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ULTIMATE HEAT SINK AND ASSOCIATED SYSTEMS IN PRESSURISED HEAVY WATER REACTOR

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FOREWORD

Safety of the public, occupational workers and protection of the environment should be assured while activities for economic and social progress are pursued. These activities include the establishment and utilisation of nuclear facilities and use of radioactive sources. They have to be carried out in accordance with relevant provisions of the Atomic Energy Act 1962.

Assuring high safety standards has been of prime importance since the inception of the nuclear power programme in the country. Recognising this aspect, the Government of India constituted the Atomic Energy Regulatory Board (AERB) in November 1983, vide statutory Order No. 4772 notified in the Gazette of India dated 31.12.1983. The Board has been entrusted with the responsibility of laying down safety standards and framing rules and regulations in respect of regulatory and safety functions envisaged under the Atomic Energy Act of 1962. Under its programme of developing safety codes and guides. AERB has issued four codes of practice in the area of nuclear safety covering the following topics:

Safety in Nuclear Power Plant Siting

Safety in Nuclear Power Plant Design

Safety in Nuclear Power Plant Operation

Quality Assurance for safety in Nuclear Power Plants

Safety guides are issued to describe and make available methods of implementing specific parts of the relevant codes of practice as acceptable to AERB. Methods and solutions other than those set out in the guides may be acceptable if they provide at least comparable assurance that Nuclear Power Plants (NPPs) can be operated without undue risk to the health and safety of plant personnel, the general public and the environment.

Codes and safety guides may be revised as and when necessary in the light of experience as well as relevant developments in the field. The annexures, footnotes, references and bibliography are not to be considered integral parts of the document. These are included to provide information that might be helpful to the user.

The emphasis in the codes and guides is on protection of site personnel and the public from undue radiological hazards. However, for other aspects not covered in the codes and guides, applicable and acceptable national and international codes and standards shall be followed. In particular, industrial safety shall be assured through good engineering practices and through compliance with the Factories Act 1948 as amended in 1987 and the Atomic Energy (Factories) Rules, 1996.

The Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants (AERB/SC/D, 1989) states the minimum requirements for ensuring adequate safety in plant design. One of the requirements is to have adequate provisions in the design to transfer residual heat to an ultimate heat sink.

This Safety Guide on Ultimate Heat Sink (UHS) and Associated Systems in Pressurised Heavy Water Reactor (PHWR) elaborates the requirements stated in the above mentioned Code of Practice and prescribes the design requirements to be considered and provisions to be made in the design of UHS and associated systems by personnel and organisation participating in the plant design. The plant design should ensure transfer of residual heat to an ultimate heat sink under normal operation, anticipated operational occurrences and accident conditions, so that acceptable design limits are not exceeded

This Safety Guide has been prepared by the staff of AERB, BARC, IGCAR and NPC. It has been reviewed by experts and vetted by the AERB Advisory Committees before issue. AERB wishes to thank all individuals and organisations who have prepared and reviewed the draft and helped in the finalisation of the Safety Guide. The list of persons who have participated in the committee meetings, along with their affiliation, is included for information.

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Chairman, AERB

DEFINITIONS

Acceptable Limits

Limits acceptable to the Regulatory Body.

Accident Conditions

Substantial deviations from Operational States[1], 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 severe accidents.

Anticipated Operational Occurrences[2]

All operational processes deviating from normal operation which may occur during the operating life of the plant and which in view of appropriate design provisions, neither cause any significant damage to items important to safety nor lead to accident conditions.

Common Cause Failure[3]

The failure of a number of devices or components to perform their functions as a result of a single specific event or cause.

Cold Shutdown

The shutdown state of the reactor with fuel, coolant and moderator at ambient temperature conditions.

Design Basis Events (DBE)

Design Basis Events (DBE), which form the basis for design of NPP include operational transients and postulated initiating events (PIEs).

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1 Substantial deviation may be a major fuel failure, a Loss of Coolant Accident (LOCA), etc. Examples of engineered safety features are: an Emergency Core Cooling System (ECCS) and containment.

2 Examples of Anticipated Operational Occurrences are loss of normal electric power and faults such as turbine trip, malfunction of individual items of control equipment and loss of power to primary coolant pump.

3 The event or cause may be internal or external to the protection system. Some examples are: a design deficiency, a manufacturing deficiency, operation and maintenance errors, a natural phenomena, a man-induced event, saturation of signals, unintended cascading effects from any other operation or failure within the plant, and changes in ambient condition.

Diversity

The existence of redundant components or systems to perform an identified function, where such components or systems collectively incorporate one or more different attributes.[4]

Hot Shutdown

The shutdown state of reactor with coolant temperature (inlet to reactor) and pressure close to normal operating condition and the coolant circulating pump running.

Independence

Independence of equipment, channel or a system is its ability to perform its function irrespective of the normal or abnormal functioning of any other equipment, channel or a system. Independence is achieved by functional isolation and physical separation.

Loss of Coolant Accident (LOCA)

An accident in which coolant is lost from primary heat transport system at a rate greater than the rate at which the make-up system can cater to.

Normal Operation

Operation of a plant or equipment within specified operational limits and conditions. In the case of nuclear power plant, this includes start-up, power operation, shutting down, maintenance, testing and refueling (see Operational States).

Operational States

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

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4 Examples of such attributes are: different operating conditions of uses, different size of equipment, different manufacturers, different working principles and types of equipment that use different physical methods.

Postulated Initiating Event[5] (PIE)

A hypothetical event that could lead to Anticipated Operational Occurrences and Accident Conditions, their credible failure effects and their credible combinations.

Prescribed Limits

Limits established or accepted by the Regulatory Body for specific activities or circumstances that must not be exceeded.

Redundancy

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

Reliability

The probability that a structure, system, component or facility will perform its intended (specified) function satisfactorily for a specified time period under specified conditions.

Residual Heat

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

Residual Heat Removal Systems

Heat transport systems of nuclear power plant for transporting residual heat loads from reactor core, safety-related structures, systems and components and spent fuel storage to UHS.

Station Blackout (SBO)

Station blackout is a design basis event and sets in with the loss of both off-site and on-site normal AC power supply including emergency diesel generators.

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5 The primary cause of postulated initiating events may be credible equipment failures and operator errors (both within and external to the nuclear power plant), design basis natural events and design basis external man-induced events. Specification of the postulated initiating events should be acceptable to the AERB for NPP.

Ultimate Heat Sink (UHS)

The atmosphere or a body of water or the ground water, to any or all of which residual heat is transferred during normal operation, anticipated operational occurrences or accident conditions.

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1. INTRODUCTION

1.1 General

To ensure adequate safety of pressurised heavy water based nuclear power plants (PHWR), one of the general safety requirements is to provide means for transferring residual heat from the reactor at a rate, such that the specified acceptable fuel design limits and the design conditions of primary heat transport system (PHTS) pressure boundary are not exceeded under normal operation and operational transients and the radioactivity release are maintained within prescribed limits.

For D B E, means should be provided for transfer of residual heat to limit fuel failure and to provide adequate cooling to containment atmosphere to keep its pressure and temperature as minimum as possible to ensure that radioactivity release to environment is within acceptable limits.

To meet the above safety requirements, the Ultimate Heat Sink (UHS) and associated residual heat removal (heat transport) systems are to be designed to transport residual heat loads from the reactor core, safety-related structures, systems and components and spent fuel storage bay to be absorbed by UHS.

1.2 Objective

1.2.1 The purpose of this safety guide is to provide guidance for design of the UHS and associated residual heat removal systems for accomplishing their principal safety functions namely,

- dissipation of residual heat during and after reactor shutdown; and
- dissipation of residual heat during and after DBE.

1.2.2 The present Guide supplements the general safety requirements specified in the Code of Practice on Design for Safety in Pressurised Heavy Water based Nuclear Power Plants (AERB Safety Series No. SC/D, 1989). To ensure adequate safety in NPP, the design of UHS and associated systems shall meet the safety requirements as specified in section 0342 of the above referred Code.

1.3 Scope

1.3.1 The Guide covers safety considerations in designing various types of UHS and associated systems in performing their function of transfer of residual heat from the reactor. The scope also covers conditions under which UHS and associated systems are used for reactor safety following DBE, as well as their selection, capacity and reliability.

The scope is limited to the design of UHS (large water body or atmosphere) and the directly associated heat transport systems and extends to and includes any make-up systems which are a necessary part of UHS itself or its associated systems.

1.3.2 Safety requirements in the design of heat transfer systems for performing their function during normal power operation are covered in the AERB Design Safety Guide on Primary Heat Transport Systems in PHWR (AERB/SG/D-8). Access control and physical protection aspects, which are to be considered in the early stages of design/layout of structures and systems associated with UHS, are covered in AERB Safety Code for Design (item 0351 on page-19 & item 0359 on page-21 of AERB/SC/D, 1989).

2. ULTIMATE HEAT SINK AND ASSOCIATED SYSTEMS

2.1 Ultimate Heat Sinks

UHS normally could be one or both of two forms: a body of water, or the atmosphere. The body of water may be sea, river, lake, reservoir, groundwater, other stored water facility or a combinations of these. All requirements of dissipation of residual heat may be met using a single heat sink or a combination of such sinks.

Temporary Intermediate Heat Sinks for Certain DBEs:

In some designs, heat sinks internal to the plant as illustrated below could provide, under certain conditions of DBE, temporary heat absorption capacity to allow some time before the UHS and associated systems start being effective as per the design intent; but they on their own cannot be regarded as constituting UHS. However credit may be taken for these in design safety analysis.

Some typical examples of temporary intermediate heat sinks are:

- moderator and vault water systems under the conditions of Loss Of Coolant Accident (LOCA) and failure of Emergency Core Cooling System (ECCS),
- containment structure during the initial phase of LOCA and
- suppression pool water.

2.2 Associated Heat Transport Systems

2.2.1 For designing associated heat transport systems, one or more of the physical processes, namely evaporation of water, rise in the temperature of a fraction of UHS or by thermal radiation, are used for dissipation of residual heat. Some of the possible ways in which heat transport processes could be used in the design of associated systems are:

- Circulation of seawater/freshwater from a large water body in once-through system,
- Wet cooling towers with make-up facility from a lake or reservoir or large pond,

- Dry cooling towers,
- Evaporation of water in steam generator,
- Convection or radiation from structures,
- Condensing systems and
- Recirculation of water through a spray pond.

2.2.2 In a typical design of the current PHWR power plants, the systems provided for residual heat removal during different reactor states and DBEs are as described in Annexure-I, Fig.1, Fig.2 and Table–I.

3. DESIGN PRINCIPLES

3.1 Design Objective

3.1.1 The UHS and associated systems should be designed to transfer residual heat from reactor core and other safety-related structures, systems and components at a rate such that,

under normal operation and operational transients

- the specified acceptable fuel design limits are not exceeded, and
- the integrity of PHTS pressure boundary is maintained,

and during and after DBE conditions

- fuel failures are limited to acceptable levels and
- the integrity of containment structure is maintained.

3.1.2 The heat transferred to and to be absorbed by the UHS should be based on the magnitude of various heat sources and their time-dependent behaviour. The various heat loads to be considered are covered in this Safety Guide and guidance for calculational methods are dealt with in the Safety Manual on Decay Heat Calculations, (AERB/SM/D-1) and the Safety Guide on LOCA Analysis Methods, (AERB/SG/D-18).

3.1.3 To meet the design objective, UHS and associated systems should have:

- high reliability (simplicity, passive features, redundancy, diversity and independence),
- operability at specified capacity and for specified period under DBEs and
- long-term availability.

3.2 Redundancy

3.2.1 Suitable redundancy in the design of residual heat removal systems associated with UHS should be provided to ensure that the system safety functions can be accomplished assuming a single failure criterion and equipment outage for maintenance. For example, multiple pumps and heat exchangers for APWS and PWCS should be provided.

3.2.2 Redundancy should also be applied to cooling water intake tunnels, discharge tunnels, cooling towers, etc. of UHS. In case redundancy is not achieved, the system reliability should be maintained at a high level by proper in-service inspection, maintenance and operating procedures to prevent their failure during service.

3.3 Diversity

Diversity should be applied to redundant systems to reduce potential for common cause failure and to improve reliability of a system.

For example, for DBE conditions including common cause failure, the required core cooling should be achieved by,

- diverse heat transfer fluids and independent feed lines to SG i.e. ABFW and firewater,
- different modes of residual heat removal i.e. cooling in SG or shutdown coolers,
- different manufacturers/design of firewater pumps and
- alternate power supplies and their distribution to pumping equipment i.e. off-site (class-IV) and on-site (class-III) power supplies from diverse electrical buses and motor control centres

3.4 Independence

The reliability of systems and components of residual heat removal systems associated with UHS should be improved by applying principles of independence in the design. This should be achieved by using,

Functional isolation: Wherever suitable interconnections are provided to have redundancy, effective isolation capabilities in redundant systems and components should be provided to take care of abnormal operation or failure.

For example inter-connections of feed water, emergency feed water and firewater to SG should have suitable isolations amongst them to ensure required make-up to SG under any abnormal operation or failure.

Physical separation: While designing plant layout to mitigate common cause failures such as fire, flooding, internally generated missiles, environment etc., separation of associated systems and components of UHS should be achieved by distance, orientation, barrier or a combination thereof.

For example housing the pumps of APWS and PWCS of UHS in a separate safety- related pump house, routing of piping and water tunnels of associated systems with adequate physical separation.

3.5 Design for Optimised Operator Performance

For optimised operator performance, an operator would need some time to comprehend and respond to the plant condition during and following a DBE, based on alarms/annunciations. The design should aim at a situation where the need for operator intervention on a short time period of less than 30 minutes following a DBE should be kept to a minimum and such time period should be sufficient to accomplish the optimised operator performance. (Ref. AERB/SC/D page 17 clause 0341).

In the case of certain DBE, such as a SBO condition, requirement of operator intervention within 30 minutes of DBE can be accepted, where the designer can demonstrate that the operator has sufficient time to decide and act, that the necessary information on which the operator must base a decision to act, is simply and unambiguously presented, and that the physical environment following the event is acceptable in the control room.

However, for safety analysis, operator intervention up to 30 minutes should not be considered.

3.6 Multi-Reactor Sites

3.6.1 Structures, systems and components of heat transport systems associated with the UHS should not normally be shared between two or more reactors at site.

Where such sharing is practised, the associated heat transport systems should be capable of meeting the design objectives for:

- simultaneous cooldown of all the reactors they serve,
- dissipation of heat following an accident in one reactor, in addition to the simultaneous cool-down of all remaining units served, and
- capabilities of isolation of the residual heat removal systems of UHS serving different reactors.

3.6.2 Sharing of civil structures of UHS or associated systems could be practised, provided that all DBEs (including seismic and fire events) have been properly considered in the design, and that adequate physical separation is provided between redundant components.

3.6.3 Sharing of systems and components associated with UHS should not degrade overall reliability due to,

- complex design features, such as multiple interlocks and automatic switchover of shared equipment to various reactors, and
- reduced availability of shared services due to their down-time for maintenance or repair.

3.6.4 Sharing of make-up systems is permissible subject to the same requirements as specified for UHS and associated systems.

4. DESIGN BASIS

4.1 Selection Criteria

Selection of UHS and associated systems shall be based on specific site conditions including sources of a heat transport medium (water or air), postulated initiating events for the site, (e.g. possibility of failure of a downstream dam) and relevant regulations pertaining to environmental protection.

UHS shall be capable of absorbing the residual heat from the reactor it serves, while itself remaining within prescribed temperature limits. The physical processes involved in heat transfer mechanism may determine these temperature limits, or they may be set by competent authorities on the basis of environmental considerations. Since residual heat removal system of UHS is safety class-3, it should be designed as an independent system.

Table-I gives typical examples of UHS and associated systems for different reactor states and DBE conditions.

4.1.1 Ultimate Heat Sink

In selecting UHS, the following site-specific events as applicable should be taken into consideration :

- **Natural events** e.g. seismic, geological, inland and coastal flooding, extreme meteorological events, shoreline erosion, silt movement, tidal waves, etc.

- **External events** e.g. loss of off-site power, fire, drifting of ship to shore line resulting in collision with UHS structures, oil slick, thermal and chemical pollution, biological life (jelly fish), algae, contaminants/debris (plastic wastes), dam failure leading to loss of UHS, etc.

- **Internal events** e.g. fire, pipe ruptures and internal flooding.

To fulfil the design objective, all relevant site-related, external and internal events shall be considered in evaluating alternatives using a combination of heat sinks and various make-up sources and heat transport systems.

In selecting UHS, the quality of medium available, heat removal capability from various heat loads and the expected extreme environmental conditions of the proposed UHS should be considered.

Availability of alternate to the proposed UHS for a limited time period should also be considered. (also Ref. 4.2.1).

4.1.2 Associated Heat Transport Systems

The selection of heat transport systems associated with UHS should be governed largely by factors involved in the selection of UHS itself.

Certain additional factors to be considered are:

- provision of once-through systems, keeping the design temperatures within limits as stipulated by environmental authorities, where large water bodies (e.g. sea, river) are selected as UHS;
- recirculation type of heat transport system combined with a cooling tower with adequate make-up provision, and
- safeguard against accidental release of radioactivity into environment from primary radioactive systems.

For example; heat rejection from primary radioactive systems (viz. PHT and associated systems; end-shield, moderator and calandria vault systems; SFSB etc.) to UHS through an intermediate heat transport system (APWS) apart from heat transport systems directly associated with UHS (PWCS). For this safeguard, there should be provision

- for timely detection of leak across primary/intermediate heat exchangers and required isolation without compromising the heat transport function;
- for transferring contaminated water from normally inactive intermediate heat transport system in case of heat exchanger tube failures; and
- for required make-up capability to replace contaminated water with inactive water within a reasonable period.

4.1.3 Heat Transport Fluids

The heat transport fluids used may not necessarily be the same along the train of the heat transfer route from heat source to UHS, for example, one stage using steam, and one or more using water of different chemistry parameters or from another system (for example fire water system) under certain situations such as during SBO.

For heat transfer systems in which heat transport fluid is used up in the process, for example, when steam is produced and released to the atmosphere, provision should be made for adequate replenishment of heat transport fluid.

4.2 Sizing Criteria

The capacity and capability of UHS and associated systems should be determined on the basis of combination/addition of peak heat loads required to be absorbed and their rate of generation from reactor core and other safety-related structures, systems and components under all normal operation states and DBE conditions to achieve design objective with respect to integrity of fuel, PHTS pressure boundary and containment.

4.2.1 Capacity of UHS

UHS should be capable of dissipating residual heat under all normal operation states and DBE conditions. In addition, there should be adequate SSE-qualified stored inventory of water to dissipate residual heat for a specified period and in any case, the specified period should not be less than seven days. (see footnote[6] and section 4.1.5.3 of the AERB Code of Practice on Safety in Nuclear Power Plant Siting, AERB/SC/S, March 1990).

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6 Typically seven days storage capacity has been provided in current (220 MWe) PHWRs, on the basis that within this period alternative source for make-up can be organised. The requirement for heat removal after seven days is approximately 0.5% of heat load at the starting of shutdown. During SBO condition, firewater system plays the role of UHS for removing residual heat. Hence firewater system should have to fulfil the required objective for the specified SBO period for the particular site.

Further, there should be a provision for assuring continued cooling beyond the minimum specified period by alternate arrangement for necessary make-up requirements. For example, readiness for creation of bore holes for additional water supply beyond the minimum specified period. The required quantity of cooling water in UHS to transfer residual heat from reactor up to the minimum specified period after shutdown, should be assessed as a function of time, based on time dependent residual heat loads as per computation in the Safety Manual on Decay Heat Calculations, (AERB/SM/D-1) and the Safety Guide on LOCA Analysis Methods, (AERB/SG/D-18).

4.2.2 Capacity of Associated Heat Transport Systems of UHS

Capacity of heat transport systems should be governed by the following factors:

- Maximum heat rejection rate to UHS from various heat loads,
- Extreme environmental conditions (e.g. water or air temperature, relative humidity, etc.), and
- Heat transfer fluid supplies.

4.2.2.1 Heat Rejection Rate to UHS

In establishing the maximum heat rejection rate, the most severe combination of individual heat loads (time dependent) should be identified for all DBEs for which UHS is called upon to perform the safety function. Considerations may be given to temporary heat storage in heat sinks within the plant, such as structures within the core, primary or secondary systems, suppression pool, containment structure, spent fuel storage pools and heat transport media. For example, auxiliary boiler feed water system operating in conjunction with available water in SG or other source of water (fire water system) on site, may be used to dissipate core residual heat for certain events during the initial period following reactor trip. These factors may be used to establish peak heat rejection rate required for sizing the associated systems of UHS by delaying the time when the UHS will be required to accept core residual heat and other heat loads.

4.2.2.2 Environmental Conditions

Design basis environmental parameters should be established as per Safety Guide on Extreme Value Analysis for Meteorological Parameters (AERB/SG/S-3). The environmental parameters should include water body temperature for once-through water-cooling systems and both dry and wet bulb air temperatures needed for wet cooling towers, cooling or spray ponds and for other heat transport systems that use cooling. Also, other parameters such as wind speed, solar radiation, water quality (chemical impurity, silt content, weeds, jelly fish etc.) shall be considered where required.

Environmental parameters specific to design should be selected with respect to controlling parameter and critical time periods during which extreme environmental conditions exist. Effects which could cause significant variations in parameters at site, such as effects on water or atmosphere, caused by other nearby facilities which also make use of the same heat transfer medium, should be considered.

4.2.3 Heat Loads :

Various heat loads (time-dependent and reactor state-dependent) which should be considered in determining the required capacity of UHS and associated systems to fulfil the design objectives are:

(i) Residual heat loads

- core decay heat (from radioactive decay and shut down fission),
- stored heat (from fuel, coolant, structure etc.), and
- heat rejected from safety-related systems:
- residual heat from moderator, calandria vault, end-shield, spent fuel storage bay,
- equipment heat from diesel generators, compressors, control room coolers, etc.

(ii) Accident-related heat sources : containment-V1 coolers, metal-water reaction and over-power excursion.

(iii) Non-accident related heat sources : pumping energy.

Table-II shows typical heat loads to UHS and associated systems for different reactor states and DBE conditions in the current PHWR-based NPP.

4.2.3.1 Core Decay Heat

Reactor core decay heat loads should be considered as per the Safety Manual on Decay Heat Calculation (AERB/SM/D-1).

4.2.3.2 Stored Heat

During reactor cooldown following shutdown, the stored heat in fuel, primary/secondary (as applicable) heat transport system (in coolant and hardware), associated components and other reactor related structures should be evaluated conservatively and should form an input to design of UHS and associated systems. Also the design should estimate the required heat rejection rate to UHS under various conditions of DBE.

While bringing the reactor from hot shutdown state to coldshut down state, the cooling should be maintained and controlled till the PHTS water temperature is brought down within the capability of shutdown cooling system.

4.2.3.3 Heat Rejected from Safety-Related Systems

The UHS and associated systems should also have sufficient capacity to absorb heat rejected from safety-related systems such as,

- moderator, end-shield, calandria vault,
- control room coolers and containment-V1 coolers,
- spent fuel storage bay, and
- diesel generators, air compressors etc.

4.2.3.4 Accident-related Heat Sources

For accident conditions, the following additional heat loads should be taken into account considering their time-dependent release,

- containment heat loads (for example, increased heat loads in containment-V1 zone due to LOCA, main steam line break),
- exothermic metal-water reaction (for example, following a LOCA and loss of ECCS there could be a exothermic reaction between zircalloy and steam/water), and
- power excursion (for example, there could be power excursion due to addition of positive reactivity introduced by voiding of coolant during LOCA),

4.2.3.5 Heat from Spent Fuel Storage Bay

The total heat load and rejection rate due to spent fuel stored in storage bay at site should be evaluated on the basis of maximum number of spent fuel bundles which are specified to be stored on-site for a particular plant at any time. This maximum number specified shall be at least equivalent to one full core unloading in addition to storage of the pre-decided number of years of spent fuel from the reactors in operation at a particular site. Either the decay heat curves for the particular fuel involved, with appropriate individual post-irradiation cooling period applied to various fuel bundles, or a conservative overall average post-irradiation cooling time for all fuel bundles shall be used for arriving at the total heat load. (Refer the Safety Guide on Fuel Handling and Storage Systems, AERB/SG/D-24).

4.3 Safety Classification and Seismic Categorisation :

Safety classification and seismic categorisation of UHS and associated systems should be as per the Safety Guide on Safety Classification and Seismic Categorisation of Structures, Systems and Components (AERB/SG/D-1).

4.4 Design Basis Events

DBE should be established for the particular site with due consideration to the likelihood and consequences of external and internal events, including combination of these events. External events and its effect on UHS and associated systems should be considered consistent with the Code of Practice on Safety in Nuclear Power Plant Siting (AERB/SC/S, 1990) and other relevant AERB Safety Guides.

For each DBE established, the UHS and associated systems shall, in conjunction with operation of other necessary safety systems, be capable of fulfilling the primary design objective considering single failure criterion. In addition, simultaneous failure of two or more components in the system should be established to be very low. All events should be evaluated as per the Safety Guide on Design Basis Events (AERB/SG/D-5).

Typical DBEs and Beyond Design Basis Event (BDBE) as applicable to UHS and associated systems are listed in Table - III.

5. OTHER DESIGN REQUIREMENTS

5.1 Provision for Surveillance and In-service Inspections

Provision should be made in the design of UHS and associated systems to permit in- service monitoring and inspection to provide adequate assurance of continued functional capability throughout the lifetime of the plant.

Adequate instrumentation should be provided to enable plant operators to verify the capability of UHS to perform its safety function. Towards this, instrumentation to monitor the system flow rate, pressure, temperatures, water level, radioactivity and other relevant parameters should be provided. (Refer the AERB Design Safety Guide on Safety related Instrumentation and Control, AERB/SG/D-20).

The design should also include provisions for periodic in-service inspection of UHS and associated systems to satisfy design intended requirements and to ensure continued availability. (Refer the AERB Safety Guide on In-Service Inspection for Nuclear Power Plants, AERB/SG/O-2). Periodic surveillance at water intakes should be carried out for appearance of jellyfish and other marine plants and organisms.

Provision for periodic testing to ensure continued availability of alternate source (water body, provisions for bore holes, etc.) for UHS/make-up water should be established.

Design provisions should also be made to facilitate ease of maintenance of associated equipment.

5.2 Chemistry and Radioactivity Aspects

Chemistry control is essential to limit corrosion and generation of corrosion products in closed-loop heat transport systems and biological growth in open-loop heat transport systems so that the required water flow and heat transfer coefficients are maintained as per design intent for transfer of heat from source to UHS.

The required design provisions should be made for chemical addition/system water purification to achieve specified chemistry control and to inhibit growth of marine organisms within cooling circuits.

Sampling provisions at appropriate locations should be made to collect representative samples of heat transport systems fluids towards monitoring specified chemistry and radioactivity control parameters.

5.3 Quality Assurance

A quality assurance programme should be in place for UHS and associated systems, from design to construction and commissioning. For guidance on QA requirements, the AERB Code of Practice and Safety Guide on Quality Assurance in Design should be referred to.

ANNEXURE - I

HEAT TRANSPORT SYSTEMS ASSOCIATED WITH UHS IN A TYPICAL DESIGN OF THE CURRENT PHWR-BASED NUCLEAR POWER PLANTS FOR RESIDUAL HEAT REMOVAL DURING DIFFERENT REACTOR STATES AND DBEs

1. Associated Heat Transport Systems

Various trains of systems and components of associated heat transport systems in a typical design are as described below: (Refer Figs.1and 2 and Table-I).

1.1 Auxiliary Boiler Feed Water System (ABFWS)

Whenever the main boiler feed pump is not available, ABFWS is used for transferring residual heat from the reactor core to UHS through steam generators (SG). To ensure that adequate level is maintained in SGs at all times, feed water to SGs is provided by Auxiliary Boiler Feed Pump (ABFP) which takes suction from deaerator storage tank/dedicated storage tank through independent suction line.

The objective of ABFWS is to provide adequate inventory of water in SG to

- maintain reactor in hot shutdown state, and
- achieve cooldown of PHTS from operating temperature to cold shutdown state

after a reactor trip or shutdown.

1.2 Active Process Water System (APWS)

This system is a safety-related secondary and intermediate cooling system. It acts as a barrier between radioactive primary heat source and the tertiary process water cooling system (PWCS) to prevent release of radioactivity to atmosphere/large water body in case of breach in heat exchangers.

APWS provides cooling to heavy water heat exchangers (HXs), light water HXs and to safety-related equipment in reactor building, service building, and reactor auxiliary building for transferring heat from primary heat sources to tertiary process water cooling water system (PWCS) through PWHXs.

APWS provides cooling to PHT shutdown cooling system pumps, moderator pumps, PHT bleed coolers, PHT main pump gland and motors, PHT shutdown coolers, moderator coolers, calandria vault coolers, end-shield coolers, ECCS HXs, containment (V1) coolers, SFSB coolers, etc.

1.3 Process Water Cooling System (PWCS)

PWCS is a safety-related tertiary system directly associated with UHS. The main objective of PWCS is to remove heat from APWS through PW HXs and dissipate the heat to UHS i.e. to atmosphere through Induced Draught Cooling Tower (IDCT) or dry cooling tower in case of recirculating type systems or to a large water body in case of once-through systems.

PWCS also provides cooling to compressors, diesel generators, auxiliary boiler feed water pumps etc.

1.4 Induced Draught Cooling Tower with its Make-up System or Dry Cooling Tower

The heat transferred from primary heat sources through APWS to PWCS is ultimately dissipated to atmosphere through IDCT by evaporative cooling, in case of recirculation type PWCS. To take care of water loss in IDCT, due to evaporation and drift loss, make-up water to PWCS is provided with necessary redundancy.

Alternatively, in case of recirculating type systems, dissipation of residual heat to atmosphere can be through dry cooling tower.

1.5 Fire Water System

The objective of fire water system is primarily for fire fighting purposes. However fire water system may be used as a back-up cooling system for mitigating certain design basis events (DBE) such as station black-out (SBO) for specified duration, failure of APWS / PWCS, etc.

Towards fulfilling the above limited objective as a back-up cooling system, fire water system is provided with dedicated diesel engine driven fire water pump and fire water is provided to secondary side of SGs and to the primary side of end-shield for SBO condition of specified duration and is also provided to secondary side of shutdown coolers and moderator heat exchangers for APWS/PWCS failure condition.

2. Residual Heat Removal During Different Reactor States and DBEs

Residual heat loads, generated during different reactor states and DBEs, are transferred to UHS through various trains of systems and components of associated heat transport systems as detailed below: (Refer Figs.1 and 2 and Table-I).

2.1 Power Operation

During power operation, heat is transferred from reactor core, through PHTS to steam cycle on the secondary side with boiler feed water (BFW) as make-up. Further, the steam is condensed with Condenser Cooling Water System (CCWS) and the heat is rejected to atmosphere through Natural Draught Cooling Tower (NDCT) or through dry cooling tower, in case of recirculation type CCWS. Alternately, the heat is rejected to a large water body (sea, lake or river), in case of once-through type CCWS.

Heat loads from other safety-related systems are transferred through APWS to PWCS. In case of recirculation type PWCS, heat is rejected to atmosphere via IDCT. In case of once-through type PWCS, heat is rejected to a large water body (sea, lake or river).

2.2 Hot Shutdown

During hot shutdown state, residual heat is transferred from the core through PHTS to steam cycle on the secondary side with ABFW to SG. Further, the steam is discharged through CSDV to condenser and cooled with CCWS. Heat from CCWS is rejected to atmosphere via NDCT or to a large water body. In addition, fast cooling is achieved by additional steam discharge to atmosphere through ASDV. Heat loads from other safety related systems are transferred through APWS to PWCS and finally to a large water body or to atmosphere.

While bringing the reactor from hot shutdown state to cold shutdown state, the above trains of cooling would be maintained and controlled till the PHTS water temperature is brought down to within the capability of shutdown cooling system.

2.3 Cold Shutdown

During cold shutdown state, the residual heat from the core is transferred through PHT shutdown cooling system (SDCS) to APWS. The heat loads from other safety-related systems are also transferred to APWS. The heat from APWS is then transferred to PWCS and finally to a large water body or to atmosphere.

2.4 LOCA

During LOCA with class-III power supply available condition, residual heat from the core is removed initially by crash cooling in SG depending on the break size and later by ECCS. Heat loads from ECCS and other sources are transferred through APWS to PWCS and finally to a large water body or to atmosphere.

2.5 LOCA and Failure of ECCS

During simultaneous LOCA and failure of ECCS with class-III power supply available condition, residual heat from core is removed to atmosphere through SG by crash cooling to some extent and largely by radiation/ convection heat transfer from PHTS through pressure tube-calandria tube (PT-CT) gap to moderator system. Heat loads from moderator system and other sources are transferred through APWS to PWCS and finally to a large water body or to atmosphere.

In case of failure of ECCS pumps for recirculation phase, residual heat from core is removed by injection of firewater to ECCS in controlled manner.

2.6 Station Blackout

During station blackout (SBO) condition, residual heat from core is removed by steam discharge to atmosphere through ASDV (i.e. crash cooling) with fire water system as make-up to secondary side in SG for a specified period. Further, residual heat from end-shield is also removed by injection of firewater.

TABLE - I

TYPICAL EXAMPLES OF UHS AND TRAINS OF ASSOCIATED HEAT TRANSPORT SYSTEMS FOR DIFFERENT REACTOR STATES AND DBES

Reactor State / DBE	Primary Heat Source	Heat Transport Systems Associated with UHS				UHS
Normal Power Operation *(INDICATED ONLY FOR CLARITY)*	PHTS	Steam cycle with BFWS		CCWS	with NDCT →	Atmosphere
					without NDCT →	Sea, lake or river
	Other safety-related Systems *	APWS		PWCS	with IDCT →	Atmosphere
					without IDCT →	Sea, lake or river
Hot shutdown	PHTS	**Steam Cycle With ABFWS**	CSDV	CCWS	without NDCT →	Sea, lake or river
					with NDCT →	Atmosphere
			ASDV			
	Other safety-related Systems*	APWS	→	**PWCS**	**with IDCT →**	**Atmosphere**
					Without IDCT →	**Sea, lake or river**
Cold shutdown	PHTS Other safety-related systems*	APWS	→	**PWCS**	**with IDCT →**	**Atmosphere**
					without IDCT →	**Sea, lake or river**
LOCA Class III available	ECCS Other safety-related systems*	APWS	→	**PWCS**	**without IDCT →**	**Sea, lake or river**
					with IDCT →	**Atmosphere**
LOCA + failure of ECCS Class III available	Core Heat to moderator system Other safety-related systems*	APWS	→	**PWCS**	**without IDCT →**	**Sea, lake or river**
					with IDCT →	**Atmosphere**
SBO	PHTS (thermo-syphoning)	**Steam cycle with fire water system**	**ASDV →**		**→**	**Atmosphere**
	End Shield Cooling	**Fire water Systems**	**Overflow to suppression pool**			

Notes and Remarks on Table-I **(See page 22)**

UHS & DIRECTLY ASSOCIATED HEAT TRANSPORT SYSTEMS ARE MARKED IN **BOLD**

* **Other safety-related systems** : Cooling Systems of End-Shield, Moderator, Calandria Vault, SFSB, Containment (V1) and Control Room Coolers, (as applicable) Compressors, Diesel Generators etc.

Nomenclatures :

APWS	:	Active Process Water System	ASDV	:	Atmospheric Steam Discharge Valve	ABFWS	:	Auxiliary Boiler Feed Water System
BFWS	:	Boiler Feed Water System	CCWS	:	Condenser Cooling Water System	CSDV	:	Condenser Steam Dump Valve
ECCS	:	Emergency Core Cooling System	FWS	:	Fire Water System	IDCT	:	Induced Draught Cooling Tower
NDCT	:	Natural Draught Cooling Tower	PHTS	:	Primary Heat Transport System	PWCS	:	Process Water Cooling System
SBO	:	Station black-out	SDCS	:	Shutdown Cooling System	SFSB	:	Spent Fuel Storage Bay

For 500 MWe PHWR units,

APWS is active process water system along with non-active process water system

TABLE - II

TYPICAL HEAT LOADS TO UHS THROUGH ASSOCIATED HEAT TRANSPORT SYSTEMS FOR DIFFERENT REACTOR STATES AND DBE

Note: 1. **Y** denotes **APPLICABLE**   **X** denotes **NOT APPLICABLE**

2. Heat load due to spent fuel in storage bay are applicable in all reactor states and DBEs.
3. Normal power operation is indicated only for clarity.

Heat Loads → **Reactor States and DBEs ↓**	Core decay heat (radioactive decay & shut-down fission)	Stored heat (fuel, coolant & structure)	Heat rejected from safety-related systems	Accident related heat sources (power excursion, metal-water reactions)	Non-accident related heat sources (pumping energy)
Power operation *(indicated only for clarity)*	**Fission Power**	**X**	**Y**	**X**	**Y**
Hot shut down	**Y**	**X**	**Y**	**X**	**Y**
Cooling from hot shutdown to cold shutdown	**Y**	**Y**	**Y**	**X**	**Y**
Cold shutdown	**Y**	**X**	**Y**	**X**	**Y**
LOCA (Class-III) power supply available)	**Y**	**Y**	**Y**	**Y**	**Y**
LOCA + Failure of ECCS (Class-III) power supply available)	**Y**	**Y**	**Y**	**Y**	**Y**
Station blackout (SBO)	**Y**	**X**	**Y**	**X**	**X**

TABLE - III

TYPICAL DESIGN BASIS EVENTS (DBE) & BEYOND DESIGN BASIS EVENT (BDBE) AS APPLICABLE TO UHS AND ASSOCIATED SYSTEMS FOR DESIGN ANALYSIS

Typical Design Basis Events (DBEs)

Category - 1 Events — **Normal Operation and Operational Transients**
Based on frequency :
greater than one per reactor-year

C1-3 Reactor shutdown from 100% FP to cold shutdown state
C1-6 Reactor Trip and cool-down

Category - 2 Events — **Events of Moderate Frequency**
Based on frequency :
~ 1 to 10^{-2} per reactor-year

C2-2.1 Loss of reactor coolant - small break size (e.g. instrument line)
C2-6.3 Shutdown cooling system pump failure
C2-7.1 Leak or failure in the system having radioactive liquid
(HX tube failure in SG, SD coolers or moderator coolers)
C2-8.1 Loss of process water system circulation
C2-8.2 Loss of off-site electrical power
C2-8.7 Instrument air failure
C2-8.8 Process water system piping failure (small size)
C2-9.2 Design basis fire
C2-9.3 Operating basis earthquake (OBE)
C2- Internal flooding
C2- Fouling of intake screen - due to accumulation of PVC sheets, jelly fish, marine weed etc.

TABLE - III (Contd.)

TYPICAL DESIGN BASIS EVENTS (DBE) & BEYOND DESIGN BASIS EVENT (BDBE) AS APPLICABLE TO UHS AND ASSOCIATED SYSTEMS FOR DESIGN ANALYSIS

Category - 3 Events	**Events of low frequency** Based on frequency : $\sim 10^{-2}$ to 10^{-4} per reactor-year

C3-2.9 Loss of reactor coolant - break size larger than feeder pipe (with class III available)

C3-8.11 Rupture at any location of piping of process water system / process water cooling system

C3-9.5 Safe shutdown earthquake (SSE)

C3-9.6 Environmental and missiles effects (e.g. missile generated due to turbine break-up)

C3-9.7 Design basis (inland/coastal) Flooding

C3-9.8 Design basis cyclone

C3-9.9 Loss of cooling water to secondary side - loss of ABFW to SG

C3-9.10 Down stream dam failure leading to loss of UHS

C3-9.10 Up stream dam failure leading to flooding

Category - 4 Events	**Multiple Failures and Rare Events** Based on frequency : $\sim 10^{-4}$ to 10^{-6} per reactor-year

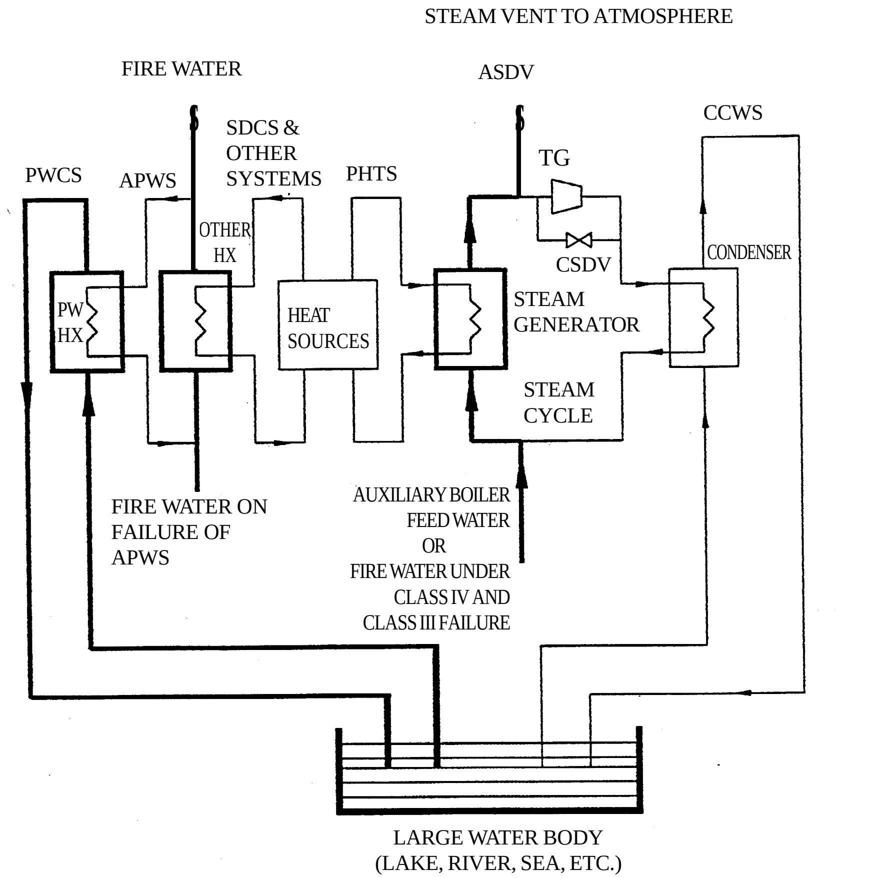
C4-2.11 LOCA plus Failure of ECCS (with class III available)

C4-9.11 Simultaneous Loss of off-site and on-site electrical power supplies - for a specified duration

Typical Beyond Design Basis Event (BDBE)

BDBE-2 LOCA plus Failure of ECCS followed by loss of moderator heat sink

Numbers of the DBEs / BDBE as listed above are given as per the Design Safety Guide on Design Basis Events (AERB/SG/D-5)

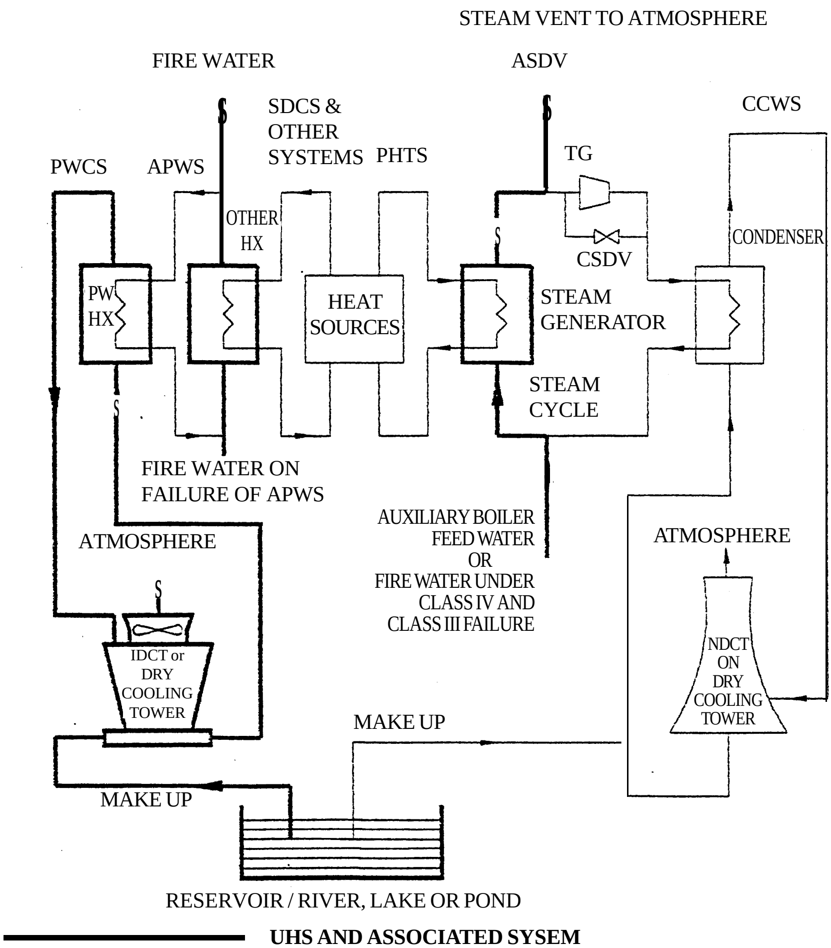


UHS AND ASSOCIATED SYSTEMS

NOTE:

1. THE STEAM CYCLE (EXCLUDING SG UPTO MAIN STEAM ISOLATING VALVE) AND CONDENSER COOLING WATER SYSTEMS WHICH PLAY ONLY A SECONDARY SUPPORTING ROLE FOR U.H.S. MAY BE DESIGNED AS A NON-SAFETY RELATED SYSTEM.
2. HEAT SOURCES: CORE DECAY HEAT, STORED HEAT, HEAT REJECTED FROM ITEMS IMPORTANT TO SAFETY, ACCIDENT RELATED HEAT SOURCE, SPENT FUEL DECAY HEAT AND PUMPING ENERGY.
3. OTHER SYSTEMS: COOLING SYSTEMS FOR MODERATOR, CALANDRIA VAULT, END SHIELD, E.C.C.S., CONTAINMENT, SPENT FUEL STORAGE, CONTROL ROOM ETC.
4. FOR ABBREVIATIONS REFER TABLE - 1.

Fig. 1. TYPICAL CONFIGURATION USING LARGE WATER BODY AS ULTIMATE HEAT SINK IN ONCE- THROUGH SYSTEM



NOTE:

1. THE STEAM CYCLE (EXCLUDING SG UPTO MAIN STEAM ISOLATING VALVE) AND CONDENSER COOLING WATER SYSTEMS WHICH PLAY ONLY A SECONDARY SUPPORTING ROLE FOR U.H.S. MAY BE DESIGNED AS A NON-SAFETY RELATED SYSTEM.

2. HEAT SOURCES: CORE DECAY HEAT, STORED HEAT, HEAT REJECTED FROM ITEMS IMPORTANT TO SAFETY, ACCIDENT RELATED HEAT SOURCE, SPENT FUEL DECAY HEAT AND PUMPING ENERGY.

3. OTHER SYSTEMS: COOLING SYSTEMS FOR MODERATOR, CALANDRIA VAULT, END SHIELD, E.C.C.S., CONTAINMENT, SPENT FUEL STORAGE, CONTROL ROOM ETC.

4. FOR ABBREVIATIONS REFER TABLE - 1.

Fig. 2. TYPICAL CONFIGURATION USING RECIRCULATING SYSTEM WITH ATMOSPHERE AS ULTIMATE HEAT SINK. (NDCT & IDCT or DRY COOLING TOWER)

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3. US NRC Regulatory Guide 1.27, Revision 2, January 1976

4. Kaiga - DBR- USI - 71250, Design Basis Report on Ultimate Heat Sink

5. MAPS - Safety Report Vol. II, Accident Analysis

6. NAPS - Safety Report Vol. II, Accident Analysis

8. KAPS - Safety Report Vol. II, Accident Analysis

LIST OF PARTICIPANTS
WORKING GROUP

Dates of Meeting:	8, January 1996	19, March 1997
	18, January 1996	8&9, September 1997
	19, November 1996	24, August 1998
	31, December 1996	28, December 1998

Members of the Working Group

Shri S. Sankar	:	BARC
Shri D. K. Dave	:	AERB
Shri P. Hajra	:	AERB
Dr. S. K. Gupta	:	BARC
Shri S. G. Ghadge	:	NPCIL
Shri R. N. Bhawal	:	NPCIL
Shri S. K. Gupta	:	NPCIL
Shri Hari Kumar (Member-Secretary)	:	AERB
Shri Deepak De (Co-opted)	:	AERB
Shri B. Dey (Co-opted)	:	NPCIL
Shri K. J. Vakharwala (Co-opted)	:	BARC

ADVISORY COMMITTEE FOR CODES, GUIDES AND MANUALS FOR SAFETY IN DESIGN OF NUCLEAR POWER PLANTS (ACCGD)

Dates of Meeting	:	February 24, 25 & 26, 1998 January 7, 1999 and July 15, 1999

Members and alternates participating in the meetings:

Shri S.B. Bhoje (Chairman)	:	IGCAR
Shri S. Damodaran	:	NPCIL (formerly)
Prof. N. Kannan Iyer	:	IIT Mumbai
Shri V.K. Mehra	:	BARC
Shri Umesh Chandra	:	BARC
Shri A.K. Asrani	:	AERB
Shri S. Sankar	:	BARC
Shri H. S. Kushwaha	:	BARC
Shri C. N. Bapat	:	NPCIL
Shri S. A. Bharadwaj	:	NPCIL
Dr. S.K. Gupta	:	BARC
Dr. R.I.K. Murthy	:	BARC (up to June, 1998)
Shri R.S. Singh (Member Secretary)	:	AERB
Shri S.A. Khan (Permanent Invitee)	:	AERB

ADVISORY COMMITTEE ON NUCLEAR SAFETY (ACNS)

Date of Meeting	:	September 25, 1999

Members and alternates participated in the meeting:

Shri S.K. Mehta (Chairman)	:	Former Director RG, BARC
Shri S.M.C. Pillai	:	Nagarjun Group Hyderabad
Prof. U.N. Gaitonde	:	IIT Mumbai
Shri S.K. Goyal	:	BHEL Hyderabad
Shri Ch. Surender	:	NPCIL
Dr. U.C. Mishra	:	BARC
Shri S.K. Sharma	:	BARC
Dr. V. Venkta Raj	:	BARC
Shri S.P. Singh	:	AERB (formerly)
Shri G.K. De	:	AERB
Shri K. Srivasista (Member Secretary)	:	AERB

PROVISIONAL LIST OF SAFETY CODE, GUIDES & MANUAL ON DESIGN OF PRESSURISED HEAVY WATER REACTOR

Safety Series No.	Provisional Title
AERB/SC/D	Code of Practice on Design for Safety in PHWR Based Nuclear Power Plant
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
AERB/SG/D-5	Design Basis Events
AERB/SG/D-6	Fuel Design
AERB/SG/D-7	Core Reactivity Control
AERB/SG/D-8	Primary Heat Transport Systems
AERB/SG/D-9	Process Design
AERB/SG/D-10	Safety Critical Systems
AERB/SG/D-11	Electrical Power Systems
AERB/SG/D-12	Radiological Protection in Design
AERB/SG/D-13	Liquid and Solid Radwaste Management
AERB/SG/D-14	Control of Air-borne Radioactive Materials
AERB/SG/D-15	Ultimate Heat Sink & Associated Systems
AERB/SG/D-16	Materials Selection and Properties
AERB/SG/D-17	Design for In-Service Inspection
AERB/SG/D-18	LOCA Analysis Methods
AERB/SG/D-19	Metal Water Reaction
AERB/SG/D-20	Safety Related Instrumentation and Control
AERB/SG/D-21	Containment Systems Design
AERB/SG/D-22	Vapor Suppression System
AERB/SG/D-23	Seismic Analysis Methodology
AERB/SG/D-24	Design of Fuel Handling and Storage Systems
AERB/SG/D-25	Computer Based Safety Systems
AERB/SM/D-1	Decay Heat Load Calculations

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