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Changing times for equipment qualification

Equipment qualification is intended to ensure that design- and age-related common cause failures will not prevent safety-related equipment from performing its required functions, and that such equipment will operate on demand under normal, abnormal, and design-basis event conditions.

By Lou Jesso

Equipment qualification in the nuclear energy industry has become increasingly scrutinized as older plants seek to extend their operating licenses, modernize difficult-to-maintain systems or components, and address evolving regulatory requirements for severe accident conditions.

Regulatory agencies, industry organizations, and utilities have taken steps to address the impact of aging on nuclear power plant safety-related systems, structures, and components as the number of utilities seeking to renew operating licenses for their plants continues to increase. These same organizations have also taken steps to require and implement more rigorous testing of new equipment and components to comply with later versions of industry standards endorsed by regulatory agencies. In addition, as the use of digital technology has become commonplace in the area of electrical and instrumentation and control systems, equipment qualification considerations for electromagnetic interference and radio frequency interference—also known as electromagnetic compatibility (EMC)—are becoming more important. This is true not only for safety-related electrical and I&C systems, but also for non-safety-related I&C systems that are important for power production.

Regulatory agencies around the world vary in their approach to equipment qualification for normal and abnormal service conditions and design-basis and postulated design-basis events. All regulations and utilities' equipment qualification programs, however, are in general based on industry standards. The most commonly used industry standards that provide qualification requirements are developed by the Institute of Electrical and Electronics Engineers (IEEE) and the International Electrotechnical Commission (IEC). In addition, there are country-specific standards that are similar to IEEE and IEC standards or that endorse these standards. IEEE and IEC have also developed joint standards that can be used globally to ensure consistency in the qualification process. A number of these standards have been endorsed by various regulatory agencies around the world.

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Purpose of qualification

Equipment qualification ensures the continued functionality of safety-related equipment under various conditions. Safety-related equipment in a nuclear power plant is equipment that is required for the performance of safety functions or whose failure under design-basis events would prevent the accomplishment of safety functions. Such equipment is needed for reactor shutdown, reactor cooling/residual heat removal, or minimization of the potential release of radioactive materials. It includes electrical and mechanical equipment, such as sensors that detect temperature, pressure, or radiation; I&C systems; motor control centers; electrical switchgear; and valves, motors, and associated field cables and connectors.

The primary purpose of equipment qualification is to provide reasonable assurance that design- and age-related common cause failures will not prevent safety-related equipment from performing its required function(s) under postulated service conditions. Equipment qualification includes well-maintained, documented evidence that safety-related equipment has been qualified to operate on demand, meeting compulsory functional requirements in normal, abnormal, design-basis, and postulated design-basis event conditions.

Testing considerations

Equipment qualification testing programs consider equipment service conditions under expected operating conditions, postulated conditions for design-basis events, aging of equipment that occurs due to the environment in which it functions during normal operations, and the environment in which the equipment operates. Changes to digital technology have introduced new EMC considerations that were not present when operating plants implemented their original equipment qualification programs but have become important to operating plants weighing license extension and to new plants coming online.

Service conditions

Service conditions include many considerations for equipment qualification: environmental, loading, power, and signal conditions expected during normal operation; expected abnormal extremes in operating requirements; and postulated conditions for design-basis events. Postulated design-basis events are those used during the design of the plant to establish the requirements for the acceptable performance of structures, systems, and components. They include large-break loss-of-coolant accidents, high-energy line breaks, main steam line breaks, and similar events that can cause high-temperature, high-pressure fluid sprays, flooding, or pipe whip. Design-basis events can also be caused by natural phenomena such as an earthquake. Service conditions also in-

Approaches to equipment qualification

As utilities work to extend the operating licenses of their plants, the need to modernize legacy systems or find readily available spares or replacements for obsolete components becomes more important. Regarding plants that are intended for operation 20 or more years beyond their original licenses, the decision must be made between modernizing older systems and components that have become difficult to maintain, and finding alternative sources for equivalent parts that enable them to keep their legacy systems functioning. These efforts include the need to qualify the equipment that will eventually be installed in the plant. Utilities have some options for addressing their equipment qualification needs.

Self-designed replacements

Some utilities may perform qualification of replacement components they design themselves using internal or third-party test facilities. This can be a costly option, since the utility must establish and maintain the design capabilities and test facilities and train personnel to perform these highly specialized functions.

Component suppliers

Most utilities procure replacement parts from equipment and component suppliers. The component suppliers typically qualify and commercially dedicate replacements and even reverse-engineer certain components. While these suppliers are not the original equipment manufacturer, they are able to engineer suitable commercial-grade components as replacement parts for nuclear safety–related applications, qualify the components, and control their procurement and delivery through a commercial-grade dedication process.

There are several methods of commercial-grade dedication. Typically, when performing a commercial-grade dedication of a component, the supplier must identify the critical characteristics that are necessary for the component to perform its nuclear safety function. Once this is done, a sample of the component that satisfies all the criteria for the critical characteristics is subjected to an equipment qualification program. Thereafter, every time that component is procured, it must pass a quality control inspection (and possibly testing) to ensure that the critical characteristics of the procured part meet the same criteria as the qualified part.

This process has allowed the nuclear industry to leverage products from commercial suppliers for use in nuclear safety–related applications. In some instances, the supplier of a safety-related component does not actually design or build components. In this case, the supplier procures a high-quality, commercially available component from a nonnuclear supplier and does all the work (equipment qualification and commercial-grade dedication) to establish the pedigree of the component as a nuclear safety–related item. This relieves the utility of the burden of establishing and maintaining the capabilities of doing that work themselves and the associated cost of maintaining a test facility and the qualified technical personnel that would be needed to support the facility.

Original equipment manufacturers

Companies that are in the nuclear business understand the disciplined approach to equipment qualification testing and development of qualification documentation. Industry standards are a common starting point for global application. Original equipment manufacturers, such as Westinghouse, also understand the differences in various regulatory codes and standards and can design and maintain an equipment qualification testing and documentation program that meets all of the requirements. Considering equipment qualification requirements as part of the equipment design process helps ensure that the equipment meets qualification testing requirements and performs as intended, which minimizes redesign and subsequent retesting efforts. Such companies have the experience and capability to supply qualified components for nuclear safety-related applications, regardless of whether a component was designed and built as a nuclear-grade item or was procured commercially and controlled through a commercial-grade dedication process. This specialty becomes even more important with the introduction of electromagnetic compatibility, which involves many different standards for various types of tests.

clude operating conditions such as self-heating, cycling, process fluid conditions, and electromagnetic interference.

Equipment aging

The aging of systems and components is a potential common cause failure mechanism. It is a particularly significant concern during postulated design-basis events for which service conditions can be substantially different from normal operating conditions.

Equipment qualification testing for the effects of aging typically applies techniques that use accelerated aging methods on test specimens to simulate years of service under the expected operating conditions.

There are practical limitations for simulated aging of test specimens. Since it is not feasible to thermally age a specimen for 20 years at the expected service temperature prior to subjecting it to design-basis event testing, methods must be used to accelerate the aging process. The method commonly used in the industry is based on the Arrhenius equation, in which a property of the organic material known as the activation energy determines how quickly the material will age at a given temperature. The test specimen is subjected to a temperature higher—sometimes much higher—than the expected service conditions it will endure while installed in the plant. Using this technique, it is possible to simulate 20 years of service in a matter of days or weeks. Similarly, when the specimen is subjected to radiation aging, a higher dose rate is applied for a shorter amount of time to simulate the total integrated dose the equipment would receive while in service and during a design-basis event.

Operating environment

The environment in which equipment operates—defined as harsh or mild—and the consideration of seismic events play a large role in determining the required qualification process. Whether the equipment is classified as electrical, electromechanical, or mechanical also influences the qualification process.

If the equipment operates in a harsh environment, then during certain postulated design-basis events, the environmental conditions or operating conditions or both may change significantly from those that occur during normal operation. Significant changes in these conditions create stresses that can be particularly serious if the affected components have experienced in-service degradation—that is, have degraded due to the effects of equipment aging.

Consequently, codes and standards almost universally require that safety-related equipment that operates in a harsh environment has a specified qualified life and must undergo qualification testing to demonstrate its performance under harsh operating environmental conditions. In a harsh operating environment, organic (nonmetallic) materials may be exposed to thermal and/or radiation conditions that cause the material to change over time. These changes may affect the critical properties of the material that are necessary for it to perform its safety function. A qualification program must simulate the effects of prolonged exposure to heat or radiation in order to age the equipment to simulate its being in service for a specified time before subjecting the test specimen to postulated design-basis events.

For accelerated aging of components that are part of a harsh-environment equipment qualification program, the sequence of steps must be carefully defined to ensure that any synergistic effects are considered. Radiation aging is performed after thermal aging so that any damage to the molecular structure of the organic materials from exposure to radiation is not repaired through an annealing process while the specimen is exposed to high temperatures. The simulated age of the test specimen at the time it is tested for the design-basis event is the qualified life of the component.

A mild environment is one that does not change significantly during postulated design-basis events. In a mild environment, the only design-basis event of consequence is a seismic event. Also, since mild environments are not considered to have significant aging mechanisms that would degrade components at an accelerated rate, safety-related equipment operating in mild environments is not required to have an established qualified life. Rather, in lieu of the qualified life, a design life is established. The design life is monitored through surveillance inspections and sustained with periodic maintenance.

Regardless of the operating environment, safety-related equipment that is subject to mechanical or physical cycling—that is, the opening and closing of a relay, or the actuation of a switch—during its operation must be subjected to some number of cycles that represent the number of times it will be cycled during its qualified life or design life, prior to testing for the design-basis event.

Seismic qualification

Seismic qualification of safety-related equipment includes meeting both structural integrity and operability requirements under such conditions. For simple safety-related equipment, seismic qualification can often be done through analysis. For complex safety-related equipment, testing must be performed to show that the equipment meets these requirements under seismic conditions. Mechanical aging is also a consideration in seismic qualification, particularly if the component is subject to prolonged operation or vibration, or if the component is subject to a mechanical change of state that may cause material fatigue of, say, a relay or switch.

Photo: Westinghouse

Temperature and humidity testing is conducted in the mild environmental test chamber, located at Westinghouse's New Stanton, Pa., facility. The company's Nuclear Parts Operations organization is headquartered there, along with the design, engineering, manufacturing, and testing groups of the Global Instrumentation and Controls, Nuclear Fuels, and Field Services organizations, which support the operating fleet and new plant projects.

Optimizing qualified life

Whether utilities are extending a plant's operating license or looking to optimize costs associated with outages, they investigate how to extend the qualified life of components or systems. Some utilities have assembled a very good history of their actual service conditions and have found that the equipment qualification program that established the qualified life of a component assumed more severe service conditions, such as a higher service temperature or pressure, than their plant experiences. When this is the case, utilities may be able to take advantage of these less severe service conditions and extend the qualified life of a component. This, however, may be more complex than changing those numbers in the Arrhenius equation and calculating the new result.

Extrapolating Arrhenius results beyond the original qualified life requires that additional considerations be made. As organic materials age, their properties may change such that at some point in time the materials begin to age at a different rate, which, in effect, may result in a different activation energy value. This approach can work, but how the activation energy was derived for use in the original equipment qualification aging program needs to be understood in order to confirm that it is an appropriate value to use for calculating a longer qualified life.

Changing scenarios

While the science of seismic and environmental qualification has been part of the nuclear industry since the 1970s, the introduction of digital technologies into nuclear power plants has made EMC qualification an equally important part of qualification programs. Microprocessors and digital electronics can be found in sensors, transmitters, and control systems, in components associated with plant electrical systems, and even in some valve controllers. The intelligence and accuracy that these devices provide are a benefit for plant operations, but they also bring a vulnerability to electromagnetic disturbances that can be present in the industrial environment of an operating power plant.

EMC is different from seismic and environmental qualification in that it is not

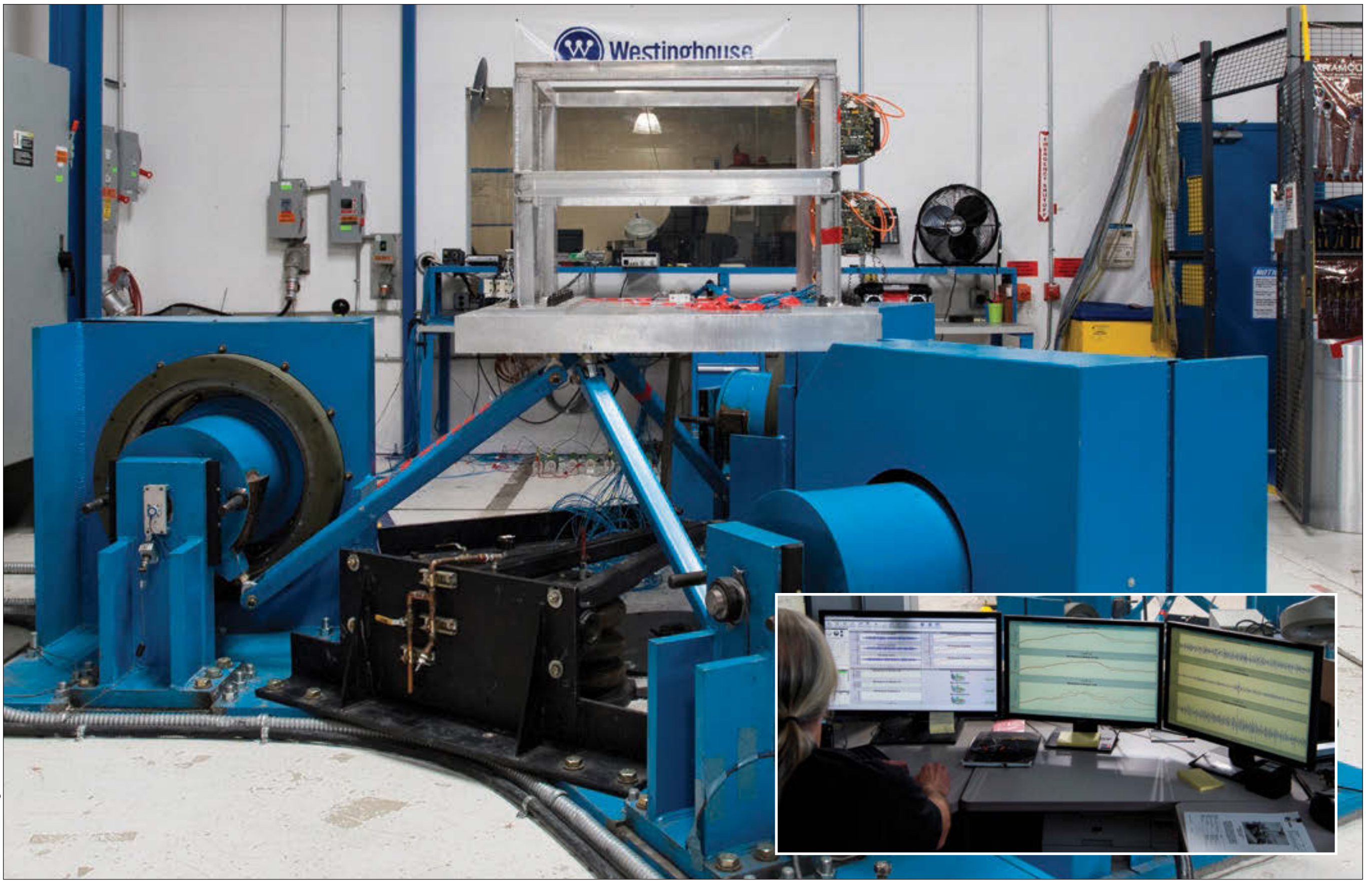

Photo: Westinghouse

Seismic testing services are provided at Westinghouse's New Stanton facility. A test of I&C system circuit boards is in progress (above) on a triaxial seismic shaker table. A technician (inset) monitors the computer system for the table, which takes feedback from accelerometers mounted on the table and controls the large electromagnetic motors to produce the required seismic levels.

associated with a plant design-basis event. EMC is a suite of conditions that can be broadly described as conducted electrical emissions and susceptibility, radiated electrical field emissions and susceptibility, radiated magnetic field emissions and susceptibility, ability to withstand electrical surges, and electrostatic discharge.

While some EMC phenomena, such as electrical surges, may be attributed to random events such as lightning strikes, for the most part, EMC is not so much an event as it is a plant condition that may be present continuously. For example, when large motors are running or large electrical currents are flowing, they may produce magnetic fields and radiated emissions. These emissions are a result of normally functioning plant equipment, not of an abnormal condition or a design-basis event.

Prior to the introduction of digital equipment into nuclear power plants, EMC testing was performed for design verification only. EMC threats were not as significant a concern with analog systems, whose discrete components were sensitive to temperature, and the footprint of printed circuit boards with their numerous soldered connections could be vulnerable in a seismic event.

Today's modern integrated circuit technologies that form the basis of digital electronics designs, with their different sensitivities, have changed this. They are often rated for temperature ranges much greater than what can be expected in mild plant environments, and the compact surface mount designs of circuit cards are more robust in terms of seismic vulnerability. Solid-state relays have replaced electromechanical ones in some designs. EMC is now often the point of greatest vulnerability for digital systems.

In new passive reactors, like the AP1000, the non-safety-related I&C systems that are important to power production have undergone extensive EMC evaluations and testing as a means to help ensure that those systems will perform in the expected EMC environment in which they are installed. This is necessary from a practical plant economics view because unplanned outages or plant trips can cost utilities a significant amount of lost revenue. These same plant economic influences may cause utilities to consider equipment qualification programs for non-safety-related equipment when renewing licenses and replacing older equipment with digital technology.

Digital obsolescence

The pace of digital obsolescence creates a new challenge for utilities that deploy digital equipment in their plants, as well as for the suppliers who provide such equipment. In contrast to legacy electrical equipment—which typically was designed and qualified once—suppliers must continuously evaluate, update, and qualify their digital products to remain technologically current. With the continual progression of digital technologies, equipment qualification may be relevant only for several months before it has to be repeated, unless the supplier has commercial dedication and robust obsolescence management programs. Digital equipment suppliers that have in-house testing capabilities have an advantage in the effort to stay ahead of the obsolescence curve, as they can perform testing and troubleshooting of prototype designs and formally qualify new components quickly and efficiently.

Licensing requirements

Historically, equipment qualification has been associated only with safety-related systems or components, and from a licensing perspective, this is accurate. Non-safety-related equipment typically does not have to meet certain regulatory requirements, but it must not negatively affect any nearby safety-related equipment. Generally, this means that non-safety-related equipment must maintain structural integrity during a seismic

Right: Inside a sealed semi-anechoic chamber, control room components are tested for regulatory compliance and operability. This includes testing for susceptibility to interference from other electrical sources and measuring emissions that could interfere with other electrical or electronic equipment, in accordance with commercial and/or military test standards.

Below: A Westinghouse specialist conducts electromagnetic compatibility surge testing inside a copper-enclosed screen room, which limits the potential for interference with other equipment nearby.

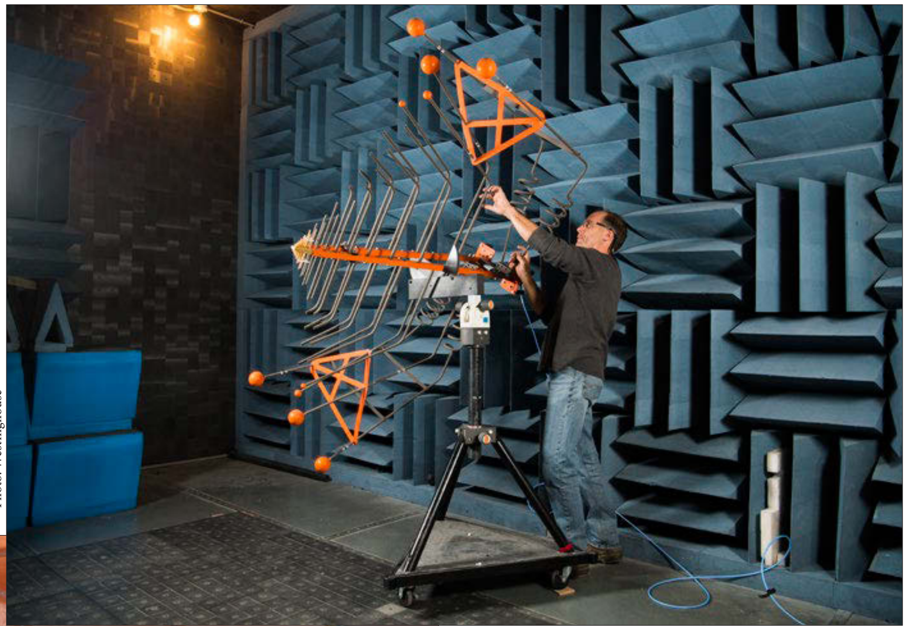

Photo: Westinghouse

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event. Therefore, early plants did not include EMC qualification as part of their licensing basis. Once EMC was considered as part of the plant design, the non-safety-related equipment was most often tested (or evaluated) for emissions only per the licensing requirements. Today, if a safety-related system or component is upgraded with digital technology, the utility and the regulator most often require EMC qualification to ensure that production is not affected, even if the licensing basis for the plant does not require it.

Typical plant modernizations often start with non-safety-related systems or components, for example, a digital upgrade to a turbine control system. Since non-safety-related I&C systems use the same or similar digital technology as safety-related I&C systems, they are vulnerable to the same EMC disturbances. While it may not be a licensing requirement or a nuclear safety consideration to perform EMC qualification testing of non-safety-related equipment, utilities may want such testing to be conducted as a means to better ensure plant availability and operational reliability.

Evolving programs

As more plants seek to renew their operating licenses, whether they are looking to justify extending the qualified life of their equipment and minimize the cost of its replacement or are considering new digital equipment and the associated qualification, regulators are applying more scrutiny.

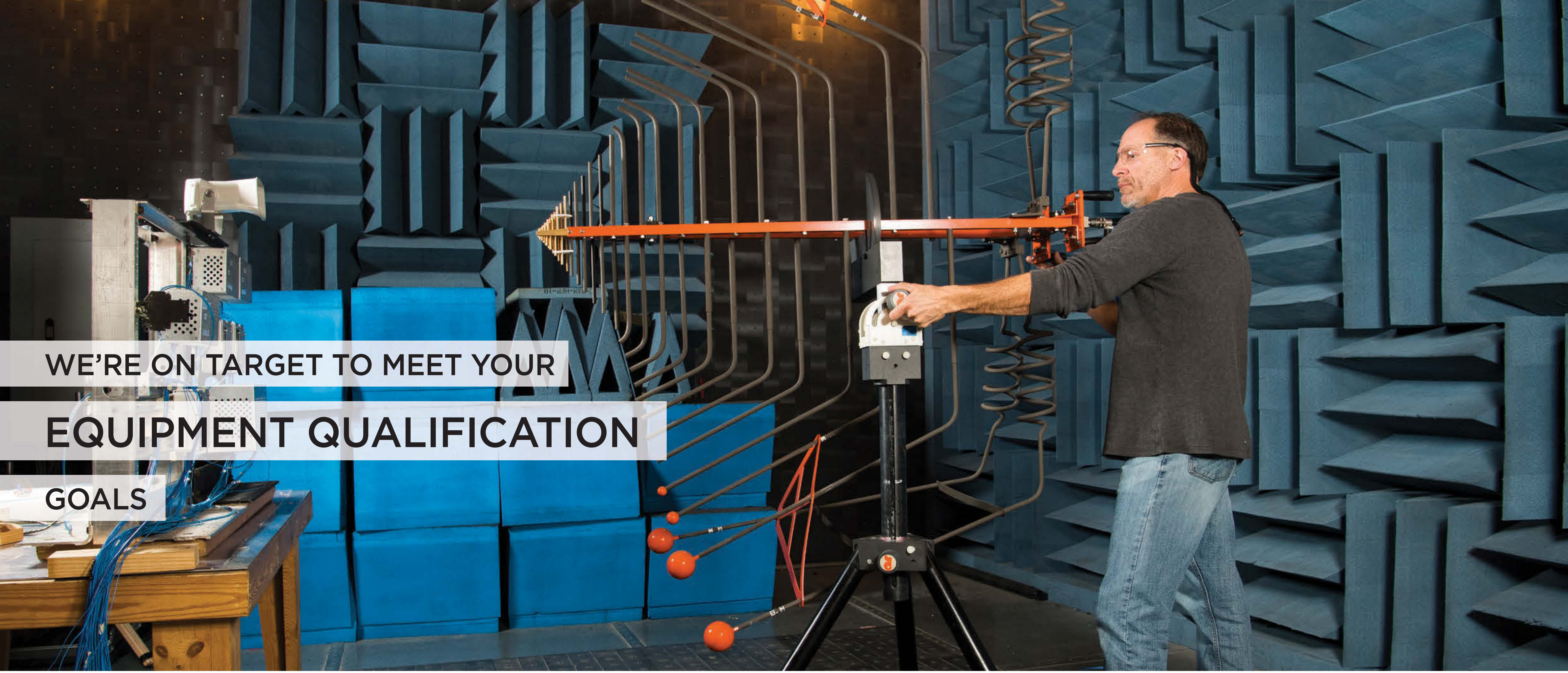
For previously qualified equipment, this includes qualification programs and their associated documentation evidence of safety-related equipment qualification, including how that documentation was maintained throughout the plant life cycle, considering modifications made and potential changes in operating conditions.

Recently, the Nuclear Regulatory Commission has embarked on a series of inspections at various plants, performing reviews of their equipment qualification documentation, including any plant modifications made over many years.

Whether equipment is new or is being updated, or its operating life is being extended, equipment qualification practices that sufficed 20 or 30 years ago may not be adequate today. Regulators are requiring upgraded safety systems for operating plants and new safety systems for new plants to qualify equipment to current versions of codes and standards, especially where digital technologies are involved.

Since the Fukushima Daiichi nuclear power plant event, regulators and licensees alike are considering beyond-design-basis events and taking action to address extended loss of power scenarios. With little or no AC power available for a prolonged period of time, areas of the plant may begin to heat up due to the lack of climate controls. Equipment qualification programs can provide data to help assess how systems or components may perform in such events.

Equipment qualification remains a key element for ensuring nuclear safety. The experiences and evolution of both the nuclear industry and the technologies it utilizes have expanded equipment qualification benefits to include extending qualified lives, assessing performance beyond design-basis accidents, deploying commercial-grade components in safety-related applications, and EMC considerations for safety- and non-safety-related items. Equipment qualification has become more important than ever in both operating and new nuclear power plants. NN



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Westinghouse’s highly skilled global Equipment Qualification team brings more than 450 years of combined experience in full-scope equipment qualification capabilities including engineering, testing and documentation. Our dedicated staff of specialists works in cooperation with our customers and design and licensing groups to qualify new, upgraded, and replacement parts and systems that meet industry guidelines and regulatory requirements worldwide.

Our suite of services includes design, testing, evaluations and life extensions analysis. We have advanced seismic, electromagnetic compatibility and environmental condition in-house testing facilities for one-stop shop service designed to provide the best value for our customers.

Whether you need to qualify upgraded equipment that utilizes existing plant structures or state-of-the-art components and new systems as part of your plant modernization, our expertise and testing facilities can fully support your goals.

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