

# 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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# 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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# DESIGN OF FUEL HANDLING AND STORAGE SYSTEMS FOR NUCLEAR POWER PLANTS

SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY  
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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.

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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.*

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# 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*<sup>1</sup>

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

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<sup>1</sup> For further guidance, see Refs [9, 10].