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IAEA SAFETY STANDARDS SERIES

Design of Fuel Handling and Storage Systems for Nuclear Power Plants

SAFETY GUIDE

No. NS-G-1.4

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Information on the IAEA's safety standards programme (including editions in languages other than English) is available at the IAEA Internet site

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DESIGN OF FUEL HANDLING AND STORAGE SYSTEMS FOR NUCLEAR POWER PLANTS

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

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FOREWORD

by Mohamed ElBaradei
Director General

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following bodies oversee the development of safety standards: the Commission on Safety Standards (CSS); the Nuclear Safety Standards Committee (NUSSC); the Radiation Safety Standards Committee (RASSC); the Transport Safety Standards Committee (TRANSSC); and the Waste Safety Standards Committee (WASSC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

The English version of the text is the authoritative version.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide was prepared under the IAEA programme for safety standards for nuclear power plants. It is a revision of the IAEA Safety Guide on Fuel Handling and Storage Systems in Nuclear Power Plants (Safety Series No. 50-SG-D10) issued in 1984. It provides recommendations on how to meet the requirements for the safety of nuclear power plants established in the IAEA Safety Requirements publication Safety of Nuclear Power Plants: Design [1].

1.2. This Safety Guide is related to three earlier publications on the storage of spent fuel: Design of Spent Fuel Storage Facilities [2], Operation of Spent Fuel Storage Facilities [3] and Safety Assessment for Spent Fuel Storage Facilities [4]. Much of the guidance they contain is also applicable to the facilities covered by this Safety Guide.

OBJECTIVE

1.3. The purpose of this Safety Guide is to provide recommendations on the design of fuel handling and storage systems for nuclear power plants. It presents recommendations on how to fulfil the requirements established in the Safety Requirements publication Safety of Nuclear Power Plants: Design [1].

1.4. This publication is intended for use by organizations designing, manufacturing, constructing and operating fuel handling and storage systems in nuclear power plants, as well as by regulatory bodies.

SCOPE

1.5. The scope of this Safety Guide is primarily the design of handling and storage systems for fuel assemblies associated with thermal nuclear reactors that are land based. It addresses all stages of fuel handling and storage, which include:

— the safe receipt of fuel at the nuclear power plant;
— the storage and inspection of fuel before use;

— the transfer of fresh fuel into the reactor;
— the removal of irradiated fuel from the reactor;
— the reinsertion of irradiated fuel when required;
— the storage, inspection and repair of the irradiated fuel and its preparation for removal from the reactor pool;
— the handling of the transport casks.

Limited consideration is given to the handling and storage of certain core components, such as reactivity control devices. The recommendations of this Safety Guide also apply to other reactor types as appropriate, such as gas cooled reactors and reactors that are designed for on-load refuelling.

1.6. Fresh fuel (including mixed oxide fuel) may emit significant amounts of radiation if it contains fissionable material recovered by reprocessing. Although such fuel can be handled without cooling, applicable recommendations are included in this Safety Guide, such as those concerning the provision of shielding.

1.7. Aspects that are not within the scope of this Safety Guide include:

— the reactor physics considerations associated with loading into and unloading out of the core of the fuel and absorber;
— the design aspects of preparation of the reactor for fuel loading (such as the removal of the pressure vessel head and reactor internals for a light water reactor) and restoration after loading;
— the design of transport casks;
— fuel storage over the long term, exceeding the design lifetime of the nuclear power plant;
— the physical protection of fuel or aspects associated with the safeguarding of nuclear material;
— loading of damaged fuel into transport casks with fuel exposed to coolant.

1.8. Reference [2] provides recommendations on the design of storage facilities for spent fuel, which are not an integral part of an operating nuclear power plant, although such facilities may be located on the same site. Such spent fuel storage facilities provide for the safe storage of spent nuclear fuel after it has been removed from the reactor pool and before it is reprocessed or disposed of as radioactive waste.

STRUCTURE

1.9. Fuel handling and storage systems and their functions are described in Section 2. Section 3 covers the general design bases for the facilities. Sections 4 and 5 provide recommendations on the handling and storage of fresh fuel and irradiated fuel respectively. Section 6 covers the handling of casks. Section 7 provides recommendations for sites with more than one reactor. Section 8 covers quality assurance and documentation.

2. FUEL HANDLING AND STORAGE SYSTEMS AND THEIR FUNCTIONS

GENERAL

2.1. Nuclear fuel contains fissile material and, after irradiation, highly radioactive fission and activation products. The most significant design features of fuel handling and storage systems in nuclear power plants are those that provide the necessary assurances that the fuel and core components can be received, handled, stored and retrieved without undue risk to health, safety or the environment. All design features of the fuel handling and storage systems are thus related to the objectives of: maintaining subcriticality of the fuel; ensuring the integrity of the fuel; cooling irradiated fuel; ensuring radiation protection and safety in accordance with the Basic Safety Standards [5]; and preventing unacceptable releases of radioactive material to the environment.

2.2. Different reactor designs and plant layouts are associated with fundamentally different approaches to the design of fuel handling and storage systems. One major difference is that some reactor types are refuelled while at power and others are refuelled in cold shutdown condition. Storage of fresh fuel may be in a dry environment (‘dry storage’) or in water filled storage areas (‘wet storage’). Irradiated fuel that has been discharged from the reactor is initially stored wet. The characteristics of fuel handling and storage facilities will depend to some extent on the individual reactor type. The four flow charts (Figs A-1–A-4) in the Annex present typical systems for the handling and storage of irradiated fuel assemblies for different reactor types, from the receipt of fuel to its final dispatch.

2.3. The design requirements for fuel handling and storage systems are established in paras 6.96–6.98 of Ref. [1]. In addition, general design requirements established in other publications, particularly on quality assurance, operation and site evaluation [6–8], apply to fuel handling in so far as they relate to the adequacy of design validation procedures, the training and experience of operators, and the external events that should be considered in the design.

FRESH FUEL

2.4. For most reactor designs, fresh fuel is first received and stored in a designated dry storage area where it may be inspected and prepared. In addition, for many reactor designs, in particular for light water reactors, the fresh fuel will then be transferred to wet storage before being loaded into the core. For this transfer and the intermediate wet storage, all applicable recommendations for fresh fuel should be fulfilled in addition to the relevant requirements for irradiated fuel. The main differences to be taken into consideration concern the higher reactivity of the fresh fuel and the significantly lower levels of radiation. Nevertheless, radiation protection for the operator may still be required if the fuel has been manufactured from reprocessed uranium or from recovered fissionable material, as is the case for mixed oxide fuel.

2.5. Physical damage to unirradiated fuel assemblies or fuel elements can result in the direct release of fuel material. However, of greater safety concern is the potential for the insertion of damaged fuel into the reactor, where it could result in a serious hazard by jeopardizing safe operation. It should be ensured by means of the proper handling and storage of fresh fuel that fuel integrity is preserved at all times, and means of monitoring the fuel prior to its use should be provided in order to minimize the risk of inserting damaged fuel into the reactor.

IRRADIATED FUEL

2.6. The spent fuel storage facility provides for the safe and secure storage of fuel from the time of its removal from the reactor until such time as it is transferred and loaded into a spent fuel cask for transport away from the reactor site for disposal as radioactive waste or for reprocessing. The facility will therefore include systems for the handling, storage, transfer and retrieval of the spent fuel. The primary safety functions of these systems should be to ensure that the fuel is maintained subcritical at all times, that the integrity of the fuel cladding is preserved, that the fuel is adequately cooled to remove residual heat, that radioactive material is contained, and that there is no undue risk to health and safety or hazard to the environment.

2.7. Irradiated fuel should be transported in shielded and adequately cooled casks that are either internally dry or partially filled with coolant. The casks should have an internal structure to keep the fuel in a well defined geometric arrangement during transport. The casks should be loaded either under water in a specific area at the storage pool or in a separate cask loading pool, or they should be loaded dry. The fuel may first be placed in a basket which may then be loaded into the cask. The systems for cask handling should be such as to ensure that the casks can be received, loaded and prepared for transport, either on the site or off the site, in such a manner that they meet the applicable requirements.

3. GENERAL DESIGN BASIS

GENERAL CONSIDERATIONS

3.1. The fuel handling and storage systems should be designed to ensure the integrity and properties of the fuel in handling and storage. The following fundamental safety functions should be fulfilled at all times to prevent health effects of radiation on plant personnel and the public:

— maintaining subcriticality of the fuel;
— removal of residual heat from irradiated fuel;
— confinement of radioactive substances.

Radiation protection should be ensured in accordance with the Basic Safety Standards [5], with application of the as low as reasonably achievable (ALARA) principle.

3.2. In the design process, proven engineering practices should be used in conjunction with suitably selected input data and assumptions for both normal operational states and credible deviations. The feedback of experience gained at similar facilities should also be considered in the design process and human errors, as components of events and accidents, should be minimized. In following these recommendations, the principle of defence in depth [1] should be applied.

3.3. In the design process, only verified methods should be used for predicting the consequences of conditions in operational states and design basis accidents for fuel storage. Similarly, input data should be conservative, albeit realistic, and should cover both operational states and design basis accidents. When uncertainties in input data, analyses or predictions are unavoidable, appropriate allowance should be made for them, and a sensitivity study should be conducted.

OPERATIONAL STATES

3.4. The fuel handling and storage systems should be designed to function safely in all operational states. The relevant design parameters for normal operation should be defined. For on-load refuelling systems, reactor operating conditions (for example, reactor power level and coolant flow rate) under which refuelling may be permitted should be defined and compliance should be ensured.

3.5. The design should require, and should be such as to ensure, the availability of essential services before any refuelling operation is commenced (for instance, refuelling operations should not be commenced if there are unacceptable faults in the essential electrical supply systems to power hoists, the cooling system or cleanup systems, or if the monitoring systems for confinement and ventilation are not operational).

POSTULATED INITIATING EVENTS

3.6. Analyses should be performed of the effects of postulated initiating events that could affect the design of fuel handling and storage systems and their associated buildings. The postulated initiating events should be selected on the basis of deterministic and probabilistic techniques and the list should include those events described in the following paragraphs. The events can be divided into two classes: events arising within the plant and events generally arising from causes external to the plant [4, 7].

Internally generated events

Dropped loads

3.7. The dropping of objects onto safety related items such as stored fuel assemblies or into the fuel pool is a potential hazard. The design objectives should be to eliminate the possibility of moving heavy objects over stored fuel and to protect stored fuel or other safety related items (such as fuel assemblies, storage racks, the pool and pool liner, and the fuel building) from any dropped loads. The reliability of the lifting equipment should be such that dropping of the load can be effectively discounted, for example, by the use of single failure proof cranes. For the purpose of determining the potential consequences, dropped loads should be considered in categories such as casks or lids, transfer cask and multipurpose sealed basket or canister, fuel and fuel storage racks, and power and hand operated tools. The possibility of a fuel handling accident should be assessed by the designer in accordance with the recommendations of para. 3.27.

Equipment failure

3.8. The design should be such as to ensure that the consequences of credible failures of equipment or systems, both within and outside the storage facility, will not exceed tolerable limits. Examples of such events are: the malfunctioning of cooling systems which may result in a temperature increase or boiling of the pool water; dilution of neutron absorbing material in the water; sticking of a fuel assembly in an improper position; lateral movement of a rack module; exceeding of the design loading weight for the refuelling machine cable; damage to fuel due to improper movement of the drive; and inability to complete the required operation safely.

Internal flooding

3.9. Protection from internal flooding should be provided in order to prevent unplanned criticalities if moderation is used for control purposes and where fuel is handled and stored in dry conditions. Protection from internal flooding should also be provided to prevent the loss or faulty operation of safety related equipment such as spent fuel monitoring systems and cooling systems.

Reactor loss of coolant accident or depressurization

3.10. For all storage areas, the effects of postulated reactor based events should be determined to assess whether any additional protective measures are appropriate and to allow for possible changes in moderation and effects on equipment. For on-load refuelling, the consequences for the refuelling machines and fuel handling operations of a loss of coolant accident or depressurization should be established.

Internally generated missiles

3.11. Missiles generated by failure of rotating machinery, rupturing of pressurized components or other credible means should be considered and protection should be provided if necessary to ensure that there will be no unacceptable consequences for safety. Particular consideration should be given to the storage of gas and conventional fuel and their associated delivery arrangements to prevent the potential for explosion.

Fires and explosions

3.12. The possible consequences of fires causing damage to dry stored fuel, to the cooling capability for fuel stored in the pool or to essential electrical supplies to equipment should be determined. The effects of fire fighting agents on the subcriticality of fuel in storage should be considered.

3.13 The possible effects of air shock waves caused by a postulated explosion at or near the plant should be considered.

Operator error

3.14. The design should have as an objective the limitation of the potential for human error. An analysis of possible operator errors should be conducted, the consequences of such errors should be considered in the design and, where practicable, interlocks and other checks should be provided to prevent their occurrence.

Externally generated events

Loss of off-site electrical power

3.15. The electrical power supplies essential to performing the required safety functions (such as cooling, monitoring and ventilation) without hazard in the event of a loss of off-site power should be provided.

Seismic events

3.16. A seismic analysis should be carried out to assess the following possible consequences of seismic events, and to determine the appropriate seismic classification of the structures, systems and components important to safety:

— dropped loads;
— pool wall failure, pipe failure leading to leakage from pool storage and cooling system failure;
— sliding, tumbling and striking of storage racks against other objects;
— deformation of storage racks;
— displacement of solid neutron absorbers;
— loss of integrity of connections of the fuelling machine to fluid circuits under reactor pressure during on-load refuelling;
— failure of support for refuelling machines, failure of the refuelling machines themselves or failure of transport systems during the movement of fuel;
— the possibility of a failure not connected with refuelling systems causing faults in fuel handling equipment;
— the possibility of a failure of seismically unprotected equipment leading to the consequential failure of components or equipment that would be required in seismic events.

High winds and tornadoes

3.17. The possible effects on fuel handling and storage buildings of missiles or forces generated by high winds or tornadoes should be evaluated, where relevant.

Floods

3.18. The possible effects of floods on the safe storage of fresh and irradiated fuel at plants located on river sites or coastal sites should be evaluated, where relevant.

Other external events [1]

3.19. The possible effects of postulated poisonous gas clouds, explosions, aircraft crashes and other external events should be evaluated, where relevant.

[1] For further guidance, see Refs [9, 10].

Combinations of events

3.20. Consideration should be given to credible combinations of events, using engineering judgement and the results of probabilistic safety analysis, where appropriate.

DESIGN BASIS ACCIDENTS

3.21. Design basis accidents for fuel handling and storage systems should be derived from the list of postulated initiating events, incorporating the boundary conditions for which the systems should be designed. The design basis accidents should include events that may affect the safety of the reactor (dropped loads, for instance).

OTHER CONSIDERATIONS

Equipment classification and qualification

3.22. All structures, systems and components (including equipment) that are important to the safety of fuel handling and storage facilities should be identified and then classified on the basis of their intended function and safety significance.

3.23. The safety classification should be based on deterministic methods complemented as appropriate by probabilistic methods and engineering judgement.

3.24. Structures, systems and components important to safety should be designed and qualified to withstand postulated initiating events commensurate with their safety classification. A fault or malfunction occurring in non-safety-related equipment should not lead either directly or indirectly to the failure of safety related equipment.

3.25. The qualification procedure should include items such as: the fresh fuel store; the spent fuel storage pool; fuel storage racks; pool water cooling systems; lifting and handling equipment; electrical instrumentation and control systems; and associated buildings. It should be ensured that these items are constructed to the highest appropriate design code or standard.[2]

[2] For guidance on seismic qualification, see Ref. [11].

Layout

3.26. The physical layout and arrangement of the fuel storage facilities should be such that subcriticality will be ensured in all operational states and during and following all design basis accidents. The storage facilities should be so designed that physical damage to the stored fuel is prevented and a coolable geometric arrangement is maintained for all conditions, including design basis accident conditions.

Radiation protection

3.27. The design is required to include systems to minimize the release of radioactive substances to the environment and to prevent the exposure of plant personnel and the public as a result of accident conditions involving fuel damage during handling or storage [5]. A limiting calculation should be considered, such as the dropping of one fuel assembly containing the largest realistic inventory of fission products and the consequential rupture of all the fuel rods, to demonstrate that, even on the basis of pessimistic assumptions regarding releases to the environment, the radiological consequences would remain within permitted limits. Less conservative assumptions, such as the damage of an entire outer row of fuel rods, should be justified by mechanistic and empirical arguments.

3.28. Shielding should be provided for the protection of plant personnel in all operations. Appropriate combinations of protection, including interlocks and administrative controls, should be used to prevent irradiated fuel or other radioactive components from being moved into unshielded positions.

Pool water

3.29. Facilities should be provided for monitoring the conditions of the pool water and maintaining acceptable conditions in terms of the level, chemistry, clarity, activity and temperature of water in which fuel is handled or stored.

Handling equipment

3.30. The design of handling equipment should ensure adequate capability for both static and dynamic loads that may be imposed on structures, systems and components.

3.31. Handling equipment should be designed for high reliability to prevent the dropping of fuel assemblies and the imposition of unacceptable handling stresses on the fuel. For all fuel movements, the design of fuel handling equipment should be such that failure of a single component or the occurrence of a single human failure will not result in fuel damage. Exceptions to the single component failure criterion, such as for highly stressed components in the lifting path for on-load refuelling, should be permitted only for specific items and components designed to the highest standards and for which a justification is made. Particular attention should be paid to handling equipment for mixed oxide fuel and appropriate requirements should be specified for handling fuel of this type.

3.32. The movement of objects above fuel storage locations or other items important to safety should be prevented by means of mechanical or electrical interlocks.

3.33. Provision should be made for the use of manually operated equipment capable of placing fuel assemblies into a safe location in the event of the failure of a fuel handling system.

Inspection, testing and maintenance

3.34. The design of facilities and equipment for storage and handling should provide for adequate accessibility to facilitate inspection, testing and maintenance of the equipment and to facilitate monitoring for radiation and contamination.

3.35. Means should be provided for inspecting and identifying individual irradiated and unirradiated fuel modules.

Damaged fuel

3.36. The design should include means for the handling and safe storage of suspect or damaged fuel elements or fuel assemblies and for the reconstitution of damaged fuel if it may be required during operation.

3.37. The design should provide for the decontamination of fuel handling and storage areas and equipment as appropriate.

Human factors

3.38. The design should take into account human factors so as to promote the development of clear operating procedures that minimize the risk of errors. The design should allow for the verification of the intended operation and the detection of any errors in operation that could lead to significant safety problems.

Decommissioning

3.39. Consideration should be given at the design stage to provisions that will facilitate the ultimate decommissioning of the fuel storage and handling facilities.

4. SYSTEMS FOR THE HANDLING AND STORAGE OF FRESH FUEL

GENERAL

4.1. The design of facilities for the handling and storage of fresh fuel should be such as to ensure at all times the fulfilment of the basic safety functions as stated in para. 3.1.

4.2. Subcriticality should be ensured at all times and at all locations where fresh fuel is stored or handled to prevent severe health effects of radiation on any plant personnel and on the public and to prevent any release of radioactive material. The design should be such as to ensure subcriticality even if two independent abnormal events occur simultaneously.

4.3. Areas for the handling and storage of fresh fuel should be maintained under appropriate environmental conditions, for example in terms of humidity, temperature and clean air. Chemical contaminants should not be permitted in such areas at any time.

SYSTEM DESIGN

Subcriticality analysis

4.4. The design should include an analysis of fuel storage facilities which demonstrates that the entire system can always be maintained in a subcritical condition under all possible (normal and abnormal) configurations and conditions, including all possible transitory configurations. The postulated conditions should include the normal dry condition, a flooding condition, with or without the injection of steam, and a totally steam injected condition so as to establish which is the most severe.

4.5. In determining the subcriticality, a conservatively calculated value of the effective multiplication value k_{eff} or, alternatively, the infinite multiplication factor k_{∞} should be used. The following recommendations apply:

(a) An adequate subcriticality margin under all conditions should be demonstrated, with account taken of all the uncertainties in the calculation codes and experimental data.
(b) If the enrichment for individual fuel assemblies is variable, exact modelling should be used or a pessimistically calculated enrichment of the fuel assembly should be assumed.
(c) If the enrichments for the fuel assemblies differ, the design of the facility should generally be based on the enrichment value corresponding to that of the fuel assembly with the most enriched fuel or the most reactive fuel assembly.
(d) 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, nuclear data), conservative values that are pessimistically calculated should be used in all subcriticality calculations. If necessary, a sensitivity analysis should be performed to quantify the effects of such uncertainties.
(e) The inventory of the storage facility should be assumed to be at the maximum capacity of the design.
(f) Credit should not be claimed for neutron absorbing parts or components of the facility unless they are permanently installed, their neutron absorbing capabilities can be determined and they are unlikely to be degraded by any postulated initiating events.
(g) Any geometric deformations of the fuel and storage equipment that could be caused by any postulated initiating events should be taken into account.
(h) Appropriate conservative assumptions for moderation should be made for anticipated operational occurrences.
(i) Consideration should be given to the effects of neutron reflection.
(j) Assumptions of neutronic decoupling for different storage areas should be substantiated by appropriate calculations.

Layout

4.6. The fuel storage configuration should be subcritical in all operational states, and during and following design basis accidents.

4.7. Handling and storage areas for fresh fuel should be secured against unauthorized access and unauthorized removal of fuel.

4.8. A fuel storage area should not be part of an access route to other areas that are not used for fuel handling operations.

4.9. Transport routes for receipt and removal of fuel should be arranged to be short and simple, consistent with safety.

4.10. The layout should provide for an easy exit by personnel in an emergency.

4.11. The layout should prevent the moving of heavy objects above stored fuel, such as racks, storage canisters or lifting devices, the dropping of which may damage the fuel or other items important to safety. Exemptions should be justified.

4.12. The layout should be such as to ensure that unirradiated core components intended to be handled or stored in the areas for fresh fuel are accommodated in a specified and safe manner.

4.13. Sufficient space should be provided to permit the necessary movement of the fuel, other core components, storage containers and handling equipment.

4.14. Adequate and specified storage positions should be available for fuel assemblies, core components and storage containers. Inadvertent placing of the fuel outside the prescribed locations should be physically prevented.

4.15. The layout should permit the inspection of fuel, fuel handling equipment including cranes, and storage containers. Space should be provided for the repair or reconstruction of damaged fuel.

4.16. A dry storage area for fresh fuel should not contain any operational equipment such as valves or piping for which routine periodic surveillance by operating personnel is necessary.

Protection against flooding

4.17. Flooding of the dry storage areas by water or any other moderating material should be prevented by means of the appropriate design of the facility to avoid inadvertent criticality due to moderating effects or physical damage to the fuel. The possible presence of moderating materials should be taken into account in the design of the dry storage area. The routing of water pipes through the dry storage area should be avoided.

Protection against fire

4.18. The design of the fuel handling and storage area should be such as to limit the risk of damage to fresh fuel by fire.

4.19. The presence of combustible materials in the fuel handling and storage areas (such as combustible packing materials or piping systems carrying combustible materials) should be limited and monitored. The routing in such areas of electrical cables that are not essential for supplying power to the equipment for the handling and storing of fresh fuel should be avoided. The fuel storage area should be so designed that subcriticality is maintained during fire and fire suppression activities. Neutron moderating materials such as water or foam should be considered for use in fire fighting only if it can be verified that their effect on subcriticality is negligible. Warning signs that state which fire fighting materials are permissible and not permissible should be placed in the fuel handling and storage areas.

Materials and construction

4.20. The materials and the construction methods used should permit easy decontamination of surfaces. Compatibility of decontamination materials and the operating environments should be considered for all operational states and for design basis accidents. Any ingress of water that could lead to localized corrosion should be prevented.

4.21. For storage systems that use fixed solid neutron absorbers, it should be possible throughout the operating lifetime of the facility to demonstrate that:

— the absorbers are actually installed;
— they have neither lost their effectiveness and physical integrity nor been displaced.

Handling of mixed oxide fuel assemblies

4.22. Owing to the higher radiation levels associated with mixed oxide fuel, consideration should be given to providing additional shielding for the handling of fresh fuel in order to limit the exposure of personnel.

4.23. Since the release of fuel particles may result in an additional chemical hazard, care should be taken to protect the integrity of fuel. As a precaution, the vertical lifting force applied during handling operations for fuel elements should be kept to the minimum necessary.

EQUIPMENT

4.24. Appropriate equipment should be provided for the handling, storage and inspection of fresh fuel. This typically includes:

- cranes or light hoisting gear;
- grippers and other tools specially designed for fuel handling;
- tilting mechanisms for bringing fuel into an upright position (for some reactor designs only);
- storage racks;
- inspection stands which permit access to the whole length of the fuel rods for detailed visual inspection;
- means of assembling, disassembling and repairing fuel;
- means of checking physical dimensions;
- appropriate monitors for contamination and criticality;
- cleaning facilities;
- appropriate shielding devices for mixed oxide or reprocessed fuel.

4.25. Equipment design and procedures for fuel handling should be such as to ensure that no damage is caused to the fuel before or during core loading.

Design loads

4.26. In the design of equipment, the following should be considered with regard to loads:

- A strength calculation of the storage, inspection and handling equipment should be performed with appropriate allowance for the design loads. Design loads should be specified and both static and dynamic loads should be considered. Seismic loads defined according to the safety classification and loads derived from operational and accident conditions, including non-symmetrical loads, should be considered for the dynamic loads. The simultaneous occurrence of the following operational loads should be taken into account:

- loads from fuel assemblies and other core components to be stored, such as reactivity control devices and fuel channels,
- loads from handling equipment, including acceleration loads.

— If vehicles are required for the transport of unirradiated fuel assemblies and their containers, their design should be based on the maximum mass and size of the objects to be transported.
— 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.

4.27. Stresses resulting from operational loads should not exceed the acceptable limits for the various structural load bearing materials.

4.28. Methods and criteria should be established for combining the individual loads. Allowable stresses resulting from postulated initiating events (see Section 3) should also be specified, for instance by the use of an established standard, and these may differ from those for normal operation. Credit may be taken in the analysis for equipment provided specifically to limit loads (through devices such as dampers or shock absorbers), and failure modes for this equipment should also be considered.

Other design considerations

4.29. Equipment for the handling and storage of fuel should not have sharp corners or edges that could damage the surfaces of fuel assemblies or that could hinder the smooth insertion or removal of fuel assemblies.

4.30. The ease of insertion and removal of the fuel assemblies should be considered in the design of the handling and storage equipment. 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. A computerized operational management system may be provided to prevent the inadvertent emplacement of a fuel assembly into an inappropriate position.

4.31. Handling and storage equipment should be so designed that lateral, axial and bending loads leading to unacceptable dimensional changes of the fuel are prevented.

4.32. Fuel handling equipment and associated systems should be recalibrated periodically or, in the case of off-power refuelling, at least before the start of a refuelling campaign. Equipment used to check the physical dimensions of the fuel should not be used for other purposes and should be periodically recalibrated.

4.33. Where fixtures such as clamps are provided to secure fuel assemblies in position, they should be visibly placed.

4.34. Where the operator requires information concerning the state of handling equipment, including the position of the fuel assembly and/or bundle and the state of the gripper, appropriate, clear and conveniently located indications should be provided.

4.35. Equipment for lifting and lowering fuel assemblies and other core components should be designed so that it cannot apply unacceptable loads to any component. To achieve this, physical limitations or automatic protection devices should be used. Methods that may be used include:

— restriction of the power of the hoist motor;
— provision of slipping clutches within the drive mechanisms;
— automatic and continuous load sensing and registering devices linked to the hoist motor or cable;
— a specified speed limitation.

4.36. The hoist gripper of the fuel handling 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 a load is applied.
(d) The gripper should only decouple from its load at specified elevations, even when no load is applied.
(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.

4.37. Equipment should be provided for emergency manual operation to ensure that, under all foreseeable circumstances, fuel assemblies may be readily placed in a safe location during handling.

4.38. 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.

4.39. Protection devices should be provided for the movement of fuel handling machines to prevent fuel damage (for instance, interlocks to prevent the movement of machines too close to pool walls or to prevent any unintended movement during fuel handling).

4.40. The design of electromechanical and electrical protection devices should comply with the single failure criterion.

4.41. Penetrations of transfer equipment into the reactor containment should be considered in the design, where relevant, and should meet design requirements that are consistent with those for the containment.

4.42. The design of fuel handling systems and equipment should prevent 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 facilities or, preferably, should be fully compatible with fuel, equipment and storage structures. Water is fully compatible and may be used in fuel handling systems and equipment.

4.43. For designs in which fresh fuel is transferred to wet storage prior to loading into the core, the recommendations of Section 5 for irradiated fuel apply as appropriate.

SUPPORT SYSTEMS

4.44. Appropriate support systems should be provided for the storage area for fresh fuel, which may typically include:

— a ventilation system;
— a drainage system;
— instrumentation and control systems and communication equipment.

Ventilation

4.45. Where fuel assemblies are stored outside their sealed transport containers, ventilation equipment should be designed to include filtration devices to prevent dust or other airborne particles entering the storage area for fresh fuel. Where unirradiated fuel assemblies are served by the same ventilation system as the irradiated fuel, the system should be designed in accordance with the recommendations of Section 5.

Drainage

4.46. Drains, where provided, should be of such a capacity as to ensure the adequate removal of water for the maximum possible ingress rate and should not represent a possible cause of flooding due to the backup of water. The possibility of blocking of the drains, particularly if the pool water contains chemical substances that can crystallize, should be taken into account, and arrangements should be made for checking the freedom of flow.

Instrumentation and control systems and communication equipment

4.47. Appropriate instrumentation and control systems should be provided. Reliable two way oral communication systems should be available between the fuel handling and storage area and the appropriate control room.

HANDLING OPERATIONS

4.48. The design of fuel handling and storage equipment should be such as to ensure that there is compliance with the applicable requirements and recommendations provided in Refs [3, 7].

4.49. The design should provide for the following:

— safe handling in all operational states and design basis accidents;
— receipt of transport containers, including identification and visual examination as well as the treatment of damaged or unacceptable fuel;
— appropriate inspection, testing and maintenance operations.

4.50. The design should also take into account interactions with other necessary operations and should include the preparation of written instructions where this is required.

5. SYSTEMS FOR THE HANDLING AND STORAGE OF IRRADIATED FUEL AND OTHER CORE COMPONENTS

GENERAL

5.1. The design of systems for the handling and storage of irradiated fuel should be such as to ensure the fulfilment at all times of the basic safety functions stated in para. 3.1.

5.2. Subcriticality should be ensured at all times and at all locations where irradiated fuel is stored to prevent any severe radiation effects on plant personnel or the public and to prevent any release of radioactive material. The design should be such as to ensure subcriticality even if two independent abnormal events occur simultaneously.

5.3. The design should include provisions for the removal of residual heat from irradiated fuel. The capability for heat removal should comply with the single failure criterion and should be such that heat is removed at a rate sufficient to prevent unacceptable degradation of the fuel assembly or storage or support systems that could result in the release of radioactive material. The limiting parameters for the heat removal systems should be specified.

5.4. Contamination levels should be monitored and minimized to ensure a safe operational environment within the plant areas and to prevent unacceptable releases of radioactive material. The design of the storage facility should be such as to prevent any water leaking from the pool from reaching the underground water.

5.5. Shielding should be provided around all areas in which irradiated fuel or activated core components can be placed. This is to protect operators and to maintain their doses due to exposure to direct radiation from fission and activation products below the prescribed limits and as low as reasonably achievable [5].

5.6. Physical damage to fuel assemblies or fuel elements during handling and storage should be prevented.

5.7. The chemistry of the cooling medium should be controlled so as to prevent deterioration of the fuel material, structural components and the pool cooling system for all postulated conditions.

5.8. All systems should have adequate reliability over the design lifetime, commensurate with the potential consequences of their failure. As determined by design specific evaluations, attaining adequate system reliability may necessitate the use of durable construction materials, the redundancy of key components, a reliability target consistent with the functioning of auxiliary services (for instance, the electrical power supply), effective monitoring plans and efficient maintenance programmes (programmes that are compatible with normal facility operations), depending on the storage technology used.

SYSTEM DESIGN

Subcriticality analysis

5.9. In addition to the design requirements that are established for the purpose of ensuring subcriticality, an analysis should be undertaken for all operational states and in conditions during and following design basis accidents to demonstrate that a critical configuration will not be formed.

5.10. In determining subcriticality, a conservatively calculated value of the effective multiplication factor k_{eff} or, alternatively, the infinite multiplication factor k_∞ should be used. The guidelines for new fuel given in para. 4.5 should be followed. In addition, the following factors should also be considered:

(a) Allowance should be made for the possible increase in reactivity due to the buildup of fissionable isotopes or the decay of neutron absorbing isotopes.
(b) Allowance should be made for the presence of burnable poisons only on the basis of a justification that is acceptable to the regulatory body and that includes consideration of the possible increase of reactivity with burnup.
(c) Where spent fuel cannot be maintained subcritical by means of the configuration alone, the design should specify additional means, such as fixed neutron absorbers or the use of a credit for burnup, to ensure

subcriticality. If the pool water contains a soluble neutron absorber, this should be taken into account in the subcriticality studies only if there is no means of providing make-up water to the pool that is capable of causing dilution. Credit both for the soluble neutron absorber and for burnup should not be applied for the same storage area.

(d) All fuel should be assumed to have a burnup level and enrichment value that result in maximum 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) The effects of neutron reflection should be taken into account in all criticality calculations.

(f) Assumptions of neutronic decoupling for different storage areas should be substantiated by appropriate calculations.

(g) The possible storage of incomplete spent fuel assemblies should be taken into account.

Layout for storage

5.11. The recommendations of paras 4.6–4.13 also apply to the layout for storage.

5.12. Adequate and specified storage positions should be used for the storage of the designated contents. This applies to fuel assemblies of all types, reactivity control devices, dummy fuel, fuel channels, instrumentation equipment, neutron sources, other core components and other items such as storage containers or shipping casks. The design capacity should not depend on the storage of fuel assemblies in unauthorized positions, and it should be made physically impossible inadvertently to place fuel outside the prescribed locations.

5.13. Adequate storage capacity for irradiated fuel should be provided to allow sufficient radioactive decay and removal of residual heat before shipment from the reactor. For mixed oxide fuel, the higher residual heat values should be taken into account.

5.14. In determining the adequacy of the storage capacity, consideration should be given to meeting the maximum requirements for fuel storage that may arise at any time during the lifetime of the reactor. In addition, depending on the reactor type, free space should be provided for unloading one full core at any time. The possible need for repair of the pool should be taken into account at the design stage.

5.15. Arrangements should be made for the safe storage of leaking or damaged fuel. In particular, the arrangements for storage of damaged fuel assemblies should minimize the risk of the spread of fissile material during handling and storage.

5.16. Provision should be made for the safe handling of a cask even with fuel storage positions filled to the maximum capacity. The design of the cask handling area should be able to accommodate the various casks envisaged for the facility.

5.17. Other considerations include the following:

— The design should permit access to all parts of the storage facility for which periodic inspection and maintenance is required (for instance, of the welds for connection between the pool sheets).
— The layout should provide for the decontamination and inspection of equipment for fuel handling and storage and casks.
— Space should be provided to permit the required inspection, identification, dismantling and reconstitution of fuel, including possible measurements of burnup.
— Space should be provided for the storage and use of the tools and equipment necessary for the repair and testing of core components and fuel handling and storage equipment. Space may also be necessary for the receipt of other fuel components.
— The layout should be such as to ensure the proper movement of fuel, and to ensure that the fuel and fuel handling equipment will not be damaged.

Protection against fire

5.18. The design intent should be to limit the risk of damage by fire to irradiated fuel, fuel storage structures, fuel handling and storage systems and safety systems.

Materials and construction

5.19. The design of a facility for the storage of spent nuclear fuel should be based on a design life, which is a specified operational lifetime. The design life should include provision for the routine inspection, repair and replacement of parts.

5.20. The safety related systems and components of a spent fuel storage facility should be designed to fulfil their function over the lifetime of the facility. If this is not possible, the design should allow for the safe replacement of such items or systems.

5.21. The selection of structural materials and construction methods should be based on standards acceptable to the regulatory body. Account should be taken of the potential cumulative effects of irradiation on materials likely to be subjected to radiation at high levels.

5.22. The materials of structures and components in direct contact with spent fuel assemblies should be compatible with the materials of the fuel assemblies and should not contaminate the fuel with foreign matter, which could significantly degrade the integrity of the fuel during storage.

5.23. Detailed consideration should be given to the effects of the storage environment on the fuel and on safety related components. In addition, any effects of changes in the storage environment (for instance, through a wetting–drying–wetting process) should be assessed.

5.24. The effects of corrosive agents inside and outside the spent fuel containers (for instance, on fuel cladding or the pool structure) should be taken into account.

5.25. For storage systems that use fixed solid neutron absorbers, it should be possible throughout the lifetime of the facility to demonstrate that:

— the absorbers are actually installed;
— they have not lost their effectiveness or their physical integrity or been displaced in any operational states and would not do so or be so for any accident conditions.

It is permissible to demonstrate the effectiveness by means of calculation.

5.26. Spent fuel storage areas can give rise to conditions such as high humidity, high temperatures and high radiation levels. Safety related items or systems should therefore be environmentally qualified, and limits and/or tolerances should be established so that remedial action is initiated if the limits or tolerances are exceeded.

Design loads

5.27. The recommendations of paras 4.26–4.28 also apply to equipment for the handling and storage of irradiated fuel.

5.28. In normal operations and in design basis 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. (See Section 6 for the consideration of casks.)

5.29. The following loads should be considered in the design:

— the load resulting from the maximum quantity of stored fuel assemblies, reactivity control devices, poison assemblies, dummies and other parts that can be stored;
— the hydrostatic pressure of the water;
— loads caused by the fully loaded cask and other transport equipment;
— temperature induced loads;
— seismic loads;
— other static and dynamic loads such as loads dropped into fuel ponds.

5.30. The effects of irradiation on structures, systems and components should be taken into account.

Pool water systems, purification systems and cooling systems

5.31. The following should be considered in the design:

— Level monitoring and temperature monitoring systems should be provided.
— Overfilling of a storage pool should be prevented. The volume of the pool should be such as to ensure that, in the event of a malfunctioning of the pool cooling systems, a long period of time will elapse before the water reaches boiling point.
— The make-up system should be designed to compensate for the loss of water in all operational states and in design basis accidents, and should use a reliable source of water. The design should also ensure that loss of shielding or loss of cooling will not preclude access by personnel as necessary to perform emergency make-up procedures.
— Pipe routing should be so arranged that, in the event of a syphon effect or the rupture of any connected piping, the water level of the spent fuel pool will not drop below the level at which the stored irradiated fuel is safely submerged. Penetrations to the pool should be above the level at which the stored spent fuel is safely submerged to minimize the effects of penetration failure.

— Where sluice gates are utilized between different pools, they should be designed to withstand full height water pressure from either side. The elevation of the bottom of the sluice gates should be sufficiently higher than the top of the stored fuel assemblies to maintain adequate shielding. Radiation resistant seals should be provided for the sluice gates. The design of the seals should be such that the loss of a support system (such as the compressed air supply) could be withstood.
— Leakage monitoring systems, collection systems and removal systems should be provided.

5.32. Limits on concentrations of radioactive substances should be specified and observed for all fuel storage and handling areas. Requirements should be established for water quality and for levels of atmospheric contamination.

5.33. Only chemically controlled water should be used. A water purification system should be provided which should be so designed that:

— 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 required limits;
— 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;
— the clarity of water can be maintained at an acceptable level;
— provision is made for the control of microbial growth, as appropriate;
— boron dilution can be prevented in pools where soluble boron is used for criticality control.

An automatic monitoring and alarm system for the boron content should be installed.

5.34. Facilities and equipment should be provided for removing impurities and suspended particles from the surface of the pool water.

5.35. For operations in which the release of radioactive material may increase or the suspension of particles may occur, for instance during fuel reconstitution, provision should be made for the local removal of pool water and for routing to the purification system or to local purification equipment. Provision should also be made to prevent 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).

5.36. If fission product removal units (usually resin based) are installed in storage ponds for irradiated fuel, appropriate arrangements should be made for the long term storage or disposal of these units so as to prevent the subsequent release of the absorbed fission products to the environment.

5.37. Systems should be provided 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.

5.38. Pool cooling systems should be designed to ensure the following:

— the removal of the maximum possible heat that could be generated by the pool inventory and maintenance of the pool temperature below the limit for normal operation;
— the maintenance of the integrity of the fuel cladding;
— control of the water level;
— control of the mean water temperature at a level consistent with the design requirements for the pool liner and structures;
— limitation of the spread of possible contamination by evaporation or boiling of the coolant (coolant boiling should be taken into account in the event of an accident condition);
— the acceptability of humidity levels inside the area in terms of maintaining the operability of equipment (such as filtration equipment and electrical equipment);
— the acceptability of the working conditions for operators;
— redundancy or functional diversity of the cooling systems;
— compliance with the single failure criterion.

5.39. Temperature limits for the pool water should be defined with consideration of design heat loads, releases of radioactive materials from the water, effects on the pool structure and on components of the cooling and purification systems, stored fuel racks and handling equipment inside the storage area, loss of water, operator comfort and effects on ancillary equipment such as electrical equipment and air filtration equipment. Different limits may be set for operational states and for accident conditions. Pool cooling systems should be designed to ensure with adequate reliability that water temperatures do not exceed appropriately set limits. If boiling losses or excessive evaporative losses of pool water could occur following an accident condition, the design limits (maximum rate of evaporation, minimum level of pool water) for the pool's structures and systems should be specified. The pool cooling systems should be qualified to ensure that they can be restarted in conditions in which the pool water is close to boiling.

Shielding

5.40. The design should ensure that adequate radiation shielding is provided in the operating area and in rooms and areas adjacent to the locations of the fuel handling systems. In the shielding analysis, it should be assumed pessimistically that:

— all possible fuel storage locations are full, all of the fuel is considered to be at the maximum design burnup for the highest rated fuel and a conservative cooling period, as appropriate, is used;
— a minimum permissible level of water above the fuel assemblies is maintained, with account taken of the maximum elevation of the fuel assembly during handling operations;
— refuelling machines and equipment are full of spent fuel or irradiated material at the maximum credible activity levels and are located in the most disadvantageous positions.

5.41. Redundant equipment should be provided for measuring the water level and should be connected to the alarm system in the appropriate control room. A reliable supply of make-up water should be provided that is available in all operational states and in accident conditions. The possibility of the rapid draining of the pool water due to the loss of leaktightness of a sluice gate should be taken into account. The water level after such a draining should be sufficient to prevent any uncovering of the fuel assembly during handling. If this cannot be demonstrated, then the probability of such a draining should be limited by the design and construction of the building (such as by means of double isolation).

5.42. Handling equipment should be designed to prevent the inadvertent placing or lifting of irradiated fuel into unshielded positions.

5.43. To reduce the radiation exposure of personnel, the design should provide, where practicable, for the remote operation and/or the automation and mechanization of all processes associated with the loading, unloading and handling of fuel assemblies, repair operations and operations involving the replacement of radioactive equipment.

Leaktightness

5.44. Handling and storage areas should be designed for zero leakage. The possible rate of loss of leaktightness following specific accident conditions should not exceed the make-up capability in order to ensure that any consequences of the leakage of water are within acceptable limits in terms of releases of radioactive material and of maintaining the inventory. For all designs, monitoring of the leaktightness should be possible.

5.45. Pools should be designed with a means to collect any leaking water. The location and mitigation of leaks in excess of approved leakage limits should be possible. Means for repairing damage to the storage pool in the event that an incident results in leakage should be provided for in the pool design. Inspection of the storage facilities should be possible in order to anticipate any potential leakage and to detect any leaks not collected by the leak collection system. A temporary storage facility should be incorporated to allow the diversion of the contents of the pool so as to permit repairs to be made to the pool structure and to associated plant and equipment.

EQUIPMENT

5.46. Equipment should be provided for the safe handling of irradiated fuel or other components, either as complete assemblies or parts of assemblies, or in specially designed containers. Such equipment typically includes:

— the fuel handling machine;
— fuel transfer equipment;
— fuel lifting devices;
— devices for lifting core components;
— equipment for fuel dismantling and reconstitution;
— fuel inspection equipment;
— handling devices for fuel storage containers;
— radiation protection equipment;
— decontamination devices.

5.47. All equipment for the handling and storage of spent fuel should meet the applicable recommendations for similar systems used for fresh fuel and the design recommendations stated in paras 5.1–5.8.

Design loads

5.48. The recommendations of paras 5.27–5.30 also apply to equipment for the handling and storage of irradiated fuel and core components.

Handling equipment

5.49. In addition to the recommendations relating to equipment for the handling and storage of irradiated fuel and certain other core components, the appropriate recommendations of Section 4 relating to equipment for the handling and storage of fresh fuel also apply, with due consideration given to the effects of irradiation.

5.50. Equipment for lifting fuel assemblies and other core components should be designed so that the lift is controlled within fixed and acceptable limits. The equipment should be recalibrated periodically or, in the case of off-load refuelling, at least before a refuelling campaign.

5.51. Fuel should be physically prevented from being lifted too far by means such as the use of rods of appropriate length connecting the hoist gripper to the crane or by mechanical stops on the hoist rope. Electrical interlocks to prevent travel of the refuelling machine while the fuel is in an incorrect position should also be provided.

5.52. Specific design considerations should include the following:

- 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;
- the design of handling systems should be such that they do not generate loose parts when used;
- where tools or conventional handling devices are provided for performing operations not relating to the handling of fuel and core components, they should be so designed that they do not prevent any safety related action.

Inspection and dismantling equipment

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

5.54. Appropriate dismantling equipment should be provided it 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.

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

5.56. Equipment for inspection, reconstitution and dismantling equipment should be designed to minimize the effects of irradiation and to prevent overheating of the fuel.

Storage equipment

5.57. Where fuel is stored prior to its transport, either in a cask away from the reactor or by means of transfer equipment to another storage area at the site, storage equipment such as storage racks or storage containers should be provided. Design considerations should include the following:

(a) All fuel storage positions should be accessible by the appropriate fuel handling equipment.
(b) Tilting of fuel racks or movement of fuel containers following postulated initiating events should be prevented, unless it can be demonstrated that no hazard would result from such a movement.
(c) The equipment should be designed to minimize the possibility of excessive lateral, axial and bending loads to fuel assemblies during handling and storage; variations in the dimensions of components as a result of operation should be taken into account.
(d) If it is necessary to tilt or rotate the transport containers or the storage containers, the equipment should be designed to support the fuel in a manner that prevents damage to the fuel elements during such operations.
(e) Provision should be made in the design of storage equipment for ease of dismantling or removal in order to permit overhauling of the racks and maintenance of the pool lining.

(f) The potential effects of heating of the materials used for storage should be taken into account in the design of storage equipment. Boiling of the water in the interspace should be prevented. The design of the storage lattice should prevent any increase in reactivity due, for instance, to the entrapment of air or steam during fuel handling or storage.

SUPPORT SYSTEMS

5.58. In addition to the recommendations for support systems for fresh fuel areas given in paras 4.29–4.43 and 4.45–4.47, the following recommendations also apply.

Illumination equipment

5.59. The pool area should be provided with the necessary equipment for illumination to permit the satisfactory handling and visual inspection and identification of the fuel assemblies. Consideration should be given to providing underwater lighting near work areas and some means for the replacement of underwater lamps. 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. Resistance to impact and to thermal shock should be provided to the extent possible.

Equipment for water cooling and purification

5.60. Equipment for cooling and purifying pool water should be provided. This equipment may use common items in order to meet the objectives for both cooling and purification. If a local or portable water removal system is used for purification, its flow capacity together with an allowance for pool leakage should be less than the make-up flow capacity.

5.61. Attention should be paid to ensuring adequate reliability of the cooling function.

5.62. Facilities should be provided for the decontamination of fuel handling equipment and tools and the cleaning and decontamination, as appropriate, of the casks.

5.63. Installed water removal systems should be actively prevented from drawing the water below the safe level.

Radiation monitoring systems and ventilation systems

5.64. Areas in which irradiated 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. Provision should be made for continuous air monitoring in any area in which airborne radioactive material may be released during the handling of irradiated fuel.

5.65. Ventilation and filtration equipment should be installed and operated in such a manner as to limit the concentration and the potential for the release of airborne radioactive material. In general, the flow of ventilation air should be from areas of lower contamination towards areas of higher contamination, with backflow prevented. The ventilation system may also be designed to prevent high humidity in wet storage facilities, to provide a controlled dust free environment in order to reduce the deposition of dust onto the pool surface and to prevent any danger from flammable or explosive gases.

5.66. Equipment for radiation monitoring and ventilation is subject to the requirements of the Basic Safety Standards [5].

OPERATION

Handling operations

5.67. The design should be such as to ensure that the specific requirements and recommendations given in Refs [3, 7] are or can be complied with.

5.68. The design should provide for:

— all intended and anticipated fuel handling operations;
— appropriate inspection, testing and maintenance operations;
— consideration of interactions with other necessary operations.

5.69. Means for ensuring subcriticality during the removal of absorbers from the core should be provided for in the design. The following administrative and protective measures should be taken, as appropriate, depending on the reactor type:

— restricting the number of reactivity control devices that can be withdrawn at any one time by limiting the provision of equipment necessary to remove them;
— ensuring that, before a fuel assembly containing a reactivity control device is removed, the adjacent fuel assemblies have been removed;
— providing sufficient absorber within the coolant to guarantee that, even if all reactivity control devices are removed, criticality could not be achieved.

On-load refuelling

5.70. The integrity of the pressure boundary for reactor heat transport should be maintained at all times while the reactor is at power. The design should be consistent with this philosophy for those fuel handling systems which refuel at power. Provision should be made to ensure the integrity of the containment at all times during the transfer of fuel across the containment boundary.

5.71. The integrity of the refuelling machine should be consistent with the integrity of the pressure boundary. The probability of a loss of coolant accident and/or the ejection of spent fuel or reactivity control devices should be minimized.

5.72. In order to ensure the integrity of the pressure boundary during fuelling operations, means should be provided to verify the leaktightness of the system before the removal and after the installation of a pressure boundary closure.

5.73. While a refuelling machine is connected to a fuel channel, any movement that could lead to breaching of the pressure boundary should be prevented. The refuelling machine should be prevented from applying excessive load to the fuel channel. The refuelling operation should not so influence the behaviour of the reactor as to cause a hazard in other parts of the reactor system. It should be possible to terminate any refuelling operation safely following an event affecting the reactor.

PROVISION FOR DISMANTLING AND RECONSTITUTION OF IRRADIATED FUEL

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

5.75. During dismantling and reconstitution of the fuel, reliable means should be provided for removing residual heat from the irradiated fuel.

5.76. The accumulation of radioactive dust and gases should be prevented by appropriate design and operation of the ventilation systems or by flows of cooling air, as well as by minimizing the tendency of features in the equipment to accumulate dust and gases. Any ventilation flows extracted from the dismantling facilities should be filtered to remove radioactive substances.

5.77. The recommendations on design for the shielding of operations and the prevention of criticality and the dropping of fuel or other assemblies also apply to dismantling operations for spent fuel.

PROVISION FOR DAMAGED FUEL

5.78. Damaged fuel, as a potential source of contamination, should be placed in appropriate storage 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.

5.79. In the design, consideration should be given to the procedures to be adopted for the removal of damaged fuel assemblies or other core components. The design of special tools for the manipulation of damaged fuel should be in accordance with the recommendations for ensuring subcriticality and shielding mentioned previously. Procedures to permit the use of non-standard equipment should be specified and strict administrative control should be observed.

HANDLING AND STORAGE OF OTHER IRRADIATED COMPONENTS

5.80. The handling and storage of other irradiated reactor core components that do not contain fuel should be considered in the design of the handling systems. These may 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.

Core components

5.81. The recommendations of paras 5.1–5.57 should be followed wherever they are applicable. For core components, particular attention should be paid to the following:

— Adequate shielding of irradiated components should be ensured.
— Where the inspection of irradiated components is necessary, interlocks and other measures should be provided, as appropriate, to ensure the protection of the operators from exposure.
— Means of transferring irradiated components into a suitable shipping container should be provided where necessary.
— Specified storage and disposal facilities should be provided, together with inspection facilities where necessary.
— Appropriate care should be taken in handling to protect stored fuel and to limit the possible spread of contamination.
— Irradiated core components should not be stored in the storage area for fresh fuel. If necessary, provision should be made for the temporary storage of such items in the storage facility for irradiated fuel.

Neutron sources

5.82. Sufficient shielding and monitoring equipment should be provided to protect personnel against ionizing radiation from neutron sources. Upon the receipt of transport containers containing neutron sources, contamination checks should be performed. The transport containers for neutron sources should be clearly marked according to the requirements of the regulatory body.

5.83. Gamma and neutron dose rates should be monitored during the handling of neutron sources.

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

Reusable reactor items

5.85. 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, flow restrictor assemblies in pressurized water reactors or plug units in advanced gas cooled 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.

5.86. 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.

5.87. The design of handling and storage systems for irradiated fuel 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 FUEL CASKS

DESIGN FOR THE HANDLING OF FUEL CASKS

6.1. The equipment provided at a reactor site should be compatible with the handling requirements for the fuel casks[3] to be used.

6.2. Structures, systems and components should be designed and procedures should be developed to prevent activities relating to reactor operations from being affected by activities for cask handling.

6.3. Structures, systems and components should be designed and procedures should be developed to prevent or minimize to the extent practicable the contamination of transfer casks and transport packages. Facilities should be provided for decontaminating the casks prior to transport or transfer to storage and to perform leakage tests, surface contamination tests and other necessary

[3] Casks that are to be transported off the site are subject to the requirements of the Regulations for the Safe Transport of Radioactive Material [12, 13] and other appropriate international standards and national regulations. Consideration of the design of the cask is outside the scope of this Safety Guide.

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.

6.4. The transport route inside the plant should be as short as possible, consistent with safety. Passage over stored fuel should be avoided. If dropping or tilting a cask is considered a postulated initiating event, then these possibilities should be taken into account in the design. Stored fuel, the fuel pool liner, and cooling systems and reactor systems essential to reactor safety should be adequately protected.

6.5. The design of lifting devices should be such as to prevent the dropping of heavy loads. 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. 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.

6.6. The cask handling area should be laid out 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.

EQUIPMENT FOR HANDLING FUEL CASKS

6.7. The equipment for cask handling should be compatible with that for lifting fuel and components and should include:

- vehicles for moving casks;
- cranes and associated lifting devices for casks, cask lids or cask internals;
- decontamination equipment;
- radiation monitoring equipment;
- a cask draining and flushing and/or purging system;
- tools for disconnection of cask lids;
- cask testing equipment;
- means and devices for preventing the radioactive contamination of external surfaces of casks;
- illumination equipment.

6.8. 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. Double braking systems, each with full-load stopping capacity, should be provided. Speed limitations on the horizontal and vertical movements of the cranes should be provided so as to ensure the safe handling of the cask.

6.9. Radiation monitoring equipment should be provided that is capable of measuring gamma radiation as well as fast neutrons and thermal neutrons from the cask where relevant. 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.

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

HANDLING OPERATIONS

6.11. The design of cask handling equipment should be such as to ensure that the applicable requirements and recommendations given in Refs [2, 7] are or can be complied with. The design should provide for:

— the conduct of all intended and anticipated fuel handling operations;
— the conduct of appropriate inspection, testing and maintenance operations;
— the conduct of necessary interactions with other operations;
— the preparation of written instructions where this is required.

6.12. Particular care should be taken to ensure by administrative means 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. Care should also be taken to certify that the consignment conforms with the relevant requirements.

7. FUEL HANDLING AT SITES WITH SEVERAL REACTORS

7.1. On sites with more than one reactor, the fuel handling and storage facilities may be either specific to each reactor or used by several reactors. In all cases the recommendations of the preceding sections should be followed.

7.2. If the transfer of any fuel or components between facilities is needed, it should be done in appropriately designed containers or by other means, as necessary, to ensure that subcriticality and heat removal are maintained at all times and that radiation exposure and radioactive contamination of plant personnel and members of the public are minimized. In addition, means should be provided for protection from mechanical damage during handling, at the reactor units dispatching and receiving the components, and during transport.

7.3. The fuel storage capacity for units sharing the same storage facilities should not necessarily be increased in line with the number of units. Factors such as the period for which storage may be needed and the rate of refuelling of each unit should be taken into account in determining the capacity to be provided.

7.4. At some plants the same refuelling machine or machines or parts of refuelling machines are used for more than one reactor; at other plants refuelling machines are associated with specific reactors and there are common arrangements for transport to shared storage areas. Where the same equipment is used for more than one reactor, it should be demonstrated that the capability of meeting the individual requirements of any one of the units is not impaired and that any faults arising at one unit will not affect the safety of any other unit.

8. QUALITY ASSURANCE AND DOCUMENTATION

QUALITY ASSURANCE

8.1. The design and material of items important to safety should be verified in accordance with the requirements and recommendations of Ref. [6].

8.2. The design specifications and analyses and the as-built data for all equipment should be documented in order to comply with the requirements of Ref. [6]. The documentation should be available to the operator.

IDENTIFICATION, LOCATION AND MOVEMENT OF FUEL ASSEMBLIES AND OTHER CORE COMPONENTS

8.3. The design of all equipment for fuel handling and storage should incorporate features that are necessary for verification of the records on:

- the number and identification of fuel assemblies and other core components;
- the location of each fuel assembly or core component.

8.4. Identification features should be made so durable that they will remain effective during the handling and operation procedures.

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Annex

FLOW CHARTS FOR TYPICAL SYSTEMS FOR THE HANDLING AND STORAGE OF IRRADIATED FUEL

A-1. Figures A-1 to A-4 show flow charts for typical systems for the handling and storage of irradiated fuel for various reactor types.

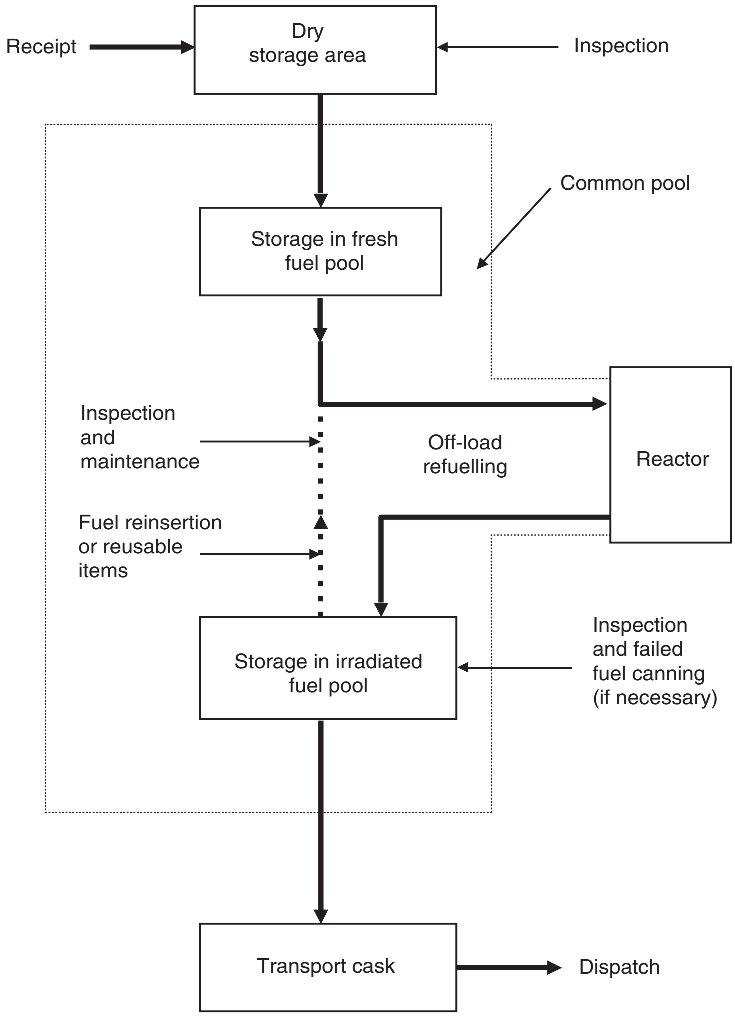

FIG. A-1. Flow chart for a typical system for the handling and storage of irradiated fuel for a light water reactor.

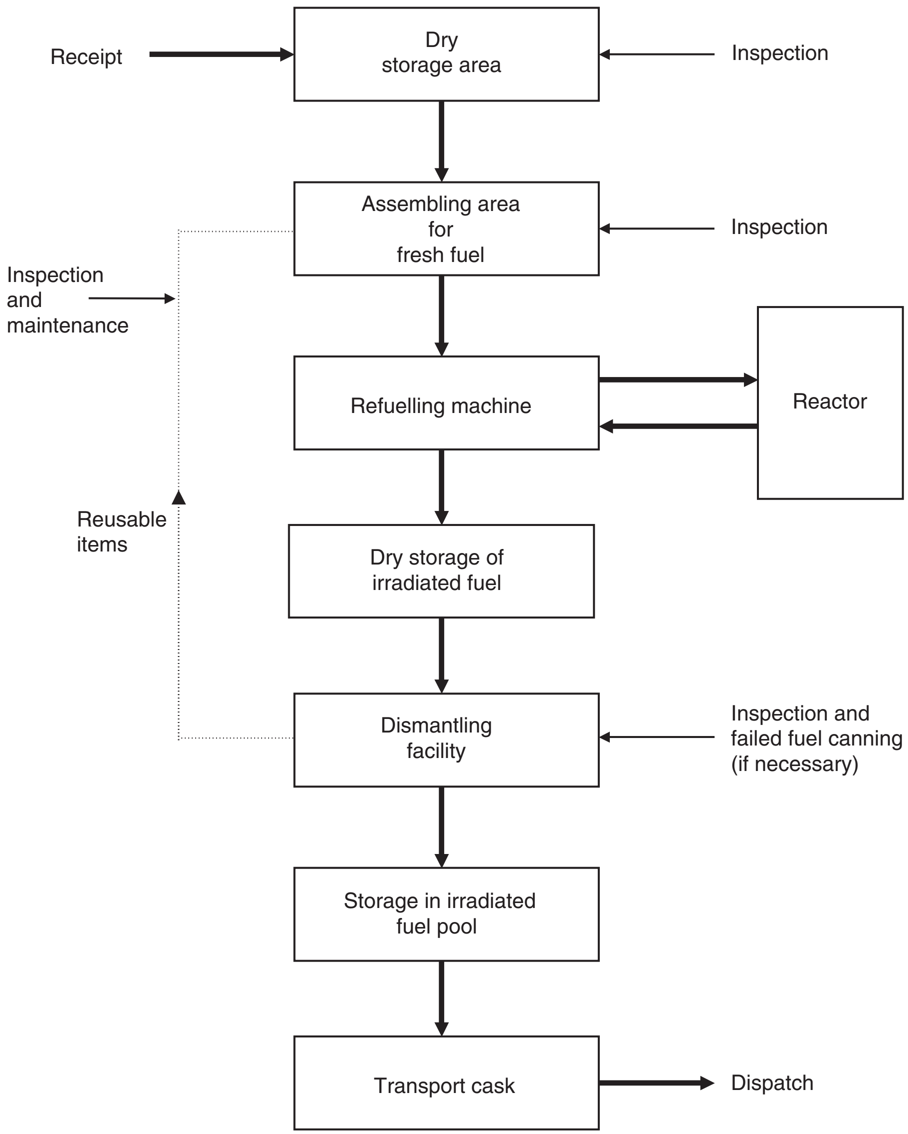

FIG. A-2. Flow chart for a typical system for the handling and storage of irradiated fuel for a gas cooled reactor.

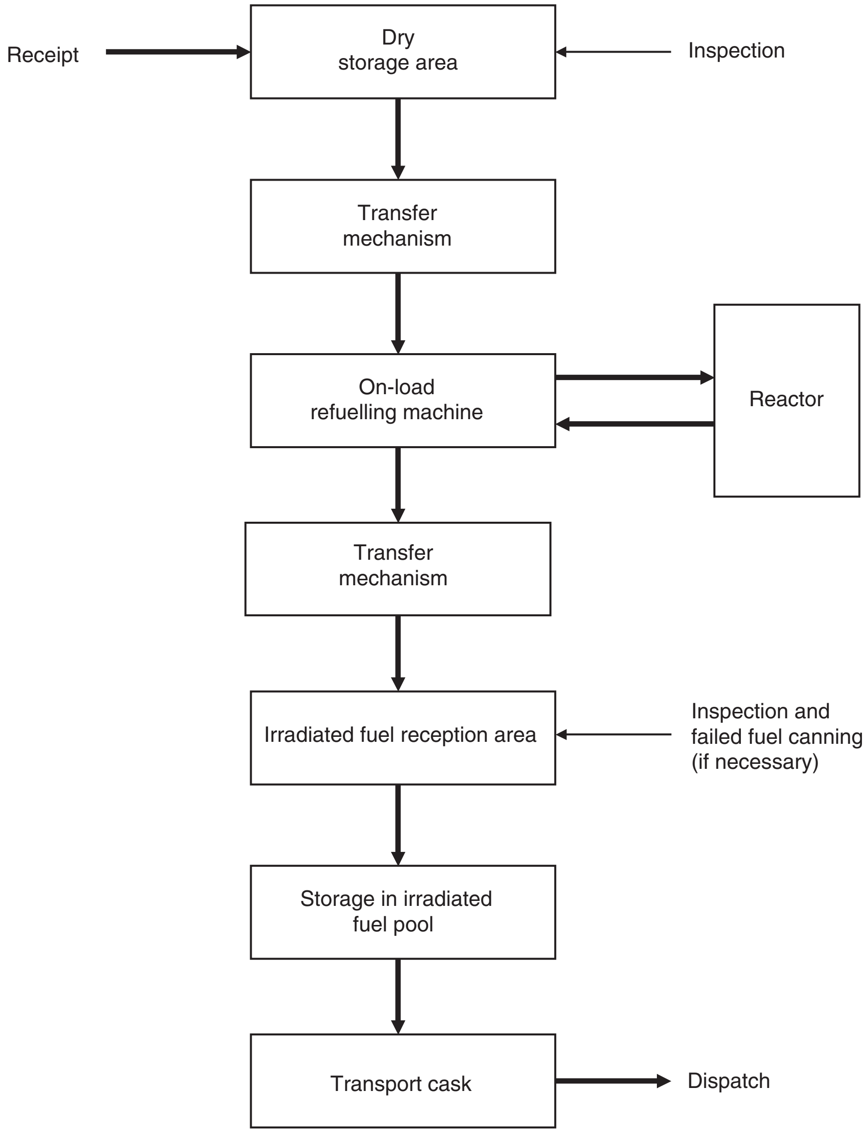

FIG. A-3. Flow chart for a typical system for the handling and storage of irradiated fuel for a pressure tube reactor.

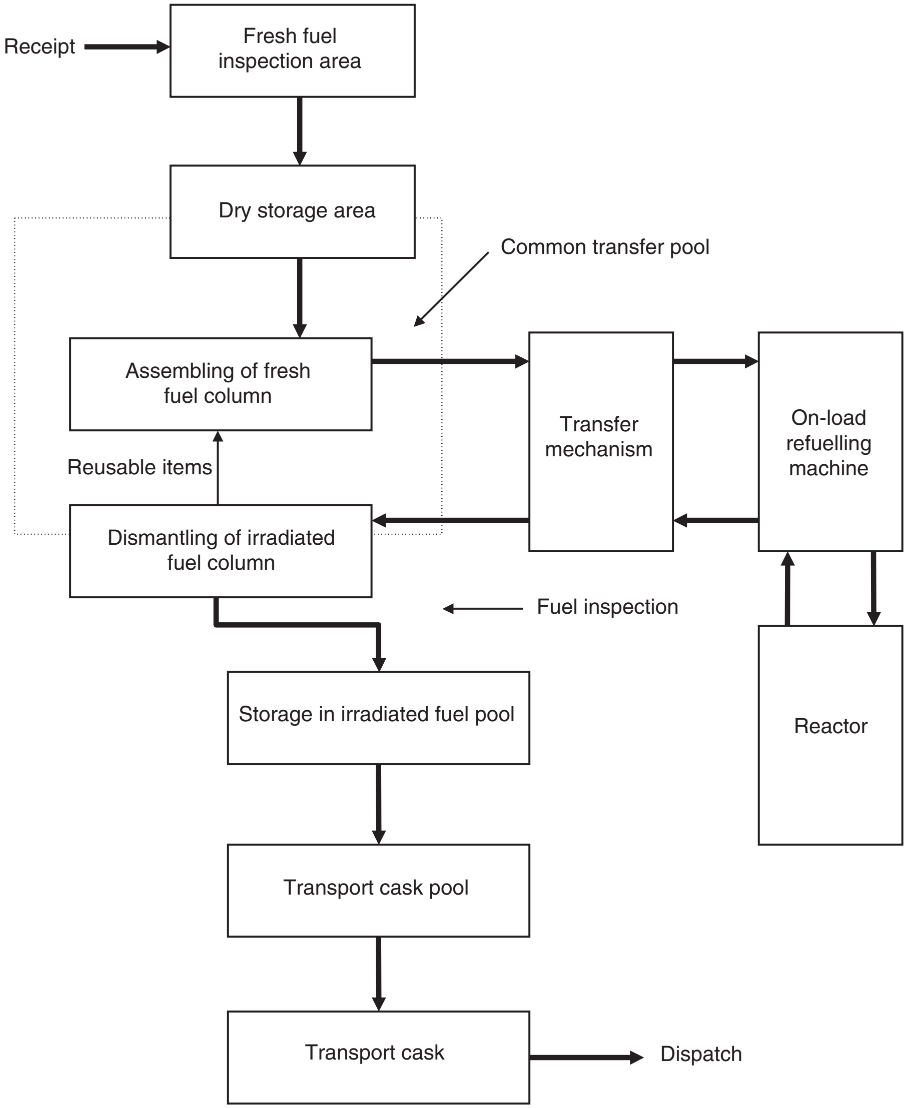

FIG. A-4. Flow chart for a typical system for the handling and storage of irradiated fuel for a pressurized heavy water reactor.

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