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GUIDELINES FOR LIGHTNING PROTECTION OF NUCLEAR POWER PLANTS

A. INTRODUCTION

Title 10, Part 50, of the *Code of Federal Regulations* (10 CFR Part 50), "Domestic Licensing of Production and Utilization Facilities," delineates the design- and qualification-related regulations that the U.S. Nuclear Regulatory Commission (NRC) has established for commercial nuclear power plants. In particular, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," set forth in Appendix A to 10 CFR Part 50, requires, in part, that structures, systems, and components (SSCs) that are important to safety in nuclear power plants must be designed to withstand natural phenomena. The design bases for these SSCs must reflect (1) appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for limited data, quantity, and period of time in which the historical data have been accumulated; (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena; and (3) the importance of the safety functions to be performed.

Fast transient overvoltages generated by lightning discharges can cause equipment damage, system malfunctions, or power interruptions at nuclear power generating plants if the plants are not adequately protected against such conditions. However, adequate equipment and system design can greatly reduce or alleviate the adverse consequences of abnormal voltage disturbances. Confirmatory research in support of this observation can be found in NUREG/CR-6866, "Technical Basis for Regulatory Guidance on Lightning Protection in Nuclear Power Plants," dated July 2005.

This regulatory guide offers guidance for NRC licensees and applicants to use in developing and implementing practices that the NRC staff finds acceptable for complying with the agency's regulatory requirements. Specifically, this guidance applies to the design and installation of lightning protection systems (LPSs) to ensure that electrical transients resulting from lightning phenomena do not render safety-related systems inoperable or cause spurious operation of such systems. The scope of the guidance includes protection of (1) the power plant and relevant ancillary facilities, with the boundary beginning at the service entrance of buildings; (2) the plant switchyard; (3) the electrical distribution system, safety-related instrumentation and control (I&C) systems, communications, and personnel within the power plant; and (4) other important equipment in remote ancillary facilities that could impact safety. The scope includes signal lines, communication lines, and power lines, as well as testing and maintenance. The scope does not cover testing and design practices that are specifically intended to protect safety-related I&C systems against the secondary effects of lightning discharges [i.e., low-level power surges and electromagnetic and radio-frequency interference (EMI/RFI)]. These practices are covered in Regulatory Guide 1.180, "Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems." Regulatory Guide 1.180, which the NRC issued in January 2000 and revised in October 2003, addresses design, installation, and testing practices for dealing with the effects of EMI/RFI and power surges on safety-related I&C systems.

The NRC issues regulatory guides to describe to the public methods that the staff considers acceptable for use in implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations, and compliance with regulatory guides is not required.

In general, information provided in regulatory guides is reflected in the NRC's "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (NUREG-0800). The NRC's Office of Nuclear Reactor Regulation uses the Standard Review Plan as guidance in reviewing applications to construct and operate nuclear power plants. This regulatory guide corresponds to the revised Chapter 7, "Instrumentation and Controls," of the Standard Review Plan.

This regulatory guide contains information collections that are covered by the requirements of 10 CFR Part 50 which the Office of Management and Budget (OMB) approved under OMB control number 3150-0011. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number.

B. DISCUSSION

Experience shows that lightning can pose operational threats to nuclear power generating plants. Therefore, protection is essential to avoid malfunctions and upsets that, in turn, can lead to reactor trips. Hence, nuclear power plants should have a well-designed and properly installed LPS to safeguard their SSCs from lightning strikes and the resulting secondary effects. To protect against the effects of lightning strikes, the LPS should incorporate strike termination devices, discharge down conductors, and a grounding system. To protect against the secondary effects of lightning strikes, such as potentially disruptive surges and EMI/RFI that can propagate to internal structures and cause damage to safety-related systems, the LPS should also incorporate appropriate individual equipment grounding systems and surge protection devices (SPDs).

Surge protection measures should include protection of the power plant, ancillary facilities that could impact safety, the switchyard, the electrical distribution system, safety-related I&C systems, and communication systems from both direct lightning strikes and the resulting power surges. SPDs should be applied at the entry and egress points for signal-, communication-, and power-line conductors. They should also be applied to any equipment that is thought to be vulnerable to high-energy surges. The selection of SPDs typically depends on the location of the devices and the size(s) needed to prevent the energy from a lightning strike from impinging a facility or piece of equipment.

Details about LPS design guidelines are available in numerous documents, but the best-known source in use today is the *Standard for the Installation of Lightning Protection Systems*, which the National Fire Protection Association (NFPA) promulgates as NFPA 780-2004. This NFPA standard is the foundational document for use in protecting facilities from direct lightning strikes. Almost all standards that discuss lightning protection reference NFPA 780. Although NFPA 780 gives well-founded guidance on lightning protection, it has a disclaimer concerning electric power generation facilities:

> Electric generating facilities whose primary purpose is to generate electric power are excluded from this standard with regard to generation, transmission, and distribution of power. Most electrical utilities have standards covering the protection of their facilities and equipment. Installations not directly related to those areas and structures housing such installations can be protected against lightning by the provisions of this standard.

A second source of well-founded information about LPS installation practices is *Installation Requirements for Lightning Protection Systems*, which Underwriters Laboratories (UL) promulgates as UL 96A-2001. UL 96A contains requirements that cover the installation of LPSs on all types of structures and applies to LPSs that are complete and cover all parts of the structure. However, like NFPA 780, UL 96A has a disclaimer for electric power facilities:

> These requirements do not cover the installation of lightning protection systems for electrical generating, distribution, or transmission systems.

Because of the exclusion of electric power generation facilities by NFPA 780 and UL 96A, the NRC staff has chosen to endorse other equivalent standards that directly apply to nuclear power plants. However, the staff has used NFPA 780 and UL 96A as a basis to guide the identification of those other standards. As a result, the NRC staff has selected for endorsement a total of four standards issued by the Institute of Electrical and Electronics Engineers (IEEE), which taken together, provide comprehensive lightning protection guidance for nuclear power plants. Specifically, the four standards are IEEE Std. 665-1995 (reaffirmed 2001), *IEEE Guide for Generating Station Grounding*, IEEE Std. 666-1991 (reaffirmed 1996), *IEEE Design Guide for Electrical Power Service Systems for Generating Stations,* IEEE Std. 1050-1996, *IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations*, and IEEE Std. C62.23-1995 (reaffirmed 2001), *IEEE Application Guide for Surge Protection of Electric Generating Plants.*

IEEE Std. 665-1995 (reaffirmed 2001) describes facility grounding practices and serves as the primary source of guidance on lightning protection for structures at power generating stations. As such, this standard identifies the grounding practices that the electric utility industry has generally accepted as contributing to effective grounding systems for personnel safety and equipment protection in generating stations. This standard also provides guidance for the design of generating station grounding systems and grounding practices applied to generating station indoor and outdoor structures and equipment.

IEEE Std. 666-1991 (reaffirmed 1996) describes grounding practices for neutral grounding and grounding methods for medium-voltage equipment. As such, this standard is a design guide intended for application to generating station service systems that supply electric power to auxiliary equipment. This design guide applies to all types of generating stations that produce electric power, and is particularly applicable to stations in which the electric power service system is required to perform continuously. Such a service system consists of a main auxiliary power distribution network that might supply many subsystems (including direct current systems and Class 1E power systems), much of which is medium-voltage (2.4–13.8 kV) equipment. This standard addresses recommendations for neutral grounding, as well as the grounding of generating station auxiliaries. It also covers grounding methods for both low-voltage (120–480 V) and medium-voltage power service systems. (The low-voltage grounding methods parallel similar guidance in IEEE Std. 665.) In addition, this standard covers surge protection of transformers, switchgear, and motors, paralleling similar guidance in IEEE Std. C62.23.

IEEE Std. 1050-1996 describes design and installation practices regarding grounding methods for generating station I&C equipment. As such, this standard recommends grounding methods for I&C equipment to achieve a suitable level of protection for personnel and equipment, as well as suitable noise immunity for signal-ground references in generating stations. IEEE Std. 1050-1996 is comprehensive, in that it covers both theoretical and practical aspects of grounding and noise minimization.

IEEE Std. C62.23-1995 (reaffirmed 2001) describes surge protection application practices applicable to power generating stations. As such, this standard consolidates many electric utility industry practices, accepted theories, existing standards/guides, definitions, and technical references as they specifically pertain to surge protection in electric power generating plants. This standard also provides information on proper surge protection techniques and interference reduction practices for communication, control, and protection circuits.

IEEE Std. C62.23 also covers the protection of transmission lines from direct lightning strikes (using overhead ground wires, tower footing resistance, counterpoise wires, and surge arresters on transmission lines); protection of distribution lines from direct lightning strikes, switching surges, and ferroresonance; and the selection of arrestors for distribution lines. In addition, this standard covers the protection of switchyard equipment from direct lightning strikes (using overhead wires or masts), protection from incoming surges on the transmission line, protection of directly connected switchyard equipment (using surge arrestors), protection from internally generated switching surges, and protection of control and communication circuits in the switchyard.

IEEE Std. C62.23 also covers the protection of both indoor and outdoor equipment (including transformers, motors, switchgear, etc.) from direct lightning strikes, incoming surges, internally generated surges, and ground potential rises. It also covers the protection of control and communication circuits and discusses the beneficial effects of shielding, grounding, and cable routing in the power plant buildings. In addition, the standard covers the protection of remote ancillary facilities, dealing primarily with protection from direct lighting strikes and the surges induced on underground cables.

The four primary standards selected for endorsement contain numerous references to other secondary standards that can clarify their information. As a result, the applicable portions of those secondary standards are included in the NRC's endorsement of the four primary standards. Table 1 lists the secondary standards referenced in the recommended primary standards.

Table 1. Secondary Standards Referenced in the Primary Standards Endorsed

Standard Number	Standard Title
IEEE Std. 80-2000	IEEE Guide for Safety in AC Substation Grounding (ANSI)
IEEE Std. 81-1983	IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System (ANSI)
IEEE Std. 81.2-1991	IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems
IEEE Std. 142-1991	IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book)
IEEE Std. 367-1996	IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault (ANSI)
IEEE Std. 487-2000	IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations (ANSI)
IEEE Std. 1100-1999	IEEE Recommended Practice for Powering and Grounding Electronic Equipment (IEEE Emerald Book) (ANSI)
IEEE Std. C37.101-1993	IEEE Guide for Generator Ground Protection (ANSI)
IEEE Std. C57.13.3-1983 (reaffirmed 1990)	IEEE Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases (ANSI)
IEEE Std. C62.92.1-2000	IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part I-Introduction (ANSI)
IEEE Std. C62.92.2-1989 (reaffirmed 2001)	IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part II-Grounding of Synchronous Generator Systems (ANSI)
IEEE Std. C62.92.3-1993 (reaffirmed 2000)	IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part III-Generator Auxiliary Systems (ANSI)
IEEE Std. C62.41.1-2002	IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits (ANSI)
IEEE Std. C62.41.2-2002	IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits (ANSI)
IEEE Std. C62.45-2002	IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits (ANSI)

The only omission in the principal lightning protection standards is concise coverage of testing and maintenance practices. The IEEE standards selected for endorsement refer to other standards that routinely cite specific practices, but none of those standards solely provide comprehensive guidance for testing and maintenance. Annex D, "Inspection and Maintenance of Lightning Protection Systems," and Section B.4 of Annex B, "Principles of Lightning Protection," to NFPA 780 do discuss a compilation of reasonable practices; however, they are not part of the NFPA 780 requirements and are included in the document for informational purposes only. Hence, although the NRC staff has not selected NFPA 780 for endorsement in this guide, the staff acknowledges that Annexes B and D to NFPA 780 can serve as good references for comprehensive testing and maintenance practices.

Section C of this regulatory guide (below) provides specific regulatory positions based on the four endorsed IEEE standards and suggested testing and maintenance practices. The scope of the NRC staff's regulatory positions includes protection of (1) the power plant, plant switchyard, and relevant ancillary facilities; (2) the electrical distribution system, safety-related I&C systems, communications, and personnel within the power plant; and (3) other important equipment in remote ancillary facilities that could impact safety. The scope also includes the protection of signal lines, communication lines, and power lines interfacing with the power plant systems. In addition, the scope includes the testing and maintenance of LPSs.

The scope does not include the protection of high-voltage power lines. In addition, the scope does not cover the testing practices intended to protect safety-related I&C systems against the secondary effects of lightning discharges (i.e., low-level power surges and EMI/RFI), as those practices are covered in Regulatory Guide 1.180, "Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems."

In general, non-safety-related equipment does not fall under the guidelines presented in this regulatory guide, but non-safety-related equipment is included if its failure can impact the function and performance of safety-related equipment. Lightning protection is also recommended for this type of non-safety-related equipment.

Alternative lightning protection methods — including lightning rods with radioactive tips, early streamer emission lightning rods, and lightning prevention devices — have been considered during the periodic review and revision of the endorsed industry standards. However, to date, none of the endorsed standards have adopted the alternative methods. The perception is that the claimed performance for such methods has yet to be validated because the methods are proprietary and detailed design information is not publicly available. Flexibility is built into the regulatory process and, to the extent that alternative methods are incorporated into the endorsed industry standards in the future, they will be reviewed and considered for acceptance by the NRC staff.

C. REGULATORY POSITION

1. Lightning Protection System Design and Installation

The NRC staff has selected for endorsement a total of four IEEE standards, including IEEE Std. 665-1995 (reaffirmed 2001), *IEEE Guide for Generating Station Grounding*, IEEE Std. 666-1991 (reaffirmed 1996), *IEEE Design Guide for Electrical Power Service Systems for Generating Stations,* IEEE Std. 1050-1996, *IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations*, and IEEE Std. C62.23-1995 (reaffirmed 2001), *IEEE Application Guide for Surge Protection of Electric Generating Plants.* The staff finds that the practices in these four standards are acceptable for the design and installation of LPSs in nuclear power plants.

The selected IEEE standards are endorsed in their entirety by the NRC staff, with one exception to IEEE Std. 665-1995. Specifically, Section 5.7.4 misquotes subclause 4.2.4 of IEEE Std. 142-1991, *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*, as stating "concrete below ground level is a semiconducting medium of about 30 Ω-cm resistivity." However, the proper reference is subclause 4.2.3, and the resistivity of concrete under the stated conditions should be listed as about 3000 Ω-cm.

The endorsed IEEE standards reference numerous other standards that contain complementary and supplementary information. Thus, as specified in Table 1, the NRC staff also endorses the portions of the referenced standards that are cited in the endorsed standards; those cited portions are to be used in a manner that is consistent with the practices in the endorsed standards. Taken together, the combination of standards provides comprehensive and acceptable guidance for the design and installation of LPSs at nuclear power generating stations.

2. Testing and Maintenance of Lightning Protection Systems

The following practices form the basis for an adequate and acceptable testing and maintenance approach to confirm the proper installation of an LPS and ensure its continued ability to provide the level of protection for which it was designed:

- All new LPSs should be inspected following installation, and the systems should be inspected on a regular, periodic basis throughout their lifetime. In particular, an LPS should be inspected whenever any alterations or repairs are made to a protected structure, as well as following any known lightning transient to the system. An LPS should be visually inspected at least annually. In areas where severe climatic changes occur, it is advisable to inspect the LPS semiannually or following extreme changes in ambient temperature. The NRC staff also recommends completing an in-depth inspection of the LPS every 3–5 years.
- Testing and maintenance procedures should be established for each LPS. The frequency of testing and maintenance will depend on weather-related degradation of protective features, frequency and severity of damage attributable to lightning transients, and required protection level. Also, an LPS testing and maintenance program should include (1) inspection of all conductors and system components, (2) tightening of all clamps and splicers, (3) measurement of the earth grounding resistance, (4) measurement of the resistance of ground terminals, (5) inspection or testing (or both) of SPDs to assess their effectiveness, (6) periodic testing and maintenance of earth grounding systems, (7) refastening and tightening of components and conductors as required, (8) inspection and testing when the LPS has been altered by additions to, or changes in, the structure, and (9) complete records.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide. This guide applies to new plants and no backfitting is intended or approved in connection with its issuance. Except in those cases in which an applicant or licensee proposes or has previously established an acceptable alternative method for complying with specified portions of the NRC's regulations, the methods described in this guide will be used in evaluating (1) submittals in connection with applications for construction permits, design certifications, operating licenses, and combined licenses, and (2) submittals from operating reactor licensees who voluntarily propose to initiate system modifications that have a clear nexus with this guidance. An LPS can be a built-in design feature associated with a component or system, or a separate dedicated protection system, as discussed in this guide.

BIBLIOGRAPHY

NUREG/CR-6866, P.D. Ewing, et al., "Technical Basis for Regulatory Guidance on Lightning Protection in Nuclear Power Plants," USNRC, July 2005.[1]

Regulatory Guide 1.180, "Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems," USNRC, January 2000, revised October 2003.[1]

NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Revision 4, USNRC, June 1997.[1]

NFPA 780-2004, *Standard for the Installation of Lightning Protection Systems,* National Fire Protection Association, 2004.[2]

UL 96A-2001, *Installation Requirements for Lightning Protection Systems*, Underwriters Laboratories, 2001.[3]

IEEE Std. 665-1995 (reaffirmed 2001), *IEEE Guide for Generating Station Grounding*, Institute of Electrical and Electronics Engineers, 1995.[4]

IEEE Std. 142-1991, *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*, Institute of Electrical and Electronics Engineers, 1991.[4]

IEEE Std. 666-1991(reaffirmed 1996), *IEEE Design Guide for Electrical Power Service Systems for Generating Stations*, Institute of Electrical and Electronics Engineers, 1991.[4]

IEEE Std. 1050-1996, *IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations*, Institute of Electrical and Electronics Engineers, 1996.[4]

IEEE Std. C62.23-1995 (reaffirmed 2001), *IEEE Application Guide for Surge Protection of Electric Generating Plants*, Institute of Electrical and Electronics Engineers, 1995.[4]

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[1] Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 [telephone (202) 512-1800], or from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161 [http://www.ntis.gov, telephone (703) 487-4650]. Copies are available for inspection or copying for a fee from the NRC's Public Document Room (PDR), which is located at 11555 Rockville Pike, Rockville, Maryland; the PDR's mailing address is USNRC PDR, Washington, DC 20555-0001. The PDR can also be reached by telephone at (301) 415-4737 or (800) 397-4205, by fax at (301) 415-3548, and by email to PDR@nrc.gov.

[2] NFPA documents may be purchased from the National Fire Protection Association, which is located at 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101.

[3] UL documents may be purchased from Underwriters Laboratories, which is located at 320 37th Avenue, St. Charles, IL 60174.

[4] IEEE publications may be purchased from the IEEE Service Center, which is located at 445 Hoes Lane, Piscataway, NJ 08855.

REGULATORY ANALYSIS

1. Problem

Title 10, Part 50, of the *Code of Federal Regulations* (10 CFR Part 50), "Domestic Licensing of Production and Utilization Facilities," delineates the design- and qualification-related regulations that the U.S. Nuclear Regulatory Commission (NRC) has established for commercial nuclear power plants. In particular, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," set forth in Appendix A to 10 CFR Part 50, requires, in part, that structures, systems, and components (SSCs) that are important to safety in nuclear power plants must be designed to withstand natural phenomena. The design bases for these SSCs must reflect (1) appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated; (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena; and (3) the importance of the safety functions to be performed.

While these regulations address lightning protection for safety-related electrical equipment, they do not explicitly provide guidance concerning the design and installation of lightning protection systems (LPSs) to ensure that electrical transients resulting from lightning phenomena do not render safety-related systems inoperable or cause spurious operation of such systems. The best-known source in use today is the *Standard for the Installation of Lightning Protection Systems*, which the National Fire Protection Association (NFPA) promulgates as NFPA 780-2004. This NFPA standard is the foundational document for use in protecting facilities from direct lightning strikes. Almost all standards that discuss lightning protection reference NFPA 780. However, although NFPA 780 gives well-founded guidance on lightning protection, it contains a disclaimer that electric power generation facilities are excluded from its guidance. Hence, there is a need to develop regulatory guidance on lightning protection specifically for nuclear power generating plants.

2. Alternative Approaches

The NRC staff considered two alternative approaches to address the problem identified above:

(1) Take no action.
(2) Develop guidance with a sound technical basis.

The first alternative, "take no action," requires no additional cost (compared to current conditions) for either the staff or applicants, because the current process will not change. However, the process of establishing lightning protection for safety-related systems may involve significant effort on the part of applicants and licensees to anticipate the type and level of evidence that is acceptable to the staff to demonstrate compatibility of equipment in response to these phenomena. In addition, the NRC staff's review may require considerable effort to evaluate submitted approaches, and the staff will have to handle reviews on a case-by-case basis.

The second alternative is to "develop guidance with a sound technical basis." This alternative would reduce the level of effort associated with each application for both the staff and applicants (compared to that associated with Alternative 1). This is because systematic staff review and endorsement of current standards and up-front resolution of open issues allow a more effective use of resources than an ad hoc, case-by-case method of handling lightning protection issues. The result of this alternative would be a complete guide on acceptable lightning protection practices.

3. Values and Impacts

The NRC staff currently performs case-by-case license reviews related to lightning protection of safety-related systems. Consequently, the staff developed a regulatory guide to endorse acceptable engineering practices for complying with the NRC's related regulatory requirements. The value of this approach is that a regulatory guide offers clear guidance on practices that enhance the safety of the nuclear power plants.

This guidance is consistent with current established practices applied throughout the commercial power industry. Therefore, costs associated with implementing this guidance are expected to be minimal. This guidance would apply to new nuclear power plants.