FIRE SAFETY

A MONOGRAPH

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1.0 Introduction

Fire situations pose one of the most serious problems in an industrial establishment with the potential loss of lives & property as well as damage to the environment. Careful pre planning, implementation of well-planned & engineered fire prevention measures and proper response by trained personnel can minimize the risk & damage caused by fire. However, in spite of several advances made in fire detection and fire fighting, fire continues to be highly unpredictable and hence the best course of action is to put the maximum emphasis on fire prevention. The consequences of fire can be more severe in a nuclear installation due to the added risk of release of radioactivity. Hence there is a need for regulating the fire protection system in nuclear facilities and strengthen the fire safety aspects to ensure nuclear and radiological safety.

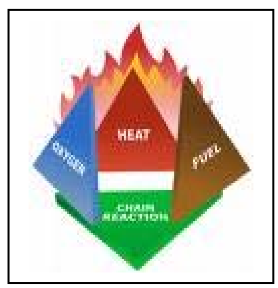
Fire safety aspects of nuclear facilities include fire prevention, detection & protection systems along with other considerations such as personnel safety, environmental safety and property protection. Fire safety system aims to achieve a defence-in-depth concept and provides direction to select the optimum combination of the three levels - prevention, detection & suppression and mitigation to ensure safety.

2.0 Theory of Fire

Fire results due to combustion of combustible materials (fuels) in the presence of air (oxygen). In order that a fire gets started there should initially be sufficient heat to ignite the fuel, and for the fire to sustain, the combustion reaction should produce enough heat to maintain the fuel temperature above its ignition temperature. Fire develops in three stages namely –Incipient stage, Smoldering stage & Flame stage. In a nutshell, for a fire to break out the following three components are essential: Fuel, Oxygen and Heat.

Combustion is an exothermic reaction between a substance and oxygen in which heat is given out in such a manner that, it maintains the temperature of reactants, thus setting up a chain reaction. In case of ignition reaction between a substance and oxygen, it is required to apply heat to maintain the reaction and the reaction stops when applied heat is removed.

The fourth factor, “chain reaction” can be described through use of a fire pyramid or tetrahedron. One face of the pyramid represents Heat, second Fuel and third represents Oxygen. The base is the combustion Chain Reaction. Removal of any face of the fire pyramid will cause the fire to extinguish.



The fire prevention or extinguishing technology is based on the principle involved in the above tetrahedron. If any one component is separated from the others, fire can be extinguished. For example – if there is an oil fire, foam is used as the extinguishing media for the fire, which covers the oil surface and deprives it of oxygen and helps in extinguishing the fire. When water is used as a fire extinguishing media, the purpose is to remove the heat from the fire, which subsequently puts out the fire. Halon alternatives such as FM200, HFC-23 etc act on the free radicals of the combustion process, which subsequently stops the chain reaction and puts out the fire.

3.0 Objectives of Fire Safety

The main objectives of fire safety are

- To minimise both the probability and the consequences of postulated fires.
- To detect and suppress fire with particular emphasis on passive and active fire protection system and adequate capacity for the systems necessary to achieve and maintain safe plant shut down with or without off-site power.
- To ensure that a failure, rupture or an inadvertent operation does not significantly impair the safety capability of the structures, systems and components.
- To address not only the direct effects of flame, radiant heat and explosion but also to the potential for the release of hazardous materials and hazardous combustion products in the event of fire and the potential for the release of water and other fire fighting media contaminated during fire fighting.

To meet these objectives, there are

Passive Fire Safety Systems (PFSS)- The Passive Fire Safety Systems are those systems, where no moving components are involved and which are provided to detect, prevent spread, or suppress fire. The examples are fire barriers, fire seals, fire detectors, fire retardant paint etc.

Active Fire Safety Systems (AFSS) - The Active Fire Safety Systems are those systems where moving components are involved and which are provided to protect against fire. The examples are fire pumps, fire hydrants, sprinklers, extinguishers, etc.

4.0 Defence in Depth Concept

With respect to the fire protection programme in all facilities, the defence-in-depth principle shall be applied to achieve an adequate balance in:

a) Preventing fire from starting,

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

c) Designing plant safety systems, so that a fire that starts in spite of prevention programme shall not prevent essential plant safety functions from being performed.

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 extinguishment of fires by a combination of automatic and/or manual fire fighting techniques and therefore relies upon active fire safety systems. For the implementation of third objective, particular emphasis shall be given to the use of passive fire barriers, which would be the last line of defence, if the first two objectives were not effective.

Nuclear facilities use the concept of defence-in-depth to achieve the required high degree of safety. In case of Nuclear Power Plants (NPPs), the nuclear safety is achieved by performing three essential safety functions namely, safe reactor shutdown, core cooling and confinement. It should be possible to achieve, maintain and monitor these three safety functions in the event of fire anywhere in the nuclear power plant. This can be achieved by building in fail-safe feature, redundancy, independence and physical separation in the design of the equipment, instrumentation and support system provided for carrying out these three safety functions.

5.0 Fire Hazard Analysis

A detailed fire hazard analysis should 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.

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 (b) the effect of postulated fires relative to maintaining the ability to perform safe shutdown functions and minimizing toxic and radioactive releases to the environment and (c) suggest remedial measures.

The fire risk can be quantified for the process industries based on the indices like Dow index (Fire & Explosion Index) and Mond index. The indices are comprehensive and give a realistic value to the risk of individual process unit due to potential fires and explosion. Facilities handling and storing flammable liquids are exposed to a potential fire risk. The fires due to flammable liquid may be a Pool Fire, Jet Fire, Flash Fire or a Boiling Liquid Expanding Vapour Explosion (BLEVE) depending on the containment, type of release and source of ignition. Computer models are available to simulate the fire conditions and estimate the potential consequences.

The fire hazard analysis should separately identify hazards and provide appropriate protection in locations where safety related losses could occur as a result of:

a) Concentrations of combustible materials, including transient fire loads due to combustibles expected to be used in normal operations;
b) Configuration of combustible contents, furnishings, building materials, or combinations thereof conducive to fire spread;
c) Exposure to fire, heat, smoke, steam that may necessitate evacuation from areas that are required to be attended for safety functions;
d) Fire in control rooms or other locations having critical safety related functions;
e) Lack of adequate access or of smoke removal facilities that impede fire extinguishment in safety related areas;
f) Lack of explosion prevention measures;
g) Loss of electric power and
h) Inadvertent operation of fire suppression systems

The possibility of a fire spreading from one unit to the other unit should be taken into account in the fire hazard analysis.i.e. The analysis of consequences of the postulated fire on safety of the plant should be conducted by the persons trained and experienced in the principles of industrial fire prevention & control and in fire phenomena from fire initiation through its propagation into adjoining spaces and it should be done in consultation with the Fire Protection Engineer.

The Fire Hazard Analysis report is reviewed by the regulatory body prior to the commissioning of the facility. Any changes emerged from review are appropriately incorporated by the facility.

6.0 Fire PSA

Deterministic and probabilistic techniques are used to assess a fire hazard. The deterministic fire hazard analysis, typically carried out first, is normally required by licensing authorities and other safety assessors. It is usually developed early in the design of new plants, updated before commissioning, and then periodically or when relevant operational or plant modifications are proposed. Probabilistic safety assessment (PSA) for fire is undertaken globally to supplement the deterministic fire hazard analysis. It should be noted that a fire PSA is recognized as a tool that can provide valuable insights into plant design and operation, including identification of the dominant risk contributors, comparison of the options for risk reduction and consideration of the cost versus risk benefit.

Fire PSA is the probabilistic analysis of fire events and their potential impact on the nuclear safety of a plant. Using probabilistic models, fire PSA takes into account the possibility of fire at specific plant locations; propagation, detection and suppression of the fire; effect of fire on safety related cables and equipment; the possibility of damage to these cables and equipment, and in severe fires the structural integrity of the walls, columns, roof beams, etc.; and assessment of the impact on plant safety. Many elements of a fire PSA are the same as those used in the deterministic fire hazard analysis. It should be noted, however, that the probabilistic approach includes some new aspects of modeling and applies different acceptance criteria for the evaluation of fire safety. The fire risk assessment methods introduce the likelihood of a fire in each plant location, the effect of the fire on equipment and cables, and the impact of equipment failures and human actions coincident with the fire. New elements of the model specific to the risk based approach include factors such as the probability and effect of plant damage beyond individual fire compartment boundaries (as a result of barrier elements being ineffective or inoperable) and random failure of the mitigation systems. The probabilistic criteria used in fire PSA are based on the risk concept. Core damage frequency is a typical criterion used for PSA Level 1 in Nuclear Power Plants. Fire PSA relies on the plant response model developed for the internal initiating events. The availability of a plant model that logically examines the contributions to core damage, plant damage, etc. is a prerequisite for a fire PSA. An internal event PSA Level 1 is highly desirable; however, a partial PSA Level 1 (for selecting the initiating events) or another logic model equivalent to PSA Level 1 may be an adequate substitute. It should be pointed out that expanding an internal events PSA to a fire PSA requires a considerable amount of plant specific data, e.g. the location of cable routes in plant compartments. This information will be readily available if a comprehensive deterministic fire hazard analysis has already been performed for the plant.

In the same way as the deterministic method, the PSA approach is based on systematic examination of all plant locations. To facilitate this examination, the plant is subdivided into distinct fire locations, which are then scrutinized individually. It is essential to demonstrate that significant fire scenarios have not been overlooked. However, a theoretically complete and exhaustive examination would be both impractical, because of the large number of possible scenarios, and unnecessary, because there are many fires that are unlikely to pose any significant risk. Therefore, an effective screening process is essential to limit the level of effort made for the fire PSA. It is advisable to perform the screening process in stages, starting with relatively simple, conservative models and progressing to more realistic representation of the fire scenarios at subsequent stages. Application of complex models that involve detailed investigation of the evolution of the fire and its impact on safety equipment, as well as the effect of the fire mitigation features, is limited to a relatively small number of fire scenarios, therefore the overall analytical effort is reduced substantially. This part of the PSA relies on physical fire growth models that are similar to those used in the deterministic fire hazard analysis. Compared with the deterministic approach, the PSA model introduces some new elements that involve statistical data and as a result, further contributors to uncertainty in the final evaluation of fire safety are added. This aspect should be taken into account when applying PSA techniques to fires in nuclear facilities. In this case, sensitivity and uncertainty analyses are essential if interpretation of the results is to be correct. It should be emphasized that the main advantages of a PSA are that it can identify a number of uncertainties, quantify and describe most of them.

Further details on Fire PSA can be obtained from the document **"TREATMENT OF INTERNAL FIRES IN PROBABILISTIC SAFETY ASSESSMENT FOR NUCLEAR POWER PLANTS"**, Safety Report Series-10 by IAEA.

7.0 Design Requirements for Fire Safety

Design requirements to minimise the potential for fire shall be specified in the early stage of design. The concept of defence-in-depth against fire and its consequences as it applies to fire prevention requires:

a) Limiting the inventory 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 functions for either of the divisions.

d) Establishing administrative procedures to control hazardous operations and introduction of combustible material.

While designing a nuclear facility the emphasis should be given in the following:

a) Building design-The plant shall be divided into several individual fire areas to reduce the risk of spread of fire and consequent damage and to prevent common mode failures of redundant safety related systems. All the buildings and working areas (each floor) of the facility shall be provided with adequate numbers of fire escape stairs / exits. Floors, walls, and ceilings separating fire areas shall have adequate fire rating. As far as practicable, use of non-combustible materials shall be specified 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 resistant coatings. The amount of combustible materials stored indoors and normally exposed to the danger of fire should be kept to the minimum, consistent with the 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. Safety-related systems should be isolated or separated from combustible materials. When this is not possible because of the nature of the safety system or the combustible material, automatic fire suppression should be provided to limit the consequences of a fire. Building design should conform to National Building Code of India, 2005.

b) Ventilation: Products of combustion from all postulated fires shall be controlled and removed to reduce the extent of fire damage and hazards to personnel. Where an area is vented into another area (e.g. from a low radioactive contamination area to a higher radioactive contamination area), the ventilation control cannot be determined on fire protection reasons alone, the consequence of heat and smoke spread shall be assessed. Wherever necessary, manual/remote controlled fire dampers shall be provided in exhaust openings of the upstream room. Means shall be provided to minimise the spread of fire, heat or smoke between the fire areas. Ventilation system of battery room shall be designed to keep the hydrogen concentration below 1% by volume and loss of ventilation should be alarmed to the control room. Each area exhaust and supply duct should have pneumatically operated or fusible link type dampers to localize the effect of fire and prevent the spread of smoke.

c) Electric Circuits & Equipment: In closed ventilated areas, where smoke/heat venting is not possible, for power cables and control cables, halogen-free, fire-retardant, low smoke (FRLS) materials shall be used for sheathing. Fire survival cables having copper conductors with special insulating materials are capable of maintaining circuit integrity for extended periods under fire conditions and meets the special Fire Survival Test as per IEC 331. These cables can safely be used in essential circuits, which serve plant safety functions. Placement of power & control cables on the cable racks should be such that high voltage cables are on the top rack and low voltage cables are on the bottom rack as per AERB Fire Standard. Cable routing should be so chosen to avoid passing close to equipment such as steam pipe lines, oil pipe lines, resistor grids and process equipment which 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 spillages.

d) Transformers: All transformers shall meet the requirements of “The Indian Electricity Rules, 1956 as amended on November 16, 2000 and “The Atomic Energy (Factories) Rules 1996”. Transformers installed inside fire areas containing systems important to safety should be of the dry type or insulated and cooled with noncombustible liquid. Transformers filled with combustible fluid that are located indoors should be enclosed in a transformer vault. Outdoor oil-filled transformers should have oil spill confinement features or drainage away from the buildings and have a fire rating of at least 3 hours. The transformers shall be protected by an automatic high velocity water spray system or by carbon dioxide or Halon alternatives fixed installation system or Nitrogen injection and drain method.

e) Cable Trenches: All cable outlet points in the trench shall be insulated / sealed with fire resistant materials / fiber wools or light PCC to prevent spreading of fire. Fire barriers shall be provided in cable trenches at periodical intervals.

f) Fire detection and alarm system: 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. For fire detection systems, this reliability may be affected by the reduction in sensitivity or of sensing devices leading to non- detection or late detection of a fire, or the spurious operation of an alarm system when no smoke or fire hazard exists. The detection system shall annunciate by audible and visual alarms in the control room and in-house fire station. Fire alarms shall be distinctive and shall not be capable or being confused with any other plant alarm. Reliable & uninterrupted power supply shall be ensured for the fire detection and alarm system. To take care of failure of main supply, emergency power from diesel generating set and back-up supply from battery system shall be provided.

The selection of detectors shall be based on the nature of products released by the heating up, carbonization, or the initial bursting into flame of the materials present in the fire hazard area. The appropriateness of the detection system shall be confirmed by Fire Hazard Analysis (FHA). Selection of fire-detection equipment shall take into account 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. Where spurious operation is detrimental to the plant, activation shall be by two lines of protection system. Provision for manually activated fire alarms shall also be made.

g) Fire Water Systems: In selecting the type of suppression system to be installed, consideration shall be given to speed of operation, the type of combustible material present as indicated in the fire hazard analysis, possibility of thermal shock, its effect on human beings (e.g. asphyxiation) and on items important to safety (e.g. reaching criticality condition during water or foam flooding in the nuclear fuel storage area). Reliable power supply should be ensured for electrically operated control valves meant for automatic suppression systems.

Fire suppression systems, which employ water as means for suppression of fire, could be principally categorized under fixed water extinguishing systems as follows:

a) Sprinkler and other water spray systems

b) Fire hydrant or standpipe and hose systems

Sprinkler and other water spray systems: Complete automatically initiated water sprinkler protection should be provided as a conservative measure in all those locations of the plant or facility where significant amounts of combustible material might be present, which would result in unacceptable fire damage in the event of an uncontrolled fire. Such a design measure may also take into account aspects other than safety (for example), 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. Sprinkler/spray extinguishing systems shall, as a minimum, conform to requirements of appropriate standards.

Fire Hydrant or Standpipe and 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 the 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" or IS: 5714-1970 "Hydrant Standpipe for fire fighting" for sizing, spacing and pipe support requirements.

8.0 Fire prevention & control

Fire prevention activities can be categorized as Engineering, Training & Enforcement functions.

Engineering refers to the careful planning of the fire safe buildings & processes. It also includes the proper interpretation of relevant fire codes & control of process hazards through design & installation of fire detection & protection systems. Engineering plays an important role in fire prevention programme. Without proper engineering, the best training & enforcement programs cannot prevent fires. It includes proper building design & construction, hazard identification & analysis and installation of suitable fire detection & prevention systems in the plant.

Training/education plays an important role in prevention of fire. Proper training in regular intervals should be imparted on all employees to increase fire consciousness among employees and to eliminate fire hazards in workplace. The training also includes basic as well as advanced fire fighting procedures.

Enforcement is the third important element of the fire prevention programme. It deals with the activities of inspecting plants to ensure compliance with the relevant fire protection standards. Carefully planned inspection by a well-trained & experienced inspection team can prevent many serious fires. Through inspection, many hazardous conditions are discovered and effective control measures are taken before a fire occurs. Inspections can be periodic, intermittent and continuous. Periodic inspections are general in nature and cover all facilities & equipment as per standard format. Regulatory bodies, insurance companies normally carry out intermittent inspections to check compliance as per codes. The plant management itself carries out continuous inspection to check the healthiness of the fire detection & protection system.

9.0 Fire Detection

Detection of fire at an early stage can prevent a catastrophic fire as necessary automatic /manual fire extinguishing action can be initiated without delay. A fire generally develops in three stages namely – incipient, smoldering and flame stage. Fire detectors are also designed to detect all the three stages of a full-grown fire. These fire detectors along with additional systems can perform a number of functions such as actuation of fire doors, smoke dampers, and shut down of power-operated equipments and of course annunciation and activation of fire suppression system. Fire detectors are mainly classified based on

i) Principle of fire detection (smoke/flame/heat)
ii) Area of coverage (spot / line type).

a) Smoke Detectors:
These detectors detect fire, based on the products of combustion. Smoke detectors are further classified into

i) Ionization Detector – This type of detector consists of one or more chambers, which has a radioactive element (Am-241- Alpha source) to ionize the air inside the chamber. The two charged electrodes inside the chamber conduct a current due to ionisation of air. The detector operates when smoke enters into the chamber and reduces the conductivity of the air inside below a pre-defined level, which in turn reduces the current between the electrodes.

ii) Photoelectric Detector – This type of detector employs the light scattering principle of smoke for detection. A light source (pulsed IR LED) and a light sensor (Photo diode) are arranged in a chamber in such a way that major portion of the light does not fall on the sensor. When smoke particles enter the light path inside the chamber, the light is scattered and this scattered light falls on the sensor which converts it into a signal for further action.

iii) Beam type Detector – This type of detector operates on the principle of obstruction of light. A light transmitter transmits a pulsed beam of IR light, which is being received by the receiver. When the received beam intensity goes below the preset level due to smoke particles, the detector issues a signal for further action.

b) Flame Detectors:
This kind of detectors work on the detection of radiant energy of the flame at different wavelengths. Basic types are Infra Red & Ultra Violet type. IR radiation is produced in all flames during burning of carbonaceous materials such as alcohol, mineral insulated oil, petrol, diesel etc. UV radiation is emitted where hydrogen and certain materials involving sulphur are burnt. IR type flame detectors have an infrared cell (PbS cell) as sensor and UV type flame detectors have a vacuum photo diode GM tube as a sensor.

c) Heat Detectors:

i) Fixed Temperature Detector – This type of detector initiates a signal when the air surrounding it goes above a preset temperature. The sensor is usually a bi-metallic strip that closes a contact or a thermistor (whose resistance decreases with temperature) along with associated circuitry.

ii) Rate of Rise Temperature Detector – This type of detector operates when the rate of rise of temperature of the air surrounding the detector exceeds the preset rate of rise. This is normally an electronic type of detector, which has two sensing elements (thermistors) .One element is exposed to the surrounding while the other is insulated from the surrounding. Both sensor data are compared and checked with preset rate of rise for signal actuation.

iii) Linear Heat Sensing (LHS) Cables – These are unique heat sensing cables made of polymer insulating material having a negative temperature coefficient of electrical resistance. These cables and associated systems can detect heat anywhere along the length of the cable. They are of two types - a) analog and b) digital. Temperature change anywhere along the zoned length of the sensor cable produces a corresponding change in the resistance of the insulating material used in the cable. In analog type LHS cables, this data is being used by the associated system for generation of alarm. In digital LHS cables, the temperature change causes an insulation break down (short-circuit) which is used by the associated system for generation of alarm. Analog LHS cables are self-restoring type if not subjected to a temperature of more than 250^0 C. Digital LHS cables are not self-restoring type. Portions affected are to be cut and replaced by new one.

iv) Quartzoid Bulb: This is the most common type of heat-sensing device used in water sprinkler systems. This is basically a quartz bulb that contains a special volatile liquid. The volumetric expansion of the liquid breaks the bulb when its temperature increases beyond a certain temperature. This phenomenon is used for further generation of fire alarm/actuation of fire suppression system.

10.0 Fire Protection

Fire protection system for each area of the facility should be designed as per the fire hazard analysis. It also should take into account of the speed of operation of the system & safety of important items. Fire protection system can be classified into three categories – water system, gaseous system & portable fire extinguishers.

a) Water system

Fire suppression system that uses water as the extinguishing medium are of three types – water sprinkler system, water mist system & fire hydrant system.

i) Water sprinkler system – Fully automatic low-pressure water sprinkler system should be installed in areas where substantial amount of combustible material might be present. Generally water sprinkler system is preferred in areas of high fire load such as electrical cable gallery. It is also used to protect large oil filled transformers. Water sprinkler system should be designed as per appropriate standards.

ii) Water mist system – Water mist system converts water in to fine mist at a pressure of around 80 to 200 bars. The US National Fire Protection Agency (NFPA) 750 standard defines water mist or water spray in which 99% of the water is in droplets whose diameter is less than 1000µm. As a result of water being atomized into such fine droplets at high pressure, the surface area available for cooling is considerably greater than that of conventional low-pressure sprinkler system. The strong cooling effects serve not only to fight fire but protecting lives and property against effects of radiated heat. Water mist is generally applied to a fire in one of three ways: local application, total compartment application, and zoned application. Water mist systems are recognised as a viable alternative for fire and explosion protection in marine applications & offshore applications where halon 1301 fire suppression system were being used.

iii) Fire hydrant system – Standpipes with hose connections equipped with fire hose & nozzles should be installed in conspicuous locations in the plant area as per fire hazard analysis requirements to suppress fire. The fire hydrant system should conform to relevant standards.

b) Fixed Foam System

Fixed foam systems are automatic, totally self-contained and require no manual intervention for operation. These systems are installed to protect areas where large quantity of flammable lquid is stored. Fixed foam systems are classified into three categories namely – low expansion, medium expansion and high expansion. Fixed foam system application can be in the form of sub surface injection, surface application, seal protection for floating tank roofs or dyke protection. Low expansion fixed foam system with sub surface injection; surface application or seal protection is normally used to protect large storage tanks of flammable liquids. Low expansion fixed foam system for dyke protection is used for protection of tank farm area with dyke which stores a number of vertical as well as horizontal flammable liquid storage tanks. Low expansion foam system is suitable for oil pool fires where a thin layer of foam on the oil surface can quench the fire by depriving it of oxygen (smothering effect). High expansion foam systems operate on the principle of mechanical expansion of the foam by air and water. These systems are suitable for fighting three dimensional fires such as a fire in LNG pump where total flooding up to the elevation of the object under fire is necessary which quenches the fire by smothering, cooling, insulation & penetration.

c) Gaseous system

Fire suppression system that uses gas as the extinguishing medium is of two types – Carbon dioxide & halon. The halons are used as fire extinguishing agents, both in built-in systems and in handheld portable fire extinguishers, but they pose a threat to the environment because of presence of chlorine & bromine. Bromine is many times more effective at destroying ozone than chlorine. They also have a long atmospheric life. Recent scientific studies indicate that the ozone depleting potential (ODP) of halon 1301 and halon 1211 are at least 12 and 6 respectively (The ODP is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of CFC-11. Thus, the ODP of CFC-11 is defined to be 1.0). Their release to atmosphere during manufacture, decanting to application cylinders and use or misuse in service has contributed to the depletion of the ozone layer. Because of detrimental effects on environment, halons are being phased out as fire extinguishers. However, halon alternatives such as FM200, HFC-23, which are safe and have zero ozone depleting potential (ODP) can be used as fire extinguishing media.

Carbon dioxide (CO_2) system

Carbon dioxide systems are normally used to suppress fires of electrical systems. Since the gas concentration greater than 5 % is a hazard (asphyxiation) to working personnel, due care should be taken in designing the system. The system should conform to relevant standards. This system should only be used in areas where required CO_2 concentration can be maintained to extinguish fire. In automatic carbon dioxide systems, there should be pre discharge alarm & discharge delay to permit personnel evacuation.

d) Portable Fire Extinguisher

Portable as well as trolley mounted fire extinguishers for different class of fire should be kept at various locations. As per AERB Fire Standard (AERB/IRSD-I), fire has been classified into four categories, namely – Class A, Class –B, Class-C and Class-D.Water is used as the extinguishing medium and is applicable to all fires (Class-A) involving ordinary combustibles such as wood, paper, cloth, rubber and the like. Foam, Dry Chemical Powder (DCP) are used as extinguishing medium for fires (Class - B) involving flammable liquids, paints, solvents and the like. CO_2 and DCP are used as extinguishing medium for fires (Class - C) involving fire in gases including liquefied gases. Special type of dry chemical power such as Ternary Eutectic Chloride (TEC) / Graphite based/ Bi-carbonate based powders should be used as extinguishing medium for fires (Class – D) involving fires in metals. It is worthwhile to note that where energized electrical equipment is involved in fire, the non-conductivity of the extinguishing media is of utmost importance and only CO_2 and DCP should be used. Once the electrical equipment is de energized, extinguishers suitable for Class- A, B or C may be used safely. The extinguishers should be kept as near as possible to the fire exits and stair case landing in addition to the places where there could be a fire hazard to safety related equipment.

11.0 Fire Programme implementation

The planning for fire protection programme shall normally start at the plant design stage itself and be carried through construction, commissioning, operation & decommissioning phases. During the implementation stages, adequate emphasis be laid on the quality assurance of the fire prevention, detection and suppression systems being installed, to ensure that the programme's objectives are fully and satisfactorily met. In the case of nuclear power plants, the applicable fire protection system shall be fully operational before the initial fuel loading in the reactor unit.

Likewise, in the case of nuclear installations other than reactors, the applicable fire protection system shall be fully operational before the facility is commissioned.

However, during construction and pre-commissioning stages, when supplies of hazardous materials arrive at plant site, adequate interim arrangement for fire protection should be provided for the same.

At sites, where operating nuclear installations exist and fresh construction work is undertaken in close proximity, means shall be provided to protect the operating unit/installation against fire hazards at the unit/installation under construction/ commissioning.

12.0 Quality and Reliability in Fire Safety

Quality Assurance Programme (QAP) shall be in effect for fire prevention and protection elements of the plant from the inception of design, through construction of the plant and during its operating life and decommissioning. The fire protection quality programme shall include the following:

a) Organizational aspect in the QAP,

b) Manuals / documents highlighting the requirements of fire prevention and protection aspects, design control, regulatory requirements and design basis which are translated into specifications, drawings, procedures etc.

c) Records of inspections, tests, administrative controls, fire drills and training

d) Measures to be taken to ensure that purchased material, equipment and services conform to the documents

e) The program for independent inspection of activities effecting fire protection

f) Procedures for handling and storage of all equipment

g) Test programme developed and implementation for meeting the design intentions

h) Measures to be taken for the identification of items that have passed required tests

i) Measures to be taken for controlling items that do not conform to specified requirements

j) Corrective measures to be taken to ensure that conditions adverse to fire protection

k) Periodic audit to be carried out with observation checklist and its review arrangement.

To achieve high reliability, the fire protection system shall utilise a system approach through an inherent fire safe design to minimise fire hazards and the effects of a fire and include fire prevention programme, detection and rapid extinguishment of fire to limit the damage. An optimum combination of these three aspects should be selected to obtain a reliable fire protection system. Fixed fire protection systems (automatically or manually initiated) are considered the “primary” means of fire suppression for areas in which they are installed. In these areas the standpipe and hose fire protection system is considered a “back-up” system. In this context any single impairment of the fire protection system or direct support systems shall not incapacitate both the primary and back-up fire protection capability.

Fire protection systems shall be designed to assure that an initiating failure such as break in fire protection lines or a single inadvertent actuation of the fire protection system can not a) Damage the safety related system of plant. b) Prevent the habitability of the main control room or other areas requiring access for safe plant shut down.

13.0 Administrative Control

Appropriate housekeeping requirements shall be specified in plant administrative procedures. As a minimum, these shall include storage of combustible materials in specifically designated areas, checking for obstruction of access to fire hazard areas and fire protection equipment, cleaning of floor drains and sumps, and delegation of responsibility for inspections. Work having potential for causing fire, particularly work involving the use of open flames, welding, cutting requires additional caution and shall be carried out subject to a written authorization and under controlled conditions. Proper administrative controls in the form of written orders shall be in force for control of combustible materials, prevention of smoking and good housekeeping. Fire Alarm system should only be disarmed under a work permit system during maintenance activities.

14.0 Personal Support Systems

a) 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.

b) Communication: Requirements for the reporting of fires and the communication during fire fighting shall be provided in the design of the plant communication system. Adequate number of telephones (land and mobile), hotlines, sirens, hooters walkie-talkie sets, Public Address system equipment, etc should be maintained. Emergency communication equipment shall be readily accessible and shall be located in the normal path of access to critical areas.

15.0 Fire Safety Regulations

The fire safety in DAE units is assessed, reviewed and regulated by various committees of Atomic Energy Regulatory Board (AERB). It has taken initiative to improve the safety culture at the plant through regulatory inspection, plant status review, promotional activities etc.

a) Document Submission

When a new nuclear facility is proposed, during design stage itself fire rating of the buildings is decided based on the fire load of the buildings and the regulatory criteria as specified for the specific facilities. Detailed Fire Hazard Analysis (FHA) report is required to be submitted for review. Three-tier committee at AERB reviews fire aspects of nuclear facilities during consenting process of any new project/ modification of existing facilities. FHA document submission is a mandatory requirement prior to commissioning stage clearance for all nuclear facilities. The requirements of fire safety for nuclear facilities are given in AERB Fire Standard (AERB/S/IRSD-I) and for design of fire protection of PHWR based Nuclear Power Plants, AERB Safety Guide (AERB/SG-D4) shall be referred.

b) Testing and Surveillance

i) Pre-operational Testing: All fire protection related systems shall be tested at preoperational stage in accordance with the documented procedures to verify that the design performance requirements are met. Procedures shall be prepared for each preoperational test. These test procedures shall as a minimum, specify appropriate test objectives, prerequisites, initial system and environmental conditions, acceptance criteria, data to be collected, special precautions, step-by-step instructions, and documentation requirements. At the completion of each test, the results shall be evaluated against the documented acceptance criteria. Any deficiencies or exceptions to the procedures requirements shall be documented and evaluated to determine the effect upon the test and to make appropriate corrective action including system retest, if required.

ii) Periodic Inspection, Testing and Maintenance: In order to ensure that all fire protection related systems and components function properly and meet design requirements, a formal inspection, testing and maintenance programme and written procedures, that specify the necessary inspection, testing, and maintenance requirements shall be established and documented. Plant administrative procedures shall appoint an officer to be responsible for overall coordination of equipment testing and maintenance. A table on frequency schedule of Fire Equipment Inspection, Testing and Maintenance is available in AERB Fire Standard.

Approval for testing any fire protection related system should be obtained from appropriate plant authorities in accordance with specified administrative procedures. If test procedures require the deactivation of a system, the procedure shall also require a safety permit and thorough check prior to the system being returned to its normal operating condition. A record shall be maintained of all tests including date, any abnormalities or failures, and corrective actions taken.

iii) Control of Cutting, Welding and Open-Flame Work: Work involving ignition sources such as welding and flame cutting shall require special attention and these operations are to be done under closely monitored conditions. When required, a person from the fire-fighting organisation should directly monitor the work and function as a fire observer. Prior to the issuance of the work permit, a responsible person shall physically survey the area where the work is to be performed and establish the necessary safeguards.

16.0 Periodic Review

a) Regulatory Inspection: Regulatory Inspections are generally carried out in all operating nuclear facilities twice in a year by AERB to check the compliance of regulatory requirements as specified in AERB Fire Standard and Safety Guide. Fire organization manpower requirements, periodical testing and surveillance records of all active and passive fire systems are checked during Regulatory Inspections. Also in project stage, this periodic review is carried out prior to all stage clearances and sometimes periodic review frequency is increased, if necessary. Performance of fire equipment like Fire Tender, Trailer pump etc. are also checked during regulatory inspections. The recommendations given at every stage, and previous inspections are being followed up.

b) Fire Safety Review: Apart from regulatory inspection, the periodic review on testing and surveillance of all active & passive fire systems shall be carried out by the concerned nuclear facilities. A unit safety committee constituted by AERB also periodically reviews the fire safety performance of the unit. There is also a centralised Apex Safety Committee called Safety Review Committee for Operating Plants (SARCOP), which reviews the fire safety systems. An Advisory Committee on Industrial and Fire Safety (ACIFS) is constituted by Chairman, AERB. The committee advises on generic fire safety issues and provides guidance on the overall planning for fire prevention, detection and protection at all DAE installations.

17.0 Personnel Training, Fire Brigades & Standing Fire Order

a) Personnel Training: Each & every plant must be self sufficient in fire fighting activities to protect its vital areas. Therefore plant personnel must be provided with adequate training on fire fighting practices. The plant must develop & document a comprehensive fire protection-training programme, which include

a) A basic course on fire fighting & fire prevention for all plant personnel.
b) A comprehensive course on fire fighting for fire brigade.
c) Refresher training for all plant personnel.
d) A course on radiological aspects/hazards specific to the plant and plant layout for the fire brigade.
e) Fire drills

Fire fighting & fire prevention training must be a part of the induction programme of the new recruits to the plant. Addition of different training modules & continuous improvement to the existing modules in the programme should be carried out to keep the plant personnel updated.

b) Fire Brigade: The organization of the fire brigades shall be as per AERB Fire Standard or as directed by AERB.

Fire Stations are brought under various classifications based on fire hazard potential, area of coverage besides functional requirement like operation of fire station and training/fire drills. Other duties, such as statutory requirements of maintenance of equipment, are sometimes outsourced.

There are three types of Fire Crew available in nuclear facilities depending on type of hazard involved in the plant: Class – I, Class – II, Class – III.

Class – I is two-crew station, i.e. a station with staff strength for two turnouts on round-the-clock operation.

Class – II is a single crew station, i.e. a station that has staff strength for a single turn out for round the clock operation.

Class – III is nominal arrangement with skeleton staff strength with at least one fireman for round the clock operation and other fire squad members.

A crew may consist of one Sub-Officer, one Lead Fire man, one Driver-cum-Operator and four Fireman who will approach the fire spot with fire tender and other auxiliaries as required.

c) Standing Fire Order: A Standing Fire Order shall be established and documented for both plant and fire brigade personnel. It shall outline the communication/ responsibilities /responses of the various agencies like the plant operating personnel, plant health physicists, plant management, attending medical professionals, fire brigade personnel etc. It shall outline the specific hazards of the plant and the type and locations of the fire suppression equipment/system provided. It shall specify the emergency equipment to be maintained at the plant and the procedures to assign responsibility for inventory, inspection and replacements of the same. The Standing Fire Order shall also have procedures for assessing the effectiveness of the periodic drills.

18.0 Fire Emergencies Preparedness & Mitigation

Fire prevention is always better than fire suppression & mitigation. However, the plant should be ready enough to handle the uneventful situation of a fire at any point of time. This is achieved by proper training to the plant personnel and an efficient emergency preparedness plan. A set of well-defined & documented step-by-step procedures, responsibilities of the plant personnel during emergency & communication system & mitigation measures for emergency form the emergency preparedness plan. This plan clearly spells out the types of emergency a plant can see & its mitigation procedures that help the plant personnel to take efficient & effective decisions during real emergency situation like fire.

The limits for the critical heat flux for emergency planning & preparedness to ensure personal safety is given in the table below:

Target	Thermal radiation limit (kW/m2)
Drenched storage tanks	38
Special buildings (no windows& fire proof doors)	25
Normal building	14
Vegetation	12
Escape routes (up to 30 sec)	6
Personnel emergencies (up to 30 min)	3
Plastic cables	2
Stationary personnel	1.5

19.0 Personal Safety

In today's high rise buildings, fire can be deadlier and more life threatening than in smaller buildings. Of late, personal protection has become a challenging and an essential exercise. The individual should assume the responsibility of protecting himself by understanding the basic characteristics of fire. The spread of fire should not be under estimated. It should be known that, there is no time to gather valuables or make a phone call. In two minutes, a fire can become a life threatening and in five minutes, a residence can be engulfed into flames.

Heat and smoke can be more dangerous than the flames. Inhaling the super-hot air can sear your lungs. Remember, fire also produces poisonous gases that make you disoriented and drowsy. Asphyxiation is the leading cause of fire deaths, exceeding burns by a three-to-one ratio.

The effect of fire due to radiant heat flux with respect to time of exposure on human beings is given in the table below.

Radiant Flux (kW/m2)	**Time to pain threshold (sec)**
1.74	60
2.33	40
2.9	30
4.73	16
6.94	9
9.46	6
11.67	4
19.87	2

The need of the routes and means of escape is the essence governing personal safety. Buildings (Residential/Commercial/Industrial) should be built in accordance with the National Building Code of India 2005, Part-4 as far as fire safety is concerned.

20.0 Typical Fires at Nuclear Facilities & Lessons Learnt

Whether it is a forest fire, kitchen fire or a factory explosion, when fire gets out of control, the damage can be devastating. Fires in industries especially in nuclear facilities have always a concern for every one as spread of radioactive material is involved. All nuclear facilities are designed with utmost care to prevent occurrence of a fire, but there were certain cases of fire in the past that has changed the perception of fire safety in nuclear facilities. Each & every incident had resulted in some valuable lessons to be learnt. These have led to continual improvement in the system design as well as fire protection design.

i) Browns Ferry, USA (March 22, 1975)

At noon on March 22, 1975, both Units 1 and 2 at the Brown's Ferry plant in Alabama were operating at full power, delivering 2200 megawatts of electricity to the Tennessee Valley Authority.

Just below the plant's control room, two electricians were trying to seal air leaks in the cable spreading room, where the electrical cables are separated and routed through different tunnels to the reactor buildings. They were using strips of spongy foam rubber to seal the leaks. They were also using candle flame to determine whether or not the leaks had been successfully plugged -- by observing how the flame was affected by escaping air.

The Technician put the candle too close to the foam rubber, and it burst into flame and the fire slowly propagated through the burning of the cable insulation and spread into the reactor building.

The resulting fire, which disabled a large number of engineered safety systems at the plant, including the entire emergency core cooling system (ECCS) of Unit -1, and had a potential to result in a core meltdown accident, demonstrates the vulnerability of nuclear plants to fire.

The fire was finally put out at around 6:00pm on the same day.

Lessons learnt

- The original plant design did not adequately evaluate the fire hazards of grouped electrical cables in trays, grouped cable trays and materials of construction (wall sealants).
- It is obvious that vital electrical circuitry controlling critical safe shutdown functions and control of more than one production unit were located in an area where normal and redundant controls were susceptible to a single localized accident.
- Procedure for leak testing was hazardous.
- Fire fighting procedures, fire-reporting procedures were not clear to the persons working.
- Emergency plan to provide simultaneous fire fighting and other activities was not available.

ii) Rajasthan Atomic Power Station –2 (July 25,1985)

The 200Mwe unit was operating at rated power when one Primary Coolant Pump (PCP) tripped on Instantaneous Over current. This was followed by a Reactor trip. An attempt was made to restart the pump but the pump did not start. Afterwards, three more PCPs tripped. Fire broke out in the boiler room of reactor building. Fast cool down of the reactor was initiated. Due to thick smoke inside the boiler room in reactor building, entry without BA set was not possible. Even after entry, locating the fire source was not possible due to dense smoke inside the reactor building. It took some hours before the smoke could be cleared.

The cause of fire was due to over heating of a straight-through cable joint in the 3.3KV power cable to the PCP. The attempt to restart the pump after an over current trip had pumped in a lot of energy to the joint to increase its temperature further resulting in the initiation of fire and the ventilation air flow across the cable path aided the growth of fire.

Lessons learnt & actions taken

- Cable joints of any type are not permitted in HT (>3 Kv) power cables.
- Fire retardant coating on cables, fire stops and fire barriers were installed after modification.
- Control & power cables were separately routed.
- All power cable trays to run above the control cable trays to prevent propagation of fire on power cables to control cables.
- Boiler room fans were interlocked to trip on smoke detector signal.

iii) Heavy Water Plant, Talcher (April 29,1986)

On April 29,1986 at 2000 hrs, there was a fire in the second stage enrichment synthesis gas boosting compressor due to leakage of synthesis gas (N_2+$3H_2$) from the suction side. The plant was in operation at that time. Control room was partially damaged along with equipment, power and control cables in the field.

Lessons learnt & actions taken

- Remote isolation system / devices for isolation of units of high inventory synthesis gas was felt necessary for immediate isolation of fuel source. The same was provided later.
- Redundant scram switch was provided in the main gate.
- Control room was very near to field equipment and hence a firewall was provided between plant and control room.

iv) Narora Atomic Power Station-1 (March 31,1993)

On March 31, 1993, a large fire broke out in the Turbine hall of NAPS-1, a 220MWe unit which resulted in a complete loss of power supply including class – II and class- I supply to the unit after 8 minutes of the fire. Such situation could be considered beyond station black-out (SBO) condition. The fire was confined to the Turbine building only.

The reactor was immediately tripped and could be maintained in a safe shutdown state. Crash cool down of the primary heat transport system was done and subsequently fire-fighting water was injected to the steam generator for maintaining the thermo-siphon cooling of the core.

Failure of turbine blades in the 5^{th} stage flow path –2 of LP stage was the initiating event. This led to severe imbalance in the turbine and excessive vibrations, which resulted in failure of hydrogen seal, and subsequently escaping hydrogen got ignited resulting in a large fire. This fire was aided by leaking seal oil and spread to control & power cables in the turbine building. Subsequently there was complete loss of power, which was almost for 17 hours.

Lessons learnt & action taken

- Design changes were made to the LP stage blades of turbine and surveillance procedures were modified.
- Passive fire protection systems such as fire retardant paint, fire stops and barriers were augmented.
- Control room ventilation system modified to avoid ingress of smoke.
- Certain emergency valves needed to be relocated for easier access.
- Physical separation of cables for redundant safety system trains was ensured through modified layout.

iv) Heavy Water Plant, Kota (March 14,1998)

On March 14,1998, at 1119 hours, a grass fire, which had started outside the main guard house at around 1119 hours, got escalated due to high wind velocity and spread to the sour oil (oil contaminated with H_2S) drums stored at the site. RAPS-1&2 and RAPS-3&4 fire tenders were also called along with HWP fire tender at around 1300 hours and the fire could be extinguished only at around 1630 hours. 789 drums containing 157800 litres of sour oil had caught fire out of a total of about 1500 drums, which were lying in the area. No personal injury had occurred during the incident.

Lessons learnt & actions taken

- Administrative control procedure for storage of used sour oil drums was not in place.
- The oil storage area did not have any approach road for a Fire Tender.
- No fire hydrants were available near the oil storage area.
- Oil storage area was used to dump combustible scrap such as cotton waste, grease/oil soaked waste, scrap wood etc.
- Fire potential of the storage was not assessed properly.
- Communication facility was not available with the fire fighting crew to contact fire station control room.
- Post fire surveillance was not proper which resulted in restart of fire.
- New Fire hydrant line installed outside the plant main gate.
- Sour oil treatment plant installed at HWP, Manguru for oil reprocessing.

v) Kakrapar Atomic Power Station-2 (October 18,2004)

On October 18, 2004, at 0139 hours "FAS Alarm in Operating Island" appeared in control room while Unit –2 was operating at 175MWe. Oil fumes/smoke was observed near Primary Coolant Pump (PCP)-3 area in pump room through CCTV camera survey. "On power" entry was made into the pump room with fire crew and it was observed that continuous oil fumes/smoke was coming from the bowl insulation of PCP-3.

Reactor was shut down by actuating primary shut down system at 0206 hours. CO_2 and DCP extinguishers were used to quench the oil fumes/smoke.

Hot oil seepage to the insulation of the PCP – 3 casing was the cause of generation of oil fumes/smoke.

Lessons learnt & actions taken

- All oil Leakages should be attended immediately.
- PCP-3 thrust bearing overhauling was carried out. Special Sealant was used to arrest minor leaks.
- PCP-3 & 4 breather height increased.
- OSU –3 & 4 oil line U-loop was replaced with a straight spool piece and chilled water-cooling jacket was provided on the straight spool piece.
- Higher capacity AHU installed in 107 MEL of reactor building to reduce room temperature.

21.0 Conclusions

The monograph on fire safety is an attempt to highlight the importance of fire safety in all nuclear facilities. The consequences of fire are colossal. It is not a subject concerning only the occupier and / or regulator but to all individuals because their interests are also involved. The means to enhance fire safety measures, are enumerated below:

a) Cognizance of Fire risk - The fire risk should never be ignored or overlooked or underestimated in industries, in residential buildings or in public places**.** As most fires start directly or indirectly by human errors, it calls for utmost caution on the part of all individuals.

b) Prevention of Fire – Efforts should be put to prevent initiation of fire through preventive measures. The preventive measures can be best engineering practices, administrative procedures, regulatory requirements, etc.

c) Prompt detection – Early detection helps a lot in mitigating losses/damages to personnel and property. Reliable devices, detectors and alarm systems should be provided. These should be regularly tested and maintained.

d) Human actions/Rescue –Approved and time-tested procedures should be available to guide the human actions. The escape routes /emergency exits should be available in poised state and all the occupants should be made aware of them through regular exercises/drills.

e) Fire Safety attitude - Personnel should be educated/trained on safe habits. The causes of fire like presence of combustibles, ignition sources and gases /vapors evolved during combustion and their hazards involved etc as well as type of fire extinguishers to be used should be demonstrated.

The information provided in this Monograph is of general nature hence very brief and not adequate for instituting a fire safety programme in a nuclear facility. Details should be obtained from respective standards, relevant books and manuals for this purpose.

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