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Design of Nuclear Facilities

NRRC-R-06 Rev. 0.1

2024

هيئة الرقابة النووية والإشعاعية
Nuclear and Radiological Regulatory Commission

Design of Nuclear Facilities

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Regulation

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Preamble

In accordance with the provisions of the Law of Nuclear and Radiological Control issued by Royal Decree No. (M/82) dated 25/7/1439 AH, and NRRC's Statute issued by the Ministers' Cabinet Resolution No. (334) dated 25/6/1439 AH, the NRRC prepared regulations that ensure control over radiological activities and practices as well as nuclear and radiological facilities.

This regulation has been prepared on the basis of International Atomic Energy Agency (IAEA) standards, international best practices, and in accordance with the Kingdom's international commitments. This regulation has been presented in "the Public Consultation Platform" for the public review, comments, and feedback.

This regulation has been approved by the NRRC's Board of Directors Resolution No. (R/1/1/2022) dated 20/04/2022.

This edition, NRRC-R-06 Rev. 0.1 (2024), of the regulation is revised and takes precedence over the previous publication, NRRC-R-06 (2022). In addition, the changes within this revision are editorial.

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Chapter 1: Objective, Scope, and Definitions

Section 1: Objective

1. The objective of this regulation is to establish, based on international recommendations and best practices, the nuclear safety-related regulatory requirements for the design of nuclear facilities, which form the foundation for a high safety and security level throughout the lifetime of the nuclear facility.

Section 2: Scope

2. This regulation applies to the design of nuclear facilities and items important to safety throughout the lifetime of the nuclear facility, with an emphasis on the design of new nuclear facilities. All requirements apply directly to nuclear power plants and other types of nuclear facilities, except for the reactor-oriented terminology that may need to be replaced by equivalent terminology to cover the main purpose of a specific requirement.

3. The regulation establishes the responsibilities and requirements for managing the design efforts and for preparing the final design itself, from the overall design of the nuclear facility down to structures, systems, and components. The provided requirements are intended to be applied to all such items that are important for the nuclear facility to fulfill the applicable safety requirements.

4. The requirements of this regulation apply as such to an applicant for, or a holder of, a construction or operating license (the licensee) and to an appropriate extent to a supplier of the nuclear facility or its major parts (vendor), suppliers of products (suppliers), and designers of items important to safety (designers).

5. This regulation focuses on the design of a nuclear facility and is supplemented by the following regulations covering licensing, management, siting, safety assessment, construction, and operation aspects:

a. Regulation on Licensing and Regulatory Oversight of Nuclear Facilities (NRRC-R-03 Rev. 0.1);

b. Regulation on Leadership and Management for Safety (NRRC-R-04 Rev. 0.1);

c. Regulation on Site Evaluation of Nuclear Facilities (NRRC-R-05 Rev. 0.1);

d. Regulation on Safety Assessment of Nuclear Facilities (NRRC-R-07 Rev. 0.1);

e. Regulation on Construction and Commissioning of Nuclear Facilities (NRRC-R-08 Rev. 0.1);

f. Regulation on Operations of Nuclear Facilities (NRRC-R-09 Rev. 0.1).

Section 3: Definitions

Controlled state

A state of the nuclear facility, following an anticipated operational occurrence or accident conditions, in which the fundamental objectives of safety functions have been achieved and which can be maintained for a time sufficient to implement provisions to reach a safe state.

Item important to safety

A structure, system, or component (i.e., an item) that is part of a safety function and/or whose malfunction or failure could lead to radiation exposure of the site personnel or members of the public.

Safe state

A state of the nuclear facility, following an anticipated operational occurrence or accident conditions, in which the reactor is subcritical, and the fundamental safety functions can be ensured and maintained stable for a long time.

Safety function

A specific purpose that must be accomplished for the safety of a nuclear facility or related activity to prevent or to mitigate radiological consequences of normal operation, anticipated operational occurrences and accident conditions.

Safety system

A system important to safety, provided to ensure the safe shutdown of the reactor or the residual heat removal from the reactor core, or to limit the consequences of anticipated operational occurrences and design basis accidents.

Chapter 2: Management of Safety in Design

Section 4: Organization

6. An applicant for, or holder of, a license for constructing or operating a nuclear facility shall be responsible for ensuring that the design of the facility fulfills all applicable safety requirements and for approving the final design.

7. The design organization shall establish and implement a management system to ensure that all established requirements for the nuclear facility design are considered and implemented in all phases of the design process and met in the final design.

8. The operating organization shall establish a management system and the necessary expertise to ensure the continuing safety of the design solutions throughout the lifetime of the nuclear facility, including a formally designated entity responsible for the safety of the facility design.

Section 5: Design Process

9. A systematic design process shall be established to ensure the quality of the design of each structure, system, and component, as well as the safety of the overall design of the nuclear facility. All organizations engaged in the design of a nuclear facility shall give safety matters the highest priority.

10. All applicable requirements shall be specified for the design, and the final design shall be validated and assessed against the requirements. Each design phase shall be based on a complete set of specifications, which will be completed by verifying and reviewing the design against the specifications. Individuals or teams not participating in the design work shall be engaged to examine the design at an appropriate level of detail to ensure sufficient quality assurance for items important to safety.

11. All interfaces with responsible vendors, suppliers, and designers engaged in design work shall be identified and controlled. The design shall be carefully documented, the design changes assessed and formally approved in accordance with the management system, and the configuration control throughout the design process and the lifetime of the nuclear facility.

Section 6: Design Assessments

12. A comprehensive set of design assessments in the form of deterministic safety analysis, probabilistic risk assessment, and design reviews and analyses shall be carried out throughout the design and construction of a nuclear facility to ensure that all applicable safety requirements are met in the final design as stipulated in Regulation on Safety Assessment of Nuclear Facilities (NRRC-R-07 Rev. 0.1).

13. The design assessments shall be reviewed and revised, as appropriate, when making design modifications to ensure that the design solutions meet the applicable safety requirements.

Chapter 3: Safety Objectives

Section 7: Defense-in-Depth

14. The design of a nuclear facility shall incorporate the principle of defense-in-depth in both the structural and functional characteristics of the facility. The defense-in-depth principle shall be applied structurally to physical barriers preventing radioactive releases and functionally to safety functions protecting the integrity

and leak tightness of the physical release barriers. The primary objective shall be to prevent accidents and, if unsuccessful, to manage accidents and mitigate their consequences.

15. The necessary number of defense levels for a nuclear facility during a specific mode of operation shall be justified based on the amount of radioactive materials involved, the consequences of the potentially most severe release scenario, and the effectiveness of physical barriers and protective safety features incorporated in the design. For the justification, five levels of defense shall be considered as the general design principle:

    a. The purpose of the first level of defense is to prevent deviations from nominal operational conditions and failures of items important to safety;

    b. The purpose of the second level of defense is to detect and control deviations from normal operation to prevent such an anticipated operational occurrence from escalating to accident conditions;

    c. The purpose of the third level of defense is to prevent fuel, reactor core, or other radiologically significant facility damage in an accident that develops due to the preceding levels, although very unlikely, not being effective;

    d. The purpose of the fourth level of defense is to mitigate the consequences of severe accidents that result, although extremely unlikely, from a failure of the third level leading to severe damage and a subsequent release of radioactive materials to the reactor containment or other confinement areas;

    e. The purpose of the fifth and final level of defense is to further mitigate the radiological consequences of environmental radioactive releases with the provision of emergency response measures.

16. The levels of defense in a nuclear facility shall be independent as far as practicable to prevent a coincidental or consequential loss of several defense levels in or following any facility state resulting from the loss of one defense level. Facility states that could lead to high radiation doses or an early or large radioactive release shall be shown to be extremely unlikely with such a high level of confidence that they can be considered eliminated by design.

Section 8: Safety Functions

17. A nuclear facility shall be designed with safety functions ensuring the safety of the facility under all facility states, as consistent with the defense-in-depth principle.

18. The safety functions are performed by structure, systems, and components. The safety functions of the nuclear facility shall fulfill the following fundamental objectives as applicable to the specific facility:

    a. Control of reactivity;

    b. Removal of heat from the reactor and fuel storage;

    c. Confinement of radioactive material, shielding against radiation, control of planned radioactive releases, and limitation of accidental radioactive releases.

19. The safety functions performed by a specific item shall be categorized with respect to their importance for the defense-in-depth principle and the fundamental safety function objectives to form the basis for determining their safety significance and the safety class of items important to safety.

20. All items required to fulfill the objective of a specific safety function in, and following, a facility state, or that could prevent this safety function from accomplishing its task shall be considered of a principally equal safety significance and treated as such.

21. Safety functions shall accomplish their fundamental objectives for the most part without human intervention, which may be relied on only after a sufficient grace period for a limited set of instructed and trained operator actions required to reach and maintain a controlled state and for reaching and maintaining a safe state.

Section 9: Safe Operation

22. The design for a nuclear facility shall establish the design features, operational procedures, and operator training that enable the facility to be operated and monitored safely for the entire duration of its design life.

23. Operational limits and conditions shall be specified for all operational states of the nuclear facility to ensure safe operations in accordance with the facility design and design assessments.

24. Thorough procedures shall be established for the operating organization to assess, prepare for, and perform a recovery from a facility state outside the specified operational limits and conditions of a nuclear facility.

Section 10: Safety Criteria

25. The design of a nuclear facility shall ensure that radiation doses to workers at the facility and to members of the public are kept as low as reasonably achievable (ALARA) for the entire lifetime of the facility and that doses to workers and members of the public can be limited as stipulated in Regulation on Radiation Safety (NRRC-R-01 Rev. 0.1).

26. Concerning all nuclear facilities that could affect members of the public, including the combined effect of several facilities, the potential radiological impact and off-site emergency actions shall be limited as follows for the different facility states:

    a. Normal operation shall cause only a negligible radiological impact beyond the immediate vicinity of the facility;

b. An anticipated operational occurrence shall not cause an effective individual dose exceeding the general radiation protection limits;

c. A design basis accident shall cause only a minor radiological impact beyond the immediate vicinity of the facility and shall not require off-site emergency actions to be carried out; and

d. A severe accident may only cause off-site emergency actions limited in area and time.

27. The potential operational and accident effects on the physical barriers of a nuclear facility shall be limited in accordance with the defense-in-depth principle. During operation, only minor leakages may occur, and in accidents, the leak tightness and integrity of the physical barriers shall be protected to meet the limits concerning radiological impact and off-site emergency actions.

28. The design of a nuclear facility shall avoid potential cliff-edge effects. The design assessments shall provide an assurance that adequate safety margins are available to avoid cliff-edge effects and to take account of the uncertainties associated with the characteristics of each facility state, the response of the facility, the performance of the safety functions, the behavior of the physical barriers, and the estimated consequences from the perspective of the safety criteria.

Chapter 4: Design Basis

Section 11: Facility States

29. The design of the nuclear facility shall apply a systematic approach to identifying a comprehensive set of facility states such that all foreseeable conditions are anticipated and considered in the design.

30. Facility states consisting of operational states and accident conditions shall be identified and grouped into a limited number of categories based primarily on their frequency of occurrence.

31. Operational states shall consist of:

    a. All phases of normal operational modes that are operated, monitored, and controlled so as not to deviate significantly from nominal operational conditions; and

    b. Anticipated operational occurrences that may be expected to occur at least once during the lifetime of the facility and may require safety function activation to prevent a significant threat to the integrity of any physical release barrier.

32. Accident conditions shall consist of:

    a. Design basis accidents resulting from failures of structures, systems, or components causing a major departure from a normal operational state and requiring safety system activation to protect the integrity of one or several physical barriers; and

    b. Severe accidents leading to extensive degradation of fuel elements in the reactor core or in the fuel storage, the consequences of which shall be mitigated to prevent large releases of radioactive material into the environment.

33. The design assessments of a nuclear facility shall identify the initiating events that fall under different facility states and that shall be analyzed to determine the facility response and the fulfillment of safety criteria. All foreseeable events with potentially significant consequences or a potentially significant frequency of occurrence shall be anticipated and considered in the design.

Section 12: Safety Features and Systems

34. Inherent or engineered safety features of the nuclear facility shall be capable of preventing, controlling, or mitigating anticipated operational occurrences and accident conditions to meet the safety criteria, reach a controlled state, and enable a stable and safe state to be reached and maintained after an initiating event.

35. Dedicated safety systems shall be designed to protect the safety of the nuclear facility and to reach a controlled state in anticipated operational occurrences and design basis accidents. Each unit of a multi-unit nuclear facility shall have its own safety systems designed and demonstrated to fulfill the highest level of design and safety requirements.

36. Each safety system shall withstand a single failure without losing its intended function. Maintenance, repair, and other outage times shall be taken into account appropriately. Interference between redundant elements of a safety system shall be prevented by means such as physical separation, functional independence, electrical isolation, and independence of communication, as appropriate.

37. The design of a nuclear facility shall take due account of the potential for common cause failures of safety systems and other items important to safety to determine how the concepts of diversity, independence, and separation are applied to achieve the necessary reliability for safety functions needed in, and following, different facility states including the design extension conditions caused by common cause failures of safety systems.

Section 13: Design Extension

38. Design extension conditions resulting from failures and hazards beyond those assumed for anticipated operational occurrences and design basis accidents shall be identified based on design assessments, and they shall be included in the design of the nuclear facility as accident conditions.

39. The design extension conditions of a nuclear facility shall be managed using dedicated safety features and measures wherever necessary to prevent unacceptable consequences. The applied criteria shall be justified as consistent and commensurate with the safety criteria applied to other accident conditions.

Section 14: Internal and External Hazards

40. All foreseeable internal and external hazards, including the potential for human-induced events that directly or indirectly affect the safety of the nuclear facility, shall be identified, and their effects shall be evaluated to ensure adequate prevention, protection, and mitigation.

41. The effects of internal and external hazards shall be incorporated in designing the layout and buildings of the nuclear facility, in determining the facility states and initiating events of the design assessments, and in specifying the loadings for items important to safety.

42. For sites with multiple nuclear facilities, the effects of external events on all facilities, shared resources or common functions, concurrent events affecting different facilities, and the potential hazards presented by each facility and related activities to the others shall be considered in the design.

Chapter 5: General Design Requirements

Section 15: Items Important to Safety

43. All items important to safety shall be identified and classified based on their safety significance from both structural integrity and a functional operation perspective. Such grading shall be used as a basis for establishing different levels of quality assurance and safety demonstration for items differing in their importance for the defense-in-depth and the fundamental safety function objectives.

44. The design of items important to safety shall specify the necessary functionality, capability, integrity, and reliability, as well as the design limits consistent with the key physical parameters for the relevant operational states, accident conditions, and internal and external hazards.

45. The design shall be such as to ensure that any interference between items important to safety will be prevented, and in particular, that any failure of items

important to safety in a system in a lower safety class will not propagate to a system in a higher safety class.

46. A qualification program for items important to safety shall be implemented to verify that items important to safety at a nuclear facility can perform their intended functions, when necessary, in the prevailing environmental and other relevant conditions throughout their design life.

47. Items important to safety shall be designed:

   a. To sustain a single failure if the item is required to perform a correct action to meet the acceptance criteria in safety analysis;

   b. To comprise fail-safe features and prevention of harmful interaction with other items, as appropriate, from the safety function and system design perspectives;

   c. To comply with the relevant codes, standards, and engineering practices relevant to the design of a nuclear facility;

   d. To be manufactured, constructed, assembled, installed, and erected in accordance with established processes and design specifications;

   e. To be calibrated, tested, maintained, repaired or replaced, inspected, and monitored, as required, to ensure their functionality, capability, integrity, and reliability in all specified conditions.

48. The design life of items important to safety at a nuclear facility shall be determined. Appropriate margins shall be provided to take due account of relevant mechanisms of aging, neutron embrittlement and wear out, and potential age-related degradation to ensure the items important to safety capability when performing their safety functions throughout their operating lifetime.

Section 16: Human Factors in Operation and Emergency

49. Effective means of operating the nuclear facility, monitoring its status, and communicating with all personnel shall be provided throughout the nuclear facility to facilitate the implementation of correct and effective measures during and following all operational states and accident conditions.

50. Human factors shall be systematically considered at an early stage in the design process for a nuclear facility and shall continue to be considered throughout the entire design process, including the control room, the human-machine interfaces, the various procedures, and the layout design of the facility.

51. A nuclear facility shall be provided with emergency procedures and features, including lighting and ventilation, access and escape routes, use of non-permanent equipment, and other services essential for the personnel to remain safe and effective in potential emergencies, based on design assessments.

Section 17: Fissile and Radioactive Material

52. Special consideration shall be given at the design stage of a nuclear facility to the incorporation of design and safety features for managing and handling fissile material and fuel, as well as radioactive material and waste, to fulfill the safety criteria of the facility.

53. All systems and buildings in a nuclear facility that could contain fissile or radioactive material, and the nuclear facility as a whole, shall be designed to keep the radiological impact as low as reasonably achievable (ALARA) to meet the discharge limits set for operational states and accident conditions, to prevent accidental criticality, overheating, and an uncontrolled radioactive release, and to mitigate the radiological consequences of accidents.

54. The design of a nuclear facility shall establish the provisions to minimize the impact of radioactive materials and associated toxic effluents from normal

operations on the public and the environment and to ensure that the discharges are within authorized limits prior to their release into the environment.

55. The design of a nuclear facility shall ensure that the facility can be safely decommissioned and dismantled and that related impacts on the environment are minimized.

Section 18: Security and Safeguards

56. Safety measures, nuclear security measures, and safeguards arrangements for the system of accounting for and control of nuclear material for a nuclear facility shall be designed and implemented in an integrated manner so that they do not compromise each other.

57. The nuclear facility shall be isolated from its surroundings with a suitable layout of the various structural elements and buildings to control access.

58. Unauthorized access to, or interference with, items important to safety, including hardware and software, shall be prevented.

Chapter 6: Specific Design Requirements for Nuclear Power Plant

Section 19: Reactor Core and Fuel

59. Fuel elements and assemblies for the nuclear power plant shall be designed to maintain their structural integrity and to withstand the anticipated radiation levels and other conditions in the reactor core, in combination with all the processes of deterioration that could occur in operational states. Design limits shall be specified on the permissible leakage of fission products from the fuel so that the fuel also remains suitable for continued use after anticipated operational occurrences.

60. The fuel elements and assemblies, their supporting structures, and other associated items shall be designed to ensure that, during operational states and in accident conditions other than severe accidents, a geometry that allows for

adequate cooling is maintained and the insertion of control rods is not impeded. The fuel elements and assemblies shall also be designed to withstand the loads and stresses caused by lifting, movement, and handling, relevant before and after use in the reactor core and during refueling.

61. Distributions of neutron flux that can arise in any state of the reactor core, including states arising after shutdown and during or after refueling and states arising from anticipated operational occurrences and from accident conditions not involving degradation of the reactor core, shall be inherently stable. Means shall be provided to measure the neutron flux distribution in all the core regions, and the demands shall be minimized for the control system to maintain shapes, levels, and stability of the neutron flux within specified design limits in all operational states.

62. Means shall be provided to shut down the reactor when necessary in operational states and in accident conditions, to maintain the shutdown condition for the most reactive conditions of the reactor core, and to prevent unintentional criticality for all foreseeable reactivity increase events in the shutdown state. The means for shutting down the reactor and maintaining the reactor in a subcritical state shall also comprise an appropriate level of diversity and independence to be effective in design extension conditions with a common cause failure affecting the primary means of reactor shutdown.

63. Means shall be provided for removing the heat generated in the reactor core such that the fuel design limits are met in all phases of normal operational modes. The engineered safety features and systems, in turn, shall be capable of shutting down the reactor sufficiently and quickly, as well as cooling the reactor core to meet the acceptance criteria specified for the fuel, as applicable for the different initiating events of the safety analysis with reactivity changes, loss of coolant, or other conditions affecting the reactor core and fuel.

Section 20: Reactor Coolant System

64. The components of the reactor coolant system for the nuclear power plant shall be designed and constructed to minimize the risk of faults due to inadequate design standards, inadequate quality of materials or manufacture, or insufficient capability for inspection during manufacture or installation or in service. The design shall provide high resistance against flaw initiation and propagation, efficient detection of unacceptable faults, and prevention of potential embrittlement conditions at the reactor coolant pressure boundary, as well as minimization of the effects of a component failure inside the reactor coolant system.

65. Provision shall be made to control the inventory, temperature, and pressure of the reactor coolant to ensure that the specified design limits of the reactor coolant system are not exceeded in any operational state, with due account taken of volumetric changes and leakage.

66. Adequate facilities shall be provided to remove activated corrosion products, fission products derived from the fuel, and other radioactive or non-radioactive substances from the reactor coolant. The capabilities of the associated clean-up systems shall be based on the specified design limits on the permissible leakage of the fuel, with adequate margins to ensure that the plant can be operated in accordance with the safety criteria and the limits set for discharges into the environment.

67. Pressure relief devices shall be provided to protect the pressure boundary of the reactor coolant system against overpressure without the release of radioactive material directly into the environment. The overpressure protection of the reactor coolant system shall be capable of limiting the pressure in accordance with the acceptance criteria applicable for the different initiating events of the safety analysis, as based on industry codes and standards. The means for overpressure protection shall comprise sufficient diversity and independence to cover design

extension conditions with a common cause failure affecting the primary means for overpressure protection.

68. Means shall be provided for the removal of residual heat from the reactor coolant system such that the design limits are met for all phases of normal operational modes, including shutdown conditions, and that the acceptance criteria of the safety analysis are fulfilled for anticipated operational occurrences and design basis accidents. The means for residual heat removal from the reactor coolant system shall cover the whole heat removal chain to the ultimate heat sink and shall also be effective in design extension conditions with an initiating event and a common cause failure or rare hazard condition affecting the residual heat removal chain or the ultimate heat sink.

Section 21: Containment System

69. A containment system shall be provided for the nuclear power plant to keep environmental radioactive releases as low as reasonably achievable (ALARA) and to meet the limits set for discharges into the environment by confinement of radioactive material, shielding against radiation from inside the containment, control of planned radioactive releases from the containment, and limitation of accidental radioactive releases into the environment. The containment system shall also contribute to providing sufficient residual heat removal from the reactor or the remains of the reactor core, whether inside or outside the reactor coolant system in a severe accident and protect the reactor against hazards with a severe physical impact potential.

70. The design of the containment system shall be such as to ensure that the loadings on the containment system meet the acceptance criteria and that any radioactive releases into the environment are in accordance with the safety criteria, as applicable for operational states, accident and design extension conditions, as well as internal and external hazards. The number of penetrations through the containment shall be kept to a practical minimum, and all penetrations shall meet

the same design requirements as the containment structure. A design limit shall be specified on the leakage rate of the containment system as a whole at design pressure, and the design of the containment system shall enable the testing of the leak tightness after construction of the containment and installation of all penetrations have been completed, and at justified intervals during the operating life of the containment.

71. Means shall be provided to enable the isolation of each line penetrating the containment. Each line that penetrates the containment as part of, or connected or interfacing with, the reactor coolant system or that is connected directly to the containment atmosphere shall be automatically and reliably sealable in the event of an accident in which isolation and leak-tightness are essential to preserving the reactor coolant inventory or preventing radioactive releases into the environment from exceeding the safety criteria. The provision of diversity and independence shall be considered in the design of isolation functions, with due attention paid to common cause failures of similar isolation devices that could lead to a reactor coolant leakage path, if any, jeopardizing cooling of the reactor core and bypassing the containment.

72. Access by operating personnel to the containment shall be through airlocks equipped with interlocking doors, ensuring that at least one of the doors is closed during reactor power operation and in accident conditions. Containment openings for the movement of equipment or material through the containment shall be designed to be closed quickly and reliably whenever the isolation of the containment is required. Reliable means shall be provided to ensure the safety of the operating personnel with respect to the use of containment access routes and openings.

73. Provision shall be made to control the pressure and temperature in the containment and its compartments and to control any build-up or release of fission products or other gaseous, liquid, or solid substances inside the containment affecting the operation of items important to safety, including the

potential effects of insulation, coverings, coatings and inappropriate materials. The design for containment shall cover the effects, conditions, and phenomena that could challenge the integrity or leak tightness of the containment system or its capability, as well as associated items and actions to control and limit radioactive releases in accident conditions. Any means used to release gases from, and to lower the pressure and protect the integrity and leak-tightness of, the containment shall not lead to an early radioactive release and shall be shown to fulfill the safety criteria of design basis accidents and design extension conditions.

Section 22: Process and Ventilation Systems

74. The design of the steam supply system, feedwater systems, and turbine generators for the nuclear power plant shall be such as to ensure that the design limits and acceptance criteria of the reactor coolant pressure boundary are not exceeded during operational states or in accident conditions. The design shall provide adequate steam supply, feedwater, isolation, and pressure relief functions, as well as turbine protection and minimization of the effects of potential turbine-generated missiles.

75. The process systems of the nuclear power plant required to cool the reactor core and to remove the residual heat from the reactor coolant system and containment system in, and following, anticipated operational occurrences and design basis accidents shall fulfill the design basis requirements of safety systems. An appropriate level of independence and diversity shall be provided in the process systems architecture of the plant to implement the defense-in-depth principle and to cover design extension conditions with common cause failures and rare hazard conditions.

76. The design requirements applied for the supporting systems and auxiliary systems that do not perform frontline safety functions but are required, either in the short or long term, to achieve the fundamental objectives of safety functions shall be consistent with the safety functions of the systems and components they serve. As

a general design principle, the supporting and auxiliary systems required for the safety systems to be effective during and following the relevant initiating events shall be considered equally important to the safety systems and treated as such.

77. Auxiliary systems shall be provided as necessary to remove the heat from the systems and components required to function during operational states and accident conditions. The design of heat transport systems shall enable the isolation of non-essential items to ensure the cooling of items important to safety.

78. The design requirements applied for the pneumatic and hydraulic systems shall be consistent with the safety significance of the items that they serve. The design of a pneumatic or hydraulic system that serves items important to safety shall specify the quality, flow rate, cleanness, and other necessary fluid conditions to be provided.

79. Systems for air conditioning, air heating, air cooling, and ventilation of buildings shall be provided as necessary in auxiliary rooms or other areas at the nuclear power plant to maintain the required environmental conditions for the items important to safety to perform their functions in operational states and accident conditions. Areas of the plant with higher expected contamination shall be maintained at a negative pressure differential with respect to areas of lower contamination and other accessible areas. The ventilation systems shall be provided with sufficient clean-up capability to prevent, limit, and control the dispersion of airborne radioactive substances and their discharges into the environment in accordance with the safety criteria of the plant and the limits set for discharges.

80. Nuclear power plants coupled with heat utilization or water desalination units shall be designed to prevent processes that could transport radionuclides from the plant to the desalination unit or the district heating unit in operational states or accident conditions.

Section 23: Instrumentation and Control Systems

81. Instrumentation shall be provided at the nuclear power plant, in accordance with the defense-in-depth principle, for determining the values of all the main parameters and supporting variables that are essential for the safe and reliable operation of the plant, for activating safety functions to reach the fundamental objectives of reactivity control, heat removal and confinement of radioactive materials, for monitoring the status of essential items, determining the status of the plant and bringing the plant into a safe state after an initiating event, and for making well-informed decisions to mitigate the radiological consequences in an emergency situation.

82. Reliable control systems shall be provided to maintain the relevant process variables within the specified operational ranges. Where appropriate, additional limitation functions shall be provided to prevent process deviations from leading to protection system activation.

83. A protection system shall be provided to detect unsafe plant conditions and to automatically actuate the safety systems necessary for reaching a controlled state in anticipated operational occurrences and design basis accidents. The protection system shall be designed to override other actions, act in a safe direction upon failure, and inform the operators about the parameters and actuation of the protection system. The protection system shall fulfill the design basis requirements of safety systems. An appropriate level of diversity and independence shall also be provided in the instrumentation and control systems architecture to cover design extension conditions with an initiating event and a common cause failure of protection system functions and to mitigate the consequences of severe accidents as independently as practicable from their potential causes.

84. In accordance with the defense-in-depth principle, the protection system shall be independent of control systems to prevent a coincidental or consequential loss of

both defense levels. Interference between the protection and control systems shall be prevented by means of separation, avoiding interconnections, and suitable functional independence and isolation. Equivalent design principles shall be applied throughout the instrumentation and control systems architecture, as appropriate for the instrumentation, control, and actuation layers of the functional architecture of the plant to comprise adequate protection against the effects of single and common cause failures and their combinations, concerning both hardware and software and to prevent potential errors, events or hazards from causing a loss of several levels of defense-in-depth.

85. A control room shall be provided from which the plant can be safely operated in all operational states and from which measures can be taken to maintain the plant in a safe state or to bring it back to a safe state after anticipated operational occurrences and accident conditions. The control room and the control room personnel shall be protected against radiological and other potential effects caused by accident, design extension, or hazard conditions so that the operators remain safe and effective for a prolonged period, as required to ensure safety. Human factors shall be incorporated in the design of the control room and the human-machine interfaces, including the use of simulator support, to finalize the design for the necessary operator information, alarms, and actions.

86. Instrumentation and control equipment shall be kept available, preferably at a single location in a supplementary control room that is physically, electrically, and functionally separated from the main control room, to enable operators to monitor the plant status and take actions if necessary, to ensure a controlled state to be maintained or reached in, and a safe state to be reached following, a situation where the main control room cannot be used as necessary. The design basis of the supplementary control room shall be based on the identification of failures, errors, events, and hazards that could require it to be used, and its accessibility, utilization, and functionality shall be protected against the conditions and effects of such situations.

87. The nuclear power plant shall be provided with the necessary on-site emergency response facilities for the personnel to perform decided tasks under severe conditions generated by accidents or hazards. Information about important plant parameters and radiological conditions at the plant and in the immediate surroundings of the plant shall be available at the emergency response facilities, with sufficient facilities to communicate with the personnel in the main and supplementary control rooms and other important locations and with the on-site and off-site emergency response organizations.

Section 24: Electrical and Lighting Systems

88. The functionality of items important to safety at the nuclear power plant shall not be compromised by disturbances in the electrical power grid, including anticipated variations in the voltage and frequency of the grid supply.

89. The nuclear power plant shall be provided with an emergency power supply capable of supplying the necessary power in anticipated operational occurrences and design basis accidents in the event of a loss of off-site power or its supply to items important to safety. When serving other safety systems, the emergency power supply system shall fulfill the design basis requirements of safety systems. An appropriate level of diversity and independence shall also be provided in the electrical systems architecture of the plant to cover design extension conditions with an initiating event and a common cause failure of the emergency power supply or associated items providing the necessary power for items important to safety.

90. Alternate power sources to the emergency power supply shall be provided and be capable of supplying the necessary power to prevent significant damage to the reactor core and to the spent fuel in the event of a loss of off-site power combined with the failure of the emergency power supply or with a common cause failure affecting passive safety systems, if any. The design basis of the alternate power supply and associated items shall be derived from failures, errors, events, and

hazards potentially leading to the loss of emergency power supply or the common cause failure of passive systems, if any, with appropriate provisions for diversity, independence, and separation.

91. Continuity of power for the monitoring of the key plant parameters and the completion of short-term actions necessary for safety shall be maintained even in the event of a complete loss of all the alternative current (AC) power sources. An appropriate capacity and margins shall be specified for the battery backup to support plant monitoring and operator actions to ensure safety and activate the AC power supply by using alternate power sources and making parallel attempts, if any, to recover the emergency or the off-site power supply.

92. Adequate lighting shall be provided in all operational areas of the nuclear power plant during operational states and in accident conditions.

Section 25: Fuel Handling and Waste Treatment Systems

93. Systems shall be provided for treating solid radioactive waste and liquid radioactive waste at the nuclear power plant to keep the radioactive releases in accordance with the safety criteria of the plant in all modes of normal operation and for storing the waste for the necessary period consistent with the availability of the relevant disposal option. The consequences of failures, errors, events, or hazards affecting systems or buildings related to waste management shall be sustained or mitigated in accordance with the safety criteria.

94. Systems shall be provided at the nuclear power plant for treating liquid and gaseous radioactive effluents in accordance with the safety criteria of the plant in all modes of normal operation. The consequences of failures, errors, events, or hazards affecting systems or buildings used for treating effluents shall be sustained or mitigated in accordance with the safety criteria.

95. Fuel handling and storage systems shall be provided at the nuclear power plant to ensure that the integrity and properties of the fresh fuel and the spent fuel are maintained during fuel handling and storage and that the consequences of

failures, errors, events, or hazards are sustained or mitigated in accordance with the safety criteria of the plant.

Section 26: Lifting Systems and Equipment

96. Overhead lifting systems and equipment shall be provided at the nuclear power plant, as necessary, and due attention shall be paid to the lifting and lowering of items important to safety and to performing any lifting or lowering in the proximity of items important to safety. The design of plant layout and buildings shall enable safe movement of the overhead lifting equipment and items being transported.

97. The overhead lifting equipment shall be designed to prevent the lifting of excessive loads and unintentional dropping of loads that could affect items important to safety. The associated risks shall be assessed as part of the design assessments to finalize the design and to specify the qualification requirements for lifting equipment, with due consideration also given to seismic and other hazard conditions. The use of overhead lifting equipment shall be limited to specified plant states by administrative means or safety interlocks, as appropriate, to ensure safety.

Section 27: Fire Protection Systems

98. Fire protection systems, including fire detection systems and fire extinguishing systems, fire containment barriers, and smoke control systems, shall be provided throughout the nuclear power plant. The design requirements and features of the associated items, including the related structures and buildings, shall take due account of the results of the design assessments and the fire hazard analysis to safely resolve potential failures, errors, events, and hazards causing or caused by fire.

99. The design of the fire safety of the nuclear power plant shall determine the appropriate level and extent of automatic extinguishing functions, non-combustible or fire retardant and heat-resistant materials, and detection

information provided promptly for the operating personnel to ensure safety and to perform the required firefighting or other actions. The design shall prevent the possibility of a rupture or a spurious or inadvertent operation of fire extinguishing systems from significantly impairing the safety functions of the plant or endangering the safety of the personnel.

Section 28: Radiation Protection

100. Provision shall be made to ensure that doses to operating personnel at the nuclear power plant can be maintained in accordance with the safety criteria. The design of the plant shall be based, as far as reasonably practicable, on minimizing fuel leakages and the generation of corrosion and activation products by proper material selection and manufacturing quality for the reactor fuel and the components and internal structures of the reactor coolant system.

101. To meet the safety criteria, the radiation sources throughout the plant shall be identified, and means shall be provided to control the activity levels and limit the transport, release, and dispersion of radioactive substances causing contamination inside the plant. The plant layout, radiation shield, and ventilation design shall enable the necessary access for the operating personnel during operation and in accident conditions. The plant shall be divided into zones indicating their expected radiation and contamination levels and associated access prerequisites.

102. The plant layout shall be such that the doses received by operating personnel during normal operation, refueling, maintenance, and inspection may be limited in accordance with the safety criteria, and due account shall be taken of the necessity for any special equipment to be provided to meet these requirements. Plant items subject to frequent maintenance or manual operation shall be located in areas with low dose rates to reduce exposure to workers. Facilities shall be provided for the decontamination of the plant's operating personnel, equipment, and items.

103. Equipment shall be provided at the nuclear power plant to ensure adequate radiation monitoring during operational states, design basis accident conditions, and, as far as practicable, design extension conditions. The stationary radiation monitoring shall comprise dose rate meters for both local and general radiation level measurements at the plant, monitors for the activity level of airborne radioactive substances in relevant areas of the plant, and monitors for radioactive effluents at the plant and for any discharges into the environment.

104. Stationary radiation monitors shall be provided at the main exit points from controlled areas and supervised areas to facilitate the monitoring of operating personnel and equipment. Facilities shall be provided to monitor the exposure and contamination of operating personnel and enable the recording and assessing of the cumulative doses over time. Instruments shall be provided and made available where necessary to measure surface contamination.

105. Process sampling systems, post-accident sampling systems, and related laboratory facilities shall be provided for determining, in a timely manner, the concentration of specified radionuclides in fluid process systems and gas and liquid samples taken from systems or the environment during all operational states and in accident conditions. Appropriate means shall be provided for the monitoring of activity in fluid systems that have the potential for significant contamination.

106. Arrangements shall be made to assess potential exposures and other radiological impacts, if any, in the vicinity of the nuclear power plant by environmental monitoring of dose rates or activity concentrations, with particular reference to exposure pathways to people, including the food chain, radiological impacts on the local environment, the buildup and accumulation of radioactive substances in the environment, and the risk of unauthorized routes for radioactive releases.

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