AERB SAFETY GUIDE NO. AERB/SG/D-4

FIRE PROTECTION IN PRESSURISED HEAVY WATER REACTOR BASED NUCLEAR POWER PLANTS

Issued in November, 1999

This document is subject to review, after a period of one year from the date of issue, based on the feedback received.

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FOREWORD

Safety of public, occupational workers and the protection of 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 the radioactive sources. They have to be carried out in accordance with relevant provisions in the Atomic Energy Act 1962 (33 of 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 Standing 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 to frame 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 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 can be operated without undue risk to the health and safety of general public and plant personnel.

The 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 appendices included in the document are considered to be an integral part of the document, whereas the annexures, foot-notes, references and bibliography are included to provide information that might be helpful to the user.

The emphasis in the codes and guides is on the protection of site personnel and public from undue radiological hazard. However, for aspects not covered in the codes and guides, applicable and acceptable national and international codes and standards shall be followed. 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 (SC/D, 1989) states the minimum requirements to be met for the design of a PHWR based nuclear power plants in India for assuring safety. While elaborating the requirements stated in the AERB Code, SC/D, 1989 this Safety Guide provides necessary guidelines in the design of the protection against fire in these plants.

This Safety Guide has been prepared by the staff of AERB and other professionals. In drafting this guide, they have used extensively the relevant International Atomic Energy Agency (IAEA) documents under NUSS programme and the national documents, including AERB Standard on "Fire Protection Systems of Nuclear Facilities", AERB/S/IRSD-1, 1996.

Experts have reviewed the guide and the AERB Advisory Committees have vetted it, before issue. AERB wishes to thank all individuals and organisations who reviewed the draft and finalised this safety guide. The list of persons who have participated in the committee meetings, along with their affiliations, is included for information.

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DEFINITIONS

Combustible Liquid

A liquid having a flash point at or above 38°C (100°F) [26].

Combustible Material

Any material, which, in the form in which it is used and under the conditions anticipated will ignite and burn, generally accompanied by flames, glowing or emission of smoke or a combination thereof.

Common Cause Failure

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

Decontamination

The removal or reduction of contamination by physical or chemical process.

Defence-in-Depth

Provision of multiple levels of protection for ensuring the safety of workers, the public or the environment.

Deluge System

A fire control or extinguishing installation with open sprinkler heads where it is desired to deliver water through all sprinklers simultaneously and to wet the entire area to be protected (see also Sprinkler System and Water Spray System).

Design Basis

A formal statement of intended physical performance, limitations and working conditions for a component or system.

Design Basis Fire

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 maximum damage in the area under consideration in the absence of active fire protection systems.

Explosion

An abrupt oxidation or decomposition reaction producing an increase in temperature or in pressure or in both simultaneously.

Fire Barrier

A device or a system limiting the spread or effects of fire to its physical boundary so that fire will not affect the performance of the intended safety function of systems located beyond the barrier for the prescribed time of approved rating.

Fire Cell

A sub-division of a larger fire compartment of concentrated fire load within a fire area (e.g. lubricating oil tank within turbine building (see also Fire Compartment).

Fire Compartment

An area, compartment of a building or a building itself bounded by a fire-resistive enclosure (walls, floor, ceiling or openings if any) of a defined fire rating (see also Fire Cell).

Fire Damper

A device located in a duct and designed for automatic or manual operation to prevent the passage of fire or provide isolation at a specified condition for specified time duration.

Fire Detection

Measures directed towards detecting automatically the presence of fire in its incipient stage and initiating an alarm system and other appropriate action.

Fire Detector

Devices designed to automatically detect the presence of fire and initiate an alarm system and other appropriate action.

Fire Load

The calorific potential of combustible materials contained in a space including the facings of the walls, partitions, floors and ceilings.

Fire Prevention

Preventive measures directed towards avoiding the incidence of fire and spread of fire to other areas/zones.

Fire Protection System

A system designed to ensure protection against fire and ensures safety to operating personnel, public and environment against risks arising out of fire, both direct as well as indirect, fire-fighting operation during normal operation, accident conditions, as well as natural disasters. It consists of prevention, detection and suppression of fire including both active and passive measures.

Fire Protection Programme

Planning, design, construction, testing and maintenance of systems (both software and hardware) related to fire protection.

Fire Resistance/Rating

The ability of an element of building construction or a component of a system or equipment to maintain for a stated period of time the required stability, integrity and/or thermal insulation and perform the design function satisfactorily as specified in the standard fire-resistance tests.

Fire Retardant

The quality of a substance as a means of suppressing, reducing or delaying markedly the combustion of certain materials.

Fire Stop

A physical barrier designed to restrict the fire within specified points in cable trays, cavities and between elements of building construction.

Fire Suppression

Measures directed towards control or extinguishment, or both, of fire through automatic or manual system/equipment utilising an appropriate agent such as water, carbon dioxide, foam, dry chemical powder, etc.

Flammable Liquid

A liquid having a flash point below 38°C (100°F) [26] and having a vapour pressure not exceeding 1.8 kg/cm^2 (g) (40 psia) at 38°C [26].

Flame Detector

A device that detects the infrared, the ultraviolet or visible radiation produced by a fire.

Heat Detectors

A device that detects a pre-determined (fixed) temperature or rate of temperature rise.

Line Type Fire Detector

A device in which detection is continuous along a path.

Physical Separation

(a) Separation by geometry (distance, orientation etc.), or

(b) Separation by appropriate barrier, or

(c) Separation by a combination thereof.

Protection System

A system that encompasses all electrical and mechanical devices and circuitry, from sensors to actuation device input terminals, involved in generating those signals associated with the protective function.

Quality Assurance

Planned and systematic actions necessary to provide adequate confidence that an item or facility will perform its intended design function satisfactorily in service.

Raceway

Any channel that is designed and used expressly for supporting or enclosing wires, cables or busbars. Raceways consist primarily of, but one not restricted to, cable trays and conduits.

Sensitivity (Detector)

The relative degree of response of a detector to the parameter to be detected. (e.g. a high sensitivity denotes response to a lower concentration of smoke than a low sensitivity, under identical smoke build-up conditions).

Shall, Should, May

The word "shall" is used to denote a mandatory requirement; the word "should" to denote a recommendation; and the word "may" to denote permission, neither a requirement nor a recommendation.

Single Failure

A random failure that results in the loss of capability of a component to perform its intended safety functions. Consequential failures resulting from a single random occurrence are considered to be part of the single failure.

Smoke Detector

A device which detects the visible or invisible particles of combustion.

CONTENTS

1. INTRODUCTION

1.1 General

This Safety Guide provides guidelines on fire protection in the design of nuclear power plants based on Pressurised Heavy Water Reactor. It also describes the requirements for the design of fire protection systems required to minimise the adverse effect of fires on structures, systems and components important to safety (i.e. systems and components provided to assure, in any condition, the safe shutdown of the reactor and heat removal from the core, and/or to limit the consequences of anticipated operational occurrences and accident conditions). In preparing this guide major attention has been focussed on aspects covering nuclear safety. Additional requirements relating to conventional fire safety should be based on national regulations and practices.

1.2 Objective

The primary objective of this guide is to elaborate the requirements related to fire protection as identified in the Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants (SC/D, 1989). The objective is also to provide guidelines for design of fire protection against the risk arising due to fire in the installations under reference. In order to meet the intent of this guide it is required to establish a fire protection programme to minimise both the probability of occurrences and consequences of design basis fires. Means are required to detect and suppress fires with particular emphasis on providing passive and active fire protection of appropriate capability and adequate capacity for systems necessary to achieve and maintain safe plant shutdown with or without off-site power. Fire protection system shall be designed to ensure that its failure, rupture or an inadvertent operation does not impair the safety capability of the structures, systems and components.

1.3 Scope

The provisions of this safety guide shall apply to the design of fire protection programme during the design stage of Pressurised Heavy Water Reactor. This guide describes the criteria for design of fire prevention, detection and suppression systems of appropriate capacities and capabilities to minimise the adverse effect of fires on structures, systems and components important to safety.

This guide does not include the subject of hydrogen explosion due to metal-water reaction in reactor or generated due to radiolysis of water sprayed into reactor building following an accident. The safety aspects regarding generation of hydrogen during an accident and its consequences are covered in the Safety Guide on Metal-Water Reaction (AERB/SG/D-19).

2. BASIC APPROACH TO FIRE PROTECTION

2.1 General

This section of the guide deals with basic approaches to be considered during the design of fire protection programmes.

Fire protection programmes shall not only address the direct effect of the flame or thermal radiation but also the potential for release of hazardous combustion products in the event of fire and potential for the release of water and other fire-fighting media contaminated during fire-fighting.

Protection from fire and fire-related explosions assumes importance in the overall design of a nuclear power plant insofar as it forms a crucial part of safety considerations, namely the protection of safety systems and other items important to safety. Overall fire safety can be subdivided into distinct activities relating to preparedness and to fire prevention, detection and suppression. Therefore planning for fire protection shall be an integral part of the design stage. Fire protection shall continue to be a well-planned, administratively controlled programme, implemented throughout the life of the plant, including the decommissioning phase.

To ensure adequate safety, the following general safety design requirements shall be met:

(a) Means shall be provided to safely shut down the reactor and maintain it in the safe shutdown condition in operational states and during and after accident conditions;

(b) Means shall be provided to remove residual heat from the core after reactor shutdown, including accident conditions; and

(c) Means shall be provided to reduce the potential for the release of radioactive materials and to ensure that any releases are below acceptable limits during accident conditions.

To meet the above requirements the reactor design should provide redundant safety systems in such a manner that no postulated initiating event, such as fire, will prevent safety systems from performing the required safety functions.

As the degree of redundancy decreases, the need to protect each redundant safety system from the effects of fire and explosion increases. This would be accomplished by improved passive protection and physical separation or greater use of fire detection and extinguishing systems.

In all cases, an adequate degree of fire protection shall be provided in nuclear power plants. This should be achieved by a defence in depth concept in the design as mentioned in section 2.2.

2.2 Defence-in-Depth

The defence-in-depth principle when applied to design should have the following three principal objectives:

(a) preventing fire from starting;

(b) detecting fires quickly, suppressing those fires that occur, putting them out quickly, and limiting the damage; and

(c) preventing the spread of those fires that have not been extinguished, thus minimising their effect on essential plant functions.

The first objective requires that the design and operation of the plant be such that the probability of a fire starting is minimised. The second objective concerns the early detection and extinguishing of fires by a combination of automatic and/or manual fire-fighting techniques, and therefore relies upon active techniques. For implementation of the third objective, particular emphasis shall be placed on the use of passive fire barriers and physical separation, including special separation and fire stops which would be the last line of defence if the first two objectives are not met.

2.3 Programme Implementation

The fire protection programme should start at the plant design stage itself and carried through construction, commissioning and operation phases. During implementation stages, adequate emphasis should be laid on quality assurance of fire prevention, detection and suppression systems being installed, to ensure that the programme's objectives are fully and satisfactorily met.

The fire protection system should be available prior to receipt of fresh fuel in the fuel storage area, and shall be fully operational before initial fuel loading in the reactor unit.

At sites, where operating nuclear installations exist and new construction work (of other units) is undertaken in close proximity, means shall be provided to protect the operating unit/installation against fire hazards from the unit/installation under construction/ commissioning.

2.4 Fire Protection System Reliability

The design of a fire protection system shall consider the effect of interaction with other system(s) to achieve high reliability (failure probability: 10^{-6} / year / reactor [34]) for minimising fire hazards and the effects of a fire and includes fire prevention, detection and rapid extinguishment of fires. The design shall select an optimum combination of these three aspects to obtain a reliable fire protection system. The design shall ensure that any single impairment of the fire protection system or direct support systems does not incapacitate both the primary and back-up fire protection capability. The design of fire protection systems shall ensure that an initiating failure such as break in fire protection lines or a single inadvertent actuation of the fire protection system cannot:

(a) damage the systems important to safety of the plant; and

(b) prevent the habitability of the main control room or other areas requiring accesses for putting the plant in shutdown state.

2.5 Fire Hazard Analysis

2.5.1 A detailed Fire Hazard Analysis (refer Appendix-I for additional guidance) shall be carried out during initial plant design to reflect the proposed construction arrangements, materials and facilities. This analysis should be revised periodically as design and construction progress and before and during major plant modifications.

2.5.2 The objective of fire hazard analysis is to verify that safety systems required to shut the reactor down, remove residual heat and contain radioactive material shall be protected against the consequences of fires so that safety systems are still capable of performing the above safety functions, taking into account the effects of a single failure as required in the Safety Guide on Single Failure Criterion (AERB/SG/D-2).

2.5.3 A fire event need not be postulated to be simultaneous with low probability non-fire related failures in safety systems unless the events in themselves can cause a fire.

2.5.4 The fire hazard analysis should be a systematic study of (a) all elements of the fire protection programme being proposed to ensure that the plant design has included adequate identification and analysis of potential fire hazards and (b) the effect of design basis fire relative to maintaining the ability to perform safe shutdown and maintain it in safe shutdown state and decay heat removal functions and minimising radioactiye releases to environment.

2.5.5 The fire hazard analysis shall separately identify hazards.

Provision should be made for appropriate protection in locations where safety related functions could be affected due to:

(a) concentrations of combustible contents, including transient fire loads due to combustibles expected to be used in normal operations such as maintenance and modifications;

(b) continuity of combustible contents, furnishings, building materials, or combinations thereof in configurations conducive to fire spread;

(c) heat, smoke, steam and including those that may necessitate evacuation from areas that are required to be attended for safe shutdown;

(d) fire in control rooms or other locations having critical safety related functions;

(e) lack of adequate access or smoke removal facilities that impede fire extinguishment in safety related areas;

(f) loss of electric power or control circuits; and

(g) inadvertent operation of fire suppression systems.

2.5.6 The design of the fire protection systems need not consider simultaneous unrelated fires in more than one unit for a multi-unit site, but the possibility of a fire spreading from one unit to another shall be taken into account in fire hazard analysis.

2.5.7 The analysis of consequences of the design basis fire on safety of the plant should be performed by persons with adequate training and background in plant safety.

2.6 Fire Classification

2.6.1 Class-A Fire

Fires in ordinary combustible materials such as wood, cloth, paper, rubber and many plastics.

2.6.2 Class-B Fire

Fires in flammable liquids, oils, greases, tars, oil-base paints, lacquers, and flammable gases.

2.6.3 Class-C Fire

Fires that involve energised electrical equipment where the electrical non-conductivity of the extinguishing media is of importance (where electrical equipment is de-energised, extinguishers for Class-A or B fires may be used safely).

2.6.4 Class-D Fire

Fires in combustible metals such as magnesium, titanium, zirconium, sodium, lithium, potassium, plutonium etc.

3. FIRE PREVENTION

3.1 General

Design requirements to minimise the potential for fire shall be specified in the early stage of design. The first level requirements of defence-in-depth are:

(a) limiting the use of combustibles to the minimum extent practicable;

(b) separation of redundant safety related divisions such that a single fire cannot prevent the performance of a required nuclear safety function;

(c) separation of critical areas from non-critical areas such that a single fire in any non-critical area cannot prevent the performance of safety function located in critical areas;

(d) establishing administrative procedures to control hazardous operations and introduction of combustible material;

(e) provision in ventilation system to control the spread of fire and smoke;

(f) control and protection against ignition sources; and

(g) high fire load areas preferably should not have systems important to safety in them.

3.2 Building Design

3.2.1 General

The plant shall be divided into several individual fire compartments to reduce the risk of spread of fire and consequent damage and to prevent common cause failures of redundant safety related systems.

The division of fire compartments should consider:

(a) restricted and non-restricted areas based on classification for radiological safety;

(b) essential plant items relevant to safety;

(c) high fire loading;

(d) areas with high value-density (such as control room, plant computer, instrument room, local concentrations of measuring instruments and control installations); and

(e) access and escape routes.

3.2.1.1 Interior finishes shall be non-combustible or approved by a recognised testing laboratory for:

(a) surface flame spread rating of 50 or less when tested under ASTM E-84 [22]; and

(b) potential heat release of 8141 kJ/kg (3500 BTU/lb), or less when tested under ASTM-D-3286 [21] or NFPA-259 [10].

3.2.1.2 Floors, walls, and ceilings separating fire compartments shall have a minimum fire rating of 1 h or more, if fire hazard analysis results demand so. Openings through fire barriers around conduit or piping shall be sealed or closed to provide a fire resistance rating at least equal to that required of the barrier itself. Door openings shall be protected with equivalent rated doors, frames and hardware that have been tested and approved by a nationally recognised laboratory. Such doors shall be normally closed and should be equipped with automatic self-closing devices with doors opening outside the fire compartment. Fire barrier openings for ventilation systems shall be protected by a fire damper having a rating equivalent to that of the barrier.

3.2.1.3 Fire Rating

The fire rating of fire barriers should be estimated based on fire hazard analysis and a fire rating of minimum of 1 h or more, if fire hazard analysis demands so, shall be provided, to

(a) isolate safety-related systems from any fires in non-safety related areas;

(b) separate redundant divisions or trains of safety-related systems from each other so that both are not subjected to damage from a single fire hazard; and

(c) separate individual units on a multiple-unit-site.

3.2.1.4 Building containing safety-related systems shall be protected from exposure or spill fires involving outdoor oil-filled transformers by providing oil spill confinement with rain water disposal arrangement or drainage away from the buildings and

(a) locating such transformers at least 15 m (50 feet) [37] distance from the building; or,

(b) ensuring that such building walls within 15 m (50 feet) [37] of oil-filled transformers are without openings and have a fire resistance rating of at least 3 h.

3.2.1.5 Transformers installed inside fire compartments containing safety-related systems shall be of the dry type or insulated and cooled with non-combustible liquid. Where transformers filled with combustible fluid are located in non-safety related areas, there shall be no openings in the fire barriers separating such transformers from areas containing safety-related systems or equipment.

3.2.1.6 Personnel access and escape routes shall be provided for each fire compartment. These routes should consider the risks, such as smoke, toxic gases, radiation doses, scalding, electrical injuries etc. and the requirements arising from plant incidents such as confinement of radioactive matter.

3.2.1.7 Fire exit routes shall be clearly marked. Fire exits shall be of sufficient capacity such that the evacuation time is less than the time required for onset of hazardous conditions, as determined by a suitable fire model.

3.2.1.8 The main control room and supplementary control points shall be so housed that a single postulated fire may not affect both the control rooms.

3.2.1.9 Floor drains sized to remove expected fire-fighting water flow without flooding equipment important to safety shall be provided in those areas where fixed water fire suppression systems are installed. Floor drains shall also be provided in other areas where hand hose lines may be used, if such fire fighting water could cause unacceptable damage to safety-related equipment in the area. Where gas suppression systems are installed, the drains shall be provided with adequate seals or the gas suppression system shall be sized to compensate for the loss of suppression agent through drains. Drains in areas containing combustible liquids shall have provisions for preventing the spread of fire throughout the drain system. Water drainage from areas that may contain radioactivity/toxicity shall have provision for sampling for analysis before discharge according to approved procedures for discharge of such effluents.

3.2.1.10 Fire barriers, fire detection and suppression and ventilation controls should be provided as considered necessary depending upon the combustibles present in an area (including radwaste and decontamination areas).

3.2.2 Specific Areas

Interior wall and structural components, thermal insulation materials, radiation shielding materials, and soundproofing shall be non-combustible.

3.2.2.1 Reactor Building (RB)

Fire protection for RB (containment) area should be provided for hazards identified by fire hazard analysis. Because of the general inaccessibility of certain areas of containment during normal plant operation, protection shall be provided by automatic or manually operated (from remote location) fixed systems. Fire barrier design should take care of conflicting requirement of openings/intercommunications between compartments during postulated incidents such as LOCA/steam line break involving release of high enthalpy fluids. Operation of fire protection systems should not compromise the integrity of the containment or other safety related systems. Cable trays having high cable densities should be provided with a detection system and automatically or remote manually operated sprinkler systems (i.e. a fire control or extinguishing installation with normally closed sprinkler heads, whereby the closing bulb of those exposed to intensive heat is shattered, thus releasing the sprinkler water). In view of the difficulty in purging out CO_2 from various areas of RB, CO_2 total flooding system shall not be used within the building.

3.2.2.2 Boiler Room/Pump Room

All high enthalpy high temperature and high-pressure fluid process systems are located in this area. Minimising the Heavy Water inventory in pipelines/system results in cramped pipe layout and criss-crossing of pipelines and support systems. Approach to pumps with oil-lubricated motors is normally congested. There are a large number of power and control cables in this area, in different cable trays. Oil leakage from the lubrication system of primary coolant pump motor bearings over hot piping could also be a source of fire. The background radiation level in this area during operation is high and hence normally inaccessible.

Based on the above problems, the selection and location of the detectors shall be decided to make fire detection system in the area effective, e.g. in the proximity of motors/and lube oil system.

A remotely operated sprinkler system should be considered for fire suppression in the area. Fire suppression system using chloride-free dry powder/water, applied locally, should be employed with utmost care.

Environment qualification of the fire-fighting system instruments and equipment may be necessary to ensure their availability in post-LOCA environment.

3.2.2.3 Fuelling Machine Vaults

Use of hydraulic oil for fuelling machine and cables in the area pose fire hazard. End fittings and feeders are areas having high temperatures. This area also has high radiation levels. The ceiling heights are high with large air currents due to vault coolers. A remotely operated sprinkler system and use of optical smoke detectors at suitable location should be considered for this area. The sprinkler system piping should normally be dry.

3.2.2.4 Moderator Room

Moderator room may have oil / grease / water lubricated motors for moderator pumps. Oil lubricated motors have low fire potential due to low operating temperature of the system. Operators should be alerted about oil leakage from the lubricating system of moderator pumps by low-level alarms of oil chambers of motors etc. It is recommended that hose reels and linear heat detection be provided along the cable trays as well as smoke detectors and use of localised sprays of water over the cable trays. The radiation level also could be very high. Smoke detectors along with heat/flame detectors could be considered. However, the frequency of replacement for smoke detectors should be looked into because of the high radiation levels and consequent reduction in sensitivity.

3.2.2.5 Other Areas Housing Safety Related Systems/Equipment

3.2.2.5.1 Control Room

The control room (including galleys, office spaces, etc) shall be protected against fire damage and shall be separated from other areas of the plant by floors, walls, and roof having minimum fire resistance ratings of 3 h. Ventilation system shall be designed to avoid ingress of smoke from peripheral areas to control room. In the case of multi-unit stations the main control rooms of individual units should be separated from the point of fire spreading.

Manual fire-fighting capability shall be provided for:

(a) fire originating within a cabinet, console, or connecting cables; and

(b) exposure fires involving combustibles in the general room area.

Portable Class A and Class C fire extinguishers (see section 4.3.3 for definitions) shall be located in the control room. A hose station shall be installed immediately outside the control room.

Each fire compartment shall be equipped with a fire detection and alarm system specifically engineered and selected for fire risk in that area. The number and location of the detectors will be such that early detection is achieved to prevent the spread of fire to other cabinets.

Breathing air either from self-contained breathing apparatus (SCBA) or a manifold system for control room operators shall be readily available.

The outside air intake(s) for the control room ventilation system shall be provided with smoke detection capability to alarm in the control room to enable isolation of the control room ventilation system and thus prevent smoke from entering the control room.

Provision shall be made to permit isolation of the re-circulating portion of the normal ventilation system. Manually operated venting of the control room shall be made available.

All cables/piping that enter the control room shall terminate in the control room i.e. no cabling should be simply routed through the control room from one area to another. All penetrations should have fire seals.

Cables in under-floor and ceiling spaces shall meet the separation criteria as outlined in section 3.5. Air-handling functions should be ducted separately from cable runs in such spaces; i.e. if cables are routed in under-floor or ceiling spaces, these spaces should not be used as air plenums for ventilation of the control room. Electrical raceways in such under-floor and ceiling spaces, if over one square foot in cross-sectional area, should have automatic fire suppression inside. Area automatic fire suppression should be provided for under-floor and ceiling spaces if used for cable runs unless all cables are run in 10 cm or smaller steel conduit or the cables are in fully enclosed raceways internally protected by automatic fire suppression.

The fire protection requirements for supplementary control room will be the same as that for the control room.

3.2.2.5.2 Control Equipment Rooms

3.2.2.5.2.1 The primary fire suppression in the control equipment room shall be remotely-operated manual CO_2 nozzle system. The sprinkler systems shall provide for manual operation at a remote station. CO_2 nozzle systems should be zoned. Automatic gas systems (preferably substitute of Halon or CO_2) may be used for primary fire suppression backed up by a fixed water system.

3.2.2.5.2.2 Control Equipment Rooms should have:

(a) at least two remote and separate entrances for access by fire brigade personnel;

(b) an aisle separation between tray stacks at least 90 cm wide and 240 cm high;

(c) hose stations with first aid hose reels installed outside the room. Adequate number of portable extinguishers should be installed both inside and outside the room; and

(d) area smoke detection.

Floor drains with proper slope shall be provided to remove fire-fighting water. When gas systems are installed, drains shall have adequate seals or the gas extinguishing systems should be sized to compensate for losses through the drains.

3.2.2.5.2.3 Physically separate routes maintaining distances in accordance with provisions of section 3.5 shall be provided for each redundant division. Cable spreading gallery or control equipment rooms should not be shared between reactors. Control equipment room shall be separated from other areas of the plant by barriers with a minimum fire rating of 3 h.

3.2.2.5.2.4 The ventilation system to Control Equipment Room shall be designed to isolate the area upon actuation of any gas extinguishing system in the area. Manually actuated smoke venting that is operable from outside the room should be provided separately.

3.2.2.5.3 Cable Spreading Gallery

3.2.2.5.3.1 The primary fire suppression in the cable spreading gallery shall be an automatic water sprinkler system. The sprinkler systems shall provide for manual operation at a remote station. The sprinkler systems should be zoned. Automatic gas systems (preferably substitute of Halon or CO_2) may be used for primary fire suppression backed up by a fixed water system.

3.2.2.5.3.2 The cable spreading gallery should have:

(a) at least two remote and separate entrances for access for fire fighting;

(b) an aisle separation between cable tray stacks at least 90 cm wide and 240 cm high;

(c) hose stations with first aid hose reels installed outside the room. Adequate number of portable extinguishers should be installed both inside and outside the cable-spreading gallery;

(d) area smoke detection; and

(e) continuous line-type heat detectors for cable trays inside the cable-spreading gallery.

Floor drains with proper slope shall be provided to remove fire-fighting water. When gas systems are installed, drains shall have adequate seals or the gas extinguishing systems should be sized to compensate for losses through drains.

3.2.2.5.3.3 Physically separate routes maintaining distances in accordance with provisions of section 3.5 shall be provided for each redundant division. Cable spreading/control equipment room should not be shared between reactors. Cable spreading gallery shall be separated from other areas of the plant by barriers with a minimum fire rating of 3 h.

3.2.2.5.3.4 The ventilation system to cable spreading gallery shall be designed to isolate the area upon actuation of any gas extinguishing system in the area. Manually actuated smoke venting that is operable from outside the room should be provided separately.

3.2.2.5.4 Plant Computer Rooms

Rooms for computers performing safety related functions that are not part of the control room complex shall be separated from other areas of the plant by barriers having a minimum fire resistance rating of 3 h and protected by detection and suppression system. Computers that are part of the control room complex, but not in the control room should be separated and protected as described in sec. 3.2.2.5.1. Computer cabinets located in the control room should be protected as other control room equipment and cable runs therein.

3.2.2.5.5 Switchgear Rooms

Switchgear rooms containing safety-related equipment shall be separated from the remainder of the plant by barriers with a minimum fire rating of 3 h. Redundant switchgear safety divisions shall be separated from each other by barriers with a 3 h fire rating. Automatic fire detectors should alarm and annunciate in the control room and alarm locally. In addition to ionisation type of smoke detectors, optical smoke detectors on cross zoning principle shall be used. Cables entering the switchgear room that do not terminate or perform any function there, should be kept to a minimum to minimise combustible loading. These rooms should not be used for any other purpose. Portable fire extinguishers shall be readily available inside and outside the area. Fire hose station should be outside the area.

Equipment should be located to facilitate access for manual fire-fighting. Drains should be provided to prevent water accumulation. Manually actuated remote ventilation system should be provided for venting smoke. All cable terminations shall be preceded by fire stops [36]/seals as protection against propagation of fire.

3.2.2.5.6 Remote Safety-Related Panels

Redundant safety-related panels remote from the control room complex shall be separated from each other by barriers having a minimum fire rating of 3 h. Panels providing remote hot shutdown capability, e.g. supplementary control room, should be separated from the control room complex by barriers having a minimum fire rating of 3 h. The general area housing remote safety-related panels should be provided with fire detectors that alarm locally and also alarm and annunciate in the control room. Combustible materials should be controlled and limited to those required for operation. Portable extinguishers and manual hose stations shall be readily available in the general area.

3.2.2.5.7 Battery Rooms

Battery rooms shall be separated from each other and other areas of the plant by barriers with a minimum fire rating of 3 h inclusive of all penetrations and openings. DC switchgear and inverters shall not be located in these rooms. Fire detection shall be provided to alarm and annunciate in the control room and also alarm locally. Ventilation systems in the battery rooms shall be capable of maintaining the hydrogen concentration below 1% [41] by volume. Hydrogen detection and alarm system should be installed to provide annunciation in the control room in case hydrogen concentration goes beyond 1% [41] by volume. Loss of ventilation should be alarmed in the control room. Standpipe and hose and portable extinguishers should be readily available outside the room.

3.2.2.5.8 Diesel Generator Areas

Diesel generators shall be separated from each other and from other areas of the plant by fire barriers having a minimum fire resistance rating of 3 h.

Fire detection shall be provided to alarm and annunciate in the control room and alarm locally.

Hose stations and portable extinguishers should be readily available outside the area. Drainage for fire-fighting water and means for local manual venting of smoke should be provided.

Automatic CO_2 fire suppression shall be installed to combat any fire in diesel generator room. Use of environmental friendly efficient Halon substitutes may also be considered.

Day tanks with total capacity less than 1 m^3 [30] are permitted in the diesel generator area under the following conditions:

(a) the day tank is located in a separate enclosure with a minimum fire resistance rating of 3 h, including doors or penetrations. These enclosures shall be capable of containing the entire contents of the day tanks and should be protected by an automatic fire suppression system, or

(b) it is located inside the diesel generator room in a diked enclosure that has a capacity to hold 110% of the contents of the day tank or is drained to a safe location.

3.2.2.5.9 Diesel Fuel Oil Storage Areas

Diesel fuel oil tanks with a capacity greater than 1 m^3 [30] shall not be located inside buildings containing safety-related equipment. If above-ground tanks are used, they should be located at least 15 m (50 feet) [24] from any building containing safety-related equipment or, if located within 15 m (50 feet) [24], they should be housed in separate building with construction having a minimum fire resistance rating of 3 h. Potential oil spills should be confined or directed away from buildings containing safety-related equipment. Totally buried tanks are acceptable outside. Requirements under Explosives/Inflammable Liquids Acts [25] shall be adhered to.

Above-ground tanks should be protected by an automatic firewater spray system. (i.e. a fire control or extinguishing installation with spray nozzles used where it is desired to deliver water simultaneously through all sprinklers of that particular group of interconnected heads and to engulf the equipment to be protected in a fog like atmosphere of finely subdivided droplets).

3.2.2.5.10 Safety Related Pumps

Pump houses and rooms housing redundant safety-related pumps and fire pumps (when used for ultimate heat sink) shall be separated from each other and also from other areas of the plant by fire barriers having at least 3 h [24] ratings. These rooms should be protected by automatic fire detection and suppression systems unless a fire hazard analysis can demonstrate that a fire will not endanger other safety-related equipment required for safe plant shutdown. Fire detection should alarm and annunciate in the control room and also alarm locally. Hose stations and portable extinguishers shall be readily accessible. Floor drains shall be provided to prevent water accumulation from damaging safety-related equipment.

Provisions should also be made for manual control of the ventilation system to facilitate smoke removal if required for manual fire-fighting operation.

3.2.2.5.11 Fresh Fuel Storage Area

Portable dry powder extinguishers shall be located within this area. Also, hose stations should be located outside this area. Automatic fire detection should alarm and annunciate in the control room as well as locally. Combustibles should be limited to a minimum in the fresh fuel area.

3.2.2.5.12 Spent Fuel Pool Area

Protection for the spent fuel pool area shall be provided by local hose stations and portable dry powder/CO_2 extinguishers. Automatic fire detection should be provided to alarm and annunciate in the control room and also to alarm locally.

3.2.2.5.14 Cooling Towers

Cooling towers should be so located and protected that a fire will not adversely affect any safety-related system or equipment in the neighbourhood. When the basins are used for the ultimate heat sink or for the fire protection water supply, cooling towers shall be of non-combustible construction.

3.2.2.6 Turbine Building

The adjacent structures to turbine building containing safety related equipment should have a fire rating of minimum of 1 h or more, if fire hazard analysis demands so. Openings and penetrations should not be located where the turbine oil system or generator hydrogen cooling system creates a direct fire exposure hazard to the barrier.

Hydrogen leak detection system should be provided around the generator, inside the bus-ducts and in the hydrogen charging station area. The ventilation should be such that the hydrogen concentration is less than 1% [41]. Storage of hydrogen in this area should be avoided. Safety related cables, piping, ducting, etc. should not be routed through the turbine building from one area to another. The electrical fittings in these areas shall be flame proof of type Class-2C of IEEE or equivalent.

Since, oil in the main oil tank and turbine oil tank forms a very high fire load, due consideration shall be given for location of these tanks with suitable embankments around the tank and fire protection system (outside non automatic sprinkler, inside automatic CO_2 system backed up by manual hose station in the neighbourhood).

Industrial safety practices should be followed as per the Atomic Energy Factories Rules, 1996.

3.2.2.7 Miscellaneous Area

Miscellaneous areas such as records storage areas, shops, warehouses, auxiliary boiler rooms, fuel oil tanks, and flammable and combustible liquid storage tanks should be so located and protected that a fire or effects of a fire, including smoke, will not adversely affect any safety-related system or equipment. Plant records should be kept at two independent fireproof rooms.

3.3 Control of Combustibles

3.3.1 The design shall use non-combustible materials as far as practicable for the construction of structure and systems. Where this cannot be achieved, efforts shall be made to reduce the quantity of combustible materials or to reduce the combustibility of the materials by using fire-retardant additives or fire resistance coatings. Precautions should be taken to prevent spillage of oil on insulating materials that have the capability of absorbing oil or other fluid combustibles.

Use of plastics that produce corrosive combustion products including smoke shall be kept as low as practicable, especially in areas of high concentration of electronic instruments and control installations that are susceptible to corrosion by gases liberated during a fire.

3.3.2 The amount of combustible materials stored indoors and normally exposed to the danger of fire should be reduced by having the supply of materials (such as oil) kept to the minimum consistent with operational requirements, whereas the bulk supply should be kept outside the buildings containing items important to safety. Use and storage of compressed gases (especially oxygen and flammable gases) inside buildings housing safety-related equipment should be controlled. Bulk storage of flammable gas should not be permitted inside the structures housing safety-related equipment and should be kept at a sufficiently remote location, such that a fire or explosion will not adversely affect any safety-related system or equipment.

3.3.3 The supply cylinders or special containers of hydrogen and their distribution manifold should be kept in a well-ventilated and sheltered location, preferably not inside such buildings containing items important to safety. Where forced ventilation is necessary, the system should be designed to maintain hydrogen concentration below 1% [41] by volume. Each station electrical battery room which may generate hydrogen during operation shall be provided with a separate ventilation exhaust arranged to discharge directly to outside, so that the hydrogen concentration is kept below 1% [41]. Redundancy in forced ventilation system should be ensured.

3.3.4 Systems containing combustible or flammable liquids or gases should have a high degree of integrity and protected from vibrations or other destructive effects to prevent leakage of such materials. Similarly, collection facilities should be provided for combustible or flammable liquids in case they leak. Flammables/lubricants used should be consistent with the functional as well as fire safety requirements to the extent possible (e.g. higher flash point consistent with local temperature).

3.3.5 Safety-related systems should be isolated or separated from combustible materials. When this is not possible due to the nature of the safety system or combustible material, automatic fire suppression should be provided to limit the consequences of a fire.

3.3.6 Storage and usage of flammable liquids should comply with the requirements of NFPA30. Flammable and Combustible Liquids Code [8].

3.4 Ventilation

3.4.1 Where an area is vented into another area (e.g. from a low radioactive contamination area to a higher radioactive contamination area), and ventilation control cannot be determined on fire protection reasons alone, the consequence of heat and smoke spread shall be assessed. Wherever pull type ventilation exists fire dampers shall be provided on the supply side.

3.4.2 Each fire compartment containing a redundant division of safety system should preferably have an independent and fully separated ventilation system. The portions of this ventilation system (e.g. connecting ducts, fan rooms, filters) situated outside the fire compartment shall either have the same fire resistance as the area or, alternatively, the fire compartment shall be isolated by fire dampers with a fire resistance rating of minimum 1 h or more if fire hazard analysis demands so.

3.4.3 If a ventilation system serves more than one fire compartment, the portions of the ventilation systems located outside each fire compartment shall also have the same fire resistance as fire compartments. Means shall be provided to minimise the spread of smoke between the fire compartment by, for example, natural ventilation or smoke prevention flaps. Alternatively, fire dampers shall be fitted at appropriate locations on the plant to isolate the affected fire compartment to prevent the spread of fire, heat or smoke to another fire compartment. For such systems, the change of pressure within the ventilation system and the affected fire compartment due to temperature rise, smoke production or equipment failure caused by fire shall also be taken into account.

3.4.4 Supplementary smoke control methods, such as portable smoke exhausters should be provided to permit accessibility for fire-fighting, maintain a habitable environment for personnel access in areas containing nuclear-safety-related systems; and control damage to nuclear-safety-related components from the spread of corrosive gases. Whenever necessary, it is advantageous to identify the exhaust points within reactor building for each floor to which the exhaust from portable smoke exhauster can be diverted though the existing ducting and filtration systems.

3.4.5 The products of combustion that need to be removed from a specific fire compartment shall be assessed to determine the methods of control. In addition, any ventilation system designed to exhaust smoke or corrosive gases shall be evaluated to ensure that inadvertent operation or single failure cannot violate the isolation requirements for the radioactive controlled areas in plant design or compromise redundant safety functions. This requirement includes containment functions for protection of public and maintaining habitability for operations personnel.

3.4.6 In areas that contain or may potentially contain radioactive materials, venting of smoke and gases shall be monitored and controlled consistent with other safety considerations.

3.4.7 Fresh-air supply intakes to all areas shall be located remotely from the exhaust air outlets and smoke vents of other fire compartments and away from any exterior fire hazards to minimise the possibility of contaminating the intake air with the products of combustion.

3.4.8 Special protection for ventilation power supply and control cables should be considered. The power supply and controls for forced ventilation systems should be run outside the fire compartment served by the system where practicable.

3.4.9 The main and supplementary control areas shall be on separate ventilation systems.

3.4.10 Continuous ventilation shall be provided in areas where flammable gases or vapours may be present.

3.4.11 Enclosed stairwells that serve as fire exits shall be designed to minimise smoke infiltration during a fire.

3.4.12 Duct system shall be designed to limit the number of fire barrier penetrations to that essential for safe operation. Ventilation ducts penetrating or serving critical areas shall be non-combustible.

Air duct penetrations in fire barriers shall be provided with approved automatic fire dampers with a fire rating equivalent to the designated fire rating of the fire enclosure penetrated. Closure of fire dampers may be initiated by several diverse means based on the hazard involved.

3.4.13 Where combustible air filters have to be used in ventilating systems posing a fire hazard that could affect systems and components important to safety, the filters shall be protected as determined by a fire hazards analysis.

High-efficiency particulate air filters used in nuclear safety related ventilating systems shall conform to the requirements of Underwriters Laboratory, Inc., Standard for Test Performance of High-Efficiency Particulate Air Filter Units, UL 586-1977.

Where charcoal absorber beds are required in ventilating systems important to safety, each redundant charcoal bed assembly shall be separated by a fire barrier having a fire resistance rating of 3 h unless a barrier of lesser rating can be justified by analysis supported by appropriate data. Fixed fire protection need not be provided for charcoal adsorber beds containing less than 45 kg of charcoal. Fixed fire protection shall be provided for larger charcoal filters, except when a temperature monitoring system, filter train isolation dampers and decay heat removal capability are provided.

3.4.14 Where natural-convection ventilation is used, a minimum ratio of vent area to floor area shall be 1 to 200 except in oil hazard areas where 1 to 100 ratio shall be provided [39].

3.4.15 Where total flooding gas extinguishing systems are used, area intake and exhaust ventilation dampers should be controlled in accordance with NFPA 12, Carbon Dioxide Systems [3], and NFPA 12A, Halon 1301 Systems [4], to maintain the necessary gas concentration for fire suppression.

3.5 Electric Circuits and Equipment

3.5.1 Fire survival cables shall be used for safety circuits where redundancy of safety circuits cannot be ensured due to various constraints.

3.5.2 Cables with fire-retardant low smoke (FRLS) sheathing should be used for power and control cables for indoor application.

3.5.3 Electric cable constructions shall pass the flame test (e.g. as per IS: 10810 (PT53) Method of Test for Cables: Part 53 Flammability Test or equivalent).

3.5.4 Oil impregnated cables shall not be used in-doors.

3.5.5 Metal cable trays and metallic tubing for conduits shall be used. Flexible metallic tubing should be used for short length connections to equipment. Wherever cable tray covers are specified, they shall be constructed of the same material as that of the cable tray.

3.5.6 Switches for lighting of a fire hazard areas should be provided outside such area.

3.5.7 Cable trays shall be separated into power cable trays and instrumentation and control cable trays and run separately. However, where it is not possible, the scheme given in section 3.5.8 should be followed.

3.5.8 Segregation of cable trays shall be followed in the following order from top to bottom:
HV power cables,
MV power cables,
I&C cables.

Instrumentation and control cables for each channel should run separately. Power cables for redundant equipment should run separately.

3.5.9 Percentage fill for power and control cable trays shall be as per NFPA code Vol-6 (National Electric Code).

3.5.10 Routing should be so chosen as to avoid passing close to the equipment such as steam pipe lines, oil pipe lines, resistor grids and process equipment that are capable of producing heat. Where cables are required to be routed for loads located close to such systems, protection shall be provided to these cables. The cables shall be protected against oil spillage.

3.5.11 When routed under grid type walkways or similar structures, additional protection shall be provided in the form of solid covers or barriers located above the cable tray.

3.5.12 On a long run of horizontal cables, fire stops [36] at suitable intervals shall be provided to check the spread of fire.

3.5.13 Cable and cable tray penetrations fire barriers (vertical and horizontal) shall be sealed to give protection at least equivalent to that of the fire barrier. The design of fire barriers for horizontal and vertical cable trays shall, as a minimum meet the requirements IS:12459-1988 (Reaffirmed 1993), Code of Practice for fire protection of cable run [23] including the hose stream test.

3.5.14 Water based fire protection systems shall be provided as the primary fire suppression for cable fires.

3.5.15 Potential fires due to lightning shall be considered. Lightning protection shall be designed as per IS-2309.

3.5.16 Cable trays shall be used for cables only.

3.5.17 Miscellaneous storage and piping for flammable or combustible liquids or gases should not create any potential exposure hazard to important cable systems.

3.5.18 Safety Related Electrical Circuits

Class 1E circuits and equipment shall be arranged to maintain the independence of equipment assigned to different safety divisions and to prevent the spread of fire from one safety division to the other. Where fire barriers are not provided due to overriding design features, the location and installation of Class 1E circuits and equipment shall meet the separation requirements of IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits, IEEE Std.-384 [19]. A fire hazards analysis shall be performed to determine any additional requirements for fire protection necessary to ensure that nuclear safety functions are maintained in the event of a fire.

3.5.19 Transformers

Automatic water sprinkler system should be provided for oil filled transformers above 5 MVA rating. Manually-operated water sprinkler system should be provided for transformers with a rating of 1 MVA to 5 MVA [35]. Adequate provision of fire hydrants near the transformers below 1 MVA rating should be made. Appropriate provisions may also be made for confining spilled transformer oil during drainage [35].

4. FIRE DETECTION AND SUPPRESSION SYSTEMS

4.1 General

Fire detection and suppression systems are important echelons of the defence-in-depth approach to achieve a degree of fire safety necessary in nuclear facilities. Fire detection devices detect fire and activate or alert for implementation of emergency action and may be used to actuate fire extinguishing systems. Automatic fixed fire extinguishing systems ensure prompt and effective application of extinguishing agents to gain maximum freedom from risks and hazards due to problems such as inaccessibility, manpower deficiencies and erroneous operation.

4.2 Fire Detection and Alarm System

4.2.1 In designing fire detection and alarm systems, it is important to consider the reliability of the system and individual components to always perform their required functions. It is required to avoid the reduction in sensitivity of sensing devices leading to non-detection or late detection of a fire, or the spurious operation of an alarm system.

4.2.2 Each fire compartment shall be equipped with reliable fire detection and specifically engineered alarm systems are selected for fire risk for that area. Combined use of different types of detectors should be made to achieve reliability of the system.

4.2.3 The detection system shall annunciate by audible and visual alarms in the control room and in-house fire station. Local audible and visual alarms, as appropriate, shall also be provided in areas normally manned at other specific locations. For the purpose of providing an early warning to personnel who may enter or who may be working in an area equipped with potentially hazardous automatic fire extinguishing systems (e.g. carbon dioxide), suitable audible and visual alarms shall be provided within and at each entrance to the area and there shall be adequate written procedures to ensure the safety of the personnel entering such areas. Fire alarms shall be distinctive and shall not be capable of being confused with any other plant alarm.

4.2.4 Reliable power supply should be ensured for fire detection and alarm system. To take care of failure of main supply, emergency power from diesel generator set and backup supply from its own battery system shall be provided.

4.2.5 Selection of detectors should be based on the nature of products released by the heating up, carbonisation, or the initial bursting into flame of materials present in the fire hazard area. Fire detectors and detection systems should be as per the guidelines provided in Appendix-II.

4.2.6 Individual detectors should be placed within a fire compartment such that the flow of air due to ventilation or pressure differences dictated by contamination control will not cause smoke or heat to flow away from the detectors and thus unduly delayed actuation of the detector alarm. Fire detectors should also be placed such as to avoid spurious signals due to air currents generated by the operation of ventilation system. The location of the detectors shall be verified by in-place testing for prompt detection.

4.2.7 Selection of fire-detection equipment shall consider the environment in which it functions, e.g. radiation fields, humidity, temperature and air flow. Where the environment (e.g. higher radiation level, high temperature etc.) does not allow detectors to be placed immediately in the area to be protected, alternative methods, such as sampling of the gaseous atmosphere from the protected area for analysis by remote detectors with an automatic operation should be considered.

4.2.8 Where necessary, certain equipment such as fire pumps, spray systems, ventilation equipment and fire dampers shall be controlled and activated by detection systems. Where spurious operation is detrimental to the plant, activation shall be by two lines/cross-zoning of detection system.

4.2.9 Provision for manually activated fire alarms shall also be made.

4.3 Fire Suppression System

This section covers fixed and portable fire suppression systems. In selecting the type of suppression system (such as portable gaseous system or portable fire extinguisher system) to be installed, consideration shall be given to the speed of operation, the type of combustible materials present as indicated in the fire hazard analysis, possibility of thermal shocks, effects on human beings (e.g. asphyxiation) and to items important to safety. Reliable power supply should be ensured for power operated control valves meant for automatic suppression systems.

4.3.1 Water Systems

4.3.1.1 Systems, which employ water as means for suppression of fire, could be principally categorised under fixed water extinguishing systems as follows:

(a) sprinkler and other water spray systems (refer to section 4.3.1.1.2 f),

(b) fire hydrant or standpipe and hose systems (i.e. a fixed piping system with hose outlets, hose, and nozzles connected to a reliable water supply to provide effective fire hose streams to specific areas inside the building).

4.3.1.1.1 Sprinkler and other water spray systems

A fully automatically initiated water sprinkler protection should be provided as a conservative measure in all those locations of the plant where significant amounts of combustible material might be present resulting in unacceptable fire damage in the event of an uncontrolled fire. Such a design measure may also take into account aspects other than safety (e.g. spread of contamination). Generally, water systems are preferred in areas containing a high fire load of electrical cable material and other combustibles where the possibility exists for deep-seated fires. Water sprinklers may also be used for large quantities of oil (for lubrication or transformer cooling). Further, in cases where gas or other extinguishing systems are provided for primary fire protection, water systems serve as a good back-up fire protection.

Fire suppression systems shall, as a minimum, conform to requirements of appropriate standards such as NFPA 13, Standard for the Installation of Sprinkler Systems [5], NFPA 15, Standard for Water Spray System [7] or IS:9972, Specification for Automatic Sprinkler Heads [18].

The type of fire suppression system to be used and the arrangement of sprinkler/spray system need to be designed specifically for the hazard. In addition to the expected fire exposure as determined in fire hazard analysis, various factors should be addressed in the design of sprinkler systems. Among these factors are:

(a) spacing and location of sprinkler heads;

(b) temperature rating and thermal response time of the sprinkler heads; and

(c) water discharge rate and discharge density necessary for application of spray or fog for extinguishment.

To provide proper response to fire emergencies, sprinkler/spray systems should be preferably automatically actuated. Manually operated sprinkler systems should only be used in cases where it has been clearly demonstrated in the fire hazard analysis that delayed operation of the sprinkler system during a fire emergency will not compromise plant safety and other considerations.

4.3.1.1.2 Fire Hydrant or Standpipe Hose Systems

Standpipes with hose connections equipped with approved fire hose and nozzles, should be provided for areas containing or exposing nuclear safety related structures, systems or components and should be spaced so that these areas are accessible to at least one hose stream. Water supply and hose capability should be provided for containment. Fire hose stations should be conspicuously located as dictated by fire hazard analysis and should not be blocked. The fire hose standpipe system should be used for fire-fighting only. Alternative hose stations should be provided for an area if the fire hazard could block access to a single hose station serving that area.

Fire hydrant or standpipe hose system, should, as a minimum, conform to requirement of appropriate standards such as NFPA 14, Standpipe and Hose Systems [6] or IS: 5714, Hydrant Standpipe for Fire-Fighting [16] for sizing, spacing and pipe support requirements. While designing the system, the following factors merit consideration:

(a) Provision should be made to supply water to standpipes and hose connections for fire-fighting in areas within hose stream reach for equipment required to provide and maintain safe plant shutdown in the event of a Safe Shutdown Earthquake (SSE).

(b) Outside manual hose installations should be sufficient to reach any external portions of nuclear safety related structures, systems or components with an effective hose stream. To accomplish this, hydrants should be installed on the yard loop system in areas adjacent to nuclear safety related structures.

(c) Selection of proper type of hose nozzle should be based on fire hazard analysis. The usual combination spray/straight stream nozzle should not be used in areas where the straight stream can cause unacceptable mechanical damage.

(d) Each hydrant hose and standpipe riser should have connections that are compatible with on-site and off-site fire-fighting equipment.

(e) Each branch line to a separate building should have at least two independent connections to the fire water main loop such that water supply is assured even in the event of failure of one connection.

(f) Sprinkler systems and manual hose station standpipes should have connections to the plant underground water main so that no single active failure can impair both the primary and backup fire suppression systems. Alternatively, headers fed from each end are permitted inside the buildings to supply both sprinkler and standpipe systems, provided steel piping and fittings meeting the requirements of ANSI B31.1, Power Piping [20] are used for headers up to and including the first valve supplying the sprinkler systems where headers are parts of the seismically analysed hose standpipe system. When provided, such headers are considered to be an extension of the yard main system. Hose standpipe and automatic water suppression systems serving a single fire compartment should have redundant independent connections to the yard main system. Each sprinkler and standpipe system should be equipped with outside screw and yoke (OS&Y) gate valve or other approved shutoff valves. Audible water flow alarms should be provided on sprinkler deluge valves. Safety-related equipment that does not require sprinkler water fire protection, but subjected to unacceptable damage if wet by sprinkler water discharge, should be protected by water shields or baffles.

4.3.1.2 Fire Water Supply System

The fire water supply should be designed to furnish anticipated firewater requirements. The pump heads shall be such as to give a minimum residual pressure of 3.5 $kg/cm^2(g)$ at the hydraulically farthest point while delivering 100% flow (capacity of 3 hydrant and largest sprinkler flow) [29]. However, the maximum operating pressure at the nozzle shall be limited to 4.5 kg/cm^2. Distribution of water supply to fire equipment should be through a main loop such that water can reach each connection from two directions.

Valves shall be provided to isolate portions of the fire water main loop. They should provide visual local indications as to whether the valves are open or closed. Valves on the main loop shall be so arranged that closure of a single valve shall not cause the complete loss of the fire extinguishing system's capability in any given fire compartment.

The fire water main loop shall not be connected with service or domestic water system piping.

At sites where pumping is required to provide the necessary amount of water, redundancy in fire pumps shall be provided to cover the single failure criterion. The pumps shall have independent controls and diverse power supplies provided by the plant emergency power supply system and independent prime movers. Alarms shall be provided in the control room indicating running of pump, power failure, or failure to start.

The storage for the fire-fighting water shall be estimated for continuous operation of 2 h of hydrants @ 171 m^3/h (750 USGPM) and 2 h of sprinklers [29], both operating simultaneously. Provision shall be made for adequate number of independently powered pumps to cater to fire protection requirement during station blackout (on-site and off-site power failure) condition.

Two separate reliable water sources should normally be provided. If only one water source is provided, then it shall be large (e.g. lake, pond, river) and at least two independent intakes should be provided. If only tanks are used, two 100% system capacity tanks should be installed. The main plant water supply capacity shall be capable of refilling either tank within 8 h. Tanks should be capable of being interconnected such that pumps can take suction from either or both tanks. Each tank should be capable of being isolated in the event of a leak. Tanks should be fitted with an attachment enabling fire engines to be connected to them.

The water supply for sprinkler systems may require chemical treatment and additional filtration to ensure that blockage of sprinklers does not occur from the effects of debris and corrosion products.

Provision should be made for inspection of sprinkler heads, and water flows should be regularly tested by discharge to provide confidence in the continued ability of the system to perform its duty throughout the lifetime of the plant.

4.3.1.3 Seismic Qualification

Fire water system shall be designed to SSE category for the systems important to safety. This should include firewater pump house, water storage, pumps as well as the distribution header serving the systems important to safety. Seismically qualified isolating valves can be used to isolate the fire water supply to other related nuclear systems.

4.3.2 Gaseous Systems

4.3.2.1 Carbon Dioxide Suppression System

4.3.2.1.1 Carbon dioxide extinguishing systems shall, as a minimum, comply with the requirements of IS-6382- Code of Practice for Design and Installation of Fixed CO_2 Fire Extinguishing System [17].

4.3.2.1.2 Carbon dioxide systems are normally used for fires involving electrical equipment such as switchgear, control consoles etc., since the gas is clean, does not leave any significant deposits and does not conduct electricity. However, since gas concentration greater than 5% or oxygen concentration below. 12% in air can be a hazard to personnel, due consideration must be given to this aspect in the design and specification of the system.

Some of the important types of hazards and equipment that carbon dioxide systems satisfactorily protect include:

(a) gaseous and liquid flammable materials;

(b) electrical hazards, such as transformers, oil switches and circuit breakers, and rotating equipment;

(c) engines utilising gasoline and other flammable fuels; and

(d) ordinary combustibles such as paper, wood and textiles.

Carbon dioxide extinguishing systems should only be used in areas where the required concentration can be ensured for a period necessary to extinguish the fire.

4.3.2.1.3 In determining the need for a carbon dioxide extinguishing system, consideration shall be given to the type of fire, reaction with other materials (including those chemicals present, which may contain their own oxygen or materials which, when burning, can extract oxygen from carbon dioxide), effects on charcoal filters, and toxic and corrosive characteristics of thermal decomposition products of gases.

4.3.2.1.4 In designing the CO_2 suppression system, consideration should be given to:

(a) the minimum required concentration, distribution, soak time and ventilation control;

(b) anoxia and toxicity;

(c) possibility of secondary thermal shock damage due to sudden cooling;

(d) conflicting requirements for venting during injection to prevent over-pressurisation versus sealing to prevent loss of agent; and

(e) location and selection of the activating detectors.

4.3.2.1.5 For enclosures housing electrical equipment (e.g. DG room), a total flooding system is recommended which consists of a fixed supply of carbon dioxide normally connected to fixed piping with nozzles arranged to discharge carbon dioxide into an enclosed space or enclosure around the hazard. The requirements and recommendations for a total flooding system are as follows:

The total quantity of carbon dioxide required should be sufficient to ensure that the oxygen content of the enclosure is reduced to a point, where combustion can no longer be sustained. For total flooding systems, a minimum design concentration of 30 to 50% in the area is required to suppress the fire [17]. In determining this, provision shall be made for leak tightness of the enclosure, the required extinguishing concentration for the particular hazard, the rate of application and the period for which the design concentration is to be held.

The possible structural effects of pressure build-up, which may occur within the enclosure as a result of the discharge of carbon dioxide, shall be evaluated and provision made for special venting, if considered necessary. Where such venting is necessary, attention shall also be paid to the space into which excess pressure (which may also contain flammable vapours) is to be relieved.

4.3.2.1.6 The minimum design rate of application shall be based on the quantity of carbon dioxide and the maximum time to achieve design concentration.

For surface fires the design concentration shall be achieved within 1 minute. For deep-seated fires the design concentration shall be achieved within 7 minutes but the rate shall not be less than that required to develop a concentration of 30% in 2 minutes [17].

4.3.2.1.7 Where automatic carbon dioxide systems are used, they shall be equipped with a pre-discharge alarm system and a discharge delay to permit personnel evacuation.

4.3.2.1.8 Time delay shall be used only where discharge delay is required for personnel evacuation or to prepare the hazard area for discharge. Time delays shall not be used as a means for confirming the operation of a detection device before automatic actuation occurs.

4.3.2.1.9 Provisions for locally disarming automatic carbon dioxide systems shall be key-locked and under strict administrative control.

4.3.2.1.10 Adequate reserve supply shall be maintained to restore systems to operating condition within 24 h. Permanent connection of both the primary and reserve supplies and the arrangement for easy changeover should be considered.

4.3.2.1.11 The system shall be installed, thoroughly inspected and tested periodically as per IS-6382 [17].

4.3.2.2 Halon Suppression Systems/or its Substitutes

Halon releases volatile bromine that has a deleterious effect on the earth's environment and therefore its use is being phased out. The requirements for the design of Halon fire extinguishing systems are, therefore, not given in the main part of the guide. Constant efforts should be made to find out chloro-fluorocarbon-free substitutes.

4.3.3 Portable Fire Extinguishers

4.3.3.1 Portable including trolley-mounted fire extinguishers shall be selected for the specific class or classes of hazards. The fire-fighting equipment suitable for different classes of fires are as follows [2]:

Class A - Pressurised extinguishers of water-CO_2 and water buckets.

Class B - Chemical foam extinguishers, carbon dioxide, dry powder type extinguishers and sand buckets.

Class C - Carbon dioxide and dry powder type extinguishers.

Class D - Special type of dry powder extinguishers and sand buckets.

4.3.3.2 Adequate number of fire extinguishers shall be provided in various plant areas and particularly in areas that contain or could present a fire exposure hazard to safety related equipment in accordance with guidelines as per IS-933 [11], 934 [12], 940 [13], 2878 [15], NFPA-10 [2] etc.

4.3.3.3 Portable fire extinguishers should be placed as close to exits or stair-case landings as possible. Buckets should be placed at convenient and easily accessible locations either on brackets or on stands.

4.4 Personnel Support Systems

4.4.1 Emergency Breathing Apparatus

Adequate numbers of self-contained positive pressure breathing apparatus with full face positive pressure mask shall be provided and maintained for the operating personnel in addition to those maintained by the fire brigade. At least two air cylinders shall be located on-site for each self-contained breathing apparatus, having an operating life of 30 minutes. In addition, an on-site 6 h supply of reserve air should be provided to permit quick and complete replenishment of empty cylinders, unless alternative and expeditious arrangement exists for getting filled cylinders.

Control room personnel may be furnished breathing air either from self-contained breathing apparatus (SCBA) or from manifold system (hose mask or airline respirator) piped from a storage reservoir. If compressors are used as a source of breathing air, only equipment approved for breathing air shall be used. Compressor shall be operable assuming a loss of off-site power. Special care must be taken to locate the compressor in areas free of dust and contaminants.

4.4.2 Communication

Requirements for the reporting of fires and communication during fire-fighting shall be provided in the design of plant communication system. Emergency communication equipment shall be readily accessible, located in the normal path of access to critical areas. Fixed emergency communication systems independent of the normal plant communication system should be installed at pre-selected stations to communicate to the control room and from control room to fire station.

In addition, portable communication devices shall be provided and reserved for direct communication amongst the different agencies co-ordinating the fire-fighting operations. This system shall not interfere with the communication capabilities of the plant. Fixed repeaters installed to permit the use of portable radio communication units shall be protected from exposure to fire. Pre-operational and periodic testing shall demonstrate that the frequencies used for portable radio communication will not affect any items important to safety such as protective relays etc.

4.4.3 Emergency Lighting

The plant emergency lighting system shall illuminate fire access routes with light having an intensity of not less than 11 lux (1.0 foot-candle) measured at floor level. The illumination shall be so arranged that the failure of any single lighting unit does not leave a fire access route in darkness. The emergency lighting system shall provide the required illumination automatically for a period of at least 8 h [24] in the event of an interruption to the normal lighting system. The emergency lighting system may be powered by batteries or diesel generator(s).

At least six battery-powered portable hand lights should be provided and maintained for emergency use by the fire brigade and other operations personnel for their movement to monitor the safe shutdown state of the reactor.

5. QUALITY ASSURANCE PROGRAMMES

5.1 General

Quality assurance programmes shall be in effect for fire protection elements of the plant from the inception of design, through construction of the plant and its operating life to decommissioning. The programme shall satisfy the specific criteria listed in the following sections [24].

5.2 Design and Procurement Document Control

Measures should be established to ensure that guidelines of the regulatory position of this guide are included in design and procurement documents and deviations therefrom are minimised.

5.3 Instructions, Procedures and Drawings

Inspections, tests, administrative controls, fire drills, and training that govern the fire protection programme systems should be prescribed by documented instructions, procedures, or drawings and should be accomplished in accordance with these documents.

5.4 Control of Purchased Material, Equipment and Services

Measures should be established to ensure that material and equipment purchased as well as services provided conform to the procurement documents.

5.5 Inspection

The programme for independent inspection of activities affecting fire protection should be established and executed by or for the organisation performing the activity to verify conformance with documented installation drawings and test procedures for accomplishing the activities.

5.6 Test and Test Control

A test programme should be established and implemented to ensure that testing is performed and verified by inspection and audit to demonstrate conformance with design and system readiness requirements.

5.7 Inspection, Test and Operating Status

Measures should be established to provide for identification of items that have satisfactorily passed the required tests and inspections.

5.8 Non-Conforming Items

Measures should be established to control items that do not conform to specified requirements to prevent inadvertent use or installation.

5.9 Corrective Action

Measures should be established to ensure that conditions adverse to fire protection, such as failures, malfunctions, deficiencies, deviations, defective components, uncontrolled combustible material and non-conformances are promptly identified, reported and corrected.

5.10 Records

Records should be prepared and maintained to furnish evidence that the criteria enumerated above are being met for activities affecting the fire protection programme and safely preserved and protected from fire.

5.11 Audits

Audits should be conducted and documented to verify compliance with the fire protection programme, including design and procurement documents, instructions, procedures, and drawings, and inspection and test activities.

5.12 Organisation for QA

An independent agency, directly reporting to a higher level in hierarchy should be designated for QA in fire protection.

APPENDIX - I

FIRE HAZARD ANALYSIS GUIDELINES

I.1 Fire hazard analysis helps to identify the fire hazards, analyse the adequacy of the fire protection measures taken and recommend measures to improve it. It also helps to determine the required fire resistance of the fire compartment boundaries and the requirements of fire extinguishment systems and fire barriers, and in turn to improve the fire safety of the plant. The fire hazard analysis [38,42] comprises the following:

(a) to screen all areas to identify hazards and postulate probable fire;

(b) to identify and establish the location of individual components of items important to safety;

(c) to analyse the anticipated fire growth and its consequences with respect to items important to safety. Items to be considered in evaluating fire growth include types of combustible materials present, their forms, heat release rates, room and distribution geometry, and ventilation rates. Fire growth may be quantified through the use of fire testing, numerical fire models, which have been suitably validated, and may be complemented by the application of probabilistic methods. Assumptions and limitations applicable to the method of analysis should be clearly stated. The effects of fire on items important to safety should be determined;

(d) to determine the required fire resistance of fire barriers. This resistance may be determined as a function of fire load combustion characteristics and the radiation and convection properties of the fire, taking into account the geometry and ventilation of the fire compartment;

(e) to determine the type of fire detection and means of protection to be provided. After the items important to safety and potential hazards for each fire compartment or fire cell have been identified, appropriate protection features can be determined. These may include detection equipment and various combinations of automatically or manually initiated fixed fire extinguishing systems and manual fire fighting capability;

(f) to identify cases where additional fire separation or fire protection is required especially for common cause failures to ensure that items important to safety will remain functional during and following a credible fire. For example, the fire hazards analysis has to determine whether the arrangement of combustibles, spatial separation of equipment and the fixed fire extinguishing system provided are sufficient to prevent fire damage to redundant divisions of a safety system without the need for further fire separation;

(g) to verify that safety systems required to shut the reactor down, remove residual heat and contain radioactive material shall be protected against the consequences of fires so that safety systems can still perform the above safety functions, taking into account the effects of a single failure as required in the Code on Design for those functions; and

(h) to verify that the intent of this guide has been met. The analysis should list applicable elements of the programme, with explanatory statements as needed to identify the location, the type of system and the design criteria.

This evaluation should verify that fire hazard analysis fulfils all the above functions.

Fire PRAs and use of fire models in hazard analysis should be given due importance. Fire PRA techniques provide advanced quantitative means to supplement other hazard identification, analysis, assessment, control, and management methods to identify the potential for such incidents and to evaluate control strategies. Efforts may be made to identify the risk areas in terms of highly critical area, critical areas, and sub-critical areas to apply fire PRA techniques to analyse the hazard. Data bank on fire incidents and the role of fire safety measures may be properly documented and used for new possible estimates of equipment reliability for the plant.

I.2 The fire hazard analysis and documentation should include as a minimum the following:

(1) Drawings of the plant layout incorporating all areas with location and identification of nuclear safety related structures/systems and proposed fire protection systems. The drawings should indicate fire protection related building design features.

(2) The estimated inventories of fixed and stored combustible and flammable materials by types and combustible loading (J/m^2) for each fire compartment, including those which present a fire exposure to critical areas. Consideration should be given to transient loading that may be expected to regularly occur during the operation of the plant.

(3) A discussion should be held as a means to implement the defence-in-depth concept based on an analysis of fire hazards for each fire compartment. This discussion should, as a minimum, include:

(a) an identification of the plant systems that occupy fire compartment;

(b) a description of the fire barriers that delineate the fire compartment;

(c) a description of the fire extinguishing and detection features within each fire compartment including all means for containing and inhibiting the progress of a fire, e.g. coatings, curbs, drains and walls, as well as the extinguishing equipment outside the area that is accessible for use within the area;

(d) an analysis of the impact of a failure or loss of automatic fire detection or protection system on the consequences of a fire;

(e) an identification of the measures required for the protection of nuclear safety related equipment against inadvertent actuation or break in a fire protection system; and

(f) a description of the smoke control measures for each fire compartment.

Fire hazard analysis should define and document those portions of the fire protection Systems, building systems important to fire safety and fire protection programme that must be maintained to ensure safe operation of the plant. The documentation should also include the background information, assumptions and descriptions.

I.3 The effects of design basis fires should be analysed for all areas containing safety systems and other locations that constitute a significant fire hazard to these areas.

I.4 There are at least three definite stages when fire hazard analysis should be performed or reviewed (and updated if required). These include:

(a) early in the design phase;

(b) prior to initial commissioning (verification of initial analysis); and

(c) whenever significant change is made (e.g. addition to combustible materials inventories; prior to and immediately following major plant (building) modifications; major modifications to fire protection systems including fire barriers, fixed suppression systems, fire detection systems etc., modifications to nuclear safety related structures, systems and components).

Fire hazard analysis is conducted and documented in three phases: the first involves a combination of planning, establishing and recording the methodology and determining basic assumptions; the second phase is an information collection process; and the third phase is the analysis of the adequacy of the fire protection programme.

I.4.1 Phase One - Methodology of Fire Hazard Analysis

The methodology of the fire hazard analysis, as a minimum should include:

(1) Description of the format to be utilised in the formulation of analysis. (An example of information to be included here can be a listing of the outline and brief summary of data contained in two and three phases.)

(2) Listing the assumptions/parameters that may be applied. (e.g. ignition is assumed, basis upon which fire loading and combustible loading is determined, cable insulation burning rates, applicable generic information, etc.).

(3) Statement concerning the general plant design features pertinent to fire hazard analysis (e.g. information pertaining to electrical cables, raceway(s), cable trays, covered trays, fire breaks in trays, horizontal and vertical separation between safety related raceway(s), other safety division(s) on non-safety raceway(s), code and standards, fire protection water source, water supply etc.).

(4) Investigative processes/methods (e.g. scale model utilised, on-site inspection, manufacturer's data, fire test of penetration seals, etc.).

I.4.2 Phase Two - Required Information

Initially this effort will require the use of engineering/architectural drawings (including plan and elevation views) and summation of information on the following as available:

(1) General description of site fire protection and plot plan including:

(a) building layout, structural and architectural parameters (walls, floors and roofs);

(b) water supplies, fire pumps, other suppression agents etc.;

(c) fire mains, hydrants, valves and hose houses;

(d) access and egress for plant security fencing, gates, and access roads; and

(e) miscellaneous plant features and structures (cooling towers, oil tanks, power transmission equipment, etc)

(2) Identification, description and location of fire compartment or fire cell of nuclear safety related systems.

(3) Identification, description and location of areas in which fires could involve systems and components resulting in the release of radioactive material.

(4) Designation by assigned number of each fire compartment containing components of systems identified in (2) and (3) above, and areas that expose these areas to fire, for each of these areas describe the following:

(a) fire resistance rating of the barrier (i.e. walls, floor and ceiling or roof);

(b) protection of openings in fire barrier (i.e. door, duct, shaft, pipe-conduit-cable penetrations) including reference to any test results or other seal qualifications; and

(c) subdivisions (fire cells) in which a unique and definable fire potential exists and where appropriate isolation features are present due to either spatial separation of partition walls, floor and ceiling, or roof;

(5) An inventory of combustible materials for each fire compartment or fire cell designated in (4) above. This should include consideration for both fixed and transient materials.

(6) List of fire detection and protection systems and equipment available for use within each fire compartment or fire cell including:

(a) fire extinguishing systems and equipment

- automatic or manual fixed systems,
- release rates (density or concentration),
- soaking periods,
- backup supplies of extinguishing agents,
- methods of operation,

- portable extinguishers-size and type,
- standpipe and hose systems.

(b) fire detection system

(c) supervisory alarms

(d) other fire control measures to contain or inhibit the progress of a fire within a given fire compartment, e.g. coatings, curbing, drains, limiting air supply, barriers, etc.

(7) Description of the measures provided for protection of nuclear safety related systems within each fire compartment or fire cell against a single inadvertent actuation or break in any fire protection system line. These may include:

(a) water control measures:

- use of precaution sprinkler systems,
- drainage, baffles, shields, etc.,
- use of water-resistant equipment.

(b) Physical protection for pressurised systems

(8) Description of ventilation system(s) and smoke control measures for each fire compartment or fire cell.

(9) A description of the impact of a failure or loss of automatic fire detection or protection systems on the consequences of a fire.

I.4.3 Phase Three - Analysis of the Adequacy of Fire Protection System

(1) Analysis

An analysis, based on all the above information, should be performed for each fire compartment or fire cell. The questions addressed in the analysis should include the following:

(a) Will the fire be contained within the fire compartment or fire cell, without or with suppression and detection equipment or systems operating?

(b) How would a fire in the fire compartment or cell be detected?

(c) How would a fire in the fire compartment or fire cell be extinguished?

(d) Does the ventilation system contribute to the spread of the fire or products of combustion to other fire compartments or fire cells which would otherwise be unaffected? Will inadvertent operation or closing of a fire damper affect nuclear safety related systems located in other fire compartments or fire cells? (i.e. loss of an engineered safety feature (ESF), loss of ventilation, etc.)

(e) Is there any equipment related to safety within the fire compartment or fire cell for which the nuclear safety function cannot be fulfilled by other equipment important to safety in other fire compartments or fire cells ?

(f) Will any nuclear safety related equipment located outside the immediate fire compartment being evaluated, be affected by a fire within such area? (i.e. electronic equipment located outside the fire compartment, but mounted on the separating fire barrier).

(g) Can the nuclear safety functions be performed despite any fire within the fire compartment?

(h) What are the temperature distributions in space? What are the effects of temperature on material/equipment?

(i) Will the structural integrity be affected?

(j) What happens to fire growth with time? Does the selection of fire detection system characteristics match fire growth? Does the speed of extinguishing system match the rate of fire growth?

(k) What are the consequences with the protection system operating and failing?

(2) **Appropriate Recommendations**

(a) Based on the analysis above, problem areas will be pinpointed. Modification/design changes may not be apparent, but solutions must be investigated. Potential modifications must be evaluated until a design is found that will result in a positive answer for question (1) (g) above.

(b) Any recommendations should be scheduled and implemented by the plant management.

(3) **Modification of Proposed Protection**

As a result of the analysis process, it may be necessary to recommend changes in the proposed levels of fire protection, in order to achieve the stated safety goals. Proposed changes should be re-evaluated in fire hazard analysis. Subsequent plant changes or modifications for any reason during the life of the power plant should be evaluated and the fire hazard analysis updated as appropriate. As the detailed design of the total plant proceeds, modifications can take place which could affect the fire hazard analysis (i.e. additional fire barrier penetrations may be proposed and pumps or pipes or cabling may be added). It is therefore appropriate at a suitable point in the design/construction programme to undertake a validatory check of the plant against the design to ensure that the design intent is being maintained.

APPENDIX - II

FIRE DETECTION AND ALARM SYSTEM

II.1 Detection, Signalling, and Alarm Devices

Detection systems are designed to detect some phase of activity occurring during one or more of the three stages of fire development. The three stages are the incipient, the smouldering and the flame stage. The incipient stage is the earliest stage of fire development wherein preheating and gasification process producing sub-micron size aerosols. The smouldering stage is one in which the decomposition reaction is further advanced and visible smoke is evolved. Aerosol and smoke travels are dependent on local airflow conditions. The flame stage covers the period from initial occurrence of the flame to a fully developed fire. Radiant energy is evolved sufficiently to be detected at appreciable distances. Thermal energy during later stages is sufficient to result in an appreciable temperature rise at ceiling level.

The length of time of these periods and therefore the effectiveness of the detector varies depending on the type of combustible material and the ignition source. If lubricating oil were discharged under pressure through a ruptured cooling system impinging on a surface above its ignition temperature, incipient and smouldering stages would be very short. Detectors that are most sensitive to the flame stage would be most effective for this type of fire. Fires initiating in cable insulation may have long incipient and smouldering stages. Detectors that are most sensitive for these stages would be most effective. Table-II-1 indicates the types of detectors available and the types of fire for which the detectors would be most effective. Table-II-2 provides guidance on the relative performance of fire detectors. Table II-3 gives general criteria for selection of detectors. Table II-4 gives the area coverage for various detectors. Table II-5 gives the general application for various detectors. Table II-6 compares the different detectors.

Detection systems can be used to perform a number of functions: actuate fire protection systems, to close fire doors and smoke dampers, shut down power operated equipment, alarm personnel, etc. Additional guidance can be found in the National Fire Protection Association (NFPA), National Fire Alarm Code, NFPA Std 72-1993[9].

(a) **Smoke Detectors**

1. **Ionisation-type detectors**:- This unit consists of one or more chambers capable of sensing air made electrically conductive. Actuation occurs when smoke particles enter the chamber and reduce the conductivity of air in the chamber below a predetermined level.

2. **Photoelectric detector**:- Actuation occurs when smoke passes through a light beam either obscuring the beam's path (beam type) or reflecting light into a photocell (spot type).

3. **Cloud chamber**. smoke detector:- This unit actuates when the concentration of particles in the incoming air sample exceeds a present value.

(b) **Flame Detectors:** respond to radiant energy of different wavelengths. The principal detector types are infrared and ultraviolet.

(c) **Heat Detectors:** Fixed temperature detector- This unit actuates when the detection element reaches a predetermined temperature.

Rate compensation detectors: A type of fixed temperature detector designed to correct for rate of temperature rise. This detector operates close to its set point regardless of whether subjected to rapid or slow temperature increases.

Rate of temperature rise detector: This unit is designed to actuate when a pre-set rate of temperature increase is exceeded.

TABLE-II-1 Relative Sensitivity of Detectors for Various Combustibles

Detector type	Effective stage	Sensitivity			
		Class A	Class B	Class C	Class D
Ionisation	Incipient	High	Medium	Medium	Not suitable
Photoelectric	Smouldering	High	Medium	Medium	Not suitable
Fixed Temperature	Flame	Low	High	Low	High
Rate of Rise	Flame	Medium	High	Low	High
Rate Compensation	Flame	Medium	High	Low	High
Ultraviolet	Flame	High	High	Medium	Low
Infrared	Flame	High	High	Low	Low

Class A - Fires involving wood, cable insulation, cardboard, packaging materials.

Class B - Fires involving flammable liquids and combustible liquids such as lubricating or cooling oils.

Class C - Electrical faults.

Class D - Metal fires.

TABLE-II-2 Relative Performance Summary of Fire Detectors

Detector Type	Sensitivity	Reliability	Maintainability	Stability
Ionisation	High	Medium	Medium	Medium
Photoelectric	High	Medium	Low	Medium
Fixed Temperature	Low	High	High	High
Rate of Rise	Medium	Medium	High	High
Rate Compensation	Medium	High	High	High
Ultraviolet	High	Medium	Medium	Medium
Infrared	High	Medium	Medium	Medium

Sensitivity Expected response time. Sensitivity can be increased for thermal and smoke detectors by reducing the spacing.

Reliability Based on the ability of individual components of system to be in proper working condition over the life of a system. Simplicity and sealed construction are factors that improve reliability.

Maintainability Based on the maintenance requirements of detectors. High means minimal maintenance, i.e. thermal units usually have no periodic maintenance requirements. Other units must be checked periodically. This is not an extensive effort that would cause problems interfering with plant operation.

Stability Based on the ability to sense fires over extended time periods without change in sensitivity.

Thermal units do not have components which change appreciably over extended periods of time. Other units have electronic components that may require periodic adjustments.

II.2. General Guidelines for Selection

The general guidelines to be followed while selecting the fire detectors to suit various environmental conditions are given below:

TABLE-II-3: Selection of Detectors

Environmental conditions	Type of detector to be used or not to be used
Presence of gas, alcohol and other vapours	Use infrared flame detector or, rate of rise heat detector. Do not use smoke detector
Dusty or smoky conditions prevail in an area	Do not use smoke detectors of either optical or ionisation type
Areas where high levels of combustion products are likely (e.g., furnace areas)	Do not use smoke detectors
Areas where sudden temperature changes occur (e.g. near furnace doors)	Do not use rate of rise heat detector
Areas connected to air handling units (AHU's) in the common return airline	Use ionisation type smoke detector
High radiation areas	Do not use ionisation type smoke detector alone
For covering large areas with high ceiling levels	Use linear beam type smoke detector
Slow smouldering fires (low energy) which may generate large size smoke Particles such as electrical cable fires	Use optical type smoke detector
For open flaming fires (high energy) that generate a larger number of smaller size smoke particles	Use ionisation type smoke detector

II.3. Area Coverage

Generally the area coverage for various types of fire detectors are as given in Table-II-4. The area coverage depends upon ceiling heights. The above values are generally applicable for ceiling heights of up to 5 m. The area coverage given above is indicative. In view of various openings, equipment/structures and ventilation patterns in the area the location of the detectors should be such that the area covered is suitably overlapped in order to achieve a response period of the detection system around a maximum of 5 minutes. Analytical methods should be used to determine the area coverage of detectors and sprinklers.

TABLE-II-4: Area Coverage of Detectors

Type of detector	Area covered (sq. m)
Fixed temperature heat detector	40 to 60
Rate of rise heat detector	16
Combined rate of rise and fixed temperature heat detector	40
Ionisation smoke detector	50 to 80
Optical smoke detector	50 to 80
Flame detector	100
Smoke and heat detector (linear beam smoke detector type)	10-100 m length

II.4. Detector Application Guide (General)

TABLE-II-5: Detector Application Guide

Stages of fire	Fire characteristics	Application types
Incipient	Invisible smoke, no heat, no visible flame	Ionisation
Smouldering	Smoke, no ceiling heat, no visible flame	Visual, ionisation, photoelectric
Early flaming	Smoke, visible flame, no ceiling heat	Visual, ionisation, photoelectric flame
Fully developed	Smoke , heat, visible flame	Visual, ionisation, photoelectric flame, thermal

II.5. Comparison of various types of Fire Detectors

A comparison of various types of fire detectors that are useful in their selection is given in Table II-6:

TABLE-II-6: Comparison of Fire Detectors

Type of detector	Advantages	Disadvantages	Application	Testable	Cleaning frequency
Thermal fusible link	Needs no electricity. Highly reliable low unit cost	Very slow. Heat must impinge.	Backup systems commercial & industrial buildings buildings-class A, B and D fires. e.g. to operate the dampers	No	1/3 yr
Fixed temperature heat	Reliable and simple. Effective indoors. Low unit cost	Slow. Affected by wind.	Indoors, enclosed areas - Class A & B fires	Yes	1/yr
Rate of rise temperature	Self-adjusting to temperature. Variations of day/night and summer/winter. Can detect rapidly growing fire quickly. Low unit cost.	Actuated by convected heat. Heat must impinge. Affected by wind.	Indoors, enclosed areas- Class A, B & D fires.	Yes	1/yr

TABLE-II-6: Comparison of Fire Detectors (Contd..)

Type of detector	Advantages	Disadvantages	Application	Testable	Cleaning frequency
Smoke - ionisation	Early warning in incipient stages for flaming fires. Low unit cost.	Response may be adversely affected by environmental dust, humidity greater than 95%, temperature (below 0°C and above 60°C) etc. Affected by high radioactive environment.	Indoors, home, offices, computer rooms-Class A, C & D Fires.	Yes	2/yr
Smoke-photoelectric	Early warning of smouldering fire. Low unit cost.	Response may be adversely affected by dust, humidity > 95%, temperatures (below 0°C and above 60°C), not suitable for black smoke.	Indoors, homes, offices, commercial buildings-Class A fires. Suitable for grey smoke-producing materials.	Yes	2/yr
Infrared(IR) flame detectors	Fast response. Moderate sensitivity Manual self-test through the window. Moderate unit	Affected by temp-erature (below 0°C and above 60°C). Subject to false alarms due to variety of IR sources in industrial environment. No automatic self test.	Indoors, air ducts, military tanks - Class A & B fires	Yes	1/yr

TABLE-II-6: Comparison of Fire Detectors (Contd..)

Type of detector	Advantages	Disadvantages	Application	Testable	Cleaning frequency
Ultraviolet (UV)	Highest speed, highest sensitivity. Automatic self test. Moderate unit cost.	Subject to false alarms from other sources in the vicinity. Blinded by thick smoke.	Outdoors/indoors-Class D fires.	Yes 1/yr	
Dual detector (IR & IR)	Moderate speed. Moderate sensitivity. Low false alarm rate.	Limited self-testing. High unit cost.	Outdoors/indoors - Class A & B fires.	Yes	1/yr
Dual detector (IR & UV)	High speed, high sensitivity. Low false alarm rate. Wide temperature range. Automatic self-test.	Thick smoke reduces range. High unit cost.	Outdoors/indoors - Class A, B & D fires.	Yes	1/yr

TABLE-II-6: Comparison of Fire Detectors (Contd..)

Type of detector	Advantages	Disadvantages	Application	Testable	Cleaning frequency
Quartzoid bulb detectors (fixed temperature)	Fast response, compact reliable, low unit cost.	Testable under destructive test	Outdoor/indoor for high velocity water spraying system, e.g. automatic sprinkler.	No	-
Linear heat sensor cables-Analogue	Fast response, compact, reliable, unaffected by smoke & humidity	Costlier than digital cables.	Indoor/outdoor cable trays & trenches	Yes	-
Linear heat sensor cables-Digital	Fast response, compact, reliable, unaffected by smoke & humidity, low unit cost	Testable under destructive test.	Indoor/outdoor cable trays & trenches	No	-
Linear smoke (beam) detectors	Fast response, reliable, and unaffected by humidity. Suitable for longer rooms and all types of fires.	Can detect fire along length only. Does not cover an area. High unit cost.	Indoors, for high ceiling, e.g., pump room. Suitable for long halls	Yes	1/yr

APPENDIX-III

CLASSIFICATION OF HAZARD AREAS

Areas Are Classified with Respect to Hazards as Follows:

AIII.1 Pipe failure hazard area

An area which contains piping normally operating at high or moderate energies.

A.III.2 Missile hazard area

An area containing missile source having sufficient kinetic energy under design basis fire conditions to damage redundant class 1E circuits routed through the area.

A.III.3 Fire hazard area

An area designated as a fire hazard area if it contains any of the following potential hazards:

1. Liquids that are classified as flammable or combustible as per NFPA-321 - Basic classification of flammable and combustible liquids.

2. Solids exhibiting flame spread index [28] of 26 or higher as per ASTM E 84 Test for surface burning characteristics of building materials [27].

3. Coatings exhibiting flame spread index of 50 or higher as per ASTME 84 [27].

NOTE: An area need not be designated as a fire hazard area if administrative control provides suppression measures for temporary ignition source, use or the introduction of the above hazards is temporary or limited to an acceptable quantity.

A.III.4 Limited hazard areas

Those plant areas from which potential hazards such as missiles, exposure fires and pipe whip are excluded.

NOTE: In both limited hazard area and a non-hazard area, the only energy available to damage electrical circuits is that energy associated with failure or faults internal to electrical equipment or cables within the area. The primary difference between a limited hazard area and a non-hazard area is that power circuits and equipment are restricted in the non-hazard area.

A.II.5 Non-hazard area

An area meeting the following requirements is designated as a non-hazard area.

(i) the area not containing high energy equipment such as switchgears, transformers, rotating equipment, or potential sources of missiles or pipe failure hazards or fire hazards;

(ii) circuits in this area are required to be limited to control and instrument functions and those power supply circuit cables and equipment located within the area;

(iii) power circuit cables in this area are required to be installed in enclosed raceways; and

(iv) administrative control of operations and maintenance activities is required to control and limit the introduction of potential hazards into the area.

ANNEXURE-I

TEST/APPROVAL INSTITUTIONS

CEN	European Committee for Standardisation
BASEFA	(British Approvals Service for Electrical Equipment in Flammable Atmospheres)
CBRI	(Central Building Research Institute, Roorkee, India)
VdS	(Verband der Sachversicherer e.V.Koln, Germany)
STELF	(Station d Essais Laboratoire du Feu, France)
FIRTO	(Fire Insurers" Research and Testing Organisation, GB)
UL	(Underwriters" Laboratories Inc., USA)
FM	(Factory Mutual Research, USA)
EC	(Elektronik Centralen, Denmark)
BMK	(Brandmeldekommission, CH)
CNMIS	(Comite National du Material d' Incendie et de Securite, France)
LPCB	(Loss Prevention Council of Great Britain)
PTB	(Physikalisch-Technische Bundesanstalt, Germany)

ANNEXURE-II

EXAMPLES OF FIRE DETECTION & SUPPRESSION SYSTEMS FOR SPECIFIC NUCLEAR POWER PLANT AREAS

SL. NO.	AREA	TYPE OF DETECTION SYSTEM	TYPE OF PRIMARY SUPPRESSION SYSTEM	TYPE OF BACK-UP SUPPR-ESSION SYSTEM
1	REACTOR BUILDING			
	(a) Main & emergency air lock, lobby & stair wells	Detection system for automatic sprinklers & smoke detectors plus heat detector for sprinkler system	Automatic sprinkler system	Manual hose stations
	(b) Primary pump area F/M vault filter, cable trays, cable penetrations	Rate of rise cum fixed temperature type heat detectors	Portable dry chemical system	Manual hose stations
	(c) All other areas	Smoke detectors*	Manual hose stations & portable extinguishers	
2	REACTOR AUXILIARY BUILDING			
	(a) Supplementary control room	Smoke detectors*	Fixed automatic halon system	Manual hose stations

* Smoke detectors mean optical ionisation type detector.

ANNEXURE-II (Contd.)

SL.NO.	AREA	TYPE OF DETECTION SYSTEM	TYPE OF PRIMARY SUPPRESSION SYSTEM	TYPE OF BACK-UP SUPPR-ESSION SYSTEM
	(b) Control equipment room and MCC room	Smoke detectors*	Portable halon extinguishers	Manual hose stations
	(c) All other areas	Smoke detectors*	Manual hose stations/ portable extinguishers	Manual hose
3	TURBINE BUILDING			
	(a) Basement floor	Smoke detectors	Manual hose stations/portable extinguishers	
	(b) Cable vault area of basement	Smoke detectors and continuous line type heat detectors for cable trays	Non-automatic sprinkler system	Manual hose Station
	(c) Ground floor (i) seal oil unit, T.O. purification system and associated facilities	Smoke detectors	Non-automatic sprinkler system foam extinguishers	Manual hose station/ portable

* Smoke detectors mean optical ionisation type detector.

ANNEXURE-II (Contd.)

SL.NO.	AREA	TYPE OF DETECTION SYSTEM	TYPE OF PRIMARY SUPPRESSION SYSTEM	TYPE OF BACK-UP SUPPR-ESSION SYSTEM
3 contd.	(ii) Switch gear room	Smoke detectors	Portable halon extinguishers	
	(iii) T.O tank and main oil tank	Smoke & heat detectors	Outside non-automatic sprinkler, inside automatic CO_2 system	Manual hose stations
	(iv) Other areas	Smoke detectors	Manual hose stations/portable extinguishers	
	(d)Mezzanine floor (i) Switchgear, MCC, transformer rooms	Smoke detectors of ionisation & photoelectric type in combination	Portable halon extinguisher and manual hose station	
	(ii) Seal oil tank	Smoke detectors of ionisation & photo-electric type in combination	Nonautomatic sprinkler system	Manual hose stations/ portable extinguishers

* Smoke detectors mean optical ionisation type detector.

ANNEXURE-II (Contd.)

SL.NO.	AREA	TYPE OF DETECTION SYSTEM	TYPE OF PRIMARY SUPPRESSION SYSTEM	TYPE OF BACK-UP SUPPR-ESSION SYSTEM
3 contd.	(d) (contd.) (iii) Other areas	Smoke detectors	Manual hose stations and portable extinguishers	
	(e) Operating floor (i) Electrical equipment rooms	Smoke detectors of ionisation & photo-electric type	Manual hose stations and portable extinguishers	
	(ii) Other areas	Smoke detectors	Manual hose stations and portable extinguishers	
	(f) Deareator floor	Smoke detectors	Portable extinguishers	
4	SERVICE BUILDING			
	All floors	Smoke detectors	Manual hose stations and portable extinguishers	
5	CONTROL BLDG.			
	(a) Basement floor	Smoke detectors	Manual hose stations and portable extinguishers	

ANNEXURE-II (Contd.)

SL.NO.	AREA	TYPE OF DETECTION SYSTEM	TYPE OF PRIMARY SUPPRESSION SYSTEM	TYPE OF BACK-UP SUPPR-ESSION SYSTEM
	(b) Cable vault	Area smoke detectors of ionisation type or continuous line type heat detectors for cable trays.	Non-automatic sprinkler	Manual hose station
	(c) Switchgear	Smoke detectors of ionisation type and photoelectric type	Manual hose stations and portable extinguishers	
	(d) Main control room, computer room, cable spreader room below computer room	Smoke detectors of ionisation type and photoelectric type	Portable halon extinguishers	Manual hose stations.
	(e) Battery rooms	Smoke detectors	Manual hose stations and portable foam extinguishers	
6	DIESEL GENERATOR BUILDING			
	(a) D.G. rooms	Smoke detectors of ionisation & photo-electric type in combination with heat detectors	Automatic CO_2 system portable foam extinguishers	Manual hosestations and

ANNEXURE-II (Contd.)

SL.NO.	AREA	TYPE OF DETECTION SYSTEM	TYPE OF PRIMARY SUPPRESSION SYSTEM	TYPE OF BACK-UP SUPPR-ESSION SYSTEM
	(b) Diesel oil day tanks (outside D.G. building)	Manual call points	Manual hose stations	Portable foam extinguishers
7	SAFETY RELATED PUMP HOUSE			
	(a) Cable vault	Smoke detectors of ionisation & photo-electric type or continuous line type heat detectors in cable trays	Non-automatic sprinkler system	Manual hosestation
	(b) Other areas	Smoke detectors	Manual hosestations/ portable extinguishers	
8	C.W. pump house	Smoke detectors - ionisation, photo-electric type with heat detectors.	Manual hose stations/portable extinguishers	
9	SAFETY RELATED CABLE TUNNEL	Smoke detectors of ionisation and photo- electric type in cable routings or continuous line type heat detectors in cable trays.	Non-automatic sprinkler system	Manual hosestations.

ANNEXURE-II (Contd.)

SL.NO.	AREA	TYPE OF DETECTION SYSTEM	TYPE OF PRIMARY SUPPRESSION SYSTEM	TYPE OF BACK-UP SUPPR-ESSION SYSTEM
10	OUTDOOR TRANSFOR-MERS Generator, unit & start-up transformers	High. temp. (Quartzoid bulb type) detectors along with heat detectors	Automatic sprinkler system	Manual hose stations
11	GARAGE		Manual hose stations and portable	
12	SWITCHYARD CONTROL ROOM			
	(a) Basement	Smoke detectors ionisation & photo-electric type together with continuous line type detectors for cable trays	Non-automatic sprinkler system	Manual hosestations & portable extinguishers
	(b) Other areas		Manual hose stations and portable extinguishers	
13	MISC. BUILDINGS			
	(a) Filtration & chlorination building, D.M. plant building, administration building, canteen, etc.	Smoke detectors	Manual hose stations/portable extinguishers	

ANNEXURE-III

EXAMPLE OF TYPICAL FIRE RESISTANCE PERIODS OF VARIOUS BUILDINGS

SL.NO.	BUILDING	AREA	FIRE-RESISTANT PERIOD(h)
1.	Control building	Outer wall and adjoining other buildings and roof	4
		Inner walls and floors	3
2	D.G. building	Outer wall joining other buildings and roof	4
		Inner walls and floors	3
3	Turbine building & Electrical Room	Outer wall and adjoining other building and roof	4
		Inner walls and floors	3
4	Reactor Auxiliary Building	Outer wall and adjoining other building and roof	4
		Floors and inner walls	3
		Electrical penetration room walls	3
5	Reactor building	Outer wall and adjoining auxiliary building and roof.	

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

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PROVISIONAL LIST OF SAFETY CODE, GUIDES AND MANUAL ON DESIGN OF PRESSURISED HEAVY WATER REACTOR BASED NUCLEAR POWER PLANTS

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	Environmental Effects and Missile Effects
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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	Hydrogen Release and Mitigation Systems under Accident Conditions in PHWR
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AERB/SG/D-22	Vapour Suppression System
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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