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Design of Fuel Handling and Storage Systems for Nuclear Power Plants

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DRAFT SAFETY GUIDE

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DESIGN OF FUEL HANDLING AND STORAGE SYSTEMS FOR NUCLEAR POWER PLANTS

FOREWORD

Later

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1. INTRODUCTION

BACKGROUND

1.1 This Safety Guide was prepared in support of safety requirements established in IAEA Safety Standards Series No. SSR-2/1, Safety of Nuclear Power Plants: Design [1], which was published in 2012 and was revised (as Rev.1) in 2016. This Safety Guide supersedes IAEA Safety Standards Series No. NS-G-1.4, Design of Fuel Handling and Storage Systems for Nuclear Power Plants, published in 2003.

1.2 This Safety Guide takes into account lessons from the accident at the Fukushima Daiichi nuclear power plant in 2011, with the application of strengthened defence in depth to the design of fuel handling and storage systems in nuclear power plants.

OBJECTIVE

1.3 The objective of this Safety Guide is to provide recommendations for the application of safety requirements stated in SSR-2/1 (Rev.1) [1] to the design of fuel handling and storage systems in nuclear power plants.

SCOPE

1.4 This Safety Guide is intended for application primarily to land based stationary nuclear power plants with water cooled reactors. All statements are applicable to light water reactors, i.e., pressurized water reactors and boiling water reactors, and are generally applicable to pressurized heavy water reactors unless otherwise specified. This Safety Guide can be referenced for conceptual application, with judgement, to other reactor types (e.g., gas-cooled reactors, small and modular reactors, innovative reactors).

1.5 This Safety Guide addresses the design aspects of fuel handling and storage systems that remain part of the operational activities of nuclear reactor(s). From this perspective, this Safety Guide covers the following stages of fuel handling and storage in a nuclear power plant:

(a) Receipt of new fuel[1];

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[1] New fuel means fuel before use in the reactor that contains a negligible fission product inventory; new fuel includes fresh fuel manufactured from unirradiated material and fuel manufactured using a mixture of unirradiated and reprocessed material.

(b) Storage and inspection of new fuel before use;

(c) Transfer of new fuel into the reactor;

(d) Removal of irradiated fuel from the reactor and transfer the irradiated fuel to spent fuel pool;

(e) Reinsertion (shuffling) of irradiated fuel from the spent fuel pool when required;

(f) Storage, inspection and repair of irradiated or spent fuel[2] in the spent fuel pool and its preparation for removal from the spent fuel pool; and

(g) Handling of fuel casks in the spent fuel pool.

Spent fuel storage systems with associated fuel handling systems that do not remain as part of the operational activities of nuclear reactor(s) (e.g., interim wet or dry storage) are addressed in IAEA Safety Standards Series No. SSG-15, Storage of Spent Nuclear Fuel [2].

1.6 Limited consideration is also given to the handling and storage of certain irradiated core components, such as reactivity control devices.

1.7 This Safety Guide is intended for application to UO_2 fuels (natural, enriched or reprocessed) and plutonium-blended UO_2 fuel (mixed-oxide fuel) with metal cladding.

1.8 This Safety Guide is mainly intended for application to fuel handling and storage systems in new nuclear power plants. It can be used for revising the design of nuclear power plants in operation, for instance in the context of a periodic safety review. It might be however not possible or practicable to apply all the recommendations in this Safety Guides to existing nuclear power plants.

STRUCTURE

1.9 Section 2 provides general recommendations for the design of fuel handling and storage systems for nuclear power plants to meet requirements mainly provided in Sections 3 and 4 of SSR-2/1 (Rev. 1) [1]. The subsequent Sections 3 through 6 provide specific recommendations to achieve the safety functions in frame of the general approach and to meet safety requirements mainly established in Sections 5 and 6 of SSR-2/1 (Rev. 1) [1]. Sections 3 and 4 provide specific recommendations for the safe design of fuel storage systems and fuel handling systems, respectively. Section 5 provides specific recommendations for the safe design of equipment used for spent fuel

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[2] Spent fuel means fuel removed from the reactor core following irradiation and that is no longer economically usable in its present form.

inspection and repair, and handling of damaged fuel. Section 5 also provides specific recommendations for the safe design of handling and storage systems for irradiated core components. Section 6 provides guidance on the design of handling equipment for spent fuel casks in the spent fuel pool.

Annex I provides simplified information with regard to the handling of spent fuel casks in the spent fuel pool.

2. SAFE DESIGN OBJECTIVES AND DESIGN APPROACH

MANAGEMENT SYSTEM

2.1 The design of fuel handling and storage systems should be conducted taking into account the recommendations of IAEA Safety Standards Series No. GS-G-3.1, Application of the Management System for Systems and Activities [3] and IAEA Safety Standards Series No. GS-G-3.5, The Management System for Nuclear Installation [4] to meet Requirements 1–3 of SSR-2/1 (Rev. 1) [1] and requirements in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [5].

SAFETY FUNCTIONS

2.2 According to Requirement 4 of SSR-2/1 (Rev. 1) [1], the design should identify the fuel handling and storage structures, systems and components which in all plant states provide the following fundamental safety functions:

(a) Maintaining subcriticality of the fuel;

(b) Removal of the decay heat from irradiated fuel; and

(c) Confinement of radioactive material, shielding against radiation and limitation of accidental radioactive releases.

DESIGN APPROACH

Maintaining subcriticality of the fuel

2.3 Recommendations in paras 2.4–2.6 provide guidance to fulfill Requirement 80, para. 6.66 (a) of SSR-2/1 (Rev. 1) [1]:

2.4 The design of fuel handling and storage systems should be such as to prevent criticality by maintaining specified subcriticality margins under all operational states and accident conditions.

2.5 The design of storage systems for authorized fuel should be such as to prevent criticality preferably by control of geometry.

2.6 The design of fuel storage systems should also consider use of physical means or physical processes to increase subcriticality margins in normal operation in order to prevent from reaching the criticality during postulated initiating events including the effect of hazards.

Removal of the decay heat from irradiated fuel

2.7 To fulfill Requirement 80, para. 6.67 (a) of SSR-2/1 (Rev. 1) [1], the design of fuel storage systems should be such as to maintain adequate fuel cooling capabilities for irradiated fuel and not to exceed fuel cladding or coolant temperature limits defined for operational and accident conditions.

Confinement of radioactive materials and limitation of radioactive releases

2.8 Recommendations in paras 2.9–2.11 provide guidance to fulfill Requirement 5 of SSR-2/1 (Rev. 1) [1]:

2.9 Design provisions should be introduced to prevent damage to fuel during handling, and to collect and filter radioactive releases from the spent fuel storage in order to keep radioactive releases as low as reasonably achievable during operational states.

2.10 Ventilation systems should be implemented as necessary to reduce the concentrations of airborne radioactive materials and, thus, to prevent or reduce direct exposure and contamination in areas with radiation hazards.

2.11 Design provisions should be provided to collect and filter radioactive materials released in case of handling accidents, and to prevent uncovering of irradiated fuel assemblies in the spent fuel storage in accident conditions.

Shielding against radiation

2.12 Recommendations in paras 2.13–2.14 provide guidance to fulfill Requirements 5 and 81 of SSR-2/1 (Rev. 1) [1]:

2.13 Fuel handling equipment and fuel storage systems should include shielding as necessary to keep occupational doses as low as reasonably achievable in operational states.

2.14 Design provisions should be implemented as necessary to prevent a loss of shielding from irradiated fuel resulting in high radiation doses for workers for operational states and accident conditions (para. 2.11 of SSR-2/1 (Rev. 1) [1]).

Interfaces of safety with security and safeguards

2.15 To fulfill Requirement 8 of SSR-2/1 (Rev. 1) [1], items important to safety of fuel handling and storage should be designed taking into account design recommendations for safety and security in an integrated manner in such a way that safety and security measures do not compromise each other. Security measures should be consistent with the guidance in [6] and [7].

2.16 The design of fuel handling and storage systems should facilitate the application and maintenance of safeguards, and nuclear material accountancy and control.

Proven engineering practices

2.17 To fulfill Requirement 9 of SSR-2/1 (Rev. 1) [1], the design of items important to safety of fuel handling and storage should be such a design that has been proven either by equivalent applications based on operational experience or on the results of relevant research programme, or according to the design and design verification/validation processes stated in applicable codes and standards.

Safety assessment in design process

2.18 To fulfill Requirement 10 of SSR-2/1 (Rev. 1) [1], the safety assessment of fuel handling and storage systems should be performed as part of the design process, with iteration between the design and safety analyses, and increasing in the scope and level of detail as the design progresses. Guidance on the deterministic safety assessment is described in IAEA Safety Standards Series No. SSG-2, Deterministic Safety Analysis for Nuclear Power Plants [8], and guidance on the probabilistic safety assessment is described in IAEA Safety Standards Series No. SSG-3, Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants [9] and IAEA Safety Standards Series No. SSG-4, Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants [10].

Other considerations

2.19 Beside safe storage, fuel handling and storage systems are required to facilitate the following activities (Requirement 80, paras 6.66 and 6.67 of SSR-2/1 (Rev. 1) [1]):

(a) Inspection of the fuel;

(b) Maintenance, periodic inspection, calibration and testing of items important to safety;

(c) Identification of individual fuel assemblies;

(d) Arrangements to permit accounting for and control of nuclear fuel; and

(e) Decontamination of areas, maintenance and future decommissioning.

2.20 To fulfill Requirement 12 of SSR-2/1 (Rev. 1) [1], design provisions should be introduced to minimize the potential for generating radioactive effluents and wastes during normal operation.

2.21 The effects of irradiation should be considered in the design of structures, systems and components.

3. DESIGN BASIS FOR STRUCTURES, SYSTEMS AND COMPONENTS OF FUEL STORAGE

3.1 In the context of this Safety Guide, items important to safety of fuel storage include: pool structure, pool liner, pool cooling systems, pool purification systems, make-up systems, gates and fuel storage racks.

GENERAL

3.2 Items important to safety are required to be designed in compliance with Requirement 80 of SSR-2/1 (Rev. 1) [1], with account taken of all other requirements of SSR-2/1 (Rev. 1) [1] relevant to:

(a) Protection of workers, the public and the environment against the effects of ionizing radiation in operational and accident conditions;

(b) Adequate reliability of the various systems; and

(c) Prevention of high radiation doses, early or large radioactive releases.

3.3 To fulfill Requirement 14 of SSR-2/1 (Rev. 1) [1], the design basis of items important to safety should be established taking into account inter alia:

(a) The safety function(s) to which they contribute;

(b) The postulated initiating events they have to cope with;

(c) The protection against the effects of internal hazards;

(d) The protection against the effects of external hazards;

(e) The safety classification;

(f) Design limits or acceptance criteria;

(g) The engineering design rules applicable to the system;

(h) Recommended instrumentation and monitoring;

(i) Provisions against common cause failures;

(j) Environmental conditions for qualification; and

(k) Selection of materials.

3.4 The design should define provisions and devices necessary to facilitate the use of non-permanent equipment for the re-establishment of safe conditions in the fuel storage in case of multiple failures, which are not accounted for in the design basis. This may include the provision of flanges and sockets for the use of mobile equipment.

DEFENCE IN DEPTH

3.5 Recommendations in paras 3.6–3.8 provide guidance to fulfill Requirement 7 of SSR-2/1 (Rev. 1) [1]:

3.6 The design of spent fuel storage systems should include multiple means to remove decay heat from irradiated fuel and to maintain subcriticality margins in the various plant states considered in the design

3.7 The need for redundancy, diversity and independency should be defined taking into account para. 3.8. Implemented combination of redundancy, diversity and independency among the various cooling means should be adequate to demonstrate that the uncovering of the fuel assemblies is prevented with a high level of confidence.

3.8 The risk for common cause failures of the decay heat removal means should be identified and the consequences assessed. In the cases that may result in fuel assemblies uncovering, the identified vulnerabilities of the decay heat removal means should be removed to the extent possible by the implementation of diverse and redundant provisions.

SAFETY FUNCTIONS

3.9 The functions performed by the system and the contribution of each major structure and component in the accomplishment of these functions should be described in a level of detail sufficient for a definition of the design bases of the structures, systems and components.

POSTULATED INITIATING EVENTS

3.10 Recommendations in paras 3.11–3.13 provide guidance to fulfill Requirement 16 of SSR-2/1 (Rev. 1) [1].

3.11 For spent fuel storage, coolant inventory in the fuel storage area is essential to the fundamental safety functions of decay heat removal and radiation protection, and can contribute to maintaining subcriticality margins. Therefore, the potential for a significant loss of coolant inventory should be a major consideration in the identification of postulated initiating events.

3.12 Postulated initiating events relevant to the design of fuel storage systems should be those events that potentially lead to a reduction in subcriticality margin, reduction in decay heat removal capability, a significant release of radioactive materials, or a significant direct radiation exposure of operating personnel. Postulated initiating events are caused by equipment failures, operating errors, external hazards, or internal hazards. Typical examples of postulated initiating events are provided in paras 3.48 and 3.50.

3.13 Bounding conditions caused by the postulated initiating events should be determined to define necessary performance capabilities of the equipment designed to mitigate their consequences.

INTERNAL HAZARDS

3.14 Recommendations in paras 3.15–3.32 provide guidance to fulfill requirements relevant to "Internal Hazards" of Requirement 17 of SSR-2/1 (Rev. 1) [1].

3.15 Items necessary for maintaining safe conditions should be designed to withstand loads resulting from or be protected against the effects of internal hazards. That protection should also consider the consequences of the failure of unprotected equipment.

3.16 The redundancies of the systems should be segregated to the extent possible or adequately separated, and protected as necessary to prevent the loss of the safety function performed by the system (prevention of common cause failures initiated by the effects of the internal hazards).

3.17 The effects of a single hazard should not result in the failure of all cooling capability of spent fuel storage systems.

3.18 The storage building should be designed to withstand the hazard loads occurring within the plant site (e.g., explosions and internally generated missiles).

3.19 Design methods and construction codes used should provide adequate margins to prevent the cliff edge effects in the event of a minor increase in the severity of an internal hazard above the design basis.

3.20 Recommendations provided in IAEA Safety Standard, Protection against Internal Hazards in the Design of Nuclear Power Plants [11] should be considered to identify the relevant hazards and develop appropriate methods of protecting equipment from the selected internal hazards.

Typical examples of internal hazards which influence the design of fuel handling and storage systems are provided in the subsequent paragraphs.

Heavy load drop

3.21 The potential for falling heavy loads to damage stored fuel or otherwise impact the continued implementation of fundamental safety functions should be considered in the design. Falling objects are primarily the result of component failures and operator errors during fuel handling.

3.22 Due to the frequency of fuel handling, a drop of a fuel assembly in any area traversed during the handling should be considered. Other potential load drops in the fuel storage area include the movement of water-tight gates, the transfer of tools, and the infrequent installation or removal of fuel storage racks.

3.23 Very heavy objects associated with refueling operations (e.g., reactor vessel head and activated reactor internal structures) and fuel transfer or storage cask loading operations should be excluded from consideration as hazards in the fuel storage area through prevention by careful design of the handling equipment , and of layout of the refueling, fuel storage, and cask loading areas.

3.24 The design and layout of fuel handling and storage systems should prevent the movement of these heavy objects over the fuel storage areas through spatial separation and prevent indirect effects through structural independence of the fuel storage area and the construction of weirs or other structures to prevent a substantial loss of coolant inventory in the event of heavy load drops that damage structures in nearby areas.

Internal flooding in new fuel dry storage

3.25 The design and layout of new fuel dry storage should provide protection against internal flooding, for example, by means of flood barriers, routing of water piping through areas isolated from the fuel storage or adequate drains in order to keep the minimum subcriticality margins.

Pipe breaks

3.26 Equipment performing the fundamental safety functions should be protected against the effect of high-energy pipe breaks.

3.27 A substantial loss of coolant inventory from spent fuel storage systems resulting from pipe breaks should be avoided by ensuring that all liner penetrations in the fuel storage area are above the elevation necessary for adequate shielding in the spent fuel pool area.

Fires

3.28 All design relevant recommendations indicated in [11] should be implemented to reduce the probability for a fire to start, to limit its propagation, to protect items important to safety and to prevent the loss of fundamental safety functions. The following paras 3.29–3.31 provide recommendations specific to fuel storage.

3.29 For spent fuel storage, the different cooling capabilities and each redundant division of a cooling system should be implemented in its own fire compartment or at least in its own fire cell, where implementing a fire compartment is not achievable.

3.30 To be protected from fire, new fuel dry storage should be implemented inside a fire compartment.

3.31 The effects of firefighting agents on the subcriticality of new fuel in dry storage should be accounted for.

Explosions

3.32 If hydrogen generation is considered as a hazard, specific design provisions should be implemented to prevent hydrogen generation or to limit hydrogen concentration (e.g., ensure material compatibility with spent fuel storage pool coolant chemistry or provide ventilation) so that the hydrogen concentration is kept at a safe level below the lower flammability limits including locations where higher hydrogen concentration may exist.

EXTERNAL HAZARDS

3.33 Recommendations in paras 3.34–3.42 provide guidance to fulfill the requirements relevant to "External Hazards" of Requirement 17 of SSR-2/1 (Rev. 1) [1].

3.34 Recommendations provided in IAEA Safety Standards Series No. NS-G-1.5, External Events Excluding Earthquakes in the Design of Nuclear Power Plants [12] should be considered to understand the general concept for a complete identification of the relevant hazards and for an adequate protection of the structures, systems and components against the effects of the selected external hazards.

3.35 Items important to safety of fuel storage designed to accomplish fundamental safety functions should be protected against, or designed to withstand the effects of the selected external hazards.

3.36 The protection should primarily rely on an adequate layout and design of the buildings at the site.

3.37 For hazards or likely combinations of hazards, structures, systems and components whose operability or/and integrity is required to maintain during or after the hazard should be identified and specified. Where protection of the building is not effective, structures, systems and components should be designed to withstand the hazard loads and loads from likely combinations of hazards.

3.38 Items important to safety of fuel storage should be classified and assigned to the appropriate seismic categories in accordance with the recommendations and guidance given in IAEA Safety Standards Series No. NS-G-1.6, Seismic Design and Qualification for Nuclear Power Plants [13]. The structures, systems and components necessary for the accomplishment of the fundamental safety functions should be designed to withstand SL-2 seismic loads and provisions should be taken to prevent their failure caused by other equipment

3.39 Seismic design specifications for items important to safety of fuel storage should be established on the basis of consequences with regard to potential damage to stored fuel assemblies, release of radioactive materials in the building and necessity to operate the storage systems during and after an earthquake.. The design analysis for seismic qualification should consider potential decrease of water inventory due to sloshing and reduction of subcriticality margins due to potential displacement of solid neutron absorbers.

3.40 For spent fuel storage, in the event of external hazards, short term actions necessary to maintain a sufficient coolant inventory and an adequate cooling of the fuel, if any, should not rely on off-site services.

3.41 Methods of design, and construction codes and standards used should provide adequate margins to prevent cliff edge effects in the event of an increase of the severity of the external hazards.

3.42 Margins provided by the design of the structures, systems and components ultimately necessary to avoid high radiation doses and a large radioactive release should be such that it can be demonstrated that the integrity of the structures, and the operability of those systems and components would be preserved in case of natural hazards causing loads exceeding those resulting from the hazard evaluation at the site. In this regards, criticality and high radiation doses should be prevented, and irradiated fuel cooling capability should be preserved.

PLANT CONDITIONS TO BE TAKEN INTO ACCOUNT IN DESIGN

Fuel storage capacity

3.43 The spent fuel storage capacity should be designed in accordance with the fuel management policy with specific design capacity and positions for stored fuel assemblies. That is, adequate capacity for spent fuel storage should be provided to allow sufficient radioactive decay time and removal of residual heat before removal from the spent fuel pool. The maximum storage capacity should consider the availability of licensed away-from-reactor storage for spent fuel and the minimum decay time required for cooling prior to transfer. At a minimum, the storage capacity should allow for storage of all expected discharged fuel assemblies (according to the fuel management policy) plus additional storage locations for unloading one full core. For mixed-oxide fuel, the higher residual heat values that may further delay transfer into storage casks should be taken into account.

Normal operation

3.44 During normal operation, the fundamental safety functions should be accomplished without exceeding the limits and bounding conditions established for normal operation with regard to subcriticality margin, coolant temperature and occupational doses (radiation level and airborne activity).

3.45 Decay heat should be removed by a dedicated cooling system designed to maintain the coolant temperature below the maximal temperature specified for normal operation.

3.46 In the design of spent fuel storage systems, adequate means should be implemented and available for:

(a) Maintaining coolant activity within the specifications established for normal operation;

(b) Maintaining coolant chemistry within the specifications established for normal operation;

(c) Compensating for water losses by evaporation;

(d) Collecting radioactive gas potentially leaking from defective fuel rods;

(e) Maintaining appropriate clarity of the coolant for fuel handling operation;

(f) Monitoring and controlling coolant temperature;

(g) Monitoring and controlling coolant water level; and

(h) Monitoring and controlling airborne activity.

Recommendations for the design of ventilation air conditioning systems are provided in IAEA Safety Standard, Design of Auxiliary and Supporting Systems in Nuclear Power Plants [14].

Anticipated operational occurrences

3.47 Anticipated operational occurrences should be identified and postulated to define design provisions necessary to maintain subcriticality margin, cooling conditions and the coolant inventory within the limits established for anticipated operational occurrences.

3.48 Typical examples[3] of postulated initiating events which are categorized as anticipated operational occurrences based on frequency of occurrence and radiological consequences, include:

(a) Loss of off-site power;

(b) Loss of coolant (small leaks) in the cooling and filtration/purification system or through the seals of gates;

(c) Loss of cooling water flow, or dilution of soluble neutron absorbers (only relevant to pressurized water reactors);

(d) Malfunctioning of a normal operation fuel cooling system;

(e) Abnormal fuel assembly configurations with single misplaced fuel assembly or dropped fuel assembly (without cladding damage) in the fuel storage.

Accident conditions

3.49 Credible equipment failures causing conditions more severe than anticipated operational occurrences with regard to the accomplishment of the fundamental safety functions stated in para. 2.2 should be postulated.

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[3] Typical examples are design dependent.

3.50 Single equipment failures and multiple equipment failures should be considered to define design basis accident conditions and design extension conditions, respectively. Typical examples[3] of such failures to be considered include:

Design basis accidents

(a) Significant loss of coolant (e.g., breaks of piping connected to the spent fuel pool);

(b) Failure of the normal operation cooling system;

(c) Abnormal fuel assembly configurations (e.g. fuel assembly positioning errors and dropped irradiated fuel assembly with cladding damage);

(d) Significant change of moderation conditions in fuel storage (e.g., large dilution of soluble neutron absorber (pressurized watwer reactor only) in wet storage area, or flooding of dry storage area).

Design extension conditions

(a) Multiple failures leading to the sustained loss of the forced cooling system;

(b) Combinations of failures selected on the basis of probabilistic risk assessments (e.g. Combination of anticipated operational occurrences or postulated accidents with a common cause failure affecting the system designed for mitigating the event of concern).

DESIGN LIMITS

3.51 Recommendations in paras 3.52–3.56 provide guidance to fulfill Requirements 15 and 28 of SSR-2/1 (Rev. 1) [1].

3.52 The performance of structures, systems and components for spent fuel storage should meet the acceptance criteria established for the different operational and accident conditions.

3.53 Stresses caused by load combinations should not exceed the stress limits defined by the codes used for the design of the structures, systems and components.

3.54 Criticality should be prevented in all operational states and accident conditions with specified margins. Examples of good practices[4] are:

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[4] Examples are design dependent.

(a) For dry storage of new fuel, the effective multiplication factor calculated for optimum moderation conditions should not exceed a value specified as per national regulations, (e.g., 0.95 –0.98, uncertainties included); and

(b) For wet storage of spent fuel, the effective multiplication factor calculated should not exceed 0.95 in normal operation and values specified as per national regulations (e.g., 0.95–0.98) in anticipated operational occurrences and accident conditions (uncertainties included).

3.55 For wet storage of spent fuel, adequate coolant inventory should be maintained over the top of the irradiated fuel assemblies for shielding in all operational states and accident conditions:

(a) For wet storage of spent fuel, the water level in the pools should be appropriate for radiological shielding of the operating personnel during fuel handling operation (to comply with the personnel dose rate limitations and objectives) during normal operation and under anticipated operational occurences; and

(b) In accident conditions, substantial coolant inventory should be maintained for radiological shielding.

3.56 For wet storage of spent fuel, decay heat removal should be adequate to maintain spent fuel pool temperature at acceptable levels for operating personnel and for normal operation purification system under all normal operating conditions, including high decay heat loads associated with refueling. For anticipated operational occurrences, decay heat removal capability should be promptly restored to return pool temperature to normal operating conditions without reaching steaming conditions. In accident conditions, adequate removal of heat should be maintained relying on inherent safety features, on operation of active or passive systems, or their combinations, that is:

(a) Maintaining forced cooling during both design basis accidents and design extension conditions;

(b) Maintaining forced cooling during design basis accidents, and relying on natural evaporation of coolant supplemented by makeup to compensate lost of inventory for design extension conditions, provide for acceptable diversity in the removal of heat in accident conditions;

(c) For both design basis accidents and design extension conditions, relying on natural evaporation of coolant, supplemented by makeup to compensate lost of inventory provides another alternative for removal of heat in accident conditions.

RELIABILITY

3.57 Recommendations in paras 3.58–3.78 provide guidance to fulfill the Requirements 18, 21 through 26, 29 and 30, and 80 of SSR-2/1 (Rev. 1) [1].

3.58 To fulfill Requirement 23, para. 5.37 of SSR-2/1 (Rev. 1) [1], the design of items important to safety of spent fuel storage should be consistent with their design bases with sufficient reliability and effectiveness.

3.59 To fulfill Requirement 80, para. 6.68 of SSR-2/1 (Rev. 1) [1], the reliability of the design for spent fuel storage systems should be such that the possibility of conditions arising that could lead to a large radioactive release is practically eliminated and so as to avoid high radiation fields on the site.

3.60 The reliability of the different means designed to operate in different plant states should be commensurate with the safety significance of the function to be accomplished.

3.61 Different factors influence the reliability and should be considered to achieve the adequate reliability of the different systems necessary to remove decay heat from spent fuel storage and to maintain an adequate coolant inventory in the pool, inter alia:

(a) Safety classification and the associated engineering rules for design and manufacturing of individual structures, systems and components;

(b) Design criteria relevant for the systems (number of redundant trains, seismic qualification, qualification to harsh environmental conditions, power supplies);

(c) Consideration of vulnerabilities for common cause failures and related design provisions (by means of, for example, diversity, separation, independence);

(d) Layout provisions to protect the system against the effects of internal and external hazards;

(e) Design provisions for monitoring, inspection, testing and maintenance.

3.62 For normal operation, anticipated operational occurrences and accident conditions, the heat removal capacity should be designed taking into account maximal heat loads and maximal heat sink temperature.

3.63 Methods to ensure the robust design of fuel storage systems should be specified in order to fulfill Requirement 18 of SSR-2/1 (Rev. 1) [1]. For all safety classes identified, corresponding engineering design rules should be specified and applied. These include:

(a) Use of appropriate codes and standards;

(b) Proven engineering practices;

(c) Conservative safety margins;

(d) Qualification.

Reliability for operational states

3.64 Gates separating the spent fuel pools from other pools or compartments should be water-tight under normal operating conditions and during anticipated operational occurrences (i.e., gates with pneumatic seals should be provided with reliable back-up air supplies to maintain pressure following a loss of offsite power).

3.65 Provisions should be implemented to detect, collect, isolate and locate any leakage through the pool metallic liners.

3.66 The cooling system operated in normal operation should be designed to maintain the coolant temperature below the maximal temperature specified for normal operation despite the unavailability of cooling components for maintenance purposes.

3.67 The cooling system should be designed to maintain the coolant temperature below the maximal temperature specified for anticipated operational occurrences in the event of the loss of the off-site power.

Reliability for accident conditions

3.68 The system(s) required to remove decay heat in design basis accidents should be designed to meet the single failure criterion.

3.69 The forced cooling system required to remove decay heat in design basis accidents should be emergency power supplied.

3.70 A single equipment failure or piping break in the forced cooling system should not lead to the total loss of forced cooling.

3.71 Means (e.g. isolation valves, anti-syphoning devices) should be implemented to minimize the loss of coolant in the event of a pipe break.

3.72 The system required to remove decay heat in accident conditions should be designed so that it can be restarted in conditions in which the pool water subcooling is lost.

3.73 Water storage pools should not be designed with penetrations below the minimum water level required for shielding and cooling of stored irradiated fuel in accident conditions.

3.74 The volume of the spent fuel pool should be adequate to ensure that, in the event of loss of forced cooling, a sufficient period of time is available to allow for implementation of corrective measures before the water reaches the boiling point.

3.75 Design layout provisions should be implemented to prevent from uncovering the top of the spent fuel assemblies and to maintain a sufficient radiological shielding in the case of inadvertent or accidental leakage through a gate between the spent fuel pool and a drained fuel handling compartment(s).

3.76 The spent fuel storage racks should be designed to maintain adequate heat transfer from each irradiated fuel assembly through natural convective flow to prevent nucleate boiling within the fuel assembly.

3.77 Design provisions should be implemented to compensate for the loss of coolant by evaporation and potential leakage associated with postulated accidents. Such provision includes a permanently installed system that provides emergency makeup to deal with coolant losses.

3.78 Additional provisions should be implemented to facilitate use of non-permanently or other permanently installed equipment to recover the coolant inventory and decay heat removal capability. Such provisions should be in an area where access can be ensured. Connecting devices should be provided outside of the spent fuel storage area. Typical provisions can include:

(a) Connection to other permanently installed systems, for example, service water system and the fire water system;

(b) Installation of piping and fittings to allow connection of cooling system or delivery of makeup water using portable equipment in areas away from the spent fuel pool; and

(c) Provisions for ventilation of the spent fuel pool area to remove decay heat and steam, or

(d) Adequate provisions to recover forced cooling of the spent fuel pool in the event with extended loss of AC power (i.e., station blackout).

STRUCTURAL INTEGRITY

3.79 Structural integrity and operability of structures and components designed to accomplish the fundamental safety functions should be maintained throughout of their own lifetime in all operational and accident conditions during which they are designed to operate. The design should take account of relevant loading conditions (e.g., stress, temperature, corrosive environment, radiation levels), and should consider creep, fatigue, thermal stresses, corrosion, changes in material properties with time (e.g. concrete shrinkage) and potential for degradation of reinforcement considered.

3.80 Loads and load combinations considered in the design should be identified, justified and documented. Typical examples of design loads, load combinations for strength analyses and evaluation of stress analysis results are described in paras 3.81–3.85.

3.81 Design loads that should be considered in the design of the new fuel storage racks include:

(a) Static loads;

(b) Fuel handling machine uplift forces on the racks (with an assumption that the forces are applied to a postulated stuck fuel assembly); and

(c) Seismic loads of the safe shutdown earthquake.

3.82 Design loads that should be considered in the design of the spent fuel storage racks include:

(a) Items (a), (b) and (c) in para.3.81;

(b) Dynamic loads resulting from the fuel assembly drop accident; and

(c) Thermal loads.

3.83 Design loads that should be considered in the design of the spent fuel storage structure include:

(a) Seismic loads associated with the safe shutdown earthquake and associated hydro-dynamic loads due to water movement in the storage area;

(b) Dynamic loads resulting from the cask drops;

(c) Loads from thermal effects of extended loss of cooling event; and

(d) Static loads.

3.84 Methods for combining the individual loads should be established according to applicable codes and standards.

3.85 The allowable stresses for given loading conditions should comply with the applicable limits of proven codes and standards. If no such standards apply, justification should be provided for the allowable stress levels selected.

SAFETY CLASSIFICATION

3.86 Recommendations in paras 3.87–3.91 provide guidance to fulfill Requirement 22 of SSR-2/1 (Rev. 1) [1]. Classification process and guidance for classification is described in IAEA Safety Standards Series No. SSG-30, Safety Classification of Structures, Systems and Components in Nuclear Power Plants [16].

3.87 For classification, the consequences of the failure of the item in terms of accomplishment of the function, the radiation level and the level of the radioactive release should be considered.

3.88 The classification should be established in a consistent manner such that all systems necessary for the accomplishment of a same function in a specific plant state are assigned in the same class or justification should be provided.

3.89 Pressure retaining equipment should be designed and manufactured according to requirements established by national or international codes appropriate to their safety classification and the applicability of the selected design standard justified. For each individual component, the requirements to be applied should be selected with due account taken of the two effects resulting from its failure (function not accomplished and radioactive release)[5].

3.90 Specific structures or components should be designed and manufactured according to requirements established by national or international codes appropriate to their safety classification and the applicability of the selected design standard justified.

3.91 According to recommendations given in [16]:

(a) Structures ensuring subcriticality margins should be assigned in SSG-30 safety class 1;

(b) Systems designed not to exceed the design limits applicable to design basis accidents should be assigned in SSG-30 safety class 2, or in SSG-30 safety class 1 if they are needed in the short term;

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[5] As examples, the pressure retaining boundary of components necessary for the accomplishment of decay heat removal in accident conditions are usually designed and manufactured in compliance with The American Society of Mechanical Engineers (ASME) Section III, Division 1, subsection NC (or Design and Construction Rules for Mechanical Components of Pressurized Water reactor Nuclear Islands – Level 2 (RCC-M2), The Japan Society of Mechanical Engineers (JSME) SNC1, Canadian Standards Association (CSA) – N285.0 or similar standards).

(c) Systems implemented as a back-up of the system designated for design basis accidents should be assigned in SSG-30 safety class 3, or in SSG-30 safety class 2 if they are needed in the short term;

(d) Systems for heat removal in normal operation should be assigned in SSG-30 safety class 3; and

(e) Systems designed for operational states and whose failure would not lead to radiological consequences exceeding the limit specified for operational states need not be safety classified.

ENVIRONMENTAL QUALIFICATION

3.92 Recommendations in paras 3.93–3.98 provide guidance to fulfill Requirement 30 of SSR-2/1 (Rev. 1) [1].

3.93 Structures, systems and components should be qualified to perform their intended functions in the entire range of environmental conditions that might prevail prior to or during their operation until their mission time be completed, or should otherwise be adequately protected from those environmental conditions.

3.94 The relevant environmental and seismic conditions that may prevail prior to, during and following an accident, the ageing of structures, systems and components throughout the lifetime of the plant, synergistic effects, and margins should all be taken into consideration in the environmental qualification. Relevant information is described in [13] and IAEA Safety Standards Series No. NS-G-2.12, Ageing Management for Nuclear Power Plants [17].

3.95 Environmental qualification should include the consideration of such factors as temperature, pressure, humidity, radiation levels, radioactive aerosols, vibration, water spray, steam, flooding, contact with chemical agents, and their combination.

3.96 Environmental qualification should be carried out by means of testing, analysis and the use of expertise, or by a combination of these.

3.97 For components subject to the effects of ageing by various mechanisms, a design life, inspection program and replacement frequency (if appropriate) should be established. In the qualification of such components, samples should be subjected to artificial ageing experiments to simulate the end of their design lives before being tested under design basis accident conditions.

3.98 Qualification data and results should be documented and kept available as part of the design documentation.

PREVENTION OF CRITICALITY

3.99 When subcritical margin cannot be maintained by control of geometry, additional means such as fixed neutron absorbers should be applied. If fixed neutron absorbers are used, it should be ensured by proper design and fabrication that the absorbers will not become separated or displaced during operational states and accident conditions, and during or after an earthquake.

3.100 When soluble absorbers are used to meet the design limit for accident conditions, it should be demonstrated that criticality is not reached if condition with pure water were assumed in normal operation.

3.101 Any geometric deformations of the fuel and storage equipment that could be caused by any postulated initiating events should be taken into account. Consideration should also be given to routine fuel movements, which could bring the fuel being moved into close proximity with stored fuel or in which fuel could be dropped and fall onto or next to stored fuel.

3.102 The lattice of the spent fuel storage racks should be designed to prevent any reduction of subcriticality margins due, for instance, to the entrapment of air or steam during fuel handling or storage.

3.103 Provisions should be made in the design of fuel storage racks to prevent placement of fuel assemblies into positions not justified for their storage.

3.104 In determining the subcriticality, a conservatively calculated value of the effective multiplication factor k_{eff} or, alternatively, the infinite multiplication factor k_{∞} should be used. (General guidance for criticality safety in the handling of fission material is described in IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [18].) The following recommendations apply:

(a) An adequate subcriticality margin under all credible conditions should be demonstrated, with account taken of all the uncertainties in the calculation codes and experimental data;

(b) If the enrichment is variable within a fuel assembly, exact modelling should be used or a conservative uniform enrichment of the fuel assembly should be assumed;

(c) If the enrichments for the fuel assemblies differ, the design of the new fuel storage racks should generally be based on the enrichment value corresponding to that of the fuel assembly with highest enrichment or the most reactive fuel assembly;

(d) All spent fuel assemblies should be assumed to have a burnup and enrichment that result in maximal reactivity, unless credit for burnup is assumed on the basis of a justification that includes appropriate measurements confirming the calculated values for fissile content or depletion level prior to storage of the fuel;

(e) Where the fuel design is variable and/or there are uncertainties in any data relating to the fuel (in terms of design, geometrical and material specifications, manufacturing tolerances and nuclear data), conservative values should be used in all subcriticality calculations. If necessary, a sensitivity analysis should be performed;

(f) The inventory of the fuel storage racks should be assumed to be at the maximum capacity of the design;

(g) Credit should not be claimed for neutron absorbing parts or components of fuel storage racks unless they are permanently installed;

(h) The fuel storage racks should be designed so that lateral, axial and bending loads leading to unacceptable dimensional changes of the fuel are prevented. Any geometric deformations of the fuel and the storage racks that could be caused by any postulated initiating event or by the design basis earthquake should be taken into account in the criticality assessment;

(i) Appropriate conservative assumptions for moderation should be made;

(j) Consideration should be given to the effects of neutron reflection, by taking into account precisely the design of the fuel storage racks including materials, dimensions and spacing between the fuel storage racks and between the fuel storage racks and the structures near the racks (e.g., floors and walls);

(k) Assumptions of neutronic decoupling for different storage zones, if applicable, should be substantiated by appropriate calculations; and

(l) Allowance should be made for the presence of burnable absorbers that are integral parts of fuel assemblies only on the basis of a justification that is acceptable to the regulatory body and that includes consideration of the possible reduction of subcriticality margins due to burnout of a burnable absorber.

RADIATION PROTECTION

3.105 The design of a spent fuel storage facility should be such as to provide for radiation protection of workers, the public and the environment in accordance with the requirements of national legislation, and account taken of the requirements established in IAEA Safety Standards Series No. GRS Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [19] and the recommendations presented in IAEA Safety Standards Series No. NS-G-1.13, Radiation Protection Aspects of Design for Nuclear Power Plants [20].

3.106 Suitable ventilation system(s) and shielding should be implemented to maintain the concentrations of airborne radioactive material and the exposure of workers to direct radiation as low as reasonably achievable in operational states without exceeding limits defined for the protection of workers [14].

3.107 Suitable confinement and filtration systems should be implemented to minimize radiological consequences to the public and the environment and to keep them below the limits defined for operational states and accident conditions.

3.108 For the design of shielding, bounding conditions should be considered for initial fuel composition, burnup and cooling times for gamma and neutron radiation, the inventory at the maximum design capacity of the spent fuel storage facility, the effects of axial burnup on gamma and neutron sources, the mobility of activated crud and the activation of non-fuel hardware.

3.109 Penetrations through shielding barriers (e.g. penetrations associated with cooling systems or penetrations provided for loading and unloading) should be designed to avoid localized high gamma and neutron radiation fields from both the penetration and radiation streaming.

3.110 In dry storage, new fuel containing fissionable material recovered by reprocessing emits a significant amount of radiation. Its handling and storage should include additional shielding to limit the exposure of personnel owing to its higher radiation levels.

MATERIALS

3.111 Structural materials and welding methods should be selected on the basis of accepted codes and standards. Consideration should be given to potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields. In addition, potential thermal effects on material degradation should also be considered.

3.112 The material used for the pool liner and other structure materials in contact with coolant (e.g. racks) should have low sensitivity to corrosion phenomena taking into account coolant chemistry.

3.113 Materials in direct contact with fuel should be compatible with, and should be such as to minimize chemical and galvanic reactions, which might degrade the integrity of the spent fuel during its storage, and should not contaminate the spent fuel with substances that might significantly degrade the integrity of the spent fuel during its storage.

3.114 Materials used in the construction of fuel storage systems should allow easy decontamination of surfaces.

3.115 Compatibility of decontamination materials with the operating environment should be considered.

3.116 Materials used in the construction of fuel storage systems should comply with the recommendations with regards to fire hazard.

3.117 For storage racks that use fixed solid neutron absorbers, it should be possible throughout the operating lifetime of the storage racks to demonstrate that:

(a) Fixed solid neutron absorbers have not lost their effectiveness; and

(b) Fixed solid neutron absorbers are chemically compatible with the other rack components and and are chemically stable when immersed in water.

MONITORING

3.118 Recommendations in paras 3.119–3.125 provide guidance to fulfill requirement 80, para. 6.68A and Requirement 82 of SSR-2/1 (Rev. 1) [1].

3.119 Adequate and qualified instrumentation should be implemented for monitoring water level in the spent fuel storage in operational and accident conditions. Reliable wide-range level instrumentation should be implemented for monitoring under accident conditions.

3.120 Adequate and qualified instrumentation should be implemented for monitoring water temperature in the irradiated fuel storage in operational and accident conditions.

3.121 Adequate and qualified instrumentation should be implemented for monitoring air activity in fuel storage and fuel handling areas in operational and accident conditions.

3.122 Adequate and qualified instrumentation should be implemented for monitoring water activity in the irradiated fuel storage for selected operational and accident conditions.

3.123 Adequate means should be implemented for monitoring chemical parameters in the spent fuel pool in operational states, including monitoring concentration of soluble absorbers, as appropriate.

3.124 Instrumentation required for monitoring of key parameters that will be used in accident management should be redundant.

3.125 Areas in which spent fuel is handled and stored should be provided with suitable radiation monitoring equipment and alarms for the protection of personnel. This should include an adequate number of radiation monitors to ensure protection for the operators of fuel handling machines. Provisions should be made for continuous air monitoring in any area in which airborne radioactive material may be released during the handling of irradiated fuel. More detailed recommendations are provided by IAEA Safety Standards Series No. RS-G-1.8, Environmental and Source Monitoring for Purposes of Radiation Protection [15].

DESIGN FOR SPENT FUEL POOL WATER PURIFICATION SYSTEMS

3.126 Limits on concentrations of radioactive substances should be specified for the spent fuel pools. Limits should also be established for water quality and for levels of atmospheric contamination.

3.127 Systems for spent fuel pool water purification should be designed to ensure:

(a) Radioactive, ionic and solid impurities arising from activation products, damaged fuel and other materials can be removed from the water so as to ensure that the radiation dose rate due to the shielding water itself can be maintained within the specified limits;

(b) The limits relating to the chemistry of the pool water (for instance, boron concentration, content of chloride, sulphate and fluoride as appropriate, pH value and conductivity) which are defined for operation in relation to maintaining subcriticality and minimizing corrosion can be complied with;

(c) The clarity of water can be maintained at an acceptable level so that fuel handling operations in water can be monitored;

(d) Capacity of purification system is able to purify the water volume in the spent fuel pool within a specified period of time; and

(e) Provision is made for the control of microbial growth, as appropriate.

3.128 Systems for spent fuel pool water purification should be designed to be able to remove impurities and suspended particles from the surface of the pool water.

3.129 The design for the spent fuel pool water purification systems should provide measures for the local removal of pool water and for routing to the purification system or to local purification equipment, to be prepared for operations in which the release of radioactive material may increase or the suspension of particles may occur, for instance, during fuel reconstitution.

3.130 The design for the spent fuel pool water purification systems should provide measures for preventing the spread of airborne radioactive materials, including halogens, from the surface of the pool (for example, by positioning the ventilation and air conditioning suction inlets near the pool surface).

3.131 The design for the spent fuel pool water purification systems should provide measures for preventing the unacceptable buildup of contamination in all storage areas and permitting contamination to be reduced to acceptable levels if buildup does occur. Piping should be designed with a minimum of flanges and other features (such as traps or loops) in which radioactive material may accumulate.

3.132 The maximal coolant temperature in normal operation should not exceed the maximal permissible temperature of the purification equipment (e.g., ion exchanger).

ILLUMINATION EQUIPMENT

3.133 Recommendations in paras 3.134–3.137 provide guidance to fulfill Requirement 75 of SSR-2/1 (Rev. 1) [1].

3.134 Operational areas for spent fuel handling and storage, including the pool area, should be provided with the necessary equipment for illumination (i.e., underwater lighting near work areas and some means for the replacement of underwater lamps) to permit the satisfactory handling and visual inspection and identification of the fuel assemblies.

3.135 Materials used in underwater lighting should be appropriate for the environmental conditions and in particular should not undergo unacceptable corrosion or cause any unacceptable contamination of the water.

3.136 Resistance to impact and to thermal shock should be provided to the extent possible.

3.137 Lighting technologies with a high temperature spectrum to maximize the depth of transmission through water should be selected.

4. DESIGN BASIS FOR EQUIPMENT AND COMPONENTS OF FUEL HANDLING SYSTEMS

4.1 Fuel handling systems are mainly used to unload and reload the reactor core.

(a) Fuel handling systems used in light water reactors include:

- Refueling machine to handle the new or spent fuel assemblies for loading and unloading the core and move the assemblies between the core and either the fuel transfer system (for pressurized water reactors) or directly to the storage location (for boiling water reactors);

- System to transfer fuel assemblies between the reactor pool and the spent fuel pool through the fuel transfer tube (for pressurized water reactors); and
- Systems to move and locate fuel assemblies at fuel storages (e.g., auxiliary crane or hoist, new fuel elevator and fuel handling machine).
- Fuel handling tools (e.g., control rod drive shaft unlatching tool, new fuel assembly handling tool, spent fuel assembly handling tool)

(b) Fuel handling systems used in pressurized heavy water reactors (channel type) include:

- System to transport new fuel assemblies to a fueling machine (i.e., new fuel transfer mechanism);
- System to load new fuels into the core and discharge spent fuels from the core (i.e., fueling machine);
- System to transfer the spent fuel assemblies discharged from the fueling machine into the storage pool water (e.g., elevator and ladder); and
- Auxiliary crane or hoist in the fuel building; and
- Fuel handling tools (e.g., fuel bundle grappler).

GENERAL

4.2 A design basis should be defined for every component and equipment of fuel handling systems, and should specify items listed in para.3.3 as applicable.

4.3 In normal operation and in accident conditions, loads should be appropriately limited to ensure that neither fuel damage nor inadvertent criticality is caused and that no damage is caused to the structure of the spent fuel storage pool or the handling equipment.

4.4 Provisions should be made in the design of fuel handling systems to avoid dropping or jamming of fuel assemblies during handling and transfer operations.

4.5 Provisions should be made in the design of fuel handling systems to avoid dropping of fuel handling tools during handling operations.

SAFETY FUNCTIONS

4.6 Fuel handling systems should be designed to maintain subcriticality margins, and to avoid fuel damage, occupational doses, and releases of radioactive material exceeding the specified limits during fuel handling operations. The contribution to the fundamental safety functions of major components and equipment should be described in a level of detail sufficient for a definition of their design bases.

POSTULATED INITIATING EVENTS

4.7 Recommendations in paras 4.8–4.12 provide guidance to fulfill Requirement 16 of SSR-2/1 (Rev. 1) [1].

4.8 Postulated initiating events relevant for the design of fuel handling systems should include equipment failures, operating errors potentially leading to reduction of subcriticality margin, or to a significant release of radioactive materials, or to a significant direct radiation exposure of operating personnel. Such postulated initiating events should be selected to design prevention measures.

4.9 Where fuel handling constraints are essential for maintaining an adequate margin of subcriticality, operational errors such as misplacement of fuel assemblies and uncontrolled drops of fuel assemblies should be considered as postulated initiating events.

4.10 Potential dropping of handled fuel assemblies should be considered as a postulated initiating event. Potential release of radioactive material should be considered regarding the protection of workers and to the environment.

4.11 Fuel misplacement should be avoided in fuel movement activities by implementing interlocks of suitable reliability and quality to preclude such events.

4.12 Mechanical damage caused by excess handling system forces or drop should be considered among internal events unless precluded by reliable interlocks. Possible handling system forces that may cause damage include: fuel assembly hang-up (and two-blocking), translation while hoisting or lowering, or opening the grapple under load. Mechanical damage resulting from excessive motion (e.g., continued lowering after seating of assembly or upward motion into a hard stop) or over-speed should also be considered.

INTERNAL HAZARDS

4.13 To fulfill the requirements relevant to “Internal Hazards” of Requirement 17 of SSR-2/1 (Rev. 1) [1], protection of fuel handling systems should be primarily assured by the layout of the building in which they are installed.

EXTERNAL HAZARDS

4.14 Recommendations in paras 4.15–4.18 provide guidance to fulfill the requirements relevant to "External Hazards" of Requirement 17 of SSR-2/1 (Rev. 1) [1].

4.15 Equipment and components of fuel handling systems should be designed or protected against the effects of external hazards and their combination.

4.16 Protection of fuel handling systems should be primarily assured by the appropriate design of the building in which they are installed. When the protection is not effective (e.g., earthquake), handling equipment should be designed to keep integrity and not to drop the loads in the event of the safe shutdown earthquake.

4.17 Handling and lifting operation during an earthquake should not result in the dropping of loads.

4.18 Seismic design specifications for fuel handling systems should be established on the basis of consequences with regard to potential damage to fuel assemblies (stored or in handling), release of radioactive materials in the building and necessity to operate the equipment during and after an earthquake.

DESIGN LIMITS

4.19 Recommendations in paras 4.20–4.21 provide guidance to fulfill Requirements 15 and 28 of SSR-2/1 (Rev. 1) [1].

4.20 Stresses caused by design load combinations should remain below allowable limits established for fuel, individual components and equipment of fuel handling systems.

4.21 Limits and conditions for the operation of handling equipment (e.g., speed for lifting, lowering, rotating and traversing movement, restricted movements of handling equipment, limitation on lifting capacity to restrict the reduction in shield in thickness, etc.) should be defined and not be exceeded by provision of interlocks.

RELIABILITY

4.22 Recommendations in paras 4.23–4.25, 4.27–4.49 provide guidance to fulfill the Requirements 22, 23, 25, 26, 29 and 30 of SSR-2/1 (Rev. 1) [1].

4.23 Required reliability for individual handling equipment should be defined. This reliability should be specified taking into account consequences of the failure of the equipment. The following factors contribute to achieving the reliability:

(a) Safety classification and the associated engineering rules for design and manufacturing of individual structures, systems and components; and

(b) Design provisions for monitoring, inspection, testing and maintenance.

4.24 Fuel handling systems should be designed by means of conservative methods for load bearing parts.

4.25 Reliability assessment should be conducted to verify whether reliability target has been achieved.

STRUCTURAL DESIGN

4.26 Recommendations in paras 4.27–4.29 provide guidance on strength analyses performed for items important to safety of fuel handling.

4.27 In the strength analyses, it should be demonstrated that stresses caused by load combinations meet the design limits established for individual structures and equipment of fuel handling systems. Typical examples of loads considered in the strength analyses include:

(a) Static loads;

(b) Dynamic loads derived from normal operation of equipment (e.g., loads from handling equipment at acceleration);

(c) Dynamic loads derived from abnormal operation of equipment (e.g., accidental drop of a fuel assembly with a maximal height) and non-symmetrical loads;

(d) Seismic loads defined according to the seismic categorization in [13];

(e) Temperature loads.

4.28 Methods for combining the individual loads should be established according to applicable codes and standards.

4.29 The strength analysis should take credit for equipment provided to limit loads (through devices such as dampers or shock absorbers), and failure modes for this equipment should also be considered.

SPECIFIC DESIGN RECOMMENDATIONS

4.30 For light water reactors, systems for lifting fuel assemblies should be designed so that abnormal handling and lifting operation cannot result in unacceptable loads for the fuel assembly, by means of physical limitations or automatic protection actions (passive or actuated by I&C system). Methods that may be used include:

(a) Restriction of the power of the hoist motor;

(b) Provision of slipping clutches within the drive mechanisms;

(c) Automatic and continuous load sensing and registering devices linked to the hoist motor or cable; and

(d) A specified speed limitation

4.31 Provisions should be made in the design for the use of manual operating equipment that is capable of placing fuel assemblies into a safe location in the event of the failure of the normal operating mode of fuel handling system.

4.32 Handling equipment should be designed to prevent from the leakage and escape of lubricants and other fluids or substances which could degrade the purity of the pool water. Such substances either should be prevented from entering wet storage systems or, preferably, should be fully compatible with fuel, equipment and storage structures.

4.33 Handling equipment should be designed to prevent the inadvertent emplacement of fuel and core components into a position that is already occupied or into an inappropriate position.

4.34 The design of fuel handling and refueling machines can include computerized operational management systems to manage and monitor fuel handling conducted in the reactor building and in the fuel building. The computerized operational management systems can be used to prevent the inadvertent emplacement of a fuel assembly into an inappropriate position and incorrect movements of the fuel assembly. The reliability of this system should be appropriate to conduct fuel loading and unloading operation. The consequences of malfunctioning of this computerized operational management system should be considered.

4.35 For light water reactors, when the fuel assembly is tilted, loads arising in the fuel assembly structure should be limited by means of supports to ensure that no damage will occur.

4.36 For light water reactors, measures should be provided in the design of fuel handling systems to limit the risk of incorrect positioning of a fuel assembly in the vessel during core refueling operations.

4.37 For light water reactors, electrical interlocks to prevent travel of the refuelling machine while the fuel is in an incorrect position should be provided.

Specific design aspects for the refueling machine

Light water reactors

4.38 The hoist gripper of the refueling machine should be designed to grasp securely and to transport fuel assemblies or other assemblies safely. Consequently:

(a) A positive indication that the hoist gripper is correctly located on the fuel assembly before lifting is commenced should be obtained;

(b) The gripper should remain latched upon loss of power;

(c) The gripper should not be capable of decoupling from the fuel while the fuel handling machine is exerting a force on the fuel assembly;

(d) The gripper should only decouple from a fuel assembly at specified elevations, even when no load is applied; and

(e) The gripper should have an inherent safety device that prevents the fuel assembly from becoming unlocked.

Recommendation (c) should be fulfilled by using mechanical interlocks.

Recommendations (a) and (d) should be fulfilled by the provision of automatic interlocks where feasible. If this is not feasible, strictly controlled administrative procedures should be applied.

4.39 Protection devices should be provided to ensure that fuel handling equipment cannot perform horizontal movements during the lifting or lowering of fuel or core components when this could result in the forcing of fuel into position.

4.40 Protection devices (electrical and/or mechanical interlocks) supplemented by administrative measures should be provided to limit the movement of fuel handling machines in order to prevent fuel damage (for instance, a safe load path that is clearly prescribed for each lift).

4.41 The design of electromechanical and electrical protection devices applied to major components of cranes (e.g., hooks, cables) should comply with the single failure criterion in order to prevent damage to fuel assemblies.

Pressurized heavy water reactors

4.42 Design provisions should be implemented to provide continuous cooling in order to prevent significant damage of the irradiated fuel bundles or the failure of the fuel elements due to insufficient cooling to the air, when the irradiated fuel bundles are stuck in the fueling machine and stay for an extended period of time until appropriate action is taken.

4.43 In designs with on power refueling, the fueling machine and interfacing equipment designs should protect the integrity and function of the reactor coolant circuit, specifically but not limited to maintaining the pressure boundary and fuel cooling functions.

4.44 Conditions or failures that could result in a fueling machine becoming stuck during the refueling cycle should be anticipated and provisions put in place to prevent or mitigate consequences. Manual provision should be made available to release the fuel handling machine from sticking position. For designs with on-power fueling, particular attention should be paid to situations where a fueling machine could become stuck on channel in a configuration that could result in local flow blockages.

4.45 The fueling machine design should prevent excessive mechanical loads on new fuel, in-core interfacing fuel, interfacing equipment and spent fuel from exceeding design limits.

4.46 The fueling machine should be designed to withstand loads caused by interfacing systems in operational states.

4.47 The fueling machine should be designed such that contamination of the fueling machine by transporting defect fuel is minimized, and should be designed so as to facilitate decontamination afterwards.

Specific design aspects for the fuel transfer system (pressurized water reactors)

4.48 In a nuclear power plant with a fuel transfer system the fuel transfer system should be designed to ensure adequate cooling of the fuel even during malfunction of the fuel transfer operation.

4.49 When the spent fuel pool is outside of the containment, design provisions should be implemented to meet the containment isolation requirements.

4.50 In case the fuel assembly is jammed due to the failure (or malfunction) of the fuel transfer system, the design of the fuel transfer system should allow access for safe retrieval in a timely manner.

SAFETY CLASSIFICATION

4.51 The equipment and components of fuel handling systems need to be classified taking into account their function and safety significance in order to fulfill Requirement 22 of SSR-2/1 (Rev. 1) [1].

4.52 According to SSR-2/1 (Rev. 1) [1], the classification of handling equipment can be directly derived from the severity of the consequences of equipment failure during handling operation (fuel damage, radiation exposure or release of radioactive materials).

4.53 Safety classified equipment should be designed and manufactured according to requirements established by national or international codes appropriate to their safety classification and the applicability of the selected design standard justified.

ENVIRONMENTAL QUALIFICATION

4.54 Any operating conditions for which the system provides safety functions should be considered in the qualification of fuel handling systems

RADIATION PROTECTION

4.55 Lifting equipment for spent fuel assemblies under water should be designed so that the lift is controlled within limits so as to maintain the minimum required depth of water shielding.

4.56 Hollow handling tools used under water should be designed so that they fill with water on submersion (to maintain water shielding) and drain on removal.

4.57 In handling new fuel (including mixed-oxide fuel) that contains fissionable material recovered by reprocessing and may emit significant amounts of radiation, consideration should be given to providing additional shielding to limit the exposure of personnel, owing to the higher radiation levels associated with the new fuel.

MATERIALS

4.58 Structural materials should be selected on the basis of accepted codes and standards. Consideration should be given to potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields.

4.59 Materials in direct contact with fuel should be compatible with, and should be such as to minimize chemical and galvanic reactions, which might degrade the integrity of the spent fuel during its handling.

4.60 Materials used in the construction of fuel handling systems should allow easy decontamination of surfaces.

5. DESIGN BASIS FOR EQUIPMENT USED FOR SPENT FUEL INSPECTION AND REPAIR, AND DAMAGED FUEL HANDLING, AND DESIGN BASIS FOR HANDLING AND STORAGE SYSTEMS OF IRRADIATED CORE COMPONENTS

EQUIPMENT USED FOR SPENT FUEL INSPECTION AND REPAIR, AND DAMAGED FUEL HANDLING

5.1 Recommendations for handling equipment used for inspection, repair (dismantling and reconstitution), and damaged fuel handling should be established considering those provided in Section 4 applying a graded approach taking into account the consequences should equipment fails.

5.2 Specific considerations to typical handling equipment are described in subsequent paragraphs:

Inspection equipment

5.3 Equipment should be provided for the inspection of fuel assemblies and other core components by visual or other methods.

5.4 Inspection equipment should be designed to minimize the effects of irradiation and to prevent overheating of the fuel.

Dismantling and reconstitution equipment

5.5 Appropriate dismantling equipment should be provided if it is necessary to dismantle fuel in order to retain reusable parts such as fuel channels, and if the dismantling of the fuel is necessary before storage.

5.6 Dismantling and reconstitution equipment should be designed to minimize the effects of irradiation and to prevent overheating of the fuel.

5.7 The dismantling and reconstitution equipment should be designed to preserve the integrity of the fuel rods. The design should prevent possible fuel damage by loads caused by the lifting of dismantled fuel assemblies or fuel rods, by other handling operations such as tilting or by changes to the fuel cladding.

5.8 In the design of dismantling and reconstitution equipment, reliable means should be provided for removing residual heat from the irradiated fuel and from the cleaning equipment of the irradiated fuel.

Damaged fuel handling equipment

5.9 Detection equipment for damaged fuel assemblies should be capable of detecting the failure of irradiated fuel assemblies without further impairing the structural integrity of the fuel.

5.10 Given a potential source of contamination, provisions should be available to place leaking fuel in appropriate special containers. The containers should be designed to withstand the temperatures and pressures resulting from the residual heat of the irradiated fuel and from chemical reactions between the fuel or its cladding and the surrounding water.

5.11 In the design, consideration should be given to the procedures to be adopted for the removal of damaged fuel assemblies or other irradiated core components. The design of special tools for the manipulation of damaged fuel should ensure adequate margin of subcriticality, adequate decay heat removal and shielding. Procedures to permit the use of non-standard equipment should be specified and strict administrative control should be observed.

5.12 Design of canisters encapsulating damaged fuel should be compatible with interim storage, long-term storage, or be capable of being safely unloaded and transferred after the interim storage period.

HANDLING AND STORAGE SYSTEMS FOR IRRADIATED CORE COMPONENTS

5.13 A number of miscellaneous irradiated core components that do not contain fuel will be stored in the spent fuel storage and handled with use of the same handling systems designed for spent fuel. Irradiated core components include components such as reactivity control devices or shutdown devices, in-core instrumentation, neutron sources, flow restrictors, fuel channels, burnable absorbers and samples of reactor vessel material.

5.14 In general, recommendations on fuel storage and handling systems provided in Sections 3 and 4 should be followed. Specific considerations to irradiated core components are described in subsequent paragraphs:

Irradiated core components

5.15 For irradiated core components, particular attention should be paid to the following:

(a) Adequate shielding of irradiated core components should be ensured;

(b) Where the inspection of irradiated core components is necessary, interlocks and other measures should be provided, as appropriate, to ensure the protection of the operators from exposure;

(c) Means of transferring irradiated core components into a suitable shipping container should be provided where necessary;

(d) Specified storage and disposal systems should be provided, together with inspection systems where necessary;

(e) Appropriate care should be taken in handling to protect stored fuel and to limit the possible spread of contamination; and

(f) Irradiated core components should not be stored in the storage area for unirradiated fuel. If necessary, provision should be made for the temporary storage of such items in the storage facility for irradiated fuel.

Neutron sources

5.16 Sufficient shielding and monitoring equipment should be provided to protect personnel against ionizing radiation from neutron sources. The design of the spent fuel pool should indicate that upon the receipt of transport containers containing neutron sources, contamination checks are performed, and that the transport containers for neutron sources are clearly marked according to the requirements of the regulatory body.

5.17 Neutron sources should be separated from the area for spent fuel handling and storage in a distance enough to ensure neutronic decoupling unless a suitable safety case is provided to ensure adequate shielding or decoupling between source and assemblies.

5.18 Arrangements should be made for the clear identification of all sources and administrative controls should be in place for controlling them.

Reusable reactor items

5.19 In most reactor types there are some core components and fuel assembly items that can be reused (such as fuel channels in boiling water reactors or flow restrictor assemblies in pressurized water reactors). These items may be highly activated. If such items are brought to the assembling areas, the spread of contamination and the radiation exposure of personnel should be minimized.

5.20 Reusable components should be capable of being inspected as necessary to ensure their dimensional stability and the absence of any possible damage resulting from operation or handling. Where reusable components contain replaceable items (such as seals) it should be possible to inspect the replaceable component.

5.21 The design of the area for reusable reactor items storage should be such as to prevent reusable components from being contaminated with materials that may affect the integrity of reactor components after the reusable components are reinserted.

6. HANDLING OF CASKS FOR SPENT FUEL

6.1 The equipment for handling the casks should be designed to be compatible with that for lifting fuel and components and should include:

(a) Vehicles for moving casks;

(b) Cranes and associated lifting devices for casks, cask lids or cask internals;

(c) Decontamination equipment;

(d) Radiation monitoring equipment;

(e) Cask draining, flushing, purging and vacuum-drying systems;

(f) Tools for disconnection of cask lids;

(g) Cask testing equipment;

(h) Means and devices for preventing the radioactive contamination of external surfaces of casks;

(i) Means for identifying leaking fuels in casks; and

(j) Illumination equipment.

Operating aspects of fuel casks are described in Annex I.

DESIGN FOR FACILITATING THE HANDLING OF CASKS FOR SPENT FUEL

6.2 General recommendations in Section 4 regarding safety classification, environmental qualification, radiation protection and material should be applied as appropriate to the design of handling equipment of spent fuel casks.

6.3 The spent fuel storage area should be designed to facilitate the handling of spent fuel casks that are to be transported off the site. Consideration of the design of the spent fuel cask is outside the scope of this Safety Guide; for detailed information see [2].

6.4 The design should include systems for decontaminating the casks prior to transport or transfer to storage and to perform leakage tests, surface contamination tests and other necessary tests on the cask. Provision should be made for draining fluids used in decontamination or flushing the cask coolant system (where relevant) to the radioactive waste system.

6.5 The transport route inside the plant should be as short as possible, consistent with safety. Passage over stored fuel should be prevented. Stored fuel, the spent fuel pool liner, and cooling systems and reactor systems essential to reactor safety should be adequately protected from the dropping or tilting of an irradiated fuel cask.

6.6 The probability of a cask drop accident should be reduced by means of an appropriate crane design and appropriate procedures for the inspection, testing and maintenance of the crane and the associated lifting gear, and also by means of adequate operator training. If the cask lifting system is such that failure of a single component could result in an unacceptable dropped load, damping devices should be used together with restrictions on the lifting height in order to be able to mitigate the potential consequences.

6.7 Spent fuel cask handling systems should be designed such as to prevent the dropping of heavy loads during transfer and during loading operations following a design basis earthquake.

6.8 The layout of the area for irradiated fuel cask handling should be designed so as to provide adequate space around the cask for inspection, radiation monitoring and decontamination tests. The necessary storage area for casks and associated equipment (such as shock absorbers) should be provided.

6.9 Administrative means should be developed to ensure that there is no loading of fuel that has been cooled for an insufficient period of time or of a combination of fuel assemblies that is not permitted in the cask.

EXTERNAL HAZARDS

6.10 Protection of handling equipment of spent fuel cask against external hazards should be primarily assured by the appropriate design of the building in which they are installed. Seismic design specifications for handling equipment of spent fuel cask should be established on the basis of consequences with regard to potential damage to fuel assemblies inside the cask and necessity to operate the handling equipment during and after an earthquake. (Design provisions for fuel storage systems are addressed in paras 3.36–3.40.)

VEHICLES AND CRANES USED IN THE TRANSFER OF IRRADIATED FUEL CASKS

6.11 The vehicles or cranes used in the transfer of casks should be designed to limit the possibility of dropping or inadvertently tilting the casks. Vehicles and cranes should be provided with a reliable braking system to ensure that they are not moved unintentionally. Consideration should be given to increasing the reliability of the lifting and transport equipment such that dropping of the load can be treated as a low-frequency event, for example, by the use of single failure proof cranes. Suitably diverse speed limitations on the horizontal and vertical movements of the cranes should be provided so as to ensure the safe handling of the cask.

6.12 To meet the transport regulations in IAEA Safety Standards Series No. SSR-6, Regulations for the Safe Transport of Radioactive Material [21], guidance is provided as follows:

(1) The design should include radiation monitoring equipment that is capable of measuring gamma radiation as well as fast neutrons and thermal neutrons from the cask where relevant.

(2) Provision should be made to measure surface contamination on the cask to ensure that the transport regulations are met before the cask leaves the plant.

6.13 If fuel is transported back to the pool from dry storage, adequate cooling of the cask and the fuel should be provided.

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ANNEX I: OPERATING ASPECTS OF HANDING SPENT FUEL CASKS

I.1 The handling of the spent fuel cask has different aspects depending on the following unloading strategies:

- Unloading by immersion of the cask in the unloading pit, and
- Unloading with connection of the cask under the unloading pit.

I.2 The main actions for each unloading strategy are as follows:

I.2.1 Unloading by immersion of the cask:

- The cask is introduced inside the fuel building on the ground floor by truck or train ;
- The shock absorbers of the cask are removed;
- The cask is tilted to the vertical using the reception hall crane;
- It is transferred to the pool floor (for example 20 meters above) to be put into the preparation pit;
- After its preparation (filling, cooling , contamination protection, etc.), the cask is handled to the unload pit;
- The cask is immersed by the filling of unload pit with pool water;
- The biologic lid is removed to start the unloading of the fuel assemblies;
- When the filling of the cask with fuel assemblies is finished, the inverse process is done.

I.2.2 Unloading with connection of the cask:

- The cask is introduced inside the preparation building;
- Its shock absorbers are removed;
- The cask is tilted to the vertical using the preparation building crane;
- The cask is transferred to the cask wagon;
- The wagon is transferred to the fuel building;
- After its preparation (filling, cooling, removing of the lid, …) the cask is connected under the unloading pit;
- After the connection of the cask, the gate at the bottom of the unloading pit is opened to start the unloading of the fuel;
- After the unloading of the fuel is completed, the inverse process is done.

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