AERB SAFETY GUIDE NO. AERB/SG/D-24

DESIGN OF FUEL HANDLING AND STORAGE SYSTEMS FOR PRESSURISED HEAVY WATER REACTORS

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FOREWORD

Activities concerning establishment and utilisation of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the provisions of the Atomic Energy Act 1962. In pursuance of the objective to ensure safety of members of the public and occupational workers as well as protection of environment, the Atomic Energy Regulatory Board has been entrusted with the responsibility of laying down safety standards and framing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety standards, codes of practice and related guides and manuals for the purpose. These documents cover aspects such as siting, design, construction, operation, quality assurance, decommissioning and regulation of nuclear and radiation facilities.

Codes of practice and safety standards are formulated on the basis of internationally accepted safety criteria for design, construction and operation of specific equipment, systems, structures and components of nuclear and radiation facilities. Safety codes establish the objectives and set minimum requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised, when necessary, in the light of the experience and feedback from users as well as new developments in the field.

The 'Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants (AERB/SC/D, 1989)' lays down the minimum requirements for ensuring adequate safety in plant design. This Safety Guide is one of a series of guides, which have been issued or are under preparation, to describe and elaborate the specific parts of the Code.

This Guide is based on the current designs of 220 MWe and 500 MWe Pressurised Heavy Water Reactors (PHWRs). It deals with the design of fuel handling and storage systems for PHWRs and prescribes the minimum requirements to be met in the design for assuring safety. While elaborating the requirements stated in the Code (AERB/SC/D), it also provides necessary information to assist the personnel and organisations participating in the design of Nuclear Power Plants (NPPs)In drafting it, extensive use has been made of the information contained in the relevant documents of the International Atomic Energy Agency issued under its Nuclear Safety Standards (NUSS) Programme.

Consistent with the accepted practice, 'shall', 'should' and 'may' are used in the Guide to distinguish between a firm requirement, a recommendation and a desirable option, respectively. Appendices are an integral part of the document, whereas annexures, footnotes, references/bibliography and lists of participants are included to provide information that might be helpful to the user. Approaches for implementation, different to those set out in the Guide, may be acceptable, if they provide comparable assurance against undue risk to the health and safety of the occupational workers and the general public and protection of the environment.

For aspects not covered in this Guide, applicable and acceptable national and international standards, codes and guides should be followed. Non-radiological aspects of industrial safety and environmental protection are not explicitly considered. Industrial safety is ensured through compliance with the applicable provisions of the Factories Act, 1948 and the Atomic Energy (Factories) Rules, 1996.

This Guide has been prepared by specialists in the field drawn from the Atomic Energy Regulatory Board, Bhabha Atomic Research Centre, Indira Gandhi Centre for Atomic Research and Nuclear Power Corporation of India Limited. It has been reviewed by the relevant AERB Advisory Committee on Codes and Guides and the Advisory Committee on Nuclear Safety.

AERB wishes to thank all individuals and organisations who have prepared and reviewed the draft and helped in its finalisation. The list of persons, along with their affiliations, who have participated in this task, is included for information.

(Suhas P. Sukhatme)
Chairman, AERB

DEFINITIONS

Acceptable Limits

Limits acceptable to the Regulatory Body for accident condition or potential exposure.

Accident

An unplanned event, resulting in (or having the potential to result in) personal injury or damage to equipment, which may or may not cause release of unacceptable quantities of radioactive material or toxic chemicals.

Accident Conditions

Substantial deviations from Operational States, which could lead to release of unacceptable quantities of radioactive materials. They are more severe than Anticipated Operational Occurrences and include Design Basis Accidents and also Severe Accidents.

Anticipated Operational Occurrences

An operational process deviating from normal operation which is expected to occur during the operating lifetime of a facility but which, in view of appropriate design provisions, does not cause any significant damage to Items Important to Safety nor lead to Accident Conditions.

Atomic Energy Regulatory Board (AERB)

A national authority designated by the Government of India having the legal authority for issuing regulatory consent for various activities related to the nuclear facility and to perform safety and regulatory functions including enforcement for the protection of the public and operating personnel against radiation.

Control System

A system performing actions needed for maintaining the plant variables within prescribed limits.

Damaged Fuel

Fuel bundle, which has undergone damage to such an extent that it may get further deteriorated if handled by normal means.

Decommissioning

The process by which a nuclear or radiation facility is finally taken out of operation, in a manner that provides adequate protection to the health and safety of the workers, the public and of the environment.

Design

The process and the results of developing the concept, detailed plans, supporting calculations and specifications for a nuclear or radiation facility.

Design Basis Accident (DBA)

A set of postulated accidents which are analysed to arrive at conservative limits on pressure, temperature and other parameters which are then used to set specifications that must be met by plant structures, systems and components, and fission product barriers.

Design Basis Events (DBE)

The set of events, that serve as part of the basis for the establishment of design requirements for systems, structures or components within a facility. Design basis events (DBEs) include normal operations, operational transients and certain accident conditions under postulated initiating events (PIEs) considered in the design of the facility. (see also Design Basis Accidents).

Fuel Bundle

(also called Fuel Assembly)

An assembly of fuel elements identified as a single unit.

Fuel Element

A component of fuel assembly that consists primarily of the nuclear fuel and its encapsulating materials.

Fuel Failure (Failed Fuel)

A fuel bundle, having failure of clad or end-plug in one or more fuel elements leading to release of radioactive material.

Fuel Handling

All activities relating to receipt, inspection, storage and loading of unirradiated fuel into the core; unloading of irradiated fuel from the core, its transfer, inspection, storage and dispatch from the NPP.

Items Important to Safety (IIS)

The items which comprise:

(1) those structures, systems, equipment and components whose malfunction or failure could lead to undue radiological consequences at plant site or off-site;

(2) those structures, systems, equipment and components, which prevent Anticipated Operational Occurrences from leading to Accident Conditions;

(3) those features which are provided to mitigate the consequences of malfunction or failure of structures, systems, equipment or components.

Normal Operation

Operation of a plant or equipment within specified operational limits and conditions. In case of nuclear power plant this includes start-up, power operation, shutting down, shutdown state, maintenance, testing and refuelling.

Nuclear Safety

Protection of all persons against undue radiological hazard.

Operating Basis Earthquake (OBE)

The 'Operating Basis Earthquake' (OBE), is that earthquake which, considering the regional and local geology, seismology and specific characteristics of local (sub-surface) material, could reasonably be expected to affect the plant site during the operating life of the plant; it is that earthquake which produces the vibratory ground motion for which the features of Nuclear Power Plant (NPP) necessary for continued safe operation are designed to remain functional.

Operational States

The states defined under 'Normal Operation' and 'Anticipated Operational Occurrences'.

Postulated Initiating Events (PIE)

Identified events that lead to Anticipated Operational Occurrence or Accident Conditions, and their consequential failure effects.

Quality Assurance

Planned and systematic actions necessary to provide adequate confidence that an item or a facility will perform satisfactorily in service as per the design specifications.

Redundancy

Provision of alternative (identical or diverse) elements or systems, so that anyone can perform the required function regardless of the state of operation or failure of any other.

Reliability

The probability that a device, system or facility will perform its intended function satisfactorily under stated operating conditions.

Residual Heat

The sum of the time-dependent heat loads originating from radioactive decay and shutdown fission and heat stored in reactor-related structures and heat-transport media in a nuclear reactor facility.

Sealing Plug (Coolant Channel)

Device used to close the ends of a coolant channel in a leak tight manner.

Single Failure

A random failure, which results in the loss of capability of a component to perform its intended safety function. Consequential failures resulting from a single random occurrence are considered to be part of the Single Failure.

SPECIAL DEFINITIONS
(Specific for the present guide)

New Fuel

Fuel bundle containing natural uranium or depleted uranium or thorium, which is not expected to emit any significant radiation.

Shipping Cask

Container for transport of irradiated fuel.

Shipping Container (Radioactive Components)

Container for the transfer or transport of irradiated core components, except irradiated fuel.

Spent Fuel

Fuel bundle removed from the reactor core after undergoing irradiation.

CONTENTS

1. INTRODUCTION

1.1 General

This Safety Guide concerns the safety aspects of the design of fuel handling and storage systems in pressurised heavy water reactor (PHWR). It describes how the objectives contained in para 1100 of the 'Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants (AERB Code No. SC/D)', hereinafter referred to as the Code, are to be achieved.

Fuel handling and storage involves activities related to the receipt of new fuel in the nuclear power plant, the storage and inspection before use, transfer of new fuel into the reactor, removal of irradiated fuel from the reactor and its reinsertion when required, transfer to the spent fuel storage bay, underwater storage and inspection, loading into a shipping cask and handling of the shipping cask. A typical arrangement of the systems is shown in Figure 1.

1.2 Objectives

The objective of this Safety Guide is to specify the minimum requirements to be met in the design of fuel handling and storage system in PHWR. It is intended to be used by the designer to ensure safety of plant and personnel by providing adequate measures for prevention of accidents and mitigation of adverse consequences, should an accident occur.

1.3 Scope

The scope of this Guide includes the design of handling and storage facilities for fuel bundles from their receipt into plant and until their dispatch from the plant. The new fuel considered in this Guide is natural or depleted Uranium or Thorium, which is not expected to exhibit any significant level of radioactivity, and can be handled without shielding or cooling. The scope of this Guide includes safety in design of equipment for handling and storage of new fuel, spent fuel and other irradiated core components, which are related to handling of fuel including handling and storage of failed or damaged fuel bundles. This Guide also addresses the safety aspects in fuel handling control and instrumentation and auxiliary equipment related to the fuel handling system. Design provisions to facilitate inspection and testing of fuel handling and storage systems are also covered in this Guide.

References are made to AERB Safety Guide on 'Safety Classification and Seismic Categorisation (AERB/SG/D-1)', 'Fuel Design (AERB/SG/D-6)', 'Core Reactivity Control in Pressurised Heavy Water Reactor (AERB/SG/D-7)' and 'Primary Heat Transport System for Pressurised Heavy Water Reactors (AERB/SG/D-8)'. However, the following are excluded from the scope of this Guide.

(i) use of new fuel containing Plutonium or enriched Uranium;

(ii) spent fuel storage facilities of a long-term nature, which are not part of the plant;

(iii) design of shipping cask;

(iv) reactor physics aspects of refuelling issues associated with fuel loading and unloading.

2. SAFETY AND DESIGN REQUIREMENTS

2.1 General

General criteria and principles for design of nuclear power plants are given in Chapter 0300 of the Code. Design approaches and requirements for fuel handling and storage system are given in Chapter 1100. Requirements for reactor coolant system specified in Chapter 0500 also include certain points for fuel handling system under sections 0521, 0522 and 0523. In addition, general requirements stated in other AERB codes and guides shall also be considered wherever applicable and relevant to fuel handling and storage. The measures for prevention of inadvertent criticality are of no concern for PHWR because natural uranium fuel cannot go critical during handling and storage. However, if enriched fuel or Mixed Oxide (MOX) fuel is used in PHWR, applicable sections of the criteria given in Appendix shall be taken into account.

2.2 Safety Requirements

Since spent fuel is highly radioactive and generates decay heat, the fuel handling and storage systems shall be designed in conjunction with other appropriate systems to prevent the following occurrences, during normal operation and all design basis events:

(i) undue radiation exposure of personnel;

(ii) radiation damage to items important to safety;

(iii) release of radioactivity beyond prescribed limits; and

(iv) damage to spent fuel bundles.

2.3 Design Requirements

In order to satisfy the above safety requirements, the following design requirements shall be met:

(i) The fuel handling and storage systems shall be classified as per the AERB Guide on 'Safety Classification and Seismic Categorisation (AERB/SG/D-1)'.

(ii) The fuel handling system/equipment shall be designed to codal/OBE/SSE requirements as applicable. Annexure-1 gives the safety classification and seismic categorisation as applicable to the fuel handling system.

(iii) Adequate means shall be provided for inspecting new as also the spent fuel.

(iv) The design shall include facilities for handling and storage of damaged fuel bundles.

(v) The design shall include heat removal under all design basis events.

(vi) Handling equipment shall be designed to prevent dropping of fuel bundles or the imposition of unacceptable handling loads on the fuel bundle.

(vii) The dropping of objects (which have the potential to cause damage) onto the fuel storage facility or other items important to safety shall be prevented.

(viii) The design shall ensure that the fuel is placed in the reactor in the intended form and manner.

(ix) Adequate shielding facilities shall be provided for the protection of personnel under all design basis events. Appropriate combinations of physical barriers, interlocks and administrative controls should prevent transfer of radioactive materials to unshielded positions.

(x) The design shall provide for decontamination of fuel handling and storage areas/equipment, where necessary.

(xi) The design shall include systems to detect and keep within acceptable limits the release of radioactivity to the public and the exposure of operators, occurring as a result of accident conditions involving fuel damage during handling or storage.

(xii) The design shall be such that procedures can be instituted to ensure proper accounting of fuel bundles.

(xiii) The design shall include a test facility for checking the function of refuelling machine, whenever required.

(xiv) The design of storage and handling facilities/equipment shall provide for adequate accessibility in order to facilitate inspection, testing and maintenance of the equipment and to allow radiation monitoring and contamination checks.

(xv) The design shall be such as to facilitate maintenance and decommissioning of the fuel storage and handling facilities.

(xvi) The design shall ensure adequate capability to withstand all static and dynamic loading that may be imposed on structures, systems and components.

(xvii) For underwater storage systems, facilities for controlling the level, temperature, chemistry, clarity and radioactivity of water in which the fuel is handled or stored, shall be provided.

(xviii) The irradiated fuel storage bay should be designed to have an additional capacity to accommodate one full-core fuel discharge under all conditions.*

(xix) Systems/components whose failure can result in loss of shielding or cooling or mechanical damage to the bundles being handled should meet the single-failure criteria. Any non-compliance shall be adequately justified.

(xx) Height of spent fuel stacked in the storage bay shall be restricted to ensure adequate water shielding all the time.

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*The general practice in PHWR is to store spent fuel discharge of about 10 full-power years in the storage bay.

3. HANDLING AND STORAGE OF NEW FUEL

3.1 General

This chapter describes the design safety requirements for the storage and handling of new fuel bundles, starting from the stage when it is received at the plant site till it is loaded in the transfer mechanism.

These requirements are specifically aimed at meeting the applicable general safety requirements as stated in Section 2.2, particularly those associated with maintenance of new fuel quality such that the fuel is placed in the reactor in the form and manner in which it is intended.

3.2 System Design Requirements

3.2.1 Layout

The design requirements associated with the layout of new fuel storage and handling system are as follows:

(i) new fuel shall be stored in a specified and exclusive area secured against unauthorised access;

(ii) the storage area shall not be part of an access route to other operating areas;

(iii) the transport routes for receipt and removal should be unobstructed;

(iv) the layout shall provide easy exit of personnel in an emergency;

(v) the layout shall prevent the movement of heavy objects, which are not part of the lifting devices, over the stored fuel bundles;

(vi) adequate and specified storage positions shall be available for fuel bundles;

(vii) the layout shall provide adequate space for the inspection of fuel bundles;

(viii) space shall be provided to permit the necessary movement of bundles, handling of equipment and storage containers; and

(ix) design should be such that minimum handling and transportation needs to be done with new fuel before loading into the transfer system.

3.2.2 Mechanical Loads

The design for fuel handling system shall ensure that the fuel bundles are not subjected to mechanical loads beyond specified limits during their handling, fuelling or transfer operations.

3.2.3 Protection against Flooding and Fire

(i) Flooding of the storage areas shall be prevented.

(ii) The design of the fuel handling and storage areas shall meet the requirements of Safety Guide on 'Protection Against Fires in Nuclear Power Plants (AERB Safety Guide No. AERB/SG/D-4)'. The design intent shall be to limit the risk of damage to new fuel bundles through fire.

Use of combustible materials in storage areas should be avoided. The piping system carrying combustible materials and electrical cables which are not directly necessary for supplying power to the equipment for handling and storing new fuel bundles shall not be routed through the storage areas.

3.2.4 Inspection

Adequate means, such as gauges for dimensional check and helium leak test for checking cladding integrity, should be provided for inspecting new fuel.

3.3 Equipment Design Requirements

The design requirements for handling equipment, storage and inspection of new fuel bundles are as follows:

(i) The equipment shall be designed for all static and dynamic loads including load arising out of OBE.

(ii) Equipment shall not contain sharp corners and edges that could damage the surfaces of fuel bundles.

(iii) Ease of insertion and removal of the fuel bundle shall be considered in the design of the storage equipment.

(iv) Unintended movements of fuel handling equipment shall be prevented by suitable protective devices, e.g. interlocks.

4. ON-POWER REFUELLING

4.1 General

This chapter describes the design safety requirements for the on-power fuelling machines and associated process systems, and also includes handling of new fuel bundles. Functions covered in this chapter are:

(i) receipt of new fuel from transfer mechanism,

(ii) loading of new fuel into the core,

(iii) receipt of spent fuel from the core, and

(iv) discharge of spent fuel into the transfer mechanism for further transportation to storage bay.

Refuelling of PHWR is normally done on-power by employing two fuelling machines located on either side of the reactor. A typical schematic representation is shown in Figure 2. The refuelling is done along the direction of the flow of reactor coolant.

Both fuelling machines clamp on the reactor channel to be refuelled and establish communication with the channel by removing the sealing plugs. The upstream machine inserts new fuel bundles and the downstream machine, acting in unison, receives the spent fuel bundles in specified time. During the initial period of reactor operation, a few partially spent fuel bundles are removed from one channel and inserted into another. Normally eight bundles are replaced by new bundles in order to optimise the operation. Administrative methods are employed to keep track of the movement of fuel bundles right from loading into reactor up to their storage in the bay.

The safety requirements associated with on-power refuelling are:

(i) maintaining integrity of pressure boundary of the reactor coolant system,

(ii) ensuring cooling of spent fuel bundles in the fuelling machine under all design basis events,

(iii) prevention of physical damage to fuel bundles,

(iv) prevention of undue radiation exposure, and

(v) prevention of unacceptable release of radioactivity.

4.2 System Design Requirements

4.2.1 Layout

Design requirements associated with the layout of fuelling machines and associated process systems are as follows:

(i) the layout shall provide for bringing the fuelling machine to an accessible service area for minor repairs and routine maintenance even when reactor is in operation;

(ii) the layout shall facilitate access to process system components to the extent necessary to carry out trouble shooting and resolving problems;

(iii) operational area of fuelling machine shall be secured against unauthorised access;

(iv) space shall be provided to allow required maintenance, inspection and testing of fuelling machines; and

(v) passage of fuelling machine through the containment shall meet the requirements of containment integrity.

4.2.2 Cooling

Provision for cooling fuel bundles under all design basis events during fuelling shall be adequate to remove residual heat to ensure integrity of fuel cladding. Necessary redundancy shall be provided to meet the above requirement.

4.2.3 Mechanical Loads

During the refuelling operation, loads shall be appropriately limited to ensure that no damage is caused to fuel bundles. The fuelling machine shall be designed to ensure that stresses caused due to loads under all operational states are within allowable limits of appropriate codes. The typical loads to be considered for analysis are:

(i) operational loads,

(ii) internal pressure,

(iii) thermal stresses,

(iv) earthquakes,

(v) temperatures for normal operation and anticipated abnormal operation, and

(vi) loads due to design basis accidents.

4.2.4 Integrity of Pressure Boundary

During on-power refuelling, the fuelling machine is considered to be a part of the reactor coolant system, starting from coupling of fuelling machine heads on to the coolant channel till its decoupling from the coolant channel. Hence, the fuelling machine integrity shall be consistent with the integrity of reactor coolant pressure boundary. To achieve this the following design provisions shall be made:

(i) Clamping mechanism of the fuelling machine head makes leak-tight connection before opening of the pressure boundary. Reliable and redundant safety provisions shall be made to prevent accidental unclamping.

(ii) Since sealing plugs form a part of the primary pressure boundary, means shall be provided for proper installation of sealing plugs and checking for leakage of heavy water.

(iii) Means shall be provided to verify the leak tightness of the system before removal and after installation of the sealing plugs.

(iv) Since the movement of fuelling machine, while connected to a coolant channel, could lead to breaching of reactor coolant pressure boundary, measures to prevent this from occurring shall be taken.

(v) Postulated off-normal situations arising out of failure of certain mechanisms and common cause failures shall be analysed and mitigating provisions made in the design. A typical list of design basis events is given as Annexure-2. Some of the incidents in fuel handling systems, as experienced, are described in Annexure-3.

4.2.5 Interaction with Reactor

The rate of change of reactivity caused during refuelling operation shall be limited so as to be consistent with the capability of reactor control system. The movement of fuel bundle during refuelling shall be compatible with the design of the fuel bundle.

Whenever refuelling against the flow direction is considered, the addition of positive reactivity shall be analysed. It shall be ensured that such reactivity excursion is within the capability of the reactor regulating system.

4.2.6 Test Facilities

Considering the complexity of the fuelling machines and their controls, it is necessary to test each fuelling machine head in conditions closely simulated to actual operation. It is also desirable to perform certain tests after a major overhaul or maintenance before going to a channel for refuelling. Different facilities designed to meet specific objectives should be provided for such testing. They can be broadly categorised as rehearsal test facility and maintenance test facility.

(i) *Rehearsal test facility*

The rehearsal test facility shall be located close to the reactor within the normal travel distance of the fuelling machine. This facility shall have provisions for carrying out a complete rehearsal of all sequences in a normal refuelling operation to watch and record important parameters and to ensure proper functioning. The fuelling machine should be accessible when it is on the rehearsal test facility, so that any snag can be conveniently rectified without undue exposure.

This facility should be designed to withstand the loads subject to it by fuelling machine and the components should be fully compatible with the fuelling machine.

(ii) *Maintenance test facility*

Separate provisions shall be made to carry out periodic maintenance, calibration and functional testing of fuelling machines, their sub-assemblies and other critical components of the fuel handling system. This maintenance test facility shall be located outside the reactor building in order to avoid radiation exposure to the maintenance personnel. This facility should consist of oil hydraulic, water hydraulic, electrical and pneumatic systems of adequate capacities to carry out the intended maintenance and calibrations.

4.2.7 Additional Uses of Fuelling Machine

Apart from the normal refuelling operations, the fuelling machine may be used for the following additional functions:

(i) *Removal of all fuel bundles from a coolant channel:*

The fuelling machine should be capable of removing all the fuel bundles from a channel and to accommodate them. Necessary tools like grappler-extensions shall be available for this purpose.

(ii) *Removal of fuel bundles by grappling:*

If one of these fuelling machines gets stuck, the fuel bundles may have to be removed by using the healthy fuelling machine with tools like grappler and grappler-extensions.

(iii) *Handling of broken bundles:*

The fuelling machine shall be capable of handling broken fuel bundles with the use of tools, like scoop.

(iv) *Life management of coolant channels:*

The fuelling machines are remote operated manipulators and it should be possible to use them for carrying out in-service inspection, repair and maintenance of the coolant channels so as to reduce man-rem expenditure and reactor down time. Typical applications are measurement of axial creep, delivery of channel inspection system, scraping of coolant tubes and collection of samples to determine hydrogen pickup, relocation of garter spring, etc.

5. HANDLING AND STORAGE OF SPENT FUEL AND OTHER IRRADIATED COMPONENTS

5.1 General

This chapter describes the design safety requirements for handling and storage of spent fuel and other irradiated components related to the fuel handling system.

The intended functions covered under this chapter include receipt of spent fuel bundles and other irradiated components from the fuelling machine, transportation to the storage bay, their storage and further dispatch. The requirements are specifically aimed at meeting the general safety requirements stated in Section-2. The design requirements associated with the various aspects of handling and storage of spent fuel shall consider the following safety requirements:

(i) Adequate shielding shall be provided around all areas in which spent fuel or irradiated components are placed. This is required to the protect plant personnel against radiation exposure beyond the prescribed limit.

(ii) Physical damage to fuel bundles during handling and storage shall be prevented since such damage can result in release of radioactivity beyond the prescribed limit, in the plant area and to the environment.

(iii) Residual heat from spent fuel shall be removed to limit the fuel-clad temperature to prevent unacceptable degradation of the fuel bundles that could cause release of radioactivity.

(iv) Adequate illumination (including underwater lighting) shall be provided in all areas.

(v) The chemistry of the cooling medium shall be controlled to prevent corrosion of the fuel cladding for all postulated conditions of spent fuel.

(vi) The spread of contamination shall be controlled to ensure a safe operational environment within the plant and prevent release of radioactivity beyond prescribed limit to the public.

5.2 System Design Requirements

5.2.1 Layout

Design requirements associated with the layout of spent fuel handling and storage systems are as follows:

(i) Handling and storage areas for spent fuel shall be secured against unauthorised access or unauthorised removal of fuel,

(ii) Storage area shall not be part of the access route to other operating areas,

(iii) Transport routes for handling should be short and easy,

(iv) Easy exit in an emergency shall be provided,

(v) Moving of heavy objects, which are not part of the lifting devices, above the stored fuel shall be prevented,

(vi) Facility for decontamination of fuel handling equipment and shipping casks shall be provided,

(vii) It shall be ensured that irradiated components, intended to be handled or stored in the areas for spent fuel, or other appropriate areas, are accommodated in a defined and safe manner,

(viii) Storage positions shall be earmarked for the storage of fuel bundles, reactivity control devices, dummy fuel bundles, fuel channels, etc. The design capacity shall not rely upon the storage of any item in an unauthorised position,

(ix) Space shall be provided to allow inspection of spent fuel and fuel handling equipment,

(x) Space shall be provided to facilitate required movement of the fuel, other irradiated components and storage containers and the transfer of these between different items of handling equipment,

(xi) Space shall be provided for safe handling of the shipping cask even if the fuel storage facilities are full to the maximum capacity,

(xii) Space shall be provided for storage and use of tools and equipment necessary for the repair and testing of irradiated components,

(xiii) To ensure safe handling, adequate storage time for spent fuel shall be provided to allow sufficient decay of its radioactivity before being shipped off site. In determining the adequacy of the storage capacity, consideration should be given to provide for the maximum fuel storage requirements at any time during the life of the reactor. In addition, free space for unloading one full core at any time shall be provided.

(xiv) Arrangements for safe storage of failed or damaged fuel shall be made,

(xv) Adequate space for bay-water purification system shall be provided,

(xvi) Arrangement of the piping shall be such that the fuel storage bay does not drain to an unacceptable level. Wherever necessary, appropriate siphon breaker shall be provided,

(xvii) The design shall permit access to all parts of the storage facility requiring periodic inspection and maintenance,

(xviii) The design shall prevent ingress of water (e.g. rain) or inadvertent addition of any material to the bay water, which could impair heat transfer or increase corrosion and degradation of the storage facilities, and

(xix) Design shall be such that it effectively prevents animals/birds inside the bay area.

5.2.2 Shielding

The design shall ensure that in the operating area, and in rooms and areas located adjacent to the fuel handling systems, shielding is provided to meet the requirements of Safety Guide on 'Radiation Protection in Design (AERB/SG/D-12)'. Following aspects shall also be considered to meet shielding requirements:

(i) For analysis, it shall be assumed that all the positions, which may contain fuel, are occupied with fuel that has reached the design burn up and the decay time is the minimum that could occur as a result of the unloading procedures and schedule,

(ii) Shielding shall be provided by considering transit time whenever fuel bundles are beeing transferred,

(iii) Handling equipment shall be designed to prevent inadvertent placing or lifting of spent fuel into unshielded positions (for example, no provision should exist for transferring the fuel bundle from transfer mechanism to new fuel magazine, thus effectively preventing inadvertent placing of spent fuel in the new fuel magazine), and

(iv) Movement of spent fuel bundle from one area to another shall be adequately monitored. Provision should exist to barricade/shield any location, in case the bundle gets stuck during its movement.

5.2.3 Cooling

(i) *During fuel handling*

Spent fuel from the reactor is received in the fuelling machine head in heavy water medium. It is stored in the storage bay under light water. To facilitate transfer from heavy water to light water media without mixing them up, it would be necessary to transfer the bundles in air in an intermediate equipment (dry transfer). Provision for cooling of spent fuel between the core and storage bay with adequate redundancy shall be made to remove residual heat.

During transfer from heavy water to light water media, it is necessary to minimise contamination of light water with heavy water and degradation of the purity of heavy water. Dry transfer should be carried out within a specified time. Adequate redundancy in cooling by way of air curtain/air spray nozzle should be provided if dry transfer time or bundle temperature exceeds the specified limit.

(ii) *In wet storage*

The cooling system shall be provided:

(a) to ensure fuel cladding integrity,

(b) to limit the spread of possible contamination by coolant evaporation, and

(c) to facilitate acceptable working conditions for operators.

Bay-water temperature limits for normal operation shall be 40^0C and shall not exceed 60^0C under accident condition. Different limits may be defined for design basis events. Bay cooling systems shall be designed to ensure adequate reliability so that water temperatures do not cross the set limits.

(iii) *In dry storage*

Where spent fuel is handled and stored dry, adequate cooling shall be provided. The fuel handling equipment, fuel storage containers, and dry storage facilities shall be so designed that the maximum permissible fuel temperatures are not exceeded.

5.2.4 Mechanical Loads

During normal refuelling operations, loads shall be appropriately limited to ensure that no damage is caused to the fuel or storage and handling equipment.

It shall be ensured that during any maloperation following a seismic event, the facility remains capable of performing its safety functions with regard to shielding, prevention of radioactive release, and the cooling of fuel bundles.

5.2.5 Leak Tightness

Handling and storage areas shall be leak proof to the extent that consequences from the leakage of water or gaseous coolant are within acceptable limits in terms of release of radioactivity and of maintaining the inventory. In all designs, it shall be possible to monitor any leak.

(i) *Wet storage*

(a) Metal-lined bays shall be designed with a system to collect leaking radioactive water in monitoring sumps. On bays with double walls, it should be possible for the interspace to be monitored for leaks with suitable leak-detection devices, such as moisture element.

(b) Detection, location and repair of leaks in excess of acceptable leakage limits should be possible.

(ii) *Dry storage in concrete cask*

Dry storage areas, should be kept under surveillance to ensure that the release of particulate activity, if any, are within acceptable limits.

(iii) *Dry storage vault*

In dry storage vaults, exhaust air shall be passed through filters before being released into the atmosphere.

5.2.6 Fire Protection

The design of the fuel handling and storage areas shall meet the requirements of 'Safety Guide on Fire Protection (AERB/SG/D-4)'.

5.2.7 Safety Classification and Seismic Categorisation of Components

The design of the fuel handling and storage areas shall meet the requirements of 'Safety Guide on Safety Classification and Seismic Categorisation (AERB/SG/D-1)'. Please refer to Annexure-1.

5.2.8 Design Basis Events (DBE)

The design basis events and the requirements as specified in AERB/SG/D-5 shall be considered. A list of typical design basis events is given in Annexure-2.

5.2.9 Material and construction

(i) The construction shall allow easy decontamination of surfaces.

(ii) Compatibility of materials with the environment shall be considered for design basis events.

(iii) Repair of equipment or replacement of parts in the fuel handling and storage systems should be possible.

(iv) Selection of materials shall be as per the appropriate codes and standards.

5.3 Equipment

All equipment for fuel handling and storage shall satisfy the design requirements described in Section 5.2.

Equipment shall be designed, where appropriate, to withstand the design basis events. If certain equipment is not required following a specific event, faults occurring in such equipment shall not lead, directly or indirectly, to failure of any required equipment.

5.3.1 Handling Equipment

Handling equipment refers to equipment designed to handle spent fuel and irradiated components. The fuel bundles may either be handled directly or by using specially designed containers.

Different types of handling equipment are identified below:

(i) fuel transfer equipment (for example, transfer magazine and ball valves for transfer from heavy water to light water),

(ii) fuel bundle lifting devices,

(iii) lifting devices for irradiated components, and

(iv) fuel storage tray handling devices.

Equipment for handling the shipping cask is dealt with in Section-9.

5.3.2 Mechanical Loads

The guidelines in Sections 3.2.2 and 4.2.3 are also applicable to this section, with appropriate consideration given to effect of radiation. The equipment design shall also include the hydrostatic pressure of water and the loads arising due to maximum postulated pressure build up inside the containment, wherever applicable.

5.3.3 Equipment Design Requirements

The design requirements for equipment used in handling and storage of spent fuel and other irradiated components shall include the appropriate clauses of Section 3.3, with due consideration given to the effects of radiation.

5.3.4 Handling Tools for Spent Fuel and other Irradiated Components

Handling tools refer to portable, manual or power-operated devices designed for handling and performing operations on spent fuel or irradiated components. These devices include tools for handling fuel elements and other components of a fuel bundle as well as other irradiated components. The following aspects shall be considered in the design of the handling tools:

(i) Handling tools shall be designed to perform their intended function without compromising personnel safety. The tools shall provide positive means of latching so as to preclude inadvertent release of radioactivity. Means shall be provided to indicate visually whether the tool is in the latched or unlatched condition. The tools shall remain in the latched condition upon loss of power (e.g. electrical power or compressed air).

(ii) Handling tools shall not contain sharp corners and edges that could damage the surfaces of fuel and other irradiated parts.

(iii) Hollow handling tools used under water shall be so designed as to get filled with water on submergence (to maintain water shielding) and be drained on removal.

5.3.5 Failed Fuel Inspection Equipment

Suitable equipment shall be provided to identify failed fuel bundles for the purpose of segregated storage. These include equipment such as sniffing facility, periscope, etc. for direct or remote inspection of fuel bundles and other irradiated components.

The equipment used for handling fuel bundles for inspection shall not cause damage to the fuel cladding. During fuel inspection, reliable means for removing residual heat from irradiated fuel shall be provided. Failed fuel assembly detection equipment shall detect failure of irradiated fuel bundles without impairing its structural integrity. Inspection equipment shall be designed to withstand the effect of radiation and decay heat.

5.3.6 Storage Equipment

Storage equipment include storage racks or storage containers where fuel is stored prior to transportation, either in shipping cask away from the reactor or by transfer equipment to another storage area at the site.

(i) The materials used in the construction shall be compatible with the storage environment. The racks shall not contaminate the fuel with foreign matter, which might degrade the integrity of the fuel bundle during its lifetime. The storage racks or container shall not contaminate the storage environment (e.g. bay water).

(ii) All fuel storage positions shall be accessible by the appropriate fuel handling equipment.

(iii) Movement of fuel trays or tilting of the stack of trays following design basis events shall be prevented, unless it can be demonstrated that no safety hazard occurs.

(iv) Ease of insertion and removal of the fuel bundles shall be considered in the design of the storage equipment. Storage equipment shall be designed to minimise the possibility of excessive lateral, axial and bending loads to fuel bundles during handling and storage.

(v) The storage containers should be designed to support fuel bundles in a manner, which prevents damage to fuel bundles during handling or transport.

(vi) Damaged fuel should be placed in storage cans to prevent further damage and to facilitate identification.

5.4 Handling and Storage of other Irradiated Components Related to Fuel Handling

Certain components related to fuel handling, such as ram extensions, get highly activated due to irradiation. The handling and storage of these components shall also be considered in the design. Provision shall be made for storage of such items in the spent fuel storage facility or in any other defined area.

The requirements of Sections 5.2 and 5.3 as applicable shall be followed. Particular consideration needs to be given to the following:

(i) Adequate shielding of irradiated components shall be ensured.

(ii) Where inspection of irradiated components is necessary, adequate shielding shall be provided to ensure protection of operators against exposure.

(iii) Provision for transferring irradiated components into a suitable shipping container shall be made, where necessary.

(iv) Storage and disposal facilities should be provided with inspection facilities, where necessary.

(v) Appropriate care in handling should be taken to prevent damage to stored fuel bundle in the bay.

5.5 Spent Fuel Storage Bay

The spent fuel storage bay shall provide for safe, stable and secure storage and handling of spent fuel. Thus the spent fuel storage bay shall have features to remove residual heat from spent fuel and to provide radiation protection for the anticipated lifetime of the installation.

5.5.1 Design Requirements

(i) The boundaries of the storage bay and other components important for retention of the cooling water shall be designed to withstand design basis events (in particular, impacts from collision or dropped loads) without significant leakage of water. The design should provide for detecting leakages, if any.

(ii) Spent fuel storage bays shall be designed to generally exclude penetrations below the elevation, which corresponds to the minimum water level required for adequate shielding and cooling of stored fuel. However, under exceptional circumstances, like entry of shuttle transport tube, where such penetrations are unavoidable, the consequences of leakage through such penetrations shall be fully analysed to ensure that minimum shielding and cooling requirements are met.

(iii) The layout of piping and other equipment shall be designed to avoid inadvertent lowering of the bay water by siphon action due to postulated pipe breakage to a level below the minimum operating level specified for the radiological safety and protection of the fuel. Wherever such a layout is not possible suitable siphon breaker shall be provided.

(iv) The bay-water make-up system shall be designed to provide water at a rate exceeding the maximum rate of loss of water during operation.

(v) Where water bays are to be connected by sluice-ways, the design of the sluice-ways and gates shall provide for containment of water and for detection, collection and removal of leakages. Sluice-gates shall be designed to withstand anticipated water pressure. The invert elevation (bottom) of the sluice-gate shall be sufficiently above the top of the stored fuel bundles in the storage bay.

(vi) Protection against over-filling of storage bay shall be provided.

(vii) For water-filled storage bay, high and low water level alarms shall be provided with connection to the alarm system in the control room.

(viii) All the piping penetrations through the containment shall meet the requirement of AERB 'Safety Guide on Containment Design (AERB/SG/D-21)'.

(ix) Design life of storage bay shall be at east 10 years longer than the life of the reactor.

5.5.2 Purification System

Spent fuel storage bay water shall be maintained within appropriate specified limits of radioactivity concentration. Requirements for water quality or atmospheric contamination shall be defined.

The following provisions shall be included:

(i) Only demineralised water shall be used. The design of cleaning and purification system shall be such that,

(a) radioactive ionic and solid impurities get removed from the bay water;

(b) quality of bay water is ensured with respect to corrosion and clarity, by controlling the parameters like turbidity, chloride content, pH, conductivity, etc., and

(c) suspended particles and dissolved impurities, which impair visibility, are removed.

(ii) Facilities or equipment shall be provided in order to enable impurities and suspended particles to be removed from the surface of the bay water.

5.5.3 Cooling System

The spent fuel storage bay cooling system shall meet the requirements indicated in Section 5.2.3. In addition, the following requirements shall also be met:

(i) The heat removal system shall be designed for adequate removal of heat, likely to be generated by the maximum inventory of spent fuel, anticipated during operation. In determining the necessary heat removal capability, the post irradiation cooling interval and the burn-up of the fuel to be stored shall be taken into consideration.

(ii) The design of heat removal systems shall include an additional margin of heat removal capability to account for processes likely to degrade or impair the system over a period.

(iii) The design of the heat removal system shall consider the maximum heat capacity of all other associated cooling systems.

(iv) Redundant or diverse heat removal systems should be provided.

6. FUEL HANDLING AUXILIARIES

6.1 General

Since the fuel handling system handles spent fuel bundles, it is necessary that the equipment are in properly sealed and shielded areas. However, it is also necessary to gain access to these equipment for periodic maintenance, calibration and testing. The design safety requirements of auxiliaries like Roll-On-Shields, Shielding-Doors in the FM vault, FT room and FM service area and Sealing-Doors which enable such access are described in this chapter.

6.2 System Design Requirements

i) Adequate shielding shall be provided so that the radiation fields in the accessible areas are within permissible limits.

ii) Adequate sealing shall be provided to achieve leak-tight isolation at various sealing doors in order to limit the air-borne activity to permissible values.

iii) The system shall have sufficient interlocks to prevent unsafe operations.

6.3 Equipment

Auxiliary equipment shall be designed by taking into consideration the various loadings and other design requirements as given below.

6.3.1 Mechanical Loads

All loads derived from the operational and accidental conditions, including the seismic loads, shall be considered. The stresses resulting from these loads shall be within permissible limits of appropriate codes. Loadings imposed on it by other systems if any, should also be considered.

6.3.2 Design Requirements

i) The equipment shall provide adequate shielding from gamma and neutron radiations, as well as sealing against spread of air-borne activity.

ii) The equipment shall be simple and reliable.

7. INSTRUMENTATION AND CONTROL

7.1 General

This chapter describes the design safety requirements of Instrumentation and Control (I&C) for fuel handling and storage systems. The design of I&C for fuel handling and storage systems shall be in accordance with AERB Guide on 'Safety Related Instrumentation and Control for PHWR (AERB/SG/D-20)'. However, the additional requirements indicated in this chapter should also be met.

7.2 Design Requirement

(i) Operation of the fuel handling and storage systems involves a large number of sequential steps, whose initiation should be in accordance with specified logic. Hence, automatic sequential logic system shall be provided to reduce the possibility of operator errors. It shall be possible to put a hold on automatic sequential operations at any stage. The design shall also provide for manual mode to facilitate operations under off-normal conditions.

(ii) Adequate safety interlocks shall be provided to prevent unsafe situations resulting from wrong commands. The interlock logic system shall be hardwired. The commands issued by the operator in the manual mode and the sequential logic in the auto mode shall be routed through the interlock logic.

(iii) A control console in the control room shall be provided to carry out most of the operations and use of local panels should be restricted to either maintenance activities or specific operations not involving high man-rem. Status of the system should be fully displayed on the respective local consoles. Control console shall provide for sitting operations during auto mode; standing operations, if any, shall be restricted to manual mode.

(iv) Auto-initiated mitigating actions shall be provided if the system is likely to become unsafe in less than 15 minutes after a DBE. If the system remains safe for more than 15 minutes after a DBE and the operator actions are depended upon for ensuring further safety, it shall be ensured that sufficient redundant indications are provided to draw the attention of the operators. Since the control console of fuel handling system is manned throughout the refuelling operation, a minimum duration of 15 minutes is considered adequate for operator intervention.

(v) For critical safety functions two out of two logic shall be provided.

(vi) All the power supply units shall be connected to a reliable power source, viz. Class II (control). Power supplies should meet the requirements of the Safety Guide on 'Safety Related Instrumentation and Control (AERB/SG/D-20)'.

(vii) The design shall ensure that the system remains safe even when the power supply unit fails.

(viii) Back-up field devices shall be provided, wherever required, for ensuring safety or ease of retrieval in the event of failure of a primary device. Diverse cabling routes shall be employed for the field devices related to safety functions.

(ix) A simulator panel shall be provided to test the functioning of the control system.

(x) The computer system, if used, shall include on-line and off-line diagnostics. Design, testing and review of the control system architecture, hardware and software shall be in accordance with the AERB Design Safety Guide on 'Computer-Based Systems (AERB/SG/D-25)'. In addition, the following requirements shall be met:

(a) The control system design shall facilitate checking of logic interlocks with the help of a simulator, which simulates the required field devices.

(b) Operator interface of the control system shall display status of various electrical, hydraulic and mechanical devices.

(c) The control system shall provide features to carry out re-calibration of the fuel handling system components at any time.

(d) A real-time clock shall be provided with computer based system. Time of the day should be synchronised with the reference clock of the station.

(e) Operation logs shall be created by a computer-based system to facilitate analysis of malfunctions and performance deterioration of mechanical and hydraulic systems.

(f) The response time of the computer system shall ensure that inconsistent outputs are not issued and positioning of all moving devices in the fuel handling system is achieved within the specified accuracy.

8. SUPPORT SYSTEMS

8.1 General

Design safety requirements for support systems, such as ventilation, vapour recovery, compressed air, cooling water, leakage collection, electrical power, lighting, communication, and fire fighting, as required for the fuel handling system, are given in this chapter.

8.2 System Design Requirements

8.2.1 Ventilation

Adequate number of air-changes, monitors, filters, flow balances, etc. should be provided to ensure the following:

(i) Dimensions of equipment should be such that persons can go in to check essential facilities, if required. Sufficient area should be provided for accessibility.

(ii) The concentration of air-borne activity is controlled to an acceptable level.

(iii) Humidity in wet storage areas is controlled.

(iv) Dust-free environment is provided in order to reduce the dust deposition on the fuel in the dry storage and on the bay surface in the wet storage.

(v) Atmospheric temperature is maintained within specified limits.

(vi) Spread of contamination to adjacent areas is prevented.

8.2.2 Vapour Recovery

There is a possibility of heavy water leaking in fuel handling areas leading to formation of vapour. The heavy water vapour has to be removed to keep the tritium activity in the air below the permissible limits. Suitable drier system shall be provided for maximum vapour recovery from the fuel handling areas and to minimise the heavy water loss through stack.

8.2.3 Compressed Air

Compressed air system shall have adequate capacity to meet the requirements of:

(i) instrumentation and control;

(ii) mask air for breathing and protective clothing;

(iii) pneumatic tools; and,

(iv) cooling of spent fuel bundles in case of an emergency.

8.2.4 Cooling Water

The cooling water system, consisting of process water and chilled water, shall be adequate for catering to the needs of various heat exchangers (e.g. bay cooling equipment, oil coolers) of the fuel handling system.

8.2.5 Leakage Collection

Handling and storage areas should be leak-tight to an appropriate degree so that leakage of heavy water is within acceptable limits in terms of release of radioactivity and of maintaining the inventory. Adequate provision shall be made to detect and collect leakage and spillage of heavy water out of the fuel handling system.

8.2.6 Electrical Power

Electrical power of adequate capacity shall be provided for the operation of various fuel handling electrical equipment. Based on the importance of equipment with reference to safety, including operability during the station black-out (SBO) condition, appropriate classes of power supply shall be used. clause No. 3.18 and 3.19 of Safety Guide on 'Emergency Electrical Power Supply Systems for Pressurised Heavy Water Reactor (AERB/SG/D-11),' may be referred to.

8.2.7 Lighting

All the fuel handling areas including bay storage areas shall be provided with normal and emergency illuminating equipment. For storage bay, consideration shall be given for providing under-water lighting near the work areas and means for replacement of underwater lamps. Materials used in underwater lighting shall be compatible with the environment and, in particular, shall not undergo degradation due to radiation, unacceptable corrosion or water contamination.

8.2.8 Communication

Accessible two-way audio communication shall be provided between the different fuel handling and storage areas and the control room.

8.2.9 Fire Fighting

The design of the fuel handling and storage areas shall meet the requirements of the Safety Guide on 'Fire Protection in Pressurised Heavy Water Based Nuclear Power Plants (AERB/SG/D-4)'. The design intent shall be to limit the risk of damage to fuel bundles through fire. The following aspects, which are of particular relevance to the present guide, should be considered:

(i) Control of the presence of combustible materials in the fuel handling and storage areas.

(ii) Routing of electrical cables, which are not directly necessary, for supplying power to the equipment for storing and handling of new fuel.

9. HANDLING AND TRANSPORT OF SHIPPING CASKS

9.1 General

Irradiated fuel is transported in adequately shielded and cooled casks, which ight be either internally dry or partially filled with the coolant. The casks usually contain an internal structure to keep the fuel in a well-defined arrangement during transport. The casks are normally loaded under water, either in a specific area at the storage bay or in a separate cask-loading bay. The fuel may first be placed in a storage container, which may then be loaded into the cask. The following sections describe the design requirements for cask reception and on-site movements of spent fuel.

9.2 System Design Requirements

The equipment provided at the reactor site shall be compatible with the handling requirements for the fuel casks to be used.

Casks, which are to be transported off-site, shall meet the requirements of the Safety Code on 'Transport of Radioactive Materials (AERB Code No.SC/TR-1)'.

The design shall restrict the interference between cask handling and loading operations being carried out in parallel with other activities related to reactor operations.

Facilities shall be provided to decontaminate the cask prior to transport and to perform such necessary pre-dispatch tests on the cask, such as leakage and surface contamination tests.

The transportation route inside the plant should be as short as possible and the movement of cask over the stored fuel shall be avoided. If dropping or tilting the cask is considered to be the design basis event, the design shall ensure safety of stored fuel and other reactor systems vital to safety.

The cask handling area shall be so laid out as to provide necessary access around the cask for inspection, radiation monitoring and decontamination tests. Adequate storage area for the cask shall be provided.

9.3 Equipment

The equipment for cask handling and transportation include:

(i) spent fuel shipping cask;

(ii) vehicles for cask movement;

(iii) cranes and associated lifting devices for cask, cask lids or cask internals;

(iv) decontamination equipment;

(v) cask testing equipment, and

(vi) means and devices for decontaminating the surfaces of the casks.

9.3.1 Cask Design Requirement

The cask design shall be in accordance with the Safety Code on ‘Transport of Radioactive Material (AERB/SC/TR-1)’. As the cask design requirement is outside the scope of this guide, the design requirements for other equipments for handling and transport of shipping cask only are considered.

9.3.2 Cask Handling and Transport Equipment

Lifting of the cask from a vehicle by a crane or vice versa may require slanting of the cask, which may need additional design requirements to the cask handling equipment. The vehicles or cranes shall be designed to limit the possibility of dropping or inadvertently tilting the cask. In general, the cask-handling crane shall meet the requirements of single failure-proof crane for nuclear power plants (Ref.No.5.). As a minimum requirement the vehicles and cranes shall be provided with a reliable braking system to ensure that they do not move unintentionally. The crane should be parked away from the storage bay and locked to prevent its motion during events like an earthquake of level SSE. Double braking systems, each with at least full-load stopping capacity, should be provided. Speed limitations on the horizontal and vertical movements of the crane shall be incorporated. With these precautions taken, the dropping of cask need not be considered as a design basis event.

9.3.3 Radiation Monitoring Equipment

Radiation monitoring equipment shall be provided to measure gamma radiation as well as the fast and thermal neutrons from the cask. Provision for measurement of surface contamination of the cask shall be made to ensure that the transport regulations are satisfied before the cask leaves the plant.

10. MULTI-REACTOR CONSIDERATIONS

For economic considerations, multiple units are located at one site. From the point of view of standardisation, twin unit modules are adopted wherein common shared facilities like calibration and maintenance test facility, spent fuel storage bay, new fuel storage area are provided.

The capacity of such shared facilities shall be sufficient to meet the requirements of both the units. The storage capacity for units sharing the same storage facilities shall be determined on the basis of the requirements of each unit and keeping additional free space for unloading one full reactor core. Where the same fuel handling equipment is used for more than one reactor, it shall be demonstrated that the capability to meet individual requirements of any of the units, including that of containment isolation, is not impaired and that the faults arising at one unit do not affect the safety of any other unit.

11. DESIGN REQUIREMENTS FOR OPERATION

11.1 General

This chapter describes the requirements to be met in design from the point of view of operations related to fuel handling and storage systems.

(i) The design shall ensure compliance with the specific guidance which is given in the 'Code of Practice on Safety in Nuclear Power Plant Operation (AERB Code No. SC/O)' and the Safety Guide on 'Core Management and Fuel Handling in Operation of Pressurised Heavy Water Reactors (AERB/SG/O-10A)'.

(ii) The design shall provide for both normal operations and operations following DBE.

(iii) The design shall facilitate for appropriate inspection, testing and maintenance of equipment and critical components.

(iv) The design should assist in special retrieval operations to take care of unusual situations like failure of certain devices, equipment or components.

(v) The design shall take into account the interactions with the operation of other systems.

(vi) The design basis for items critical to operational safety should be documented at the design stage to enable subsequent preparation of operating procedures.

11.2 Requirements

(i) It is necessary that refuelling operations do not so influence the performance or behaviour of the reactor that it causes a hazard to the other parts of the reactor systems. Influence of the refuelling operation on the neutronic behaviour of the reactor shall be consistent with the capability of the reactor control system. It is also necessary that events affecting the reactor shall not be hazardous to the fuel being handled.

(ii) The design should be such as to prevent damages to the equipment by faulty operator action.

(iii) The design should include provisions to enable the operator to ensure that the loading of the cask is in conformance with appropriate AERB regulations.

(iv) Provision shall be made through equipment and procedures for retrieving spent fuel from storage or from wrong locations arising from malfunctioning of the equipment.

(v) The design shall ensure that the system can be maintained or repaired by use of suitably designed tools, so that the radiation exposure to the maintenance personnel is minimal.

(vi) The design should provide for measures to check proper functioning of the equipment after maintenance.

(vii) If manual interventions in the reactor building are to be depended upon for ensuring safety after a failure, the system should ensure safety for a minimum of 30 minutes before action by the operator.

12. QUALITY ASSURANCE

12.1 General

This chapter describes the quality assurance (QA) programme in the design safety requirements for the fuel handling system and the documentation requirement.

12.2 Requirements

(i) The design of the system shall be subject to a quality assurance programme to cover the activities, systems, components and material specified in this guide. It shall be in accordance with the principles and objectives of the AERB 'Code of Practice on Quality Assurance for Safety in Nuclear Power Plants (AERB Code No.SC/QA)'.

(ii) The design of safety related systems and system components shall be subject to QA requirements commensurate with their importance to safety.

12.3 Documentation

(i) The design specifications, analyses, the 'as built' data and pre-service and in-service inspection data on all equipment shall be documented in order to comply withthe requirement given in Clause 13.2. The documentation shall be maintained in accordance with an established QA programme and made available to the operators.

(ii) The design shall incorporate features, which are necessary for verification of the records on

(a) the number and identification of fuel bundles;

(b) the location of each fuel bundle; and

(c) the number and identification of fuel handling components.

Identification features shall be sufficiently durable as to remain effective during any operation, handling or storage.

13. IN-SERVICE INSPECTION

13.1 General

This chapter describes the in-service inspection (ISI) programme for meeting the design safety requirements of fuel handling and storage systems.

13.2 Requirements

(i) The design of the system shall provide for ISI of safety-related components and systems, which include safe and adequate access to all systems, areas and components requiring periodic inspection. In case of fuel handling, the ISI should consist of hydrostatic test and visual examination of the fuelling machines and other equipment.

(ii) Handling and storage area shall be leak-tight to an appropriate degree so that the consequences of leakage of water or gaseous coolant are within acceptable limits in terms of release of radioactivity and of maintaining the inventory. In all designs, it shall be possible to test and monitor the leak tightness and locate the leak, if any.

(iii) Design provision shall exist for verification of calibration of various actuators, which apply force on the fuel bundle.

(iv) Design provision shall exist for carrying out ISI of containment isolation related to the fuel handling systems.

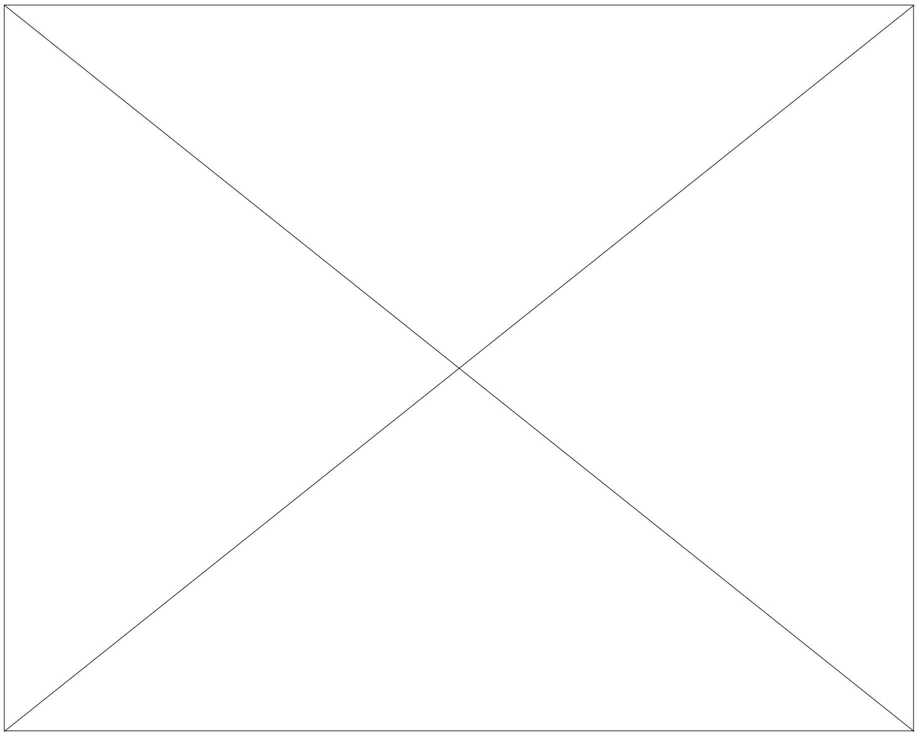
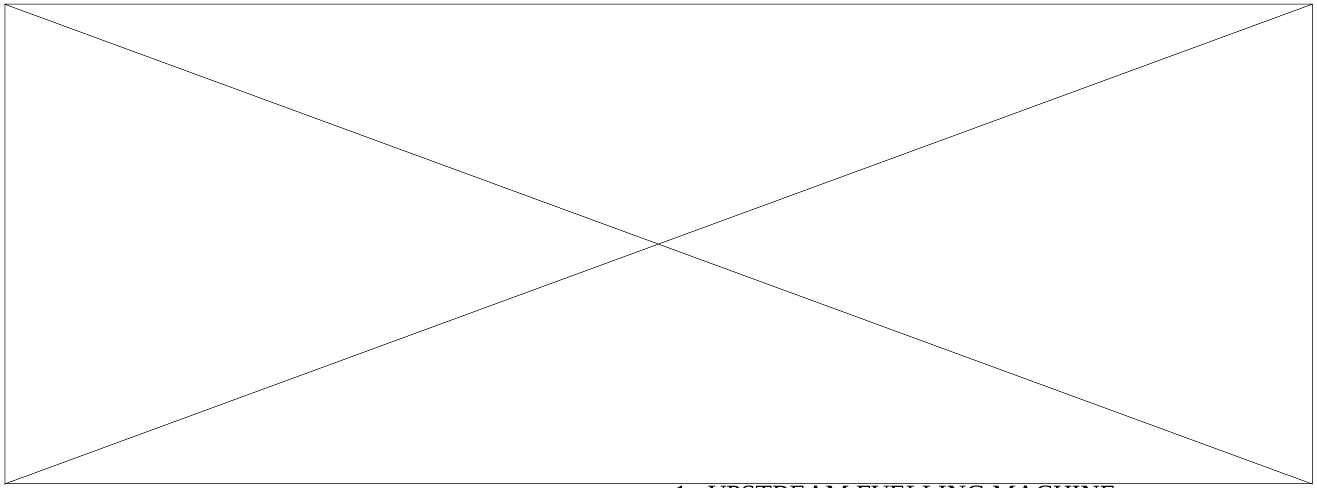


FIGURE-1 : TYPICAL ARRANGEMENT OF FUEL HANDLING SYSTEM



1. UPSTREAM FUELLING MACHINE
2. SEALING PLUG
3. COOLANT CHANNEL
4. FUEL BUNDLE
5. DOWNSTREAM FUELLING MACHINE
6. END SHIELD

FIGURE-2: SCHEMATIC OF ON-POWER REFUELLING

APPENDIX

NEW FUEL STORAGE

The new fuel used in Indian PHWRs contains natural uranium or depleted uranium or thorium. This fuel is not expected to become critical during storage or handling and no significant radiation is expected.

In case of any future fuel design involving enriched uranium or plutonium or MOX, the following aspects should be given due consideration in addition to those mentioned in this guide.

(i) All fuel handling systems, including the new fuel handling system, shall be so designed that the physical layout and arrangement will ensure adequate sub-criticality margin during all operational states and design basis accidents. Where the fuel cannot be maintained sub-critical through the storage configuration alone, the design should specify additional means, such as fixed neutron absorbers.

(ii) Flooding of the new fuel storage area and spent fuel dry storage area by water or other moderating material should be prevented by an appropriate design to avoid inadvertent criticality.

(iii) Adequate shielding and confinement shall be provided in the design of new fuel storage and handling system to ensure protection of personnel against radiation.

ANNEXURE-1

SAFETY CLASSIFICATION AND SEISMIC CATEGORISATION OF FUEL HANDLING SYSTEM

(Refer AERB/SG/D-1)

Sl. No.	Fuel Handling System	Safety Class	Seismic Category	Remarks
A	CIVIL STRUCTURES			
4	Spent fuel storage building, spent fuel storage bay, spent fuel transfer duct	3	1	
B	MECHANICAL			
3.10	FM supply and return circuit	3	1	D_2O system upto and including first isolation valve forming part of the primary pressure boundary has safety function (k), and is safety class 1. It would be safety class 2 and seismic category 1, provided the size is within the capacity of the inventory control system.
6.5	Spent fuel storage bay cooling system	3	1	
15.1	Fuelling machines (x, y, z drive systems)	3		

SAFETY CLASSIFICATION AND SEISMIC CATEGORISATION OF FUEL HANDLING SYSTEM

(Refer AERB/SG/D-1)

(contd.)

Sl. No.	Fuel Handling System	Safety Class	Seismic Category	Remaks
15.2	FM head and FM D_2O system (high pressure) upto first isolation valve	1	1	
15.3	Fuelling machine carriage, bridge and columns	4	1	
15.4	Bridge power packs and roll-on shields	3	1	
15.5	Spent fuel transfer D_2O/ H_2O systems	2	2	
15.6	Spent fuel dry transfer system	2	2	
C	ELECTRICAL			
4.1	FM supply pump motors	EB	1	If pump motor is required for reactor coolant inventory control or for pressure control, safety class shall be EA.
16.4	Spent fuel storage bay cooling pump motors	EB	2	
16.5	Spent fuel storage bay purification system pump motors	NNS	3	

SAFETY CLASSIFICATION AND SEISMIC CATEGORISATION OF FUEL HANDLING SYSTEM

(Refer AERB/SG/D-1)

(contd.)

Sl. No.	Fuel Handling System	Safety Class	Seismic Category	Remarks
D	I & C SYSTEM			
2.8a	Fuelling machine supply and return circuits: For keeping PHT solid and supply to FM as PHT system pressure boundary and for fuel cooling	IB		When FM has hot bundles and is unclamped, seismic category 2 may be adopted.
2.8b	Fuelling machine supply and return circuits: Rest of I&C	NNS		
15.1	Fuelling machine clamping control and leak detection	IA	1	
15.2	Safety interlocking system	IB	1	
15.3	Position monitoring systems	IC	2	
15.4	Dry transfer control	IB	1	
15.5	Sequential operational logic	IC		
15.6	CCTV	NNS		
15.7	Rest of I & C	NNS		

Note: Safety functions, Safety class and Seismic category are explained in AERB/SG/D-1.

ANNEXURE-2

LIST OF APPLICABLE DESIGN BASIS EVENTS FOR FUEL HANDLING SYSTEM

(Refer AERB/SG/D-5)

Event No.	Event
C3-2.10	Failure of a coolant channel with ejection of fuel bundles from coolant channel and consequential LOCA.
C2-7.3	Failure of the cooling of a Fuelling Machine when off reactor or on reactor, containing full complement of irradiated fuel.
C2-7.2	Fuel handling accidents during transfer to Spent Fuel Storage Bay including loss of cooling to pair of spent fuel bundles during dry transfer from Transfer Magazine to Shuttle Station.
C2-2.5	Seal Plug fails to seal after refuelling (with Fuelling Machine remaining latched on to the coolant channel. No ejection of fuel bundle from the channel).
C2-9.4	Accidental dropping of Spent Fuel Cask into the Spent Fuel Storage Bay unless it is proved to be avoided by design features.
C4-9.11	Station Blackout (Simultaneous failure of Class-III and Class-IV Electrical Power Supply) for specified duration.
C2-9.3	Operating Basis Earthquake (OBE): [Ref. AERB/SC/S, 1990: Code of Practice on Safety in Nuclear Power Plant Siting].
C3-9.5	Safe Shutdown Earthquake (SSE).

LIST OF APPLICABLE DESIGN BASIS EVENTS FOR FUEL HANDLING SYSTEM

(Refer AERB/SG/D-5)

(contd.)

Event No.	Event
C2-9.2	Design Basis Fire (such as in Reactor Building, Main Control Room): A hypothetical fire, which is assumed for the purpose of fire protection design or analysis. Fire is assumed to be one that would lead to the most severe damage in the area under consideration in the absence of fire suppression by automatic or manual systems.
C3-9.7	Design Basis Flood [Ref. AERB/SC/S, 1990: Code of Practice on Safety in Nuclear Power Plant Siting].
C3-9.8	Design Basis Cyclone.

ANNEXURE-3

TYPICAL INCIDENTS IN FUEL HANDLING SYSTEM

Some of the significant incidents that have taken place during the last three decades of reactor operation are briefly given below. The inherent strengths of the fuel handling system which were useful in mitigating the incidents, the lessons learnt and the design improvements carried out in subsequent projects are also indicated:

1. **Fuelling Machine Head**

   (i) ***Failure of rams:*** B-Ram, C-Ram and Latch stalled in their movements in different incidents. It was possible to operate them by changing the parameters, like pressure and flow in many instances. When one of these rams was not available, it was possible to use the other rams in special combinations of operations to carry out the functions needed for retrieval.

   (ii) ***Failure of magazine rotation:*** Rotation of magazine was stalled in some incidents either due to its own problem or due to obstructions caused by drifting of the guide sleeve, guide sleeve tool, fuel bundle, shielding plug etc. In such cases the obstruction was removed by use of special operations of the rams or separators or by using special tools.

   (iii) ***Failure of guide sleeve*** to retract from end fitting caused a hold up. It was retracted by using special tools.

   The following features of the fuelling machine were useful in mitigation:

   (i) A certain amount of overlapping of the functions of B-Ram and C-Ram.

   (ii) Margins available in the design to increase the forces and change the speeds of operation when needed. Magazine pressure could be used to aid the rams under certain conditions.

   (iii) Capability of the fuelling machine to grapple the spent fuel bundles from the channel when the fuelling machine at the other end gets incapacitated.

   (iv) Capability of separators to push the obstructing component and clear the magazine rotation.

   (v) Possibility of the use of coolant channel flow to push the bundles into the downstream fuelling machine.

The following features were incorporated in the design in view of the experience acquired:

(i) Oil hydraulic power pack and control panel were taken out of the fuelling machine vaults and located in the normally accessible area. This helped in attending to them whenever required and also manipulating the forces, speeds and directions as desired for special procedures used in mitigation.

(ii) The Z motion stroke was increased so that even when the guide sleeve is not retracted, the fuelling machine can be disengaged from the channel with the guide sleeve projecting out of the snout in extended position.

2. Fuelling Machine Bridge and Carriage

(i) Position indications were lost or disturbed due to disconnection or slipping of the potentiometers. As a result there were instances of erroneous movements in X and Y directions. Since this equipment can be seen on the closed circuit TV or through the window, the machines were moved to proper position in the manual mode for mitigation.

(ii) Fail-safe brake did not get released due to control problem and stalled the movement in some incidents. The manual override lever was actuated either directly or through a tool to overcome this problem.

(iii) The fuelling machine bridge was moved down with the fuelling machine head in line with the reactor due to operator error in the manual mode operation. It was possible to normalise the system with the reactor in shutdown condition.

(iv) The mechanism providing 90? rotations of fuelling machine head got disconnected due to shearing of one key. As a result the fuelling machine head swung into an unusual skewed position. It was manually rotated to the correct position. The joint including the key was strengthened and the torque of the rotary actuator was reduced to prevent recurrence.

The inherent robustness and structural strength of the components limited the damage in any incident to the minimal extent. The redundancy and the margins available in drive systems were useful in mitigation. Provisions like manual override of fail-safe brakes helped in mitigation.

The position-sensing arrangements were modified to get the measurement as directly as possible and avoid the sources of errors as far as possible. A number of additional backup switches and interlocks were introduced to stop unintentional movements beyond a limit in case of failure of potentiometers, thus avoiding possibilities of collisions.

3. Fuel Transfer System

(i) Fuel bundles were stuck in different parts of the fuel transfer system such as the ball valve, transfer magazine and shuttle station due to stalling of some of the rams or their inadvertent movements or due to gross misalignments. In most of these incidents it was possible to move the bundles in the opposite direction by using corresponding healthy rams and attend to the problematic ram. In some cases, when the bundle was damaged in the incident, it was taken into a special shielded can using special tools and transferred to the bay on a trolley.

(ii) The shuttle carrying the spent fuel bundles got stuck in the transport tube in some instances. In some of these it was found that its nosepiece was broken. The shuttle was moved from the stuck position either by manipulating flows or by pushing it with a special shuttle tool. The nosepiece was strengthened and the root cause of its breakage was removed by suitable modifications.

(iii) In some incidents the spent fuel bundle came out of the shuttle. It was picked up into a special scoop shuttle and brought into the spent fuel receiving station.

(iv) Either the shuttle or the bundle was stuck in the spent fuel receiving station due to misalignments or malfunctioning of some of the rams. However, since the under-water equipment can be seen from above, rectification was done by using special long-handled manual tools, operated from a man bridge located above the water level.

A number of improvements in components/mechanisms, sensing devices and safety logic interlocks were carried out to prevent recurrence of some of these incidents. Proximity switches were installed on the spent fuel transport tube to track the movement of the shuttle. Strict alignment requirements were enforced in installation of various equipment and shuttle transport tubes.

4. Coolant Channel Sealing

(i) Sealing plugs were not able to make a perfectly leak-tight joint when reinstalled after refuelling in some incidents. This was either due to some problem in the operating mechanisms of the sealing plug, or problems in the rams of the fuelling machine or a dent or scratch on the sealing surface of the end fitting. In each case the cause was ascertained by rigorous trouble-shooting and investigations by logical analysis of available information. If the sealing plug was suspected of malfunctioning, it was replaced with a spare sealing plug, which is always carried in the fuelling machine. If the fuelling machine was deficient, special procedures using its inherent strengths, as given above were used for mitigation. In case of degradation of the sealing surface in the end fitting, the channel was temporarily blanked by an external gasketted blank. It was subsequently lapped, quarantined or replaced.

(ii) Leakage of heavy water due to ineffective sealing at the interface between the end fitting (E face) and the fuelling machine head is a problem with a higher frequency of recurrence. Hence, it is illustrated here in more detail to give an indication of the complexity of the situation. This could happen due to any of the following reasons and was detected by visual observation:

- ? The hydrodyne seal was damaged.
- ? Scratch mark on sealing face inside FM-head.
- ? Scratch or dent on sealing face of end fitting.
- ? Z motion stroke is insufficient, thus fuelling machine head was not fully engaged with the end fitting.
- ? Centralising and levelling mechanisms were not properly adjusted. Thus the head was in a tilted condition and not exactly aligned to the end fitting.
- ? Snout probes were problematic; thus correct feed-back was not available.
- ? Clamping force was insufficient because of either mechanical inefficiency or due to oil hydraulic system problem.
- ? Malfunctioning of lock and motion control valve resulting in releasing the clamping pressure.

- ? Malfunctioning of lever bearing/clamping post.
- ? Reverse flow of the hot heavy water from the channel causing thermal ratchetting.

None of the above factors can be remotely verified when the fuelling machine is clamped to a channel of the reactor operating on power. So the refuelling operation was suspended and the machine was brought to FM service area for investigation. Then systematic inspection, calibration and testing were done to identify the cause and appropriate corrective action was taken.

5. Miscellaneous Failures

(i) Catenary hoses have failed due to ageing, abrasion, entanglement, etc. resulting in loss of heavy water and impairment of operation. Excess flow check valves, used on important lines, close and stop further loss of fluid through the ruptured hose. Duplicate hoses are provided for critical functions, thus stand-by supply is available for mitigation. Catenary hoses are being replaced with new ones after a specified time.

(ii) Some incidents caused due to loose wiring or wrong connections, as soon as identified, were rectified. Regular checking of the system through the simulator can minimise such incidents.

(iii) It was observed in one reactor that the fuel bundles charged from one side were frequently failing shortly after the refuelling operation. On thorough inspection and trouble-shooting it was found that the tubes of new fuel magazine were not getting aligned properly every time and the fuel bundles were forced into misaligned tubes. In this process there was a possibility of getting some dent marks, which could cause clad failure when taken to high power. This problem disappeared after improvement in the periodic inspection and calibrations for alignments.

(iv) A shielding plug, which was not properly installed during the initial manual installation, drifted from its position with flow and followed the sealing plug into the downstream fuelling machine during the first refuelling visit. It was pushed back into position by special ram operations. Certain procedure was also evolved for the first refuelling of rest of the channels to check the initial position of the shielding plugs and avoid their drifting.

6. General Observations

(i) Components of the fuel handling system are generally designed with liberal margins for safety and can withstand higher loads for a short time. Similarly, the drive systems are provided with substantial margins for increasing forces and torques, if needed. However, as a prudent practice, they should be adjusted to values, which are just sufficient to perform the intended operation in order to minimise normal loads. In case the intended movement does not take place at normal settings, the cause for the failure should be investigated before changing the settings. In such an approach, functional failure will not result in damage to the equipment and retrieval will be easy. The settings should be normalised as soon as the retrieval is completed. Some incidents have taken place because of an attempt to get going by simply increasing the forces, which actually resulted in worsening the jamming. In some cases, the settings changed for handling an emergency situation continued in normal operation also, thus reducing the margins for subsequent contingencies.

(ii) Normal operation in automatic mode is carried out in a well-defined sequence of steps and each step is well guarded with safety interlocks. Whenever there is a need to complete the refuelling in manual mode, the same sequence of steps is required to be followed. If any interlock is temporarily jumpered or feedback is not available due to a control problem, it is necessary to obtain the information indirectly by other means, and ascertain the safety before taking the next step. Human error in not following this meticulously has resulted in some incidents.

(iii) The reactor has a well defined 'safe shutdown state' and separate provisions, to make it remain in that state as long as required. Thus, in case of any serious malfunctioning of any reactor system, the protective system automatically trips the reactor and brings it to the 'safe' state. In the case of fuel handling system it is not possible to follow a similar philosophy. The safest place for the spent fuel removed from the reactor is the storage bay. Normal operation is also directed to take the spent fuel bundles to the storage bay in a safe manner. However, if problems in the intermediate equipment arise, a judicious decision is necessary on whether to cautiously proceed ahead in a degraded mode or move the spent fuel in the reverse direction for temporary storage in one of the health equipment until the problem is resolved. This decision depends upon factors, like nature of the problem, nature of the corrective actions required, accessibility of the equipment, etc. Generally, provision of the cooling system is quite satisfactory and reliable. As the operations can be put on 'hold' at any stage and the spent fuel bundles are safe in all parts of the fuel handling system, there is no urgency to move them in any direction, in most cases. Reasonable time can be spent in understanding the nature of the problem and working out a solution. Some incidents have taken place due to an error of judgment or decisions taken in a hurry on the basis of inadequate or erroneous information.

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	April 23, 1996	April 22, 1998
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	October 15, 1996	March 09, 2000
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PROVISIONAL LIST OF SAFETY CODE, GUIDES AND MANUAL ON DESIGN OF PRESSURISED HEAVY WATER REACTORS

Safety Series No.	Provisional Title
AERB/SC/D	Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants
AERB/SG/D-1	Safety Classification and Seismic Categorisation
AERB/SG/D-2	Application of Single Failure Criteria
AERB/SG/D-3	Protection Against Internally Generated Missiles and Associated Environmental Conditions
AERB/SG/D-4	Fire Protection in Pressurised Heavy Water Based Nuclear Power Plants
AERB/SG/D-5	Design Basis Events for Pressurised Heavy Water Reactor
AERB/SG/D-6	Fuel Design
AERB/SG/D-7	Core Reactivity Control in Pressurised Heavy Water Reactor
AERB/SG/D-8	Primary Heat Transport System
AERB/SG/D-9	Process Design
AERB/SG/D-10	Safety Critical System
AERB/SG/D-11	Emergency Electric Power Supply Systems for Pressurised Heavy Water Reactor
AERB/SG/D-12	Radiation Protection in Design
AERB/SG/D-13	Liquid and Solid Radwaste Management
AERB/SG/D-14	Control of Air-borne Radioactive Materials in Pressurised Heavy water Reactors
AERB/SG/D-15	Ultimate Heat Sink and Associated Systems in Pressurised Heavy Water Reactor

PROVISIONAL LIST OF SAFETY CODE, GUIDES AND MANUAL ON DESIGN OF PRESSURISED HEAVY WATER REACTORS (contd.)

Safety Series No.	Provisional Title
AERB/SG/D-16	Materials Selection and Properties
AERB/SG/D-17	Design for In-Service Inspection
AERB/SG/D-18	Loss of Coolant Accident Analysis for Pressurised Heavy Water Reactor
AERB/SG/D-19	Hydrogen Release and Mitigation Measures under Accident Conditions
AERB/SG/D-20	Safety Related Instrumentation and Control
AERB/SG/D-21	Containment System Design
AERB/SG/D-22	Vapour Suppression System for Pressurised Heavy Water Reactor
AERB/SG/D-23	Seismic Qualification
AERB/SG/D-24	Design of Fuel Handling and Storage Systems for Pressurised Heavy Water Reactors
AERB/SG/D-25	Computer based Safety Systems
AERB/SM/D-1	Decay Heat Load Calculations