).

operating basis earthquake. An earthquake which could reasonably be expected to affect the plant site during the operating life of the plant. It is that earthquake which produces the vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

passive component. A component the functioning of which does not depend on external input. It has no moving part and, for example, only experiences a change in pressure, temperature or fluid flow while performing its functions. In addition, certain components which function with very high reliability on the basis of irreversible action or change may be assigned to this category.

postulated initiating events. Events that lead to anticipated operational occurrences or accident conditions and their consequential failure effects. The primary causes of postulated initiating events may be credible equipment failures and operator errors, or person induced or natural events.

records. Documents which furnish objective evidence of the quality of items or services and activities affecting quality.

redundant equipment. An equipment accomplishing the same requested function as other equipment to the extent that either may perform the required function.

regulatory body. National authority or a system of authorities designated by a State, assisted by technical and other advisory bodies, and having the legal authority for conducting the licensing process, issuing licences and thereby regulating nuclear power plant siting, design, construction, commissioning, operation and decommissioning or specific aspects thereof.

reliability. Probability that an SSC will perform its intended functions satisfactorily for a specified time under stated operating conditions.

root cause. Fundamental reason(s) for an observed condition of an SSC that, if corrected, prevent(s) recurrence of the condition.

root cause analysis. Synonym for failure analysis. A systematic process of determining and documenting a root cause of failure of an SSC.

safe shutdown earthquake. An earthquake which produces the maximum vibratory ground motion for which certain structures, systems and components are designed to remain functional.

safety function. Specific purpose that has to be accomplished for safety.

safety related systems. Systems important to safety which are not safety systems.

safety systems. Systems important to safety, provided to ensure the safe shutdown of the reactor or the residual heat removal from the core, or to limit the consequences of anticipated operational occurrences and accident conditions.

safety system support features. Collection of equipment that provides services such as cooling, lubrication and energy supply required by the protection system and the safety actuation systems.

saturation. Thermodynamic state of a condensable gas when the gas temperature equals the saturation temperature based on gas partial pressure.

severe accidents. Nuclear power plant states beyond accident conditions, including those causing significant core degradation.

single failure. Random failure which results in the loss of capability of a component to perform its intended safety functions. Consequential failures resulting from a single random occurrence are considered to be part of the single failure.

source term. A term referring to the magnitude and timing of fission product releases from the reactor during accidents that produce core damage.

superheat. Thermodynamic state of a condensable gas when the gas temperature exceeds saturation temperature based on gas partial pressure.

surveillance. Act of monitoring or observing to verify whether an item or activity conforms to specified requirements.

surveillance testing. Periodic testing to verify that structures, systems and components continue to function or are in a state of readiness to perform their functions.

testing. Determination or verification of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental or operational conditions.

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Technical Committee Meetings

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