IAEA-TECDOC-1944

IAEA TECDOC SERIES

IAEA-TECDOC-1944

Fire Protection in Nuclear Power Plants

IAEA
International Atomic Energy Agency

FIRE PROTECTION IN NUCLEAR POWER PLANTS

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
COMOROS
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA-TECDOC-1944

FIRE PROTECTION IN NUCLEAR POWER PLANTS

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2021

For further information on this publication, please contact:

Nuclear Power Engineering Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

Printed by the IAEA in Austria
February 2021

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Fire protection in nuclear power plants / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2021. | Series: IAEA TECDOC series, ISSN 1011–4289 ; no. 1944 | Includes bibliographical references.
Identifiers: IAEAL 21-01386 | ISBN 978-92-0-134821-0 (paperback : alk. paper) |
ISBN 978-92-0-134721-3 (pdf)
Subjects: LCSH: Nuclear power plants — Safety measures. | Nuclear reactors — Safety measures. | Fire prevention. | Fire protection engineering. | Fire.

FOREWORD

The lessons learned from experience in nuclear power plant operation indicate that fires in nuclear power plants pose a real threat to nuclear safety and that their significance extends far beyond the scope of a conventional fire hazard. Considerable progress has been made over the past several decades in the design and regulatory requirements for fire safety, in fire protection technology and in related analytical techniques. Substantial efforts have been undertaken worldwide to implement these advances in the interest of improving fire safety in both new and operating nuclear power plants.

This publication provides information and insights on lessons learned and best practices to reflect the recent status of the worldwide nuclear power industry and assist in enhancing the fire safety of operating NPPs.

The publication is targeted to nuclear power plant fire protection experts in nuclear utilities, regulators, and technical support and service organizations.

The IAEA officer responsible for this publication was V. Roué of the Division of Nuclear Power.

CONTENTS

C-40 (May 13)

1 INTRODUCTION

1.1 BACKGROUND

Lessons learned from experience in nuclear power plant (NPP) operation indicate that fires pose a real threat to nuclear safety and that their risk extends far beyond the scope of a conventional fire hazard. Considerable progress has been made over the past several decades in the design and regulatory requirements for fire safety management, fire protection technology and related analytical techniques. Substantial efforts have been undertaken worldwide to implement these advances in the interest of improving fire safety in both new and operating NPPs.

Fire safety management information is currently provided to the nuclear industry by IAEA as well as by individual country standards or regulations. International NPP operating experience spans decades, and a need has been identified to share valuable experiences from this history — successful fire protection programmes (FPPs) and their operational experience are discussed below. The aim of this publication is to shorten the learning curve and provide updates and insights to the nuclear power industry.

1.2 OBJECTIVES

1.2.1 General design criteria

Develop a station specific detailed fire hazard analysis (FHA) to ensure independent fire detection and alarm systems are installed where necessary. In addition, it would be beneficial for the station to be provided with a complete plant-wide system of fire hoses and hydrants supplemented with portable fire extinguishers. These hose/hydrant/extinguisher locations are needed to cover all station areas for manual firefighting.

Using the FHA, or requirements from the authority having jurisdiction (AHJ), determine the specific fire protection systems and equipment necessary. The type of fire detection and extinguishing agents to be used will depend on several factors. Examples include the nature of the fire hazard (solid, liquid, or gaseous material), the sensing ability of various fire detection equipment (smoke, products of combustion, etc.), the potential effect of the various fire extinguishing agents on equipment in the area (direct suppressant damage, over pressurization, thermal shock, clean-up, and occupant health hazards).

1.2.2 Objectives

This publication will assist Member States in providing detailed best practices and insights on those elements of NPP management and operation that are necessary to achieve and maintain high levels of fire safety.

The objectives of this publication are to provide guidelines to develop, implement, and integrate FPP into an NPP's overall safety/risk management programme.

Fire protection insights in this publication will help in:

- Establishing a fire protection philosophy;
- Integrating fire protection within an NPP's overall risk management programme;
- Implementing an FPP.

1.3 SCOPE

The practical experience gained by industry experts is used in this publication to highlight the 'defence in depth' (DID) principle (which states that a fire will not prevent the necessary safe shutdown functions from being performed and that radioactive releases to the environment in the event of a fire will be minimized), as well as fire protection systems, organizational FHA, firefighting issues, training, quality assurance (QA), as well as activities to address plant changes and maintenance. Generic guidelines and good practices on fire safety management are also presented. This NPP publication provides insights that are also applicable to a broad range of nuclear installations (past and present).

Jurisdictions that provide requirements for fire protection include federal, state, and local agencies. This publication, as a technical document, bridges the regulatory requirements and industry standards with practical application and provides:

- A useful tool for making fire protection decisions;
- Specific examples of fire protection criteria.

While life safety issues (plant personnel not involved with post-fire safe shutdown activities) are not a primary focus of this publication, they are an integral part of good fire protection design. There is a very close relationship between fires and explosions. An explosion could be the initial event, followed by a significant fire; or a fire could trigger an explosion. This publication does not address the prevention of explosions, methods to quantify the severity of an explosion, or explosion suppression techniques. In addition, wildfires will not be covered in this publication other than to note they may need to be considered.

1.4 USERS

This publication is designed to be used in the fire safety management of NPPs. It is meant to be used by personnel who manage NPP operation, maintenance, regulation, training, support, and design. It can also be used by outside agencies and provides supporting documentation for other IAEA Safety Standards.

Decision makers on fire protection will benefit from this publication. Further, since fire protection is an important aspect of an NPP's overall safety/risk management, this publication will benefit many different people within an organization:

- Corporate leadership;
- Site managers;
- Line management;
- Project managers;
- Engineers;
- Health and safety professionals.

1.5 DOCUMENT STRUCTURE

The insights provided in this publication are organized to cover a broad range of fire protection activities. Section 2 provides some details for the basic principles of fire protection, defence in depth strategy and organization and management good practices. Section 3 addresses numerous fire protection systems and maintenance practices found prudent to ensure the systems help control fires that do occur. Section 4 identifies insights for fire prevention activities to help prevent fires from occurring. Section 5 goes over fire risk concept issues important to post-fire safe shutdown. Finally, section 6 provides the scope of an effective emergency response plan.

2 FIRE PROTECTION OVERVIEW

2.1 PRINCIPLE OF FIRE PROTECTION

Using the DID principle, introduced above, the goal of FPPs for NPPs is to prevent, as much as possible, the likelihood of having a fire occur, and to limit the damage caused. As noted above, the DID principle states that a fire will not prevent the necessary safe shutdown functions from being performed and that radioactive releases to the environment in the event of a fire will be minimized. Existing IAEA Safety Standards provide an overview that is expanded in this publication from NS-G-1.7 Ref. [1] and NS-G-2.1 Ref. [2].

Nuclear safety/risk management is vital for effective control of radioactive releases to the environment. Fire protection is an essential part of nuclear safety/risk management in an NPP. Appropriately designed, installed, and maintained, fire protection systems are paramount to mitigating the direct consequences and preventing the escalation of fires in processing nuclear power generation.

It would be beneficial for the FPP to be established at each NPP, laying down the fire protection policy for the protection of structures, systems, and components (SSCs) important to safety at each plant. It can also elaborate the procedures, equipment, and personnel required to implement the programme at the plant site.

2.1.1 Fire basics

2.1.1.1 Fire and flame

Fire is the combustion (rapid oxidation) of a material, releasing heat, light, and various reaction products. Other oxidation processes are not addressed, like rusting or digestion.

The visible portion of the fire is the flame and it consists of glowing hot gases. If hot enough, the gases may become ionized to produce plasma. Depending on the substances alight, and any impurities outside, the colour and intensity of the flame will differ. Fire in its most common form can result in conflagration, which has the potential to cause physical damage through burning.

Fires start when a flammable and/or a combustible material is exposed to a source of heat or ambient temperature above the flash point for the material, in combination with a suitable oxidation environment to sustain a chain reaction for rapid oxidation.

2.1.1.2 Fire triangle

Three elements i.e., heat, oxygen and fuel are required in a certain combination for ignition and combustion to occur. This is called the fire triangle. If any one of the three is absent or if they are not in proper balance, ignition or combustion will not occur. Variations in balance among the heat, oxygen, and fuel govern the intensity of a fire, and determine whether the fire will smoulder and spread slowly or flame brightly and travel rapidly. For fire to exist, all these elements must be in place and in the right proportions.

FIG. 1 below, provides a graphical image of what parameters, or elements, are needed to allow this rapid oxidation to occur. The fuel portion of this fire triangle may be in the form of a solid, liquid, or gas. However, the solid or liquid type fuels must be heated enough to vaporize before they will burn. The oxygen and heat portions of these triangles must be sufficient to enable rapid oxidation. Different fuel sources will require different parameters for the oxygen and heat needed.

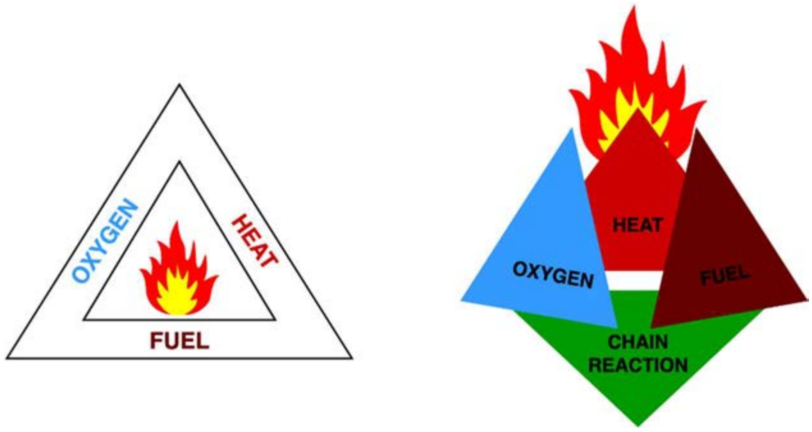

FIG. 1. Fire triangle & fire tetrahedron

Once ignited, a chain reaction must take place whereby fires can sustain their own heat by the further release of heat energy in the process of combustion and may propagate, provided there is a continuous supply of oxidizer and fuel.

The fire tetrahedron is made by an addition to the fire triangle (see FIG. 1). It adds the requirement for the presence of the chemical reaction (chain reaction), which is the process of fire. Fire can be extinguished by removing any one of the elements of the fire tetrahedron.

2.1.1.3 Phases of fire

The burning process occurs in clearly defined stages. When a firefighter recognizes the different phases (or stages), she/he can better understand the process of burning and fighting the fire at different phases and with different tactics and tools. Each phase (or stage) is characterized by differences in room temperature and atmospheric composition. These stages are illustrated graphically in FIG. 2, below.

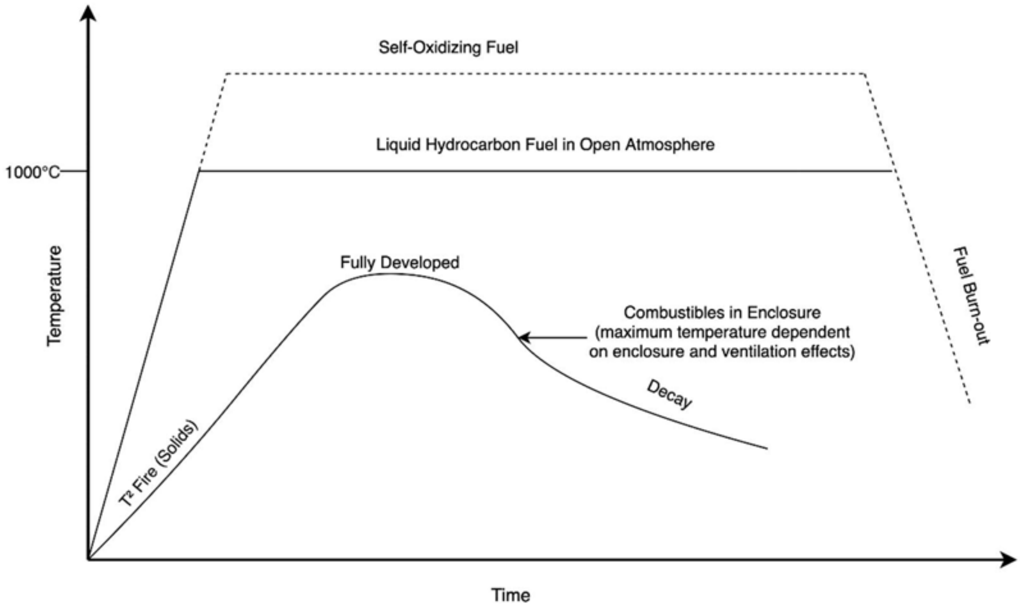

FIG. 2. Generalized fire growth characteristics for solid, liquid, and self-oxidizing fuel

A firefighter may be confronted by one or all the following phases (or stages) of fire at any time.

The early phase of fire development is the incipient stage that is generally limited to a single fuel source when the heat developed is not capable of transferring enough heat to adjacent fuel sources for their combustion. The next phase occurs when the incipient fire has increased enough that the heat transfer to nearby adjacent fuel sources is large enough to pyrolyze them such that fire growth occurs due to the heat transfer. As noted on FIG. 2, the maximum temperature of a fire would be limited to the enclosure size and ventilation effects. In some cases, not all, a flashover phase could occur. A flashover occurs when all the surfaces within the enclosure are exposed to a large enough thermal radiation from the fire to allow simultaneous ignition for total room involvement. The fully developed phase then occurs, whether flashover is involved or not, when the peak heat release rate of the combustibles in the compartment is reached. The final stage is the decay phase when the fuel load begins to decrease in the compartment, or the amount of available oxygen to support combustion, is reached.

2.1.1.4 Product of a combustion

Rapid oxidation (combustion) of a given material is a chemical process that is unique to each material/oxidizer involved. The given material must be transferred to a pyrolyzing or vaporizing combustible from the heat available or created by the heat feedback of the combustible material once it is ignited. When a fuel burns, there are four products of combustion:

— Fire gases;
— Flame;
— Heat;
— Smoke.

The fire gases released from most fires consist of a mixture of oxygen, nitrogen, carbon dioxide, carbon monoxide gases, finely divided carbon particles (soot), and miscellaneous products that have been released from the material involved. These gases may lead to fire spread or potential toxic impacts on personnel affected near the fire location.

Flame, and the resulting heat/smoke, from a fire are the primary concerns for equipment/personnel damage that must be minimized or controlled for each NPP. These products of combustion are highly variable and require careful planning to address all potential combinations.

2.1.2 Fire protection and fire prevention

2.1.2.1 Fire protection vs. fire prevention definitions

Fire protection is the science of reducing loss of life and property from fire by control and extinguishing of the fire. Fire protection includes detection of a fire, providing systems to control or mitigate the fire, and providing manual firefighting capabilities.

Fire prevention involves activities to prevent any fires from starting. Fire protection (identify, control, and extinguish fires) and fire prevention (not allow fires to start) go hand-in-hand. FPPs can include a fire prevention programme. For example, control of ignition sources is important in minimizing the risk of fire but does not meet the definition of fire protection as per this publication.

Much of NPP planning and operation deals with the prevention of catastrophic events, such as radioactive releases to the environment resulting from a fire or firefighting activities. In addition, the concerns raised by smoke releases and/or firefighting water drainage containing either radioactive materials, harmful chemicals, or environmentally damaging materials may be considered, and control methods developed in the plant FPP.

2.1.2.2 General control methods

It would be beneficial for the fire protection systems to be designed to accomplish a combination of the following objectives:

- Prevention of fire;
- Detection and Annunciation of fire:
- Confinement of burning;
- Exposure protection;
- Extinguishing the fire.

2.2 FIRE PROTECTION PHILOSOPHY IN NPP

2.2.1 Defence in depth

2.2.1.1 Nuclear safety defence in depth

Principle 8 of the IAEA safety standard series on “Fundamental Safety Principles” Ref. [3] is that the design of nuclear installations must include the appropriate application of the DID principle Ref. [4]. These levels of protection are intended to compensate for human errors or plant failures and may encompass radiation protection and the prevention and mitigation of accidents.

NPPs use the concept of DID which uses five levels to return the plant to a safe state which includes using engineered safety features, safety systems and procedures.

Objectives of DID

The primary objectives of DID for nuclear safety are to reach and maintain safe shutdown which includes minimizing the release of radioactive material to the environment. The five levels of defence in depth are covered in Ref. [4] and generally include (1) preventing abnormal operation or failures, (2) controlling abnormal operation or detection of failures, (3) controlling accidents within the design basis (including fire), (4) controlling severe plant conditions, and (5) minimizing radiological releases to an acceptable level.

Levels of defence

DID is not an installation examination technique with a particular technical solution, but a method of reasoning and a general framework enabling more complete examination of an entire installation.

Each level of defence is designed to provide reasonable assurance that failure of any one level will not defeat the remaining levels. In addition, the severity expected from a given fire related accident may be exceeded due to unforeseen situations at the time of planning. This is why each level needs to be independent to ensure reasonable assurance is provided to cope with all situations that may arise.

2.2.1.2 Fire protection defence in depth

Fire is a hazard which has the potential to create a common cause failure, for which prevention and mitigation measures ought to be provided Ref. [3].

To ensure adequate fire safety management in NPPs during the life cycle (construction, operation, outages, modifications, refurbishment, plant life management for extended operation, decommissioning etc.), it would beneficial for DID to be maintained at an appropriate level, through the fulfillment of the three principle objectives identified in the Agency document Ref. [2].

DID is incorporated into fire protection regulations for nuclear power plants. It requires preventing fires, detecting and extinguishing fires that do occur, and ensuring the capability to safely shutdown, see FIG. 3.

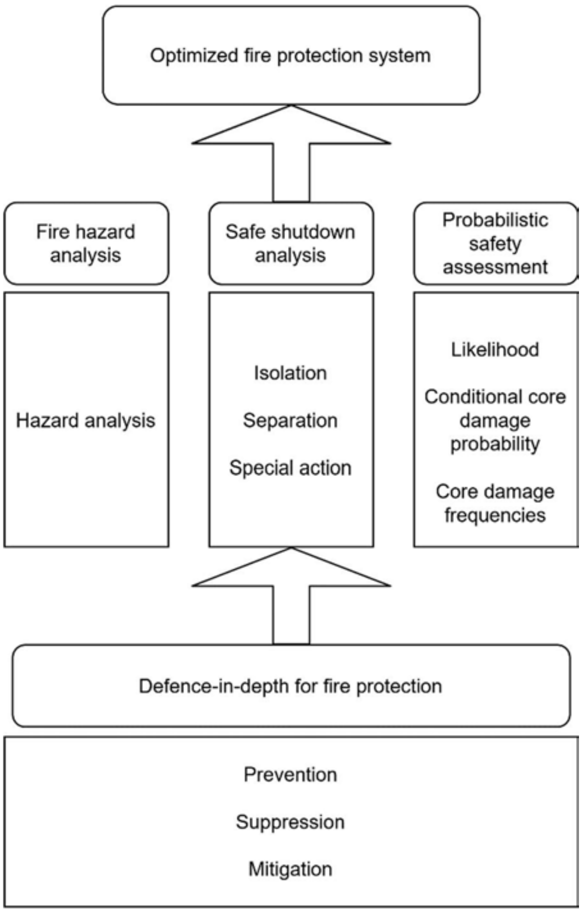

FIG. 3. Defence in depth for fire protection

As shown in the above figure several layers are defined to provide a foundation for the DID principle. These layers provide an overlapping scope of protection for the NPP to provide reasonable assurance that a fire would not occur (prevention), but if a fire does occur that it may be adequately controlled (suppression and mitigation), and that in a final layer the plant nuclear safety is assured even if the other layers of protection are not adequate.

Preventing fires from starting

Fire prevention is the first line of DID for fire protection. The fire prevention attributes of the programme are directly related to the fire protection objective to minimize the potential for fire to occur in the first place. As described in Ref. [5] these programme items include:

— Design and administrative measures to protect against fire hazards;
— Administrative controls and procedures to minimize fire hazards (especially in areas containing SSCs important to safety);
— Management review of proposed plant modifications, and maintenance activities;
— Implementation of compensatory measures, as needed, such as fire watches or temporary fire barriers.

Detecting and extinguishing fires and limiting damage

Fire detection and fighting systems of appropriate capacity and capability ought to be provided and designed to minimize the adverse effects of fires on SSCs important to safety. The second line of defence is to quickly detect and extinguish fires that occur to limit damage. Fire detection, fire suppression, and manual suppression are key to ensuring this level of defence is maintained.

Protecting SSCs important to safety

Overall, there is a high degree of fire protection reliance on DID principles by maintaining an acceptable balance among fire prevention, fire suppression, and fire confinement to a single train of redundant important to safety equipment in order to achieve the required degree of reactor safety. The DID process entails the use of echelons of administrative controls, fire protection systems and features, and safe-shutdown capability, such as redundancy, to achieve the desired degree of reactor safety.

2.2.2 Fire protection strategy

A fire protection strategy is a systematic approach to identifying, reducing, and managing fire hazards. A common aspect of any fire protection strategy is defining how hazards are managed and describing the order of priority for managing those fire hazards. A fire protection strategy serves as a bridge between the NPP’s perceptions of fire-related risks and the details of how to manage specific risks. The fire protection strategy can be considered as the tool that defines when certain protection levels are required for an NPP. The attempt to define general performance requirements or controls for specific situations is part of the fire protection strategy and coordinated with the plant physical protection staff.

Determining an appropriate fire protection strategy involves considering and balancing a number of technical and economic factors, including the following:

— Main concern:

- Nuclear safety;
- Radioactive material release;

— Secondary concern:

- Life safety (non-safe shutdown site personnel);
- Environmental aspects (chemical and/or toxic gases, etc.);
- Plant damage/business interruption;
- Type of fixed fire protection if any, automatic or manual, passive or active, emergency response capabilities, maintenance and testing capabilities, etc.

2.2.2.1 Key factors in a fire protection strategy

Prevention of internal hazards is always a better solution than their mitigation. Nevertheless, the best practices and operating experience (OPEX) reveal that fire hazards are a significant part of the overall hazards in the lifetime of an NPP. Even the best designs have observed a frequency in the order of one significant fire event per year per reactor, so mitigation remains a fundamental part of the fire protection strategy.

To be efficient, a fire protection strategy must be considered as a whole and successfully put in place the different aspects of the FPP, which include the following.

— Company organizational resources: necessary to address fire safety design, maintenance, prevention and response, including their associated requirements:

  - Availability of the necessary human resources;
  - Adequate mission and responsibility distribution;
  - Adequate education of the different populations.

— Correct analysis and control of fire hazards issues: this relates to the FHA, which is based on an adequate knowledge of detailed plant configurations, together with an adequate management of fire-hazard related materials, configurations and equipment.

— Adequate installation of fire protection equipment: based on the hazards identified in the FHA. The issues addressed include the choice of properly designed and qualified materials (in relation to the fire hazards they will have to withstand), their maintenance and the strict administrative controls to ensure their availability.

Technical process solutions and materials used to limit the risk (prompt response to postulated fire hazards), during the design of the plant, remain the most fundamental aspect of the fire protection strategy. This fundamental aspect is beneficial to be regarded and utilized for new plant construction and for modifications to the existing NPP.

2.2.2.2 Integration of fire protection into nuclear safety programme

A fire protection strategy can demonstrate how it is integrated into the company’s overall risk management system (RMS) philosophy as presented on FIG. 4.

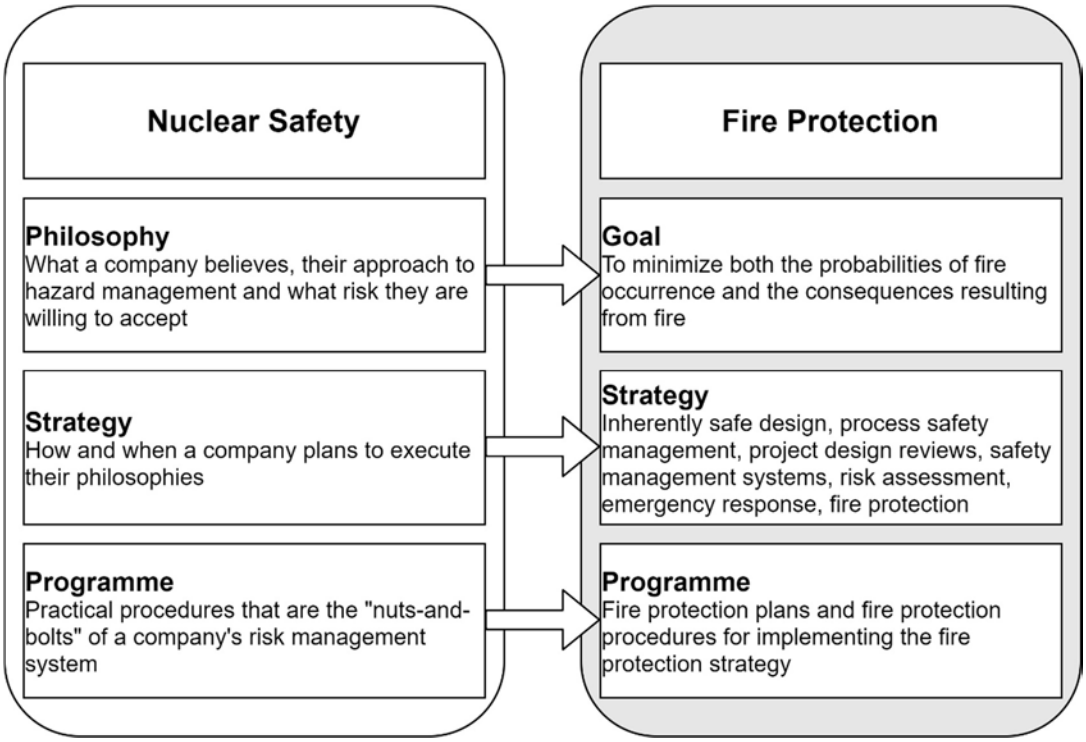

FIG. 4. Integration of fire protection into nuclear safety system

2.2.2.3 Strategy for reducing fire risk

In general, the strategy for reducing risk, whether directed toward reducing frequency or consequence of potential accidents, falls into one of the following categories:

- Passive: eliminating or minimizing the hazard by process and equipment design features that do not eliminate the hazard but reduce either the frequency or consequence of the hazard without the need for any device to function actively (e.g., the use of non-combustible material when practical and passive fire barriers of suitable rating);
- Active: using engineering controls (such as fire detection systems, and automatic suppression systems activation alarms if no detection is present to detect developing fire conditions) which would allow personnel to take appropriate and timely corrective action;
- Procedural: using administrative controls (such as operating procedures, administrative checks, emergency response, and other management approaches) to minimize the potential for incidents or the effects of an incident.

2.2.2.4 Balancing protection

Three factors contribute to the extent of any fire loss. The first involves an act, omission, or system failure allowing an ignition source and fuel to combine. The second involves the potential for continued fire growth and escalation. The third factor is potential impact (equipment damage, environmental release, etc.). Providing the right level of protection can be a delicate balancing act.

Overprotection results in unnecessary capital expenditure and higher ongoing costs. The added complexity of a protection system will likely require more capital expenditure to install as well as for training on fire protection system operations, testing, and maintenance which could be unnecessary based on the fire risk expected. Overprotection may result in over confidence in the ability of the system to address situations and a subsequent deterioration in readiness. The protection system, when not necessary, may cause other risks not associated with fire (e.g., water leaks in electrical equipment areas where inert gas suppression could have been used).

While less protection may initially reduce the capital investment and ongoing maintenance costs, the additional risk to company assets, employees, the environment, and the public could be substantial. The potential for escalation of plant and equipment damage increases due to the lack of fire protection systems. If a company chooses less protection, potentially adverse effects, such as damage to reputation, increased insurance costs, loss of business and customers, as well as possible charges of criminal negligence could become factors in the event of an incident.

2.3 ORGANIZATION AND MANAGEMENT

The insights provided in this chapter are based upon industry best practices and operational experience from international best performing plants. Corporate leadership is essential for ensuring appropriate site support of the fire protection organization, and alignment between hierarchy of site managers, line management, and engineers.

2.3.1 Roles and responsibilities

2.3.1.1 Corporate oversight

Plant management could establish an on-site group specifically responsible for ensuring the continued effectiveness of the fire safety arrangements. A strong plant management presence has been identified as instrumental in FPP development.

It would be beneficial for the group to have a meeting periodically, for example every quarter, and one meeting needs to cover the experience of, for example, testing installations, industry as well as plant incidents and what has been improved over the last year according to the operating experiences.

The group could consist of representatives from operation, system engineering, insurance, fire brigade and testing fire installations, fire risk analysis and maintenance.

2.3.1.2 Fire protection senior manager

The organization establishes a fire protection senior manager position directly reporting to the senior site manager or other corporate executive independent of reporting up the production or operations reporting lines. The reporting relationship is sufficiently high enough to ensure an adequate balance of operational and production needs with fire safety. The fire protection senior manager is responsible for the following tasks:

- Directing the development of corporate fire protection goals, governance, and policies in accordance with regulatory requirements, corporate loss control objectives and business needs;
- Directing the development and improvement of the FPP to achieve the fire protection goals;
- Assigning resources to implement the fire protection policies and the FPP;
- Monitoring and reporting on the effectiveness of the FPP;
- Interfacing with senior managers and corporate executives;
- Managing the implementation and coordination of the FPP across the organization;
- Advocating fire protection issues and resource needs to the senior management team and corporate executives;
- Acting as a single point of contact for fire protection for external organizations including regulatory authorities of each utility, fleet, or plant.

2.3.1.3 Fire protection programme/engineering oversight

The organization establishes FPP/Engineering oversight position reporting to the fire protection senior manager. The fire protection oversight role is focused on the development of the FPP, physical design, design basis and supporting analysis of fire protection for the site and is responsible for the following tasks:

- Development, assessment and continuous improvement of the FPP, and engineering elements of the plant change process to meet regulatory requirements, loss control objectives, and business needs;
- Development of programme compliance and performance evaluation criteria;
- Documentation and maintenance of the fire protection design basis, supporting fire protection analysis, including fire risk analysis, fire safe shutdown analysis, and fire code reviews;
- Monitoring, auditing and reporting on programme performance and compliance;
- Management of the fire prevention group;
- Management of the fire protection systems through an inspection, testing and maintenance (ITM) programme, as described in section 3.4;
- Managing research and investigations related to fire protection engineering;
- Ensuring self-assessments are performed and reported to identify strengths and weaknesses for continuous improvement;
- Ensuring the completion of fire protection ITM activities at the site;
- Acting as the single point of contact for internal or external audits and evaluations, mutual aid organizations (including external fire departments), and for fire protection engineering;
- Providing technical support to the engineering organization on fire protection engineering- or analysis-related issues.

2.3.1.4 Fire protection fire brigade oversight

The organization establishes a fire protection fire brigade oversight position reporting to the fire protection senior manager. The fire protection fire brigade oversight role is focused on the development and delivery of fire brigade oversight and related fire protection training and is responsible for the following tasks:

- Development, delivery and continuous improvement of fire brigade equipment and fire protection and emergency response training to employees and contractors for initial training and requalification training;
- Documentation and maintenance of training needs assessments and training programme documents;
- Documentation and maintenance of fire brigade training procedures and related teaching aids and documents;
- Management of drills and exercises;
- Acting as the single point of contact for fire protection and emergency response training;
- Ensuring the training of fire brigade members for emergency mitigation equipment (EME) deployment;
- Ensuring training is provided in accordance with regulatory requirements and applicable codes and standards;
- Development and delivery of training for fire brigade to deploy EME in accordance with the site emergency plan;
- Ensuring training records are documented and filed with the records repository.

2.3.1.5 Fire and emergency response staff (fire brigade)

Qualified personnel are assigned to be members of a site fire brigade to provide fire protection and emergency response services. full-time fire brigade members report to the fire protection fire brigade oversight. Volunteer fire brigade members report to various department managers on a day-to-day basis. However, in the event of an emergency, fire brigade members fall under the direction of the fire protection fire brigade oversight or an official delegated by them.

The fire brigade team comprises a leader and numerous responders. The team leader requires a high level of plant operational, incident command, and firefighting knowledge. As determined by site-specific emergency response needs analysis, a minimum number of responders and at least one team leader are available at all times at the site to respond to emergencies. Fire brigade team members are only assigned “drop and go” work to be able to immediately respond to an emergency. Fire brigade team members must be trained to an appropriate level commensurate with their position and the actions they are required to perform.

2.3.1.6 *Fire protection engineers and technical officers*

The following positions may be combined into fewer personnel than identified below, but this allows a more thorough description of the responsibilities for implementing efficient organization.

Fire protection system responsible engineer

The fire protection system responsible engineer (FPSRE) is responsible for monitoring the operation and health of fire protection systems, including active and passive ones, to ensure they are available as needed.

Fire protection programme engineer/fire technical officer

The organization establishes a fire protection programme engineer (FPPE)/fire technical officer (FTO) position reporting to the FPP/engineering oversight. The FPPE/FTO is responsible for the implementation of the FPP and its continuous improvement. This includes supporting external audits, assessing compliance of programme elements via internal audits or self-assessments and including operational experience into the program. The FPPE/FTO conducts drills of the fire brigade to ensure compliance.

Fire Protection Engineer

The Fire Protection Engineer (FPE) is responsible for designing and modifying structures, systems and components in compliance with the FPP and applicable codes and standards. This work includes the development of technical specifications and analysis to demonstrate the design compliances with the technical specifications. The FPE is also responsible for the maintenance of the FHA and Fire Safe Shutdown Analysis to reflect current plant configuration.

Fire prevention officer

The fire prevention officer (FPO) is responsible for ensuring compliance with and reporting the prevention elements of the FPP in general, and specifically the following:

- Hot work management;
- Ignition source control;
- Transient material control;
- Unapproved modifications control;
- Operational readiness of fire protection SSCs;
- Management of dangerous goods or hazardous substances.

Fire service instructor

The fire service instructor (FSI) provides training as required by the training programme document and training needs analysis as per the facilities training procedures, including emergency medical equipment and fire protection SSCs inspection, testing and maintenance.

2.3.2 Fire safety management training

As part of the larger corporate systematic approach to training (SAT), a comprehensive training programme is implemented to achieve, maintain, and improve personnel knowledge, skill, and performance to support plant safety and performance goals in fire protection. The fire protection and emergency response training requirements are based upon the identified needs from a training needs analysis (TNA). Work activities performed inside the protected area, related to the nuclear facility or which may impact the nuclear facility, are included in the TNA. The TNA documents the results of a systematic assessment of requirements for specific job functions and their required requalification frequencies. The TNA is based upon the following elements:

- Regulatory requirements (which may contain prescriptive or performance-based requirements);
- Implementation of applicable codes and standards (which may contain prescriptive or performance-based requirements);
- Requirements determined from a systematic assessment of task requirements.

2.3.2.1 Training for plant personnel

In addition to the requirements identified in the TNA, individuals who work or regularly access the protected area as a minimum complete a basic course in Fire Safety Training which needs to include the following topics:

- FPP goals;
- Fire prevention;
- Life safety;
- Understanding the use of portable fire extinguishers;
- Emergency procedures;
- The control of transient material, hot work, and ignition sources;
- Housekeeping;
- Reporting a fire and accounting.

It would be beneficial for personnel who work in, or regularly access, the protected area to receive hands-on fire extinguisher training on a live fire or fire simulator. The required requalification period and method of delivery can be determined based on the results of the TNA.

2.3.2.2 Training for licensed operations staff

In addition to the requirements identified in the TNA, it would be beneficial for licensed operations staff to be familiarized by formal training with the following major topics:

- Postulated fires, including the design basis fire;
- Fire protection organization and fire protection goals;
- Fire protection analysis, code compliance report, fire hazard analysis, fire safety shutdown analysis (FSSA) documentation;
- Roles and responsibilities during a fire event.

2.3.2.3 Training for fire protection design and system engineering

In addition to the requirements identified in the TNA, the FPEs and FPSREs require specific training in the design, procurement, installation, operation, inspection, testing and maintenance of fire protection SSCs. Report cards are developed which utilize evaluation criteria for programme and system health monitoring. FPEs involved in the use or maintenance of the FSSA or FHA require specific training in these topics, including fire modelling.

2.3.2.4 Training for fire protection programme staff

In addition to the requirements identified in the TNA, FPPE and FTOs require specific training in the following areas:

— Application and updating of programme governance;
— Programme document updating;
— Drill evaluation;
— Self-assessments;
— Audits and evaluation;
— Correspondence writing;
— Report card development and maintenance for overall programme performance;
— Fire prevention including codes, governance compliance and inspections;
— Fire investigation and fire modelling.

2.3.2.5 Training for fire protection training staff

In addition to the requirements identified in the TNA, specific training for the design, development, delivery and evaluation of fire protection training including:

— Drill and exercise development, control and evaluation;
— Self-assessments;
— Internal audits;
— Reporting and responding to external audits;
— Third party reviews and evaluations.

2.3.2.6 Training for fire protection response staff

In addition to the requirements identified in the TNA, specific training in plant design and operation such as:

— Appropriate level of radiation protection training to respond safely to a fire or other emergency event and escort responders from off-site mutual aid departments;
— Initial fire response training to be qualified for advanced interior and exterior firefighting activities;
— Necessary requalification fire training to perform advanced interior and exterior firefighting activities;
— Training to use specialized manual firefighting equipment;
— Incident command training to the level needed to perform in their designated position;
— Familiarization of the postulated fires including the design basis fire and associated hazards;
— Familiarization of the manual firefighting equipment location and capabilities;
— Importance of maintaining a level of physical fitness for their designated position;
— Drill evaluation;
— Self-assessments;
— Audits and evaluations.

2.3.3 Fire protection performance and assessment

2.3.3.1 Fire protection programme performance objectives

The FPP is defined as the set of planned, coordinated and controlled activities which are implemented and documented. The objective of the FPP is to ensure that the facility's fire protection goals are achieved, and transparent processes exist to ensure the required activities are performed. This includes the DID approach to physical design of the facility, analysis to demonstrate the design meets the required safety objectives, operational controls to manage and minimize hazards, and emergency response capability.

2.3.3.2 Examples of performance assessment criteria

Fire protection programme resources, roles and responsibilities

Measure the adequacy of resources to support the implementation and maintenance of the FPP in the fulfillment of key FPP objectives.

Performance indicators are:

— Programme management;
— Programme ownership;
— Fire protection engineer adequate resources;
— Fire protection system engineer adequate resources;
— Fire safe shutdown engineer adequate resources;
— Qualified contingency of staff in key roles;
— Key staff turnover;
— Programme human performance incidents.

Programme oversight and health

This programme measures the ability of external agencies to identify gaps within the FPP, and the ability to identify appropriate causes and resolve those gaps in a timely manner.

Performance indicators are:

— Identification of issues identified by internal and external programme audits and self-assessments which resulted in findings not previously identified;
— Effective implementation of corrective actions in a timely manner;
— Trending and repeat findings.

Fire Protection and Configuration Management

It measures inconsistencies or deviations in configuration control relative to station documentation and the fire protection program or station analysis basis.

Performance indicators are:

— Number of open design or analysis issues;
— Number of obsolete critical fire protection components;
— Number of deviations between plant design or analysis and field conditions.

Fire prevention

It measures key attributes directly related to the prevention of fires at the station, including the identification of reported fire events.

Performance indicators are:

— Number of deviations from administrative controls (e.g. expired permits, or lack of permits) or commitments identified by station fire protection personnel;
— Completion of regular housekeeping inspection (% areas completed in period);
— Number of housekeeping deviations from station standards, emergency equipment blockages identified by station fire protection personnel (corrective action programme);
— Number of housekeeping deviations from station standards, emergency equipment blockages identified by station (excluding fire protection) personnel;
— Number of hot work procedure violations;
— Number of reported fire events that have occurred at the station;
— Number of housekeeping management observations;
— Number of active fire watches and walkdowns at the station.

Fire protection system health

Measurement of the general health and availability of fire protection structures, systems and components to support the fire protection goals.

Performance indicators are:

— System health reports information;
— ITM or preventative maintenance completion rates;
— Number of deferred ITM activities;
— Minimization of unplanned impairment duration times;
— Number of fire barrier deficiencies in credited barriers;
— Number of deferrals on planned fire protection activities and fire drills.

Fire and emergency response

It measures the ability of the industrial fire brigade (IFB) to respond to fire events in a timely and safe manner, to support the fire protection goals at the station.

Performance indicators are:

— Overall drill performance as per measured critical objectives;
— Intervention timelines meet benchmarks;
— Training performance indicators;

- Training and drill observations identified;
- Number of open corrective actions.

Programme continuous improvement

It measures the ability to prioritize and improve the fire protection programme-related issues.

Key performance indicators are:

- Identifying trends and adverse conditions;
- Utilization of audits, inspections, benchmarking, self-assessments and third-party reviews;
- Development of effective corrective action plans that demonstrate the resolution and sustainability.

2.3.3.3 Impairment to fire protection provisions

Fire protection SSCs features and procedural controls can become degraded or unavailable due to a variety of reasons such as equipment failure, changes in field conditions or environmental effects. The FPP ensures processes are in place to monitor the degradation or unavailability of fire protection measures or changes in fire risk and implements compensatory measures to maintain the same or lower level of fire risk. In addition, corrective actions are developed and implemented to restore the impaired or degraded features.

A comprehensive impairment process contains the following major elements:

- Impairments are managed to minimize their duration to the shortest time possible;
- Compensatory measures are promptly implemented to maintain or reduce the level of risk as a result of the impairment;
- Impairments are monitored by management for escalation to ensure the minimization of their duration;
- Authorities having jurisdiction are notified of impairment when the protective feature or fire protection system is unable to meet its design intent or when the impairment affects a fire sensitive area as determined by the fire safe shutdown analysis;
- Post maintenance testing is performed to ensure systems are restored and fully functional;
- The IFB and plant operations are notified of all impairments;
- Impaired SSCs are identified in the field by tagging or other means;
- Operational activities are evaluated to minimize the risk of fire and its consequences in consideration of the impairment;
- Additional oversight and inspections are performed to monitor field conditions and the implementation of compensatory measures.

2.4 CONFIGURATION CONTROL AND QUALITY ASSURANCE

Any monitoring programme or assessment must aim to produce information that is accurate, reliable and adequate for the intended purpose. This means that a clear idea of the type and specifications of the information sought must be known i.e., there must be a data quality objective. Data quality objectives are qualitative and quantitative specifications that are used to design the system that will limit the uncertainty to an acceptable level within the constraints allowed. Configuration controls are needed to assure uniform standards are provided throughout the NPP for fire protection systems/structures as well as other safety systems, safety related and non-safety related systems/structures.

Fire protection features are not generally classified as safety systems and thus they may not be subject to the rigorous qualification requirements and the associated QA programme applied to safety systems. However, fire has the potential to give rise to common cause failure and thus to pose a threat to safety, and therefore the installed active and passive fire protection measures may be considered as important to safety systems, or safety related systems. An appropriate level of QA would then be applied to fire protection features.

3 FIRE PROTECTION SYSTEMS

3.1 GENERAL

The selection of appropriate fire protection for a specific type of facility or item of equipment may be based on the results of FHA and the lifecycle stage of the facility. An overview is provided in NS-G-1.7 Ref. [1] with some insights provided below.

Typically, the protection features available will include one or more of the following:

— Elimination of the hazard and its resulting scenarios;
— Prevention (reduction of probability) of its occurrence;
— Detection and control;
— Mitigation of its consequences;
— Emergency response.

A system or operation is considered an inherently safer design if it remains in a non-hazardous state after the occurrence of unacceptable deviations from normal operating conditions.

Theoretically, a facility is considered an inherently safer design when all hazards have been eliminated. In practice, a facility can only be made inherently safer with respect to specific hazards and not all possible hazards. Safety can be built into an operation by using, where feasible, less hazardous process materials or less severe operating conditions. An operation can also be made inherently safer by careful site selection, plant layout and equipment, and building design. An example of how the design affects operation would be that the permitted storage volume of the combustibles is limited by the barriers' fireproof time rating, such as 1-hour. Also, the combustible storage or hot work activities may be prohibited under cable trays. This is also further discussed for the active fire protection systems in section 3.3.1.

3.1.1 Specific fire protection for nuclear risk

3.1.1.1 Combustibility of building components and features

Non-combustible and heat-resistant materials must be used wherever practical throughout the unit (Ref. [1] section 3.4). Interior wall and structural components, thermal insulation materials, radiation shielding materials, and soundproofing as far as practicable need to be non-combustible. It is beneficial for the FHA to identify in-situ combustible materials used in plant SSCs and specify suitable fire protection.

Metal deck roof construction needs to be non-combustible and identified as "acceptable for fire" in industry standards by a recognized testing laboratory.

Interior finishes need to be non-combustible. A detailed listing of materials that are acceptable for use as interior finish without evidence of test and listing by a recognized testing laboratory are provided in Ref. [5].

Suspended ceilings and their supports need to be of non-combustible construction. Concealed spaces need to be devoid of combustibles.

3.1.1.2 SSCs important to safety

A summary of the SSCs that are located within each fire compartment are appropriate to be identified in the FHA. As noted in Ref. [1] section 6.2 one of the main objectives of fire protection is to prevent damage to items important to safety. The information within the FHA for issues such as fire loading (fixed and transient), potential ignition sources, fire protection features, and separation between redundant SSC equipment allows an assessment of whether additional plant changes are needed to ensure post-fire safe shutdown. This documentation ensures future plant changes can be assessed to maintain adequate protection for SSCs important to safety. As plant operating equipment is changed or updated, over the life of the plant, the scope of the original SSCs important to safety may need to be confirmed since plant layout of equipment could be affected (i.e. cable routing, power supplies, etc.).

3.1.1.3 Prevention of radioactive material release caused by fire

The release of radioactive material needs to be minimized to ensure the safety of the public, the environment, and plant personnel during and after a fire event. Any ventilation system designed to exhaust radioactive smoke or heat can be evaluated to ensure that inadvertent operation or a single failure will not violate the radioactive material release limits in controlled areas of the plant. Water released during fire suppression operations containing radioactivity needs to be drained to a location acceptable for the containment of radioactive materials. Water disposal considerations might limit certain sprinkler system tests within radioactive controlled areas. Fire barriers, fire detection, and automatic fire suppression are appropriate to be provided as determined by the fire hazards analysis. Manual ventilation control to assist in smoke removal can be provided if necessary, for manual firefighting.

In addition, examples of materials that collect and contain radioactivity that are appropriate to be addressed is provided in Ref. [1] and Ref. [5].

The NPP’s fire brigade and local fire department need to be informed by fire pre-plans of the radiologically hazardous areas and radiation protection barriers. This includes radioactivity and health physics considerations, to ensure that each member is thoroughly familiar with the steps to be taken in the event of a fire. The relevant training will contribute to maintaining the best possible preparedness for such contingencies. Training of the plant fire brigade may be coordinated with the local fire department to address unique nuclear power plant issues they may not be familiar with so that responsibilities and duties are delineated in advance.

3.1.1.4 Security issues on fire safety

It is not the intent of this publication to deal in depth with facility security issues. However, effective fire prevention in a nuclear facility depends on people in addition to systems, to detect developing fires and other incidents and to detect unauthorized intrusion into the facility. Intruder-caused vandalism, damage, spills, releases, or fires are not common, but are a credible threat. The potential fire prevention and protection requirements to manage the risk of security events from terrorism need to be considered in the overall fire protection system design.

3.2 PASSIVE FIRE PROTECTION SYSTEM

3.2.1 Spacing and layout

The overall design of NPPs must consider spacing and layout as a key means of preventing the spread of fires. It is appropriate for hazard analyses of planned changes, modifications, and new projects to specifically review the adequacy of spacing and layout of process and support equipment. An overview of passive fire protection systems is provided in Ref. [1] with some insights provided below.

Areas to address during spacing and layout include both those that will minimize the incident size and those that will minimize the incident impact.

3.2.1.1 Compartmentalization

Compartmentalization is to subdivide a structure into "fire compartments" which may contain single or multiple rooms for the purpose of limiting the spread of fire, smoke and flue gases, in order to enable the plant safety, property protection, and continuity of operations in general industry.

SSCs important to safety must be designed and located to minimize the probability and effect of fires. The concept of compartmentalization uses passive fire barriers to subdivide the plant into separate compartments or cells. Their primary purpose is to confine the effects of fires to a single compartment or cell, thereby minimizing the potential for adverse effects from fires on redundant SSCs important to safety.

3.2.1.2 Fire compartment and fire cell

Fire compartment

A fire compartment (also known as fire area in some member states) provides an enclosure that is fire rated to withstand the fire loading on both sides per national standards used in the respective member state. The fire barrier that defines the fire compartment may be made up of numerous components of construction that physically support the barrier (i.e., columns, structural steel, beams or joists) or provide coverage for openings in the barrier (i.e., doors, dampers, ducts, windows or penetration seals). Interior, as well as exterior, walls are addressed to ensure SSCs important to safety are adequately separated.

The FHA (see fire hazards analysis in section 5.2) provides the realistic fire loading that each fire compartment will need to withstand. The location of the SSCs important to safety that are relied upon to ensure post-fire safe shutdown and minimize radioactive release are appropriate to be provided in the FHA. With this information the basis for adequate fire compartment rating can be defined to ensure adequate fire separation for the SSCs important to safety.

If a wall or floor/ceiling assembly are not adequately fire rated, or contains major unprotected openings, such as hatchways and stairways, plant locations on either side of such a barrier can be considered part of a single fire compartment, although they can be evaluated as separate fire cells in the FHA, as described below. If success path A is separated by an adequate cumulative horizontal distance from success path B, with no intervening combustible materials or fire hazards, and both elevations are provided with fire detection and suppression, the area would be considered acceptable separation as different fire cells.

Fire cell

Certain plant layout areas, such are yard areas or inside containment, are not suitable to be classified as a single fire compartments, since there often is a need to provide adequate separation within. These smaller components of a fire compartment may be classified as fire cells (or fire zones in some member states) to document within the FHA how adequate fire separation is provided. Normally this separation may be by reasonable separation with no intervening combustibles, or a lesser fire rated separation based on the actual fire loading involved.

An exterior yard area, or containment area, considered as a unique fire compartment area that may consist of several fire cells. The FHA can be used to determine the boundaries of the fire cells. External fires may be considered with specific analysis which may include detailed fire modelling, in Ref. [6] and [7] to more precisely address the lack of fire barrier separation. The protection for redundant, alternative, or dedicated shutdown systems within a yard area are appropriate to be determined based on the largest postulated fire that is likely to occur and the resulting damage. The boundaries of such separation between divisions; the presence of in-situ and transient combustibles, including vehicular traffic; grading; available fire protection; sources of ignition; and the vulnerability and importance of the post-fire safe shutdown-related systems.

3.2.2 Structural barriers

3.2.2.1 Fire barriers

Fire barriers are the components for a fire compartment that provide suitable fire separation. The scope of these fire barriers is to provide adequate separation for redundant safe shutdown components, or separate those components from significant fire hazards, as needed.

Fire barriers used to provide the fire compartment enclosure can be composed of a fire tested material. Such material can be generically tested by approving laboratories such that a fire rating in terms of hours of resistance to a standardized fire size is specified. The configuration of the tested assembly must be confirmed against the installed configuration, since a sample tested in a wall configuration would not necessarily provide reasonable assurance that a ceiling installed configuration would be acceptable; while a ceiling tested sample would suffice for any wall, floor, or ceiling installation due to the bounding nature of such a tested configuration.

Any openings through fire rated barriers, such as doors, dampers, penetration seals, etc., must also be fire rated consistent with the associated fire barrier. If any additional modification to these components (such as position indication or security monitoring attachments) need to be added they may require confirmation that no adverse impact on the fire rating is created. If the closure devices/seals do not match tested configurations, then an engineering evaluation may be performed. This evaluation, performed by a qualified fire protection engineer, can address whether the deviation is significant such that it essentially meets the tested configuration, or if the configuration is adequate for the hazard presented. Details for these evaluations are addressed in Ref. [5] and [8].

Fire doors need to be installed in accordance with the tested configuration, maintained to ensure adequate operation, and surveilled to ensure nearby components do not interfere with operation. Their function always depends on adequate closure of the fire barrier opening when not being used for access/egress, and adequate strength to withstand pressure differentials between the fire compartments being separated. See Ref. [5] for details on fire door issues.

Fire dampers need to be installed in accordance with the tested configuration, maintained to ensure adequate operation, and surveilled to ensure clean operating components within the respective duct so as do not interfere with operation. The fire damper function depends on adequate closure during “worst-case” duct flow operations, or appropriate duct flow shutdown, as needed, as well as closure against potential pressure differential from a fire on either side of the respective barrier. Ref. [9] shows that the adequately installed duct, without a fire damper, is adequate to provide a 1-hour fire rating which would limit the need for fire dampers for areas where the fire loading is at or below this value.

Openings through the fire barriers for pipe, conduit, and cable trays that separate fire compartments need to be sealed or closed to provide a fire-resistance rating at least equal to that required of the barrier itself. See Ref. [5] for details on proper conduit internal sealing and penetration seal options.

Penetration seals need to be installed by qualified individuals in accordance with the tested configuration, maintained to ensure adequate operation, and surveilled to ensure environmental or physical characteristics are maintained. Additional details for allowed variations in penetration seals can be found in Ref. [10].

3.2.2.2 Structural steel protection

Fire barriers that are supported by exposed structural steel are appropriate to be protected in an equivalent manner to the fire barrier rating when the fire barrier depends on the support provided. An analysis may be performed to justify a lack of fire protection, or limited fire protection, based on the fire loading identified in the area by the FHA. Structural steel will lose strength based on the temperature increase from fire exposure, but if the structural steel is used solely for dynamic loads (e.g., seismic) not associated with fires then protection is not required.

3.2.3 Electrical cable system

Redundant cable systems important to safety are appropriate to be separated by passive fire barriers from each other and from potential fire exposure hazards. In areas where electrical circuits important to post-fire safe shutdown cannot be separated by means of rated structural fire barriers, cable protection assemblies can be applied to conduit and cable trays to meet adequate fire rated separation requirements. The conduit and cable trays for the cabling need to be of substantial metal construction, with limited use of flexible metallic tubing. Where limited fire-resistive barrier adequacy is applied, then automatic fire detection and suppression can also be installed to compensate.

Automatic fire detection and automatic or manual fire suppression used to compensate for a lack of appropriate fire-resistive barriers need to meet suitable standards for their installation, such as provided by NFPA codes. These codes will specify suitable spacing, type of device that would be suitable, maintenance requirements, power supplies, etc. Electrical cabinets, or other termination points for electrical cables, present an ignition source for fires and a potential for explosive electrical faults that can result in damage not only to the cabinet, but also to equipment, cables, and other electrical cabinets in its vicinity. If passive barrier separation is not reasonable for such areas then proper spatial separation along with area-wide automatic fire detection, fire suppression, and manual back-up fire suppression capability are appropriate to be added. Internal fire detection may be needed if the fire loading is large enough to propagate outside of the cabinet, if redundant components are located nearby.

Examples of electrical fault concerns include lightning strikes and High Energy Arcing Faults (HEAF) in electrical cabinets. Possible protection includes installing protective relays to limit the lightning surge or over current in the electrical circuits to reduce fire risks. Also, digital relays have been installed to reduce the risk of the fire caused by the HEAF's in some member states. See Ref. [11] for testing done to document the potential damage from HEAF conditions.

3.2.4 Heating, ventilation, and air conditioning design

The room interconnections that are created by heating, ventilation, and air conditioning (HVAC) ducting may allow the potential for fire to spread and products of combustion (including radioactive material) into adjoining fire compartments. The design needs to consider the need to isolate, ventilate, or exhaust each fire compartment as well as the potential loss of function due to fire damage to HVAC equipment within the fire compartment. Fire compartments containing safe shutdown (SSD) equipment/components are appropriate to have air intakes located away from exhaust outlets and smoke vents of other fire compartments. Details on other related HVAC concerns can be found in Ref. [5] concerning:

- Combustibility of filter media;
- Smoke control/removal;
- Habitability (control room, SSD areas, personnel access/egress & stairwells);
- Fire dampers.

3.2.5 Containment and drainage

Each fire compartment is designed to contain a fire to prevent damage to other areas, but other essential design features such as floor drains, or openings under compartment doors, are appropriate to be evaluated for impacts on non-fire related areas. The fire-fighting fluids such as water (automatic or manually applied), gaseous suppression systems, and their potentially associated radioactive material will enter fire compartment drainage systems or flow under the fire doors into adjacent areas. The facility design needs to address this concern to minimize impact on redundant post-fire SSD equipment/components in adjacent areas or where the floor drains will discharge.

If the fire compartment contains flammable fluids that could escape through the floor drains or under the associated fire door, then the spread of fire to other areas are appropriate to be addressed.

3.2.6 Emergency lighting

Emergency lighting is needed for essential personnel to perform necessary safety functions during a fire event. The lighting may be fixed or portable to allow site personnel to use access and egress paths for fire-fighting activities, and operator actions to allow post-fire safe shutdown duties. Some of the considerations for adequate emergency lighting include:

- Level of illumination needed for access/egress or to perform equipment operation;
- Suitable power supplies for length of time needed and protected from fire damage;
- Periodic inspection and maintenance to ensure availability when needed;
- Verification that future plant changes do not adversely impact installed lighting.

3.2.7 Communications

Both the on-site fire brigade and operations personnel involved in post-fire safe shutdown activities will require portable communications equipment. Multichannel portable radios may be used if the use and assignment of channels ensures the fire brigade, operations, and security can all carry out their separate functions during a fire emergency. Any supporting equipment such as repeaters are appropriate to be evaluated for fire damage or limitations created by a plant fire. Periodic surveillance and maintenance of this communications equipment is needed to ensure availability when needed.

Off-site fire department radios need to be evaluated for adverse plant impacts. For example, some plant equipment may be sensitive to radio frequency interference. Training and posting of such areas would prevent unexpected plant equipment operation.

3.3 ACTIVE FIRE PROTECTION SYSTEMS

3.3.1 Automatic versus manual activation

3.3.1.1 Automatic activation

Automatic activation refers to fire protection devices that are integrated with a detection system designed to activate upon sensing fire. An overview of automatic and manual activation fire protection systems is provided in Ref. [1] with some insights provided below. The advantage of automatic activation is to minimize response time delay and, thus, significantly reduce the chance of a larger fire developing. One disadvantage is that when faults occur in the detection or logic associated with the system, there is the potential for unwanted activations which can result in damage to the protected equipment, shutdown of production, and require the fire protection system to be recharged. A second disadvantage is that if there is a failure of the detection system or the activation mechanism, the system does not operate. This is one reason why automatic systems have a manual activation option and manual stop.

3.3.1.2 Manual activation

Manual activation requires plant personnel to activate the system by pushing a button or opening a valve in response to either an observation of a fire or a signal from a detection system.

The advantages of manual systems are low cost regarding both installation and maintenance and are less complex. The disadvantage is that manual systems are liable to result in significant delays in activation due to the reliance upon human action. Such delays inevitably result in growth of the fire and the associated damage. Delays associated with manual systems may be exacerbated by the growing tendency for having fewer plant personnel in the field.

Both automatic activation and manual activation are key elements for all levels of the defence in depth principle, and its effectiveness can be evaluated in the safety assessment by applying a graded approach. The primary defence in depth protection is provided by the automatic activation, when provided, considering its reliability and human factors issues. In addition, backup manual activation, that can be provided for all plant areas, will be an operation that is relied upon for a higher level of defence, considering the resilience of human activity in all situations that may arise.

It must be noted that the design of active (automatic) fire protection systems will be unavailable for short periods of time based on maintenance or surveillance procedural needs to maintain the respective system. For example, a fire detection activated fire suppression system has maintenance needs for both systems that could temporarily make the overall system unavailable. Appropriate compensatory measures are needed during these short outage intervals. In addition, the design of the number of fire detectors and fire sprinklers located in the protected area affects the rapidness and reliability of the notification for both the internal fire brigade and external fire department.

3.3.2 Detection and alarm system

Automatic or manually activated fire protection systems require a detection and alarm system. These monitoring systems alert plant personnel to take necessary actions to minimize fire damage or automatically start the connected fire suppression system, if any. The fire response personnel, both on-site and potentially off-site, are activated to begin taking appropriate actions based on the severity of the alarm.

Timely post-fire safe shutdown actions are dependent on prompt notification of fire location. Property losses are minimized, safety of personnel is enhanced, and limiting community impact from an NPP fire is a key element for fire detection and alarm. Global area coverage of the facility is beneficial to be considered, even if there is no redundant safe shutdown equipment or significant fire load in certain areas.

Some key components of fire detection and alarm provided in the control room are to provide a continuously manned location to initiate necessary actions for emergency plan, off-site fire response, post-fire safe shutdown actions, and oversight guidance between the fire-fighting activities and the post-fire safe shutdown actions.

There are generally two approaches to the placement of fire detection:

— Point fire detection is based on good judgment, such as addressing post-fire SSD components, and past practices to predict where fire hazards are likely to occur and cause unacceptable damage;

— Grading approach fire detection is based on defining fire detection performance requirements for sensitivity, response time, and availability based on risk of fire escalation.

3.3.2.1 Fire detection system

In general, FHA and regulatory requirements determine the scope of fire detection and suppression in the plant, whereas the applicable industry codes and standards, such as NFPA, provide the details for type, proper installation, and maintenance/testing for the systems and components. Fire detection needs to be provided in areas that are identified to contain, or present an exposure fire hazard, to post-fire SSD equipment, or SSCs important to safety. However, in some member states, global coverage is beneficial to be considered to address changing plant storage conditions and temporary changes, as well as redundant detector systems in rooms with reactor safety equipment. These fire detection systems need to be capable of operating with or without off-site power.

Full area, or partial area, coverage is appropriate to be provided in fire compartments where it is identified in the FHA to be needed. However, any partial area fire detection can be justified with the FHA to ensure adequacy of the design, similar to the fire cell justification versus fire compartment. The fire detection and alarm system options provided in Ref. [5] and Ref. [1] includes the following objectives:

— The areas that contain equipment important to safety ought to have automatic fire detectors that alarm and annunciate in the control room;
— Fire detection and alarm systems ought to comply with the requirements of standard(s) based in your country;
— Where zoned fire detection systems are used in a given fire compartment, then local means may be used to identify which detector zone has actuated;
— Fire alarms, similar to other plant system alarms, ought to be distinctly different sounding to help identify them from other alarms;
— Backup power supplies are appropriate to be provided for the fire detection system and for any electrically operated control valves for automatically operated fire suppression systems. This can be accomplished by using normal off-site power as the primary supply, with a battery supply as a secondary supply, and by providing the capability for manual connection to the emergency power bus during the loss of off-site power. Such connection ought to follow the applicable guidance of national standards;
— In areas of high seismic activity, plants need to consider the need to design fire detection and alarm systems to function following a safe shutdown in the event of an earthquake;
— The fire detection and alarm systems are beneficial to be able to retain their original design capability for: (a) natural phenomena of less severity and greater frequency than the most severe natural phenomena; and (b) potential manmade site-related events that have a reasonable probability of occurring at a specific plant site.

3.3.2.2 Fire detector types

Fire detectors are the fundamental component for this second line of defence to help ensure prompt firefighting activities as soon as possible. The selection of detector type and location depends on many factors, including area size, configuration, inherent fire hazards, occupancy, combustible loading, and the importance of the protected assets. The diverse types of fire detection systems include smoke detectors (ionization and/or photoelectric), heat detectors, and radiant energy (flame) detectors as well as others. More details about the various types are discussed in Ref. [1] Appendix V.

3.3.3 Water supply system

The fire protection water supply system needs to meet the following criteria, as well as other more detailed issues, from Ref. [1] and Ref. [5]:

- The fire-water supply is appropriate to be defined by the plant license or applicable national standard(s). Environmental considerations can be addressed during this process;
- Two separate, reliable freshwater supplies are desired. Saltwater or brackish water may not be used unless all freshwater supplies have been exhausted. Closed water systems may be used in some countries;
- The fire-water supply can be calculated based on the largest expected flow for a reasonable time period expected for fighting the fire, plus the largest design demand of any sprinkler or deluge system;
- If tanks are used for a closed water supply system, the capacity of the tanks are appropriate to be in accordance with national standard(s). Redundancy and independence need to be provided such that either tank may be used, or both, depending on the fire suppression needs. Failure involving filling or draining one tank may not adversely affect the redundant tank;
- Common water supply tanks, freshwater lakes, or ponds are acceptable for fire and sanitary or service water storage as long as the design and/or administrative controls ensure that minimum fire-water volumes are maintained, and redundant suctions are provided;
- The design may consider external events such as earthquakes and how this could affect the system installation and availability for use (see section 5.6.1.2 for the Kashiwazaki Kariwa incident).

3.3.3.1 Fire pumps

Fire pump installations, if needed to meet pressure or flow requirements, need to be redundant and independent from each other and meet the following criteria:

- Ensure that 100% capacity is available, assuming failure of the largest pump or loss of off-site power (e.g., three 50% pumps or two 100% pumps) using either electric motor or diesel engine powered pumps;
- The seismic impacts can be considered for options for the fire-water supply system (see section 5.6.1);
- Individual fire pump connections to the yard fire main loop are separated with sectionalizing valves between connections. Each pump and its driver and controls are located in a room separated from the remaining fire pumps by an appropriately rated fire wall per the FHA;

- The fuel for the diesel fire pumps is separated so that it does not provide a fire source that exposes equipment important to safety;
- Alarms or annunciators located in the Control Room are appropriate to be provided to indicate pump running, driver availability, failure to start, and low fire main pressure.

3.3.3.2 Fire mains

A fire main loop may be installed to furnish anticipated water requirements, normally this piping would be located underground and would not be used for other water supplies (e.g., service or sanitary water). The pipe material and water treatment needs are key design considerations, with long-term maintenance as one of the parameters for periodic inspection and flushing. The loop configuration from the separate fire pumps, or water supplies, allows for at least two flow paths from the water source. A common yard loop may serve multi-unit NPP sites if cross-connected between units. Sectional control valves permit independence of the individual loop around each unit. For multiple-reactor sites with widely separated plants, separate yard fire main loops may be used. For example, from Ref. [4] separated NPP units approaching 1.6 kilometer (1 mile) or more apart.

Connections to the fire main loop for sprinkler systems, manually operated hose stations, and yard hydrants will require extensive valve isolation options. The valving (control and sectionalizing valves) will require either electrical supervision, with Control Room indication, or administrative control (e.g., tamper proof seals or physical locks) that will be periodically inspected to ensure water supplies are available when needed. The valve locations ought to ensure that individual component isolation is possible without shutting off the supply to both primary and backup fire suppression systems to allow maintenance activities. Additional details are provided in Ref. [1] and Ref. [5].

3.3.4 Fire suppression system

Fire suppression systems may be installed as based on the FHA to control the reasonably sized fire starting near a given system in order to protect redundant systems or components necessary for safe shutdown and SSCs important to safety.

In areas of high seismic activity, it would be beneficial for plants to consider the need to design the fire suppression systems to be functional following a safe shutdown in the event of an earthquake.

The fire suppression systems are appropriate to be able to retain their original design capability for: (a) natural phenomena of less severity and greater frequency than the most severe natural phenomena; and (b) potential manmade site-related events that have a reasonable probability of occurring at a specific plant site. Periodic updates to these geographic and man-made site related events may be considered.

For fire suppression systems that use metal plates for heat collection above individual sprinkler heads that are located well below the ceiling of a fire compartment (e.g., at some intermediate height in the room, below a ceiling-mounted pipe and cable tray), plants ought to confirm that this design will ensure acceptable actuation times. The objective of such metal plates is to reduce the system response time by collecting heat to more effectively activate the sprinkler head. However, this objective is often not met in actual practice.

General example data for fire suppression systems may be found in APPENDIX I.

3.3.4.1 Water-based systems

Water-based systems (sprinkler or spray systems) are suitable for most types of solid fuel-based fires (generally not appropriate for flammable liquid-based fires), but equipment located in the spray pattern may need protection from the water. An example would be electrical cabinets that may be adjacent to a fire could be damaged by the water spray, even if the fire is contained by the same water spray. In addition, floor drains needed to remove the water from the area will need to be sized and routed to avoid water-based damage (e.g., flooding or wetting) to equipment located outside of the fire damaged compartment. Water mist suppression systems may be useful in specialized situations, particularly in those areas where the application of water needs to be restricted.

Certain fires, such as those involving flammable liquids, respond well to foam suppression. Plants ought to consider the use of foam sprinkler and spray systems, which need to conform to appropriate standards.

3.3.4.2 Gaseous fire suppression

Gaseous fire suppression systems, unlike water-based systems, could create habitability issues upon discharge to personnel located in the area. The primary function of gaseous fire suppression is often to reduce the oxygen content to preclude a continuation of the fire in the area for a long enough time to ensure no reflash occurs. This loss of habitability would affect any personnel located in the area, or requiring passage through the area (e.g., fire brigade or operations personnel). Pre-discharge alarms, a discharge delay, and provisions for local disarming with strict administrative controls while personnel are located with the area are required and specified by appropriate standards, such as NFPA. The principle groups of gaseous fire suppression systems include carbon dioxide (CO_2), Halon, and clean agents (alternatives to Halon).

Where total flooding gas extinguishing systems are used, area intake and exhaust ventilation dampers are appropriate to be controlled, in accordance with suitable standards, to maintain the necessary gas concentration for a suitable amount to time without over-pressurizing the compartment. The adequacy of gas suppression systems and protected-area boundary seals to contain the gas suppressant needs to be tested.

Manually actuated gaseous suppression systems ought not be used as the primary suppression system for protecting SSCs important to safety. They are acceptable as a backup to automatic water-based fire suppression systems.

Plants ought to ensure preventive maintenance and testing of these gaseous fire suppression systems, including verifying agent quantity and quality. Periodic monitoring of the strict administrative controls used for disarming automatic systems while personnel are in the area are needed to ensure inappropriate disabling when no personnel are located in the area.

3.3.5 Manual suppression systems and equipment

Manual firefighting capability, as a backup to existing automatic fire suppression systems or coverage throughout the NPP premises, is needed to limit the extent of fire damage as per the national standards. Standpipes, hydrants, and portable equipment consisting of hoses, nozzles, and portable extinguishers ought to be provided for use by properly trained firefighting personnel. See section 6.3 for more detail on personnel training.

3.3.5.1 Standpipes and hose stations

Interior firefighting by trained fire brigade members is made possible by properly located manual hose installations, as specified in the FHA, supplied on each elevation by properly sized standpipes. Standpipes are appropriate to be provided with hose connections equipped with woven-jacket, lined fire hose and suitable nozzles. These systems ought to conform to national standards for sizing, spacing, and pipe support requirements for standpipes. For example, from Ref. [5] a maximum hose length of 30.5 m (100 ft) of 38 mm (1.5 in) hose sized per NFPA standards. Water supply calculations need to demonstrate that the water supply can meet the standpipe pressure and flow requirements of national standards.

In general, two hose stations would be needed for each fire compartment to ensure the fire location would not interfere with access. If the fire compartment is large enough then several hose stations could be needed to ensure full area coverage from fire hazards that could affect equipment important to safety or used for post-fire safe shutdown. Several types of hose nozzles are available to support firefighting needs and minimize equipment damage or harm to firefighting personnel. An assessment is appropriate to be made to ensure the proper type (spray, straight stream, fog, or combination) is provided for each fire compartment.

3.3.5.2 Hydrants and hose houses

Outside manual hose installations need to be adequate to provide an effective hose stream to any on-site location where fixed or transient combustibles could jeopardize equipment important to safety or used for post-fire safe shutdown. Hydrants ought to be installed in accordance with the national standard on the yard main system. For example, from Ref. [5] the spacing of approximately every 76 m (250 ft) is used for NFPA standards. A hose house equipped with hose and combination nozzle and other auxiliary equipment can be provided, as needed, per the national standard. Also, from Ref. [5] hose house spacing of at least every 305 m (1000 ft) is used for NFPA standards. Alternatively, a mobile means of providing hose and associated equipment, such as hose carts or trucks, may be used. When provided, such mobile equipment needs to be provided as per the national standard. For example, the equivalent of three hose houses can be provided as per NFPA standards and maintained to be readily available for firefighting activities.

3.3.5.3 Manual foam

For flammable and combustible liquid fire hazards, plants ought to consider the use of foam systems for manual fire suppression protection. For example, these systems need to comply with the requirements of national standards, such as NFPA.

3.3.5.4 *Fire extinguishers*

Fire extinguishers need to be provided in areas that contain or could present a fire exposure hazard to equipment important to safety or used for post-fire safe shutdown and be appropriate for the type of potential fire hazard. Extinguishers may be installed with due consideration given to possible adverse effects on equipment in the area. Mounting details need to include seismic or other environmental considerations.

The selection of the best portable fire extinguisher for a given situation depends on the several factors, as outlined in Ref. [12]. Several types of portable extinguishers are available and include dry chemical, CO_2, water, Halon, as well as others. Considerations for the effect of the extinguishing agent on the equipment in the area, ability to extinguish the type of fire expected, including environment factors.

Portable fire extinguishers may be used to fully extinguish limited size fires, or to delay the growth of fires until the fire brigade can respond. They are needed in areas, even if other automatic or manual firefighting options are available, as part of the defence in depth used for fire protection.

Conspicuous markings that readily identify the suitable fire extinguisher are particularly important where fire extinguishers are grouped or where multiple fire hazards are present in an area. This allows personnel to more quickly determine the appropriate unit to be used under stressful conditions.

Multiple classification systems exist in countries with different designations for the various classes of fire. The United States of America (USA) uses the NFPA system, while Europe uses the European standard, classification of fires. An example of classification can be found in Ref. [12] where fires are classified into 5 types: class A, B, C, D, and K depending on the type of fire (ordinary combustible, flammable liquid, electrical, metal or cooking media).

3.3.5.5 *Fixed manual suppression*

Some fixed fire suppression systems may be manually actuated. Manual actuation is generally limited to water spray systems and ought not to be used for gaseous suppression systems, except when the system provides backup to an automatic water suppression system. A change from an automatic system to a manually actuated system can be supported by an appropriate evaluation.

3.4 INSPECTION, TESTING, AND MAINTENANCE

Inspection, testing, and maintenance (ITM) would be beneficial to meet the safety objectives of licensing of the NPP and maintain the performance level of operation and reliability of fire protection in the NPP. An overview is provided in NS-G-2.1 Ref. [2] including the scope desired with additional insights provided below.

The ITM of active systems is required to provide a high degree of reliability for the operation and performance of the fire protection system.

It would be beneficial for the plant to establish fire protection administrative controls to address the following issues:

- Qualified personnel designated to inspect, test and maintain fire protection features;
- An administrative process in place for the management of fire risk due to impairments to fire protection provisions such as: egress paths, emergency lighting, notifications systems, fire barriers, fire detection, and fire suppression systems. Compensatory measures established where areas are impaired, or systems disarmed during maintenance (e.g., fire watches).

3.4.1 Ownership and qualifications

It would be beneficial for a qualified member of the management team to be responsible for managing the FPP and assuring that an adequate budget is provided for fire protection maintenance. A person or department accountable for ITM will be responsible for:

- Creating an ITM programme;
- Documenting ITM;
- Documenting alternate measures during impairment of fire equipment;
- Maintaining records of ITM and following up on corrective actions for deficiencies identified during ITM.

The ITM of fire protection systems by qualified personnel are essential to ensure the operability of the systems during an emergency.

3.4.1.1 Fire protection focal point

The person assigned the responsibility of managing the integrity of fire protection equipment and systems must have a general knowledge of the facility and its fire protection needs, be familiar with the facilities fire protection systems, and have access to resources to ensure the equipment and systems are operable.

Inspection personnel

Facility personnel who perform inspections on fixed fire protection systems must be knowledgeable of the systems and have received training on the inspection protocols.

Testing and maintenance personnel

Facility personnel who perform testing and maintenance on fire protection equipment and systems must be experienced and knowledgeable in the systems and on the protocols for testing and maintenance. Knowledge can include work history, educational experience, craft certification, manufacturer certification, field verification, and job assessment and testing. Testing and maintenance personnel may be pump mechanics, pipe fitters, instrument technicians, electrical technicians, millwrights, fire protection personnel or other qualified personnel.

Fire protection service companies

Many facilities outsource either all or part of the ITM functions to fire protection service companies. These companies perform a variety of services, including inspection of portable and fixed systems, flow test of water systems, operational test of portable equipment, testing of fixed powder system, maintenance and repairs of portable and fixed systems, and design and installation of new systems.

It is important that the outside service company meet the facility pre-qualification criteria. As part of the review, the facility pre-qualification must determine if the service company is knowledgeable and experienced in the types of fire protection systems they will be servicing. Some member states have licensing laws that require the service company designate a responsible managing employee who is licensed by the state. It would be beneficial for the service company to provide evidence that the personnel performing the ITM are qualified to perform the work.

The qualification may include licenses and craft certification certificates issued by a recognized issuing authority.

3.4.2 ITM programme and activities

An ITM programme will be created to address the fire protection systems in the NPP. The ITM programme is to address:

- Actions/features to be inspected, tested and maintained;
- The frequency of visual inspections and actual testing of equipment;
- Frequency of the inspections, tests and maintenance actions;
- Equipment required to meet the fire needs analysis;
- Level of protection required by the original fire hazard assessment.

The following systems, as described in Ref. [2] are subject to ITM and examples of detailed ITM requirements for fire water systems can be found in international or national fire codes and standards. Examples of insights from existing programs are provided in the following sections.

3.4.2.1 Sprinkler systems

Sprinkler protection includes:

- Wet sprinkler systems;
- Dry pipe sprinkler systems;
- Foam water sprinkler systems;
- Pre-action sprinkler systems;
- Water curtains;
- Transformer spray protection.

The ITM for sprinkler protection is required to address:

- Obstruction to sprinkler discharge;
- Unobstructed access to the fire protection equipment;
- Valves including control valves, backflow preventers and pressure controlling;
- Spare sprinkler heads, including confirming temperature, orifice size and operating temperature;
- Presence of a wrench in the spare sprinkler box;
- Ensure that no services or equipment have been supported on the fire protection piping.

3.4.2.2 Standpipe and hose systems

- Hoses and nozzles ought to be inspected;
- Hoses ought to be inspected and re-racked periodically (i.e. annually);
- Hose valves ought to be inspected for leakage;
- Pumps supplying standpipe and hose systems ought to be tested to confirm flow and pressure;
- Hose cabinets and hose stations and access to them ought to be maintained clear and unobstructed;
- These provisions are also applicable to fixed (stationary) and portable monitors and turrets.

3.4.2.3 Fire pump

- Fire pumps ought to be inspected;
- Fire pumps ought to be tested to confirm flow and pressure;
- Fire pumps ought to be tested at rated flow, 150% of rated flow and at rated pressure;
- Drivers for fire pumps such as diesel-driven engines ought to be inspected and maintained.

3.4.2.4 Fire hydrants and water supply systems

- Fire hydrants ought to be inspected;
- Fire hydrants ought to be flow tested on a regular basis;
- Fire hydrants ought to be drained before freezing weather;
- Where appropriate, antifreeze ought to be pumped into the fire hydrant barrel to prevent freezing;
- Water supplies ought to be maintained in an operating condition:

    - Where the quantity of water for firefighting is maintained by pumping equipment and measuring devices (float valve), that equipment and measuring devices ought to be inspected and maintained on a periodic basis;

- Unobstructed access ought to be maintained to fire hydrants, yard valves and fire department connections;
- Fire hydrants ought to be identified so as to be readily visible to responding fire crews:

- Where appropriate, means ought to be provided to locate and identify fire hydrants in inclement weather, snow and in poor lighting.

3.4.2.5 Fire alarm and emergency voice communication systems

— Fire alarm and emergency voice communication systems ought to be maintained in an operational condition;
— Where credited as a part of the fire hazard assessment, this ought to include plant communication systems, radios and public address systems;
— Fire alarm and emergency voice communication systems ought to be inspected and tested on a periodic basis, to confirm that the system is operating;
— It would be beneficial for the testing to include:

- Notification devices (audible and visual devices);
- Activation devices (smoke detectors, heat detectors, very early smoke detection (VESDA) type (incipient) detection, flow and pressure activation devices);
- Supervisory devices (valve and other supervisory devices);
- Emergency power supplies;
- Central station monitoring connections;
- Notification to emergency first responders.

3.4.2.6 Clean agent systems

— Clean agent systems are required to be subject to ITM based on the manufacturer's recommendation for the specific system;
— Actuating devices and systems are subject to ITM in accordance with the fire alarm provisions.

3.4.2.7 Fire separations, fire barriers and closures

— The integrity of fire separations and fire barriers ought to be maintained;
— Penetrations of fire separations and fire barriers ought to be reviewed and approved;
— Approved penetrations of fire separations and fire barriers ought to be protected with:

- An approved fire stop system;
- An approved closure (fire door, fire damper or fire shutter);
- Approved penetrations of fire separations and fire barriers, to be inspected and tested on a periodic basis;

— The fire protection rating of a closure in a fire separation or fire barrier needs to be equal to the fire rating of the fire separation or fire barrier, or justified by an analysis, as needed;
— Operational components of a closure (such as hinges, latches, self-closing devices) needs to be maintained in an operational condition;
— Fire separations, fire barriers and closures[1] ought to be inspected on a periodic basis.

---

[1] Closures includes opening protective components such as doors, shutters and dampers

3.4.2.8 *Portable fire extinguishers*

- Portable fire extinguishers ought to be maintained in an operational condition;
- Portable fire extinguishers ought to be inspected on a periodic basis;
- This inspection ought to confirm pressure, weight of agent, actuator, hose and nozzle;
- Portable extinguishers ought to include wheeled portable extinguishers.

3.4.2.9 *Emergency lighting*

- Needs to be maintained in an operational condition;
- Needs to be inspected on a periodic basis;
- Needs to be tested on a periodic basis to confirm that it will operate for the required/design duration;
- Other lighting equipment credited in the fire hazard assessment such as flashlights, portable lighting and emergency task lighting ought to be subject to the same ITM as fixed emergency lighting.

3.4.3 Documentation and alternative approach

It is beneficial that ITM records be maintained and retained. Records ought to identify the person responsible for witnessing/conducting the ITM and be available for review by the AHJ/Licenser. Records of ITM need to be kept for a time period which is both acceptable to the AHJ and provides historical data on equipment performance.

Keeping ITM records for an extended period of time may assist in alternate measure submissions to the AHJ to substantiate:

- Alternate ITM protocol such as the frequency between ITM of a piece of equipment or system; or
- The number of devices to be inspected or tested in a given time period.

Alternate approaches to ITM can be proposed for review and approval by the authority. Alternate approaches need to demonstrate an equivalent level of safety and it would be beneficial to take into account:

- Past system performance;
- Measures to be implemented to confirm on-going performance of systems;
- Statistical data, where appropriate.

3.4.4 Examples of inspection and testing requirements

Examples of inspection and testing requirements for sprinkler system ITM can be found in TABLE 1. This information, as well as for TABLE 2, TABLE 3 and TABLE 4 are specified from text found in NFPA 25, "Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems." (See Ref. [13]).

TABLE 1. SPRINKLER SYSTEM ITM [13]

Item	Frequency
— Inspection	
• Gauges (dry, pre-action, and deluge systems)	Weekly/monthly
• Water flow alarm devices	Quarterly
• Valve supervisory alarm devices	Quarterly
• Supervisory signal devices	Quarterly
• Gauges (wet pipe systems)	Monthly
• Hydraulic nameplate	Quarterly
• Buildings	Annually (prior to freezing weather)
• Hanger/seismic bracing	Annually
• Pipe sprinklers	Annually
• Information sign	Annually
• Fire department connections	Annually
• Obstruction, internal inspection of piping	5 years
— Test	
• Water flow alarm devices	
o Mechanical devices	Quarterly
o Vane and pressure switch type devices	Semi-annually
• Antifreeze solution	Annually
• Gauges	5 years
• Sprinklers	
o Extra-high temperature	5 years
o Fast response	20 years; every 10 years thereafter
o Dry	10 years; every 10 years thereafter

Examples of inspection and testing requirements for standpipe and hose ITM can be found in TABLE 2.

TABLE 2. STANDPIPE AND HOSE ITM [13]

Item	Frequency
— Inspection	
• Piping	Annually
• Cabinet	Annually
• Gauges	Weekly
• Hose, and Hose storage device	Annually
• Hose nozzle	Annually and after each use
• Hydraulic design information sign	Annually
— Test	
• Hose storage device	Annually
• Hose	5 years/ 3 years
• Hydraulic test	5 years
• Flow test	5 years

TABLE 2. STANDPIPE AND HOSE ITM [13]

Item	Frequency
— Maintenance	
• Hose connections	Annually
• Valves (all types)	Annually/ as needed

Examples of inspection and testing requirements for fire pump ITM can be found in TABLE 3.

TABLE 3. FIRE PUMP ITM [13]

Item	Frequency
— Inspection	
• Pump house, heating ventilating louvers	Weekly
• Fire pump system	Weekly
— Test	
• Pump operation (No-flow condition)	
○ Diesel engine driven fire pump	Weekly
○ Electric motor driven fire pump	Monthly
• Flow condition	Annually
• Fire pump alarm signals	Annually
— Maintenance	
• Hydraulic	Annually
• Mechanical transmission	Annually
• Electrical system	Varies
• Controller, various components	Varies
• Motor	Annually
• Diesel engine system, various components	Varies

Examples of inspection and testing requirements for water storage tank ITM can be found in TABLE 4.

TABLE 4. WATER STORAGE TANK ITM [13]

Item	Frequency
— Inspection	
• Water temperature	
○ Low temperature alarms connected to constantly attended location	Monthly
○ Low temperature alarms not connected to constantly attended location	Weekly
• Tank	
○ Exterior	Quarterly
○ Interior – without corrosion protection	3 years
○ Interior – all others	5 years
• Support structures	Quarterly

TABLE 4. WATER STORAGE TANK ITM [13]

Item	Frequency
• Catwalks and ladders	Quarterly
• Hoops and grillage	Annually
• Painted/ coated surfaces	Annually
• Expansion joints	Annually
— Test	
• Tank heating system	Prior to heating season
• Low water temperature alarms	Monthly
• High temperature limit switches	Monthly
• Water-level alarm	Semi-annually
• Level indicators	5 years
• Pressure gauges	5 years

4 FIRE PREVENTION ACTIVITIES

Since fire hazard is a major contributor to a plant's operational safety risk, control of combustible materials and ignition sources are an essential part of a fire prevention programme. The fire prevention programme in an NPP is focused on SSCs important to safety which includes safety related areas where it is necessary to prevent fires from starting or, if a fire starts, to keep the fire as small as possible. An overview of the need to control combustible materials and fire prevention design measures is provided in Ref. [2], chapter 6 and Ref. [1], chapter 4 with some additional insights provided below.

Each plant ought to develop a fire prevention strategy and maintain it useful throughout the life cycle of the plant. The fire prevention strategy could be given to and used by a fire protection expert for expansions at the plant. The fire prevention strategy ought to demonstrate how it is integrated into the plant's overall fire protection philosophy.

A common aspect of any fire prevention strategy is defining how hazards are managed and describing the order of priority for managing those fire hazards.

A fire prevention programme ought to research fire hazards throughout the NPP to identify them, determine how to reduce them when possible, manage the ones that cannot be removed to limit their impact. The point of this activity is to ensure protection of SSCs important to safety or used for post-fire safe shutdown. If fires can be prevented in these critical areas, then fire protection DID does serve as a fail-safe backup if a fire starts due to human or equipment errors.

4.1 CONTROL OF COMBUSTIBLE MATERIALS

A programme is necessary for identifying all combustible materials in the plant and making workers aware of the hazards of these materials and the necessary precautions to be taken to prevent or control fire hazards to SSCs important to safety. Combustible materials hazard identification and information gathering is an essential element of fire prevention. The hazardous properties of all substances used in the plant are needed in order to develop the appropriate design, routine handling practices, and fire prevention plan.

While the flammability of materials is clearly important for fire prevention, there are other properties that are also significant for safe plant operation, such as lubrication, cleaning, filtering, etc.

4.1.1 Combustible materials hazard identification

The development of a combustible materials hazard identification programme is required to obtain knowledge of a material's toxicity and reactivity, as well as flammability. Some key elements of a combustible materials hazard identification programme are:

— Assign responsibility for the programme to determine the physical and chemical properties of each material handled at the facility;

— Collect available information, evaluate the hazardous properties, and identify the relative hazard levels of each substance and any necessary handling precautions;
— Identify those potentially hazardous materials for which important properties are unknown and conduct appropriate material hazards evaluation tests;
— Distribute material hazard information and handling precautions to employees, emergency response organization, local community response agencies, and others as appropriate.

Each plant ought to obtain data about a substance from the chemical manufacturer's material safety data sheets (MSDSs) or from other published sources. In order to identify, evaluate, or respond safely to incidents involving hazardous material brought on-site by contractors, it is also important to include outside contractors in the materials hazard identification programme.

An inventory of flammable and combustible materials needs to be developed for each fire compartment within a plant. This list ought to contain the type, quantity, form of materials, material characteristics, storage configuration, and location.

It is important to document the assumptions used in determining the inventories for the FHA. The inventory list ought to be maintained throughout the life cycle of the plant by the management of change (MOC) process to update the FHA.

4.1.2 Types of combustibles

The typical NPP will have solid, liquid, and gaseous materials that are combustible or flammable, similar to most industrial facilities. The construction materials of concrete and/or steel are non-combustible, but the machinery and equipment located within will require combustibles such as fuels (e.g., gasoline, diesel, propane, or natural gas), lubricants (oils or grease), hydraulic oils, thermal or electrical insulation, plastics, filter material (e.g., charcoal, oil bath, etc.), packaging material, and cleansing materials. Some flammable gases are used for cooling, welding, or a product of processing such as hydrogen, while oxygen is also involved even though it is not a flammable gas, but an oxidizer requiring similar controls.

Temporary but predictable and repetitive concentrations of flammable and combustible materials ought to be considered as discussed in Ref. [2], section 6.6. Typical examples include one or more of the following:

— Replacement of lubricating or hydraulic oils;
— Repainting equipment or structures;
— Replacement of combustible filter materials;
— Scaffolding or dunnage necessary to maintain or replace equipment;
— Spare or new equipment in shipping crates or boxes awaiting installation.

4.1.3 Control of combustibles

4.1.3.1 General

The FHA is a good summary location for the realistic fire loading identified in each fire compartment. However, more detailed supporting documents, such as fire loading detailed calculations, need to be provided to allow updates as plant changes are made through the life of the plant. The fire compartment margin of safety between the realistic fire loading and the fire compartment maximum permissible fire loading is beneficial.

A process under the FPP to intercept combustibles prior to delivery into the facility ought to be implemented to help ensure fire loading in compartments identified as important to safety are maintained as low as reasonably practicable. The combustible interception programme is most effectively implemented in the department responsible for incoming receipt and inspection where non-essential combustible material is removed (including substitution of non-combustible pallets) prior to transporting into the NPP.

Plant administrative controls (procedures) ought to be established and implemented to periodically inspect and control the delivery, storage, handling, transport and use of flammable and combustible solids, liquids, and gases in areas identified as important to safety. The procedures need to be established in accordance with national practice standards, such as NFPA.

Flammable and combustible liquid storage and use needs to be in accordance with the national standard. Where oil-burning equipment, stationary combustion engines, or gas turbines are used, they need to be installed and used in accordance with the national standard(s). Flammable and combustible liquid and gas piping are in accordance with industry standards such as, for example, ANSI B31.1, code for power piping, or ASME boiler and pressure vessel code, section III, as applicable.

4.1.3.2 Transient combustible loading

The control of temporary fire loads in the plant, other than those that are an inherent part of the operation, ought to be restricted to designated storage compartments or spaces. Only non-combustible scaffolding, decking, panels or flame-retardant tarpaulins or approved materials of equivalent fire-retardant characteristics ought to be used. Particular attention is given to the elimination or control of plastics, wood, or cardboard.

Plant administrative procedures, such as issuing work permits, ought to be established and implemented to provide effective control of temporary fire loads in areas identified as important to safety during maintenance and modification activities lasting longer than one shift or when left unattended. The fire prevention personnel that are responsible for reviewing proposed work activities for potential temporary fire loads in order to determine whether the proposed work activity is permissible before work may begin. The review ought to specify any additional compensatory fire protection measures that are needed (such as the provision of portable fire extinguishers and/or the use of fire watch personnel, as appropriate).

All combustible packing containers ought to be removed from the plant area where it is transported to upon delivery immediately following unpacking. No such combustible material is to be left unattended during lunch breaks, shift changes, or other similar periods without an impairment issued. Loose combustible packing material such as wood or paper excelsior, polyethylene sheeting, or expanded polystyrene ought to be placed in metal containers with tight-fitting, self-closing metal covers.

Fire protection personnel ought to conduct periodic plant walk-through inspections, for example weekly, to confirm implementation of required fire prevention controls. During major maintenance operations or plant refueling outages, the frequency of these plant walk-throughs ought to be daily. The results of these walk-through inspections are to be documented and retained for a suitable time designated by national standards or the plant license.

For example, when combustibles are stored in a controlled storage area, there exist measures to reduce fire consequences (Ref. [14]), such as:

- Combustibles stored in fireproof storage facilities or containers;
- Combustibles stored in a place surrounded by concrete walls and ceilings effective in preventing fire spread;
- Combustibles stored in metallic cases;
- Combustibles covered with non-flammable sheets without gaps;
- Other measures equivalent to the effectiveness of the above.

FIG. 5 shows examples of fireproof storage facility and container (Ref. [14]):

FIG. 5. Example of fireproof storage facility and fireproof storage container (left to right)

The systematic approach incorporating the FHA for the storage and control of combustibles can limit the risk of fire and can also generate additional space for such storage that protects it from external fire for a period of time. See also section 5.5.3 for the application of the FHA.

4.2 CONTROL OF IGNITION SOURCES

A fundamental element of fire prevention as part of the DID principle is the control of ignition sources. It is beneficial for the process to be designed, implemented, and operated to minimize or prevent the release or spill of flammable gases, liquids, or combustible dusts, as well as eliminate or control of ignition sources. The basic controls for these unwanted ignition sources are described in Ref. [2], sections 6.9 through 6.17 and are summarized as:

- Control of hot work (e.g., welding, soldering, etc.);
- Control of personal ignition sources (e.g., heaters, cooking, smoking materials, etc.);
- Control of static electricity and stray electrical currents (temporary wiring);
- Electrical area classification.

This process ought to be implemented using procedures to control daily personnel activities, periodic inspections, or maintenance and modification activities to minimize the potential for an ignition source and combustible material to be present at the same time. Compensatory measures may be needed in cases where an ignition source is introduced into an area using fire watch personnel trained in the use of portable extinguishers. Work activity may be prohibited in areas where redundant SSCs important to safety or systems needed for post-fire safe shutdown if the redundant features are out of service in a separate fire compartment. Overall plant restrictions on smoking, use of open flames for testing, use of portable heaters, cooking appliances, candles, or temporary wiring ought to be included. As noted below hot work activities will require strict controls.

4.2.1 Hot work

Operating, maintaining, repairing, and modifying a typical process facility in an NPP frequently involves activities that produce sparks or use flame. The portability of spark and flame producing equipment and its inappropriate or careless use in areas not specifically designed for its safe use can increase the likelihood of a fire.

Temperatures sufficient to start fires or ignite explosive materials may come from a number of sources including:

- Open flame of a torch used for heating or thawing process lines;
- Torch cutting;
- Welding;
- Improperly applied electric arc welding grounding clamps;
- Molten slag or metal that flows from the work piece;
- Improperly handled soldering iron or propane torch;
- Grinding sparks that fly from the work;
- Electric motor-powered hand tools;
- Portable heaters;
- Forklift trucks or other industrial powered vehicles not rated or classified for use in a potentially hazardous area;
- Vacuum tank trucks removing spilled flammable/combustible material;

— Roofing installation or repair using hot-mopped asphalt or using open-flame heating devices to seal roofing sheet membrane seams.

The above is a listing of just a few sources, there are many others.

Diesel engines are used periodically at most sites for welding, air compressors, etc. These engines need to be remotely sited or provided with flame arrestors, insulation on hot surfaces/exhausts, etc.

Painting or cleaning work using volatile organic solvents also have a risk of generating flammable gases and heat.

The principal hazard associated with these and other flame-, heat-, or spark-producing work is the introduction of unauthorized ignition sources into areas of the facility without appropriate compensatory measures.

Control of hazards related to portable equipment and hot work requires developing and maintaining a comprehensive hot work procedure.

To ensure that necessary hot work for maintenance, construction, or modifications is done safely to prevent ignition of fires and protect life and property, the hot work control procedure may include the following as a minimum:

— Assigned responsibility for the programme;
— A permit system requiring:

  - Job site to be inspected before work begins;
  - Testing for the presence of flammable vapours and inspection for combustible materials;
  - Personal protective equipment appropriated to the job;
  - Additional temporary protections, e.g., a fire watch with fire extinguisher and emergency notification procedure that includes covering sewer openings, construction of fire boxes of flame-resistant material to contain sparks, monitoring the area after work is completed for a limited time period, etc.;
  - A time limit for the duration of the permit;
  - Signed approval by a designated authorized person;
  - Close-out of work permit;

— Training of personnel;
— Providing/maintaining necessary equipment, e.g., flammable vapour detectors;
— Auditing and periodic review of programme.

At the NPP where construction work or large-scale modification work is being carried out, it is particularly important to monitor the hot work and carefully control activities during welding and fusing work. It those cases, it is important to ensure there are detailed instructions on setting up the monitoring area for fire watch personnel and how to overlap the flame-resistant materials on the floor and ceiling areas, depending on the type of work. It is also important that the operating organization at the NPP qualifies the products to be used such as fireproof tape, any fume collectors and related hoses used by the contractors engaged in the hot work activity. Examples of fire control during hot work can be found in TABLE 5.

TABLE 5. EXAMPLES OF FIRE CONTROL DURING HOT WORK (Ref. [14])

Work classification	Example of protection *(Protection and monitoring levels will be changed depending on the rank)*
Rank 1S Gas welding and other generating slags	Buffer materials, e.g. a non-flammable sheet, shall be place on the inside of the slag pan as necessary, which shall be cooled by spraying water, etc. Floor protection: Double protection with a non-flammable sheet and tin plate. The tin plate shall be bent up 100mm or so.
Rank 1A a. Tungsten inert gas (TIG) welding and other generating little slag b. Gliding and other generating sparks	Perform monitoring (qualified fire watch personnel) Interrupt hot work as necessary and instruct the correction of protection
Rank 1B Burner work and other generating fires	Perform monitoring (qualified fire watch personnel) Interrupt hot work as necessary and instruct the correction of protection
Rank 2 Electric heaters and others	Perform monitoring (qualified fire watch personnel) as needed, provided that monitoring is performed at all times on nights and holidays. Interrupt hot work as necessary and instruct the correction of protection Perform

Warning signs ought to be erected at the entrances to areas containing combustible materials to warn personnel of restrictions or access requirements and of the necessity to permanently control ignition sources (e.g., electrical equipment, hot work, or vehicle).

4.2.2 Personal ignition sources

Controls are required for ignition sources that may be carried into a hazardous area. These ignition sources include any material, object, or device that is potentially incendiary or capable of producing a spark.

Fires in the workplace continue to be caused by matches, lighters, and carelessly discarded cigarettes and other smoking materials that ignite near combustible materials. Control of these potential ignition sources is essential for an effective fire prevention programme. Facility management may consider involving those working in the facility in the development of a policy on smoking and related issues in order to ensure support and compliance.

Personal electronic or electrical devices that may require control are pagers, smart phones, personal digital assistants, and personal radios or music players. Few, if any, of these devices are evaluated to determine if they may be safely used in hazardous areas. Typically, such devices do not claim to be “intrinsically safe” or of “non-incendiary circuit” design.

4.2.3 Static electricity

Sparking potentials from numerous sources of static electricity are best handled by ensuring their electrical charge differential can recombine harmlessly. If potential sparking conditions cannot be avoided, then a means to ensure there are no ignitable mixtures at points where static electric sparks may occur. Plant procedures to address these concerns can include how fluid transfer, blending of powder, use of wet steam, moving nonconductive rubber belts or conveyors, personnel static buildup, and stray electrical currents may cause such discharges or arcing. Personnel awareness is key to minimizing these unexpected ignition sources. A programme to ensure that a well-designed and effective electrical earth-grounding system and equipment bonding system is in place is an essential first step in the control of potential static electricity ignition sources. Such a system must be regularly checked by testing or visual inspection to ensure groundings are fully secured.

4.2.4 Electrical area classification

Electrical equipment can be the source of ignition where flammable materials are handled. Wherever possible, electrical equipment and wiring are best located outside hazardous locations, where electrical sparks could cause ignition potential. Where these ignition sources cannot be located outside the hazardous area, they ought to be controlled by defining electrically classified areas and designing, procuring, and installing equipment accordingly. One national standard divides hazardous location into three classes according to the nature of the hazard:

— Class I Flammable liquids and gases;
— Class II Combustible dusts;
— Class III Easily ignitable materials.

4.3 HOUSEKEEPING

Industrial experience and insurance loss records indicate that poor housekeeping contributes to an increased frequency of loss and greater loss potential. The added quantity and distribution of fuel in the facility caused by poor housekeeping practices can result in the following issues:

— Greater continuity of combustibles that makes fire spread easier and increases the area of involvement;
— Impaired ingress and egress;
— Increased overall combustible loading that provides more fuel to feed a fire and can increase the severity of the fire;
— Increased potential for severe secondary dust explosions when dust accumulates;
— Increased probability of fire;
— Increased probability of spontaneous ignition in residue accumulations or thick dust layers;
— Increased potential that excessive material due to poor housekeeping practices may affect flood drainage paths.

Poor housekeeping may also be a symptom of other fundamental problems, such as careless operation, frequent temporary repairs, and generally inadequate maintenance. These conditions can result in process leaks, releases, and spills, missing or open covers on equipment and electrical panels, unpainted rusting metal, and nonfunctional gauges and instruments.

4.3.1 Housekeeping programme

Proper housekeeping does not just happen. Good housekeeping requires the leadership and wholehearted support of facility management, staff, and operating and maintenance supervision and the cooperation of all employees. Housekeeping administrative controls are specified in Ref. [2], section 6.5 and insights are provided below.

To develop a good housekeeping programme as an element of fire prevention, the following actions can be taken:

- Appoint specific personnel to be responsible for proper housekeeping; participation could be on a rotated basis with a designated chairperson;
- Inform all employees of their authority and responsibility;
- Establish acceptable levels of cleanliness and orderliness in conjunction with the housekeeping committee with particular regard to:
  - Process liquid spills and residue accumulations;
  - Dust control;
  - Storage and handling of combustibles and flammables;
  - Post maintenance cleanup of materials/equipment;
  - Programme for handling empty containers;
  - Blockage of fire protection systems and equipment;
- Require specific personnel to conduct regular periodic inspections of the facility and record results by area;
- Report the housekeeping inspection results by area to recognize improvements and encourage competition;
- Actively demonstrate support of proper housekeeping practices through regular, positive reinforcement. In addition to verbal reinforcements, written commendations and award for individuals, areas, and departments can be effective positive reinforcement.

4.3.2 Process area housekeeping

Inadequate housekeeping controls in laboratories, process, maintenance, storage, or operating areas can result in process waste, leakage, and spillage accumulations that can lead to increased fire losses. Such accumulations are typically from one of several causes:

- Doors left open;
- Dust or other material released from normally closed containers or systems;
- Improper or excessive storage of materials, i.e., materials, including flammables, stored under stairways/escape paths;
- Improper or inadequate removal of accumulated process wastes or residues;
- Leakage of process or lubricating fluids, steam, or condensate;
- Trash, packaging, or debris left because of carelessness;

— Trash, packaging, or debris resulting from an inadequate pickup schedule;
— Unnecessary scaffolding still in place.

Housekeeping practices that allow spilled or released combustible or flammable process materials to accumulate could provide fuel for a fire to start or allow more rapid or vigorous fire spread than protection systems can manage.

4.3.3 Dust control

Areas where combustible powders are handled in bulk quantities or areas containing dust-producing equipment ought to be cleaned on a regularly scheduled basis. Horizontal overhead surfaces, such as tops of beams, stacked cable trays, and concealed or other out-of-sight spaces where dust can accumulate, need to be identified and included in the cleaning schedule or modified to minimize the potential for dust collection.

Using compressed air to blow dust off surfaces is discouraged because dust suspended in the air during blow-down operations may produce a potentially explosive mixture. Vacuum cleaners ought to be used. These may be either portable or attached to a central system. When portable units are used, they need to be appropriately approved for use in any hazardous location at the facility.

4.3.4 Inappropriate storage and handling

Poor housekeeping practices can allow materials, containers, debris, or unused equipment items to be stored, placed, or handled so that they impair fire protection systems. Examples of such inappropriate storage and handling are:

— Open drain lines;
— Leaks on tank roofs;
— Pallets jammed against fire doors that prevent them from closing when needed;
— Materials, particularly combustibles, or equipment placed inside storage tank dikes;
— Materials or equipment blocking access to hose stations or sprinkler control valves;
— Materials or containers stacked or placed so that they block the effective discharge of sprinkler or deluge fire protection systems or fire monitor nozzles;
— Sample storage;
— Trash bins not emptied or removed from process area.

Inappropriate storage of cleaning equipment, drawings/manuals, spare parts, and various other maintenance supplies may not be allowed in switchgear, boiler, compressor, instrument cabinets, and other equipment rooms. Suitable storage closets, spare parts storerooms, and utility rooms ought to be made available for such storage.

Small quantities of flammable or combustible paints, solvents, or cleaning materials, including aerosol cans, ought to be stored in approved flammable liquid storage cabinets. Larger quantities of these materials need to be stored in separate, remote, or fire-rated rooms or areas that will not present a fire hazard to other areas of the facility as specified by appropriate national standards.

4.3.5 Housekeeping and equipment

Poor housekeeping may increase the failure or breakdown of electrical and mechanical equipment. Even without considering the possibility of a resulting fire or explosion, electrical and mechanical breakdowns can result in damage or destruction of major pieces of equipment or injury to personnel. Poor housekeeping can lead to breakdowns in the following ways:

— Accumulation of dust and other debris can create a thermal blanket or block air flow, resulting in inadequate cooling of electrical equipment and cause the equipment to fail or run hotter, thereby reducing efficiency and life expectancy;
— Oil, grease, and other contaminants can damage electrical insulation on cables and in motor windings, resulting in electrical short-circuits and failures;
— Rags and debris provide a fuel source;
— Electrical flashover or short-circuiting in switchgear and other enclosed electrical equipment, as well as corrosion may occur if contaminates such as dirt, dust, soot, or excess moisture are allowed to accumulate;
— Improper isolation practices can lead to flammable fluid spills in plugs and drains.

4.3.6 Cleaning materials

Cleaning materials and their methods of use can present significant and frequently undetected fire hazards. Any cleaning chemical or material brought into a facility ought to be reviewed for potential hazards using MSDS information as a part of the material's hazard identification element of the overall fire prevention programme. Cleaning activities ought not to be allowed to add unreasonable hazards to a facility by proper storage and use.

5 FIRE RISK ANALYSIS

5.1 FIRE RISK ANALYSIS OVERVIEW

5.1.1 Objectives of fire risk analysis

The fire risk analysis objective is to demonstrate that the plant will maintain the ability to perform safe shutdown functions and minimize radioactive releases to the environment in the event of a fire. Fire risk analysis ought to be performed by qualified fire protection and reactor systems engineers. Both of these engineering groups would address in-situ as well as postulated transient fire hazards, as well as determine the postulated damage of a fire in any fire compartment or cell on the ability to safely shutdown the reactor or on the ability to minimize and control the release of radioactive material to the environment.

The analysis needs to specify or identify the necessary measures for fire prevention, fire detection, fire suppression, and fire containment and alternative shutdown capability as required for each fire compartment or cell containing SSCs important to safety that is in conformance with the appropriate guidelines and regulations.

5.1.2 Fire risk analysis concept

This section introduces the concept of the fire risk analysis. Regardless of the requirements of Member States, each country generally performs the following analyses:

- Fire hazards analysis;
- Safe shutdown analysis;
- Fire probabilistic safety analysis.

International operating experience from the 30- to 40-year history of these operating NPPs, has shown that an integrated approach yields an optimized FPP. FIG. 6 depicts this integrated approach for the Fire Risk Analysis concept.

This section will provide examples of successful FPPs and generic guidelines and good practices associated with this topic.

Each of the following sections provides insights and examples of the following:

- Identifying and analyzing fire hazards in the plant (Section 5.2);
- Safe shutdown analysis (Section 5.3): analyses the capability of a safe shutdown in case a fire related emergency;
- Probabilistic safety analysis (Section 5.4): examines performing a fire probabilistic safety analysis;
- Vulnerability determination (Section 5.5): this section analyses vulnerabilities against acceptance criteria to determine the optimal protection strategy.

5.1.3 Fire risk analysis documentation

The fire risk analysis may include the following elements and attributes:

- The applicable regulatory requirements and insights ought to be evaluated and documented for future update as plant changes are made;
- In-situ and postulated transient fire and explosion (although explosions are not addressed here) hazards for each fire compartment ought to be documented. Examples of fire hazards include, but are not limited to, floor/wall coatings, flammable and combustible materials located in the fire compartment, and electrical cable jacketing, as well as other items. This documentation would address the potential for fire spread, and the sources of ignition;
- External exposure hazards from plant site equipment/tanks, support buildings, or nearby vegetation that could potentially expose SSCs important to safety to damage from the effects of fires need to be identified. Depending on the NPP location, wildfire hazards may also be addressed if there is the potential for a wildfire to damage SSCs important to safety (although external fires are not addressed here);
- The scope of automatic fire detection and suppression capabilities ought to be addressed. The effects of lightning strikes may be included in the design of fire detection systems;
- An analysis, either deterministic or risk based, ought to be documented on the potential for SSCs important to safety to be impacted by a realistic fire within each fire compartment. This would include the assessment of fire spread within each fire compartment to define the scope of damage due to the amount of combustible material (in-situ and transient), fire protection features (fire wrap, sprinklers, radiant barriers, separation distance, etc.), potential ignition sources, and physical location of the post-fire SSD equipment in relation to the postulated fire sources;
- Reliance on and qualifications of fire barriers and related penetration fire seals, including fire test results, the quality of the materials and barrier system, and the quality of the barrier installation ought to be described;
- Fire compartment construction (walls, floor, and ceiling materials, including coatings and thicknesses); fire proofing of structural members; area dimensions and volume; normal ventilation and smoke removal capability; and level of congestion as it applies needs to provide sufficient information to determine that fire compartments have been properly selected, based on the fire hazards present and the need for separation of SSCs important to safety;
- Manual fire suppression capability ought to be identified and documented. This may include systems such as portable extinguishers, hose stations, hydrants, fire brigades, pre-fire plans and procedures, fire training and drills, off-site mutual aid, and accessibility of fire compartments for manual firefighting. The location and type of manual firefighting equipment, including, accessibility for manual firefighting may be identified;
- Possible disabling effects of fire suppression systems on post-fire SSD capability ought to be identified and documented. The term “damage by fire” includes damage to equipment from the normal or inadvertent operation of fire suppression systems, such as water damage. The FHA, or other documentation, needs to address the effects of firefighting activities;
- Potentially explosive environments from flammable gases or other potentially energetic sources such as hydrogen processing areas or high voltage electrical cabinets may be identified;

- Inerted containments where a lack of oxygen exists may be identified;
- Fire compartments/cells where adequate separation of redundant post-fire safe shutdown systems cannot be achieved ought to be identified with guidance for where alternative or dedicated shutdown capability is provided.

Concurrent events involving worst-case fires concurrent with non-fire-related failures in safety systems, other plant accidents, or the most severe natural phenomena, do not need to be assumed unless beyond design basis accident (BDBA) analysis indicates this is necessary.

Unrelated fires occurring simultaneously in two or more units at multiple reactor sites need not be assumed. Shared facilities between units and manmade site-related potential fire events that could affect more than one reactor unit (such as aircraft crash/forest fire) ought to be identified and considered.

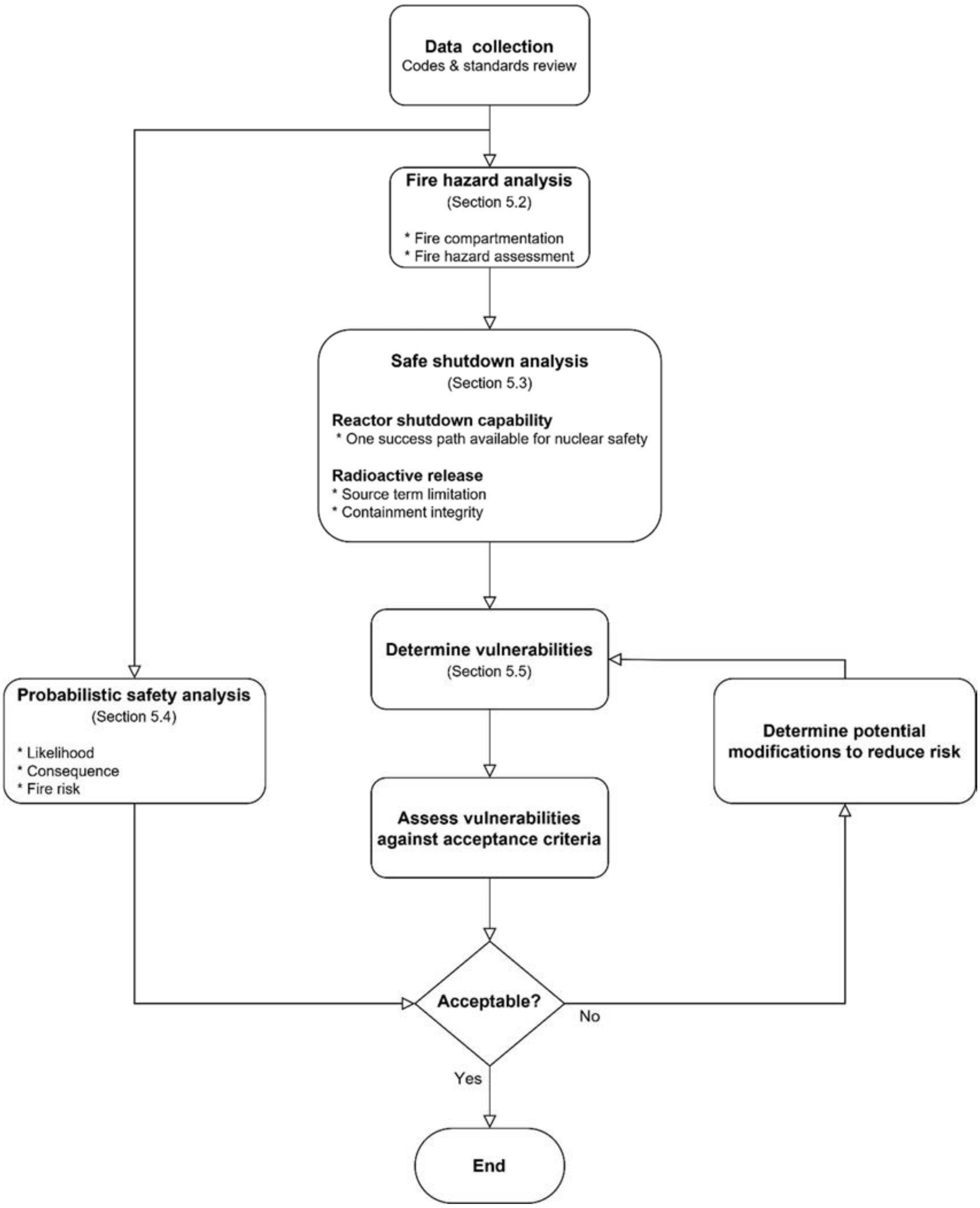

FIG. 6. Fire risk analysis overview

5.2 IDENTIFYING AND ANALYZING FIRE HAZARDS IN THE PLANT

Fire is a dynamic process of interacting physics and chemistry. Predicting what is likely to happen under a given set of circumstances is difficult in the quantitative analysis as well as the qualitative aspect. The fire modeling tools used to quantify variations of fire dynamics range from straightforward hand calculations such as algebraic equations to sophisticated finite element computer codes. It is necessary to understand the advantages and limitations of a specific model in a particular situation to best achieve the required objective. Often the simplified models are used to help set up the more complex models in a more efficient manner.

Constituted of basic elements (see FIG. 7), there are generally two different methods to identify and analyze fire hazards in an NPP for summary in the FHA:

— Establishing a design basis fire;
— Evaluating specific fire scenarios.

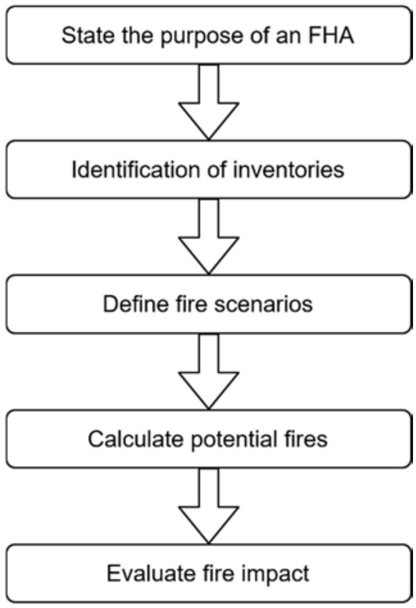

FIG. 7. Basic elements of a fire hazard analysis

5.2.1 Design basis fire

The definition of design-basis fire is one method of evaluating fire hazards in an NPP. If fire breaks out in a confined fire compartment or cell, it is assumed that the fire is developed in local areas without any manual or automatic fire suppression or any firefighting action and all the combustibles burn out without regard to the available oxygen pertinent to the fuel-controlled or ventilation-governed fire. It means that total heat released is calculated by the total amounts of the fuel inside the fire zone multiplied by the heat release rate per unit weight. The design basis fire is the most severe fire that could cause the most detrimental damage within the postulated fire compartment or cell and would provide a bounding summary.

5.2.2 Calculate potential hazard

This approach is related with the fire load calculation construed from the concept of the fire resistance requirements in the building codes. In most cases, this kind of fire load or severity approximation is more severe than is determined by the more accurate quantitative analysis.

The fire load relationship was the first method to predict the severity of a fire that would be anticipated in various fire compartments including the fire cells in NPPs. It was used to determine required fire resistance rating for fire barriers and structural components. Commonly, fire load is expressed in terms of the average fire load which is the equivalent combustible weight divided by the fire compartment area. In general, a 1-hour fire rating is equivalent to $9.08 \cdot 10^8$ J/m^2 and 2 or 3-hour fire rating is $1.82 \cdot 10^9$ J/m^2 or $2.27 \cdot 10^9$ J/m^2, respectively.

Technical methods to calculate the actual fire load or fire-resistance rating are available by use of common building-occupancy-contents combination. These methods by approximation or more exact calculation have been accepted under the performance-based building codes adopted with the purpose to conservatively analyze potential fires in NPPs as well.

5.3 SAFE SHUTDOWN ANALYSIS

5.3.1 Effect on SSCs important to safety

A single fire event, including an exposure fire, could damage post-fire SSD equipment or result in the release of radioactive material to the environment in this or an adjacent area. The postulated fire in a given fire compartment ought to be assumed to involve either in-situ or transient combustibles or both to bound the possibilities. The radiant energy, temperature increase, or smoke from a fire are the principle concerns for damage to post-fire SSD equipment or to allow uncontrolled release of radioactive material.

A single fire involving one post-fire SSD success path may provide an exposure fire for the redundant SSD success path or paths located in the same area. In addition, a fire involving combustibles not adjacent to either redundant SSD success path may result in an exposure fire for both redundant SSD success paths located in the same area. The extinguishing system effects on post-fire SSD equipment need to be considered also as a potential adverse impact on SSCs.

5.3.2 Deterministic approach and probabilistic approach

Human factors are more at play in the probabilistic approach and are not part of the deterministic approach. The risk of human actions can be more appropriately evaluated in probabilistic safety analysis. The relationship between the deterministic and risk-based approaches, such as minimizing the financial cost overall to focus on high risk areas ought to be considered and addressed. At some NPPs where the risk-based approach was used to replace the earlier deterministic fire protection program, unexpected high-risk areas where identified where new equipment was added to provide additional DID for post-fire SSD equipment. In one example, the deterministic approach of providing a redundant safety related source of emergency feedwater was found through a detailed probabilistic safety analysis to have a significant risk of failure due to power supply common failure from a fire. The increased risk at more than one NPP resulted in the addition of a non-safety related additional emergency feedwater source with an independent power supply to lower the overall plant risk due to a fire.

5.4 PROBABILISTIC SAFETY ANALYSIS

The classical or deterministic fire protection guidelines do not address unique NPP specific designs at each plant location. The classical or deterministic approach is a generalized way to address fire hazards that may cause post-fire SSD hazards without consideration of the actual risk in a given area which could lead to excessive expense to meet with no real safety benefit. Insights, such as provided in Ref. [15] allows the use of probabilistic safety assessment (PSA) to use risk-informed or performance-based alternatives to the classical or deterministic fire protection guidance. In some cases, the use of PSA will identify that the risk of post-fire safe shutdown adverse consequences is so insignificant that some deterministic standards are not necessary. The PSA approach will allow a cost-effective use of limited resources to more properly implement safety standards to protect the health and safety of the public from fire induced radiological concerns. This approach is an extensive topic that will not be addressed in this document due to the information already available elsewhere. For example, one approach is provided in Ref. [16].

5.5 VULNERABILITY DETERMINATION

The use of both classical or deterministic and PSA or risk-informed performance-based assessments may be used. The foundation of a deterministic approach provides a suitable base to build the NPP fire protection program since some elements such as fire-fighting water supplies, fire barriers, control of ignition sources, etc., are beneficial and may cover the entire NPP buildings/structures. However, more specialized additional fire protection, or additional post-fire SSD equipment may be needed due to higher risk of post-fire SSD hazards that can only be determined by a PSA assessment of the risks in each fire compartment. As such the vulnerability determination relies on both aspects to ensure a cost-effective approach is used to ensure public health and safety from postulated fire impacts on each unique NPP configuration.

Older generation NPP's that were not originally designed to meet the deterministic standards, as they had not been documented at that time, but were updated to meet them such that defence-in-depth was assured and found to be reasonable. However, in the case of some older pressurized water reactors, by using the fire PSA methodology of Ref. [16], found an unacceptably high risk for certain post-fire SSD systems. As a result, a third option of emergency feedwater supply was added, or incipient detection was provided to critical electrical panels to allow faster response to lower the risk to acceptable levels. In addition, the importance of some of the fire protection features was found to be less important to overall plant safety, and the FPP could focus more precisely on the relatively higher risk areas to allow a more cost-effective program to be established.

5.5.1 Introduction

5.5.1.1 Assumptions

In the FHA, a fire is not considered to occur simultaneously with non-fire related failures in safety systems, plant accidents, or the most severe natural phenomena, except the loss of off-site power. The following conditions are assumed in the design-based fire evaluation at each fire compartment or cell:

- There is potential effect on safe shutdown and important to safety equipment if all equipment within each fire is lost;
- There is potential for release of radioactive materials in the event of a fire within each area that contains such material.

For the off-site power loss condition, for example the criteria of Ref. [17], section III.L of Appendix R to 10 CFR 50 could be used.

5.5.1.2 Fire impact to structures, equipment, personnel

Fires produce four major outputs: gases, flame, heat, and smoke. The materials involved in the fire will determine the combination of these four outputs. In confined situations, the fire may also cause significant pressure effects. These outputs can have consequences on structures, personnel and equipment.

Examples of fire impact are discussed in Ref. [9].

5.5.2 Post-fire safe shutdown analysis

The goals of post-fire safe shutdown analysis is described in Ref. [18] to assure that a single credible fire in any plant fire compartment or cell will not result in any fuel overheating or cladding damage, rupture or leakage of the primary coolant boundary or rupture or leakage of the primary containment to the environment. These goals prevent an unacceptable radiological release as a result of the postulated fire.

Post-fire safe shutdown analysis is part of each NPP's defence-in-depth FPP which has layers of protection to offset unknowns. The age of the NPP and unique regulatory commitments define the scope and detailed guidance developed.

The information provided in Ref. [18] chapters 4 and 5 provide useful insights in resolving the issues of multiple spurious operations (MSO)[2]. Since the postulated fire may cause numerous electrical faults in various systems the ability to identify and address MSO issues that are credible is needed. The resolution methodology described in chapters 4 and 5 and in the appendices referenced within Ref. [18] is one way for a licensee to address the MSO issue.

5.5.2.1 Deterministic methodology

When using the deterministic methodology, a basic assumption is that there will be fire damage to all systems and equipment located within a common fire compartment or cell. Fire damage is assumed to occur regardless of the amount of combustibles in the area, the ignition

[2] Note: The term "MSO" will be used throughout this publication to denote one or more fire-induced component failures due to fire-induced circuit failures, including, but not limited to spurious operations resulting from hot shorts.

temperatures, or the lack of an ignition source. The presence of automatic or manual fire suppression and detection capability is also not credited.

It is with these assumptions regarding fire damage that use of the deterministic methodology begins to identify the scope of damage. The methodology continues by selecting systems and equipment needed for post-fire safe shutdown, on identifying the circuits of concern relative to these systems and equipment as well as equipment located outside the fire compartment with supporting circuits going through the fire compartment. Next the actions required outside this area needed to mitigate each fire-induced effect to the systems, equipment and circuits for the required safe shutdown path in each fire compartment is determined, whether from the control room or local manual operator actions. This methodology ensures a comprehensive and safe conservative approach for assuring that an operating NPP can be safely shut down in the event of a single fire in any plant fire compartment or cell.

The deterministic methodology details from Ref. [18] includes identifying the systems/equipment needed for SSD functions such as reactivity control, pressure control, inventory control and decay heat removal for the NPP. Once the systems/equipment needed to perform these functions are identified, then any support equipment ought to be identified using both piping and instrument diagrams or electrical routing diagrams. The final stage of this process is to identify the mitigating actions needed from outside the fire compartment or cell. Actions from the control room or local manual actions by operations personnel need to be documented in plant procedures with appropriate timing confirmation to ensure post-fire safe shutdown meets the SSD functions listed above.

5.5.2.2 Risk significance methods

the resolution methodology for determining the plant-specific list of MSOs is contained in Ref. [18] chapter 4 (Refer to that chapter for additional details). The method details both the determination of applicable plant-specific MSOs and the disposition/mitigation of the MSOs using either deterministic methods, fire modelling or risk (e.g. focused scope fire probabilistic risk assessment) methods.

5.5.3 Application of fire hazard analysis

5.5.3.1 Overview

Many countries use different methodologies of FHA documentation. The common principles of different methodologies are based on a deterministic approach. Certain NPPs additionally use risk informed analysis.

The deterministic FHA is a simple methodology controlling the effect of changes to plant configuration related to changing fire hazards. The choice of a correct database is an important question. Either a fully deterministic approach with worst case fire assumptions, or a more realistic risk-based approach is acceptable depending on regulatory requirements for the site location.

The original FHA will show fire hazards at the time the document was prepared. In case of plant modifications or changes, the fire hazards could change. Therefore, in this case, the NPPs ought to modify or update the FHA. The FHA is updated at most NPPs during the period the modification is being designed, keeping the design documentation consistent; the FHA needs to be updated periodically.

Examples of modifications to FHA include the following:

- When new cable lines are installed: leading to additional fire load in different areas, or rooms;
- When new electrical cabinets are installed: leading to additional fire load, additional ignition sources in different areas, rooms;
- When changes in oil or fuel quantities are made: leading to additional fire load in different areas, or rooms;
- When fire doors are changed: leading to fire or smoke spreading barrier changes;
- When there are changes in cable penetrations: leading to fire or smoke spreading barrier changes;
- When new ventilation ducts or pipes are installed: leading to fire or smoke spreading barrier changes;
- When changes are made in the thermal isolation of equipment;
- When changes are made regarding walls;
- When there is any modification of the facility itself.

APPENDIX IV has a fire hazard analysis report format.

5.5.3.2 Use FHA to evaluate modifications to NPP

The FHA provides a base document to evaluate fire protection modifications. When gaps are identified by analysis in the FHA the need for additional plant modifications can be specified. For example, in the fire compartment that has an increase in the fire load identified then it can be evaluated to see if there needs to be additional fire detectors, more or different portable extinguishers, etc. Suitable plant changes needed to mitigate the weaknesses are more apparent based on the FHA information.

Permit approval

The first step before plant changes, such as modifications, is to investigate the effect of changes to safety, and what changes to fire protection are needed. This is an important question in case of plant modifications, or temporary changes (storage of combustibles, using combustibles at maintenance locations, hot work activities, etc.). The changes and their postulated impact on fire protection may be allowed, or require compensatory measures, based on permit requirements. The FHA can be incorporated to the online control when it is required for the continuous permission for temporary plant conditions (i.e., temporary modifications, maintenance activities, etc.), such as the storage of combustibles or hot work control. Some systematic approaches, such as the fire load calculation by intranet or display system, have been used in operating NPPs. The combination of area control of temporary plant conditions and fire load control of combustible material could result in more effective plant operation. For example, the risk from the temporary modification and combustibles in a fire compartment which contains SSD facilities may be low during the outage periods, after the nuclear fuel elements were removed from the reactor, and it can allow more space to be used or time available for the combustible storage without increasing the plant risk from fires for that area Ref. [19].

Maintain performance level

The original or modified level of FHA is a basic level at the time of document development. In case of later plant maintenance activities, the plant could change plant configurations (such as additional electrical cables or components) from the original analysis, store different combustibles from what existed earlier, and these changes can be evaluated in relation to the different fire hazard through an FHA update.

Work planners

Day-to-day use of the FHA ought to be occurring during work planning activities. In case of minor temporary changes in fire protection, the plant could use a simplified FHA type process during work planning and work order permitting, in order to identify suitable compensatory measures. As most NPPs use hot work permits, specific industrial safety hazard analysis would be based on the content of the simplified FHA type document. Work planning needs to include an analysis of the potential impact on both SSD and overall fire risk, as well as worker safety in accordance with national regulations.

5.5.3.3 Fire hazard analysis may be used to evaluate other plant work

- Needs analysis for fire responders and minimum complement fire protection staffing;
- Space allocation and transient material permitting (SATM);
- Engineering plant change control;
- Fire pre-planning.

5.5.4 Impacts of plant modifications

Permanent or temporary plant modifications can affect fire protection equipment or features and must be evaluated and authorized prior to implementation. In some cases, compensatory measures will be required during temporary plant changes which may involve scaffolding or other features which may block or obstruct fire protection equipment or fire brigade access. FHA becomes a source of reference for evaluating the impact of plant modifications to determine acceptability, need for compensatory measures, or changes prior to implementation.

During the course of operation, it can be expected that changes will be made that impact fire protection capabilities. These changes could result in increased hazards, resulting in changes to:

- Fire protection strategy;
- Emergency response capabilities.

5.5.4.1 Modifications impact on fire protection equipment

Examples of modification impacts that ought to be considered are identified below. These are limited examples of the most frequent items that typically occur at operating nuclear power plants and would not be consider an exhaustive list. The fire database and good practices ought to be consulted to help develop a more comprehensive list of modification impacts.

Sprinklers obstructed

Fire sprinkler systems are designed to ensure adequate coverage to limit the spread of credible fires in areas where they are installed. In some cases, the additional installation of equipment, temporary scaffolding, piping or cable lines can obstruct sprinkler head spray pattern as these may have been located based on the original design configuration. The consequence could be an ineffective fire extinguishing capability. Limited sprinkler head obstruction during temporary plant configuration changes may be allowed, as long as the plant management, operations personnel, and fire brigade teams are made aware of these changes. Compensatory measures such as roving fire watches ought to be considered during these situations.

Hoses/equipment blocked

Similar to fire sprinkler obstructions, access to fire hoses, portable extinguishers or other firefighting equipment may be blocked or obstructed due to permanent or temporary plant modifications. The consequence could be ineffective access to this essential fire extinguishing equipment. In all cases, these plant modifications will need to be evaluated for acceptability, considered for compensatory measures, or revised prior to implementation. Once the final design is allowed for implementation and still involves some obstruction or blockage, for a limited time, the plant management, operations personnel, and fire brigade teams ought to be made aware of such obstruction or blockage.

Impact on fire detection

Fire detection systems may be based on sensing smoke, heat, radiant energy or incipient gases that are based on a plant configuration at the time of installation. Numerous plant modifications to plant heating or cooling systems, obstructions to original air flow patterns or line of sight configurations, or other changes may be considered for adequate fire detection. The consequence could be ineffective fire detection and extinguishing capability.

In all cases, these plant modifications will need to be evaluated for acceptability, considered for compensatory measures, or revised prior to implementation. Once the final design is allowed for implementation and still involves some negative detection impact, for a limited time, the plant management, operations personnel, and fire brigade teams ought to be made aware of such negative detection impact.

Water supply

A primary foundation for fire suppression is an adequate water supply volume and flow rate for either automatic fire suppression or manual fire suppression by fire brigade intervention. The use of fire water supply systems for non-fire protection purposes ought to be minimized or prevented during power operation. The lack of suitable fire water supply would result in ineffective fire extinguishing capability.

Exit obstruction

The life and safety of personnel can be adversely impacted by plant changes if such changes obstruct exit routes for a fire compartment. Structural changes, equipment additions, security door changes, or temporary changes need to be evaluated for acceptability prior to implementation.

Fire response access

Generally, two paths for firefighting personnel to reach a fire compartment are provided, when possible. Like the exit obstructions listed above the fire response access may be impacted. The consequence could be an ineffective or loss of manual firefighting capability.

5.5.4.2 Change in combustible loading/fire severity

In cases where the fire load changes, the fire risk is also impacted. In the process of modernization, the plant changes could impact fire load, for example, when installing new cables. In older plants, the fire load could be reduced changing out older cables. In addition, the installation of new electrical equipment could increase the ignition probability.

5.5.4.3 Installation of new walls

The installation of new walls could affect ventilation effectiveness, access/egress paths, or need to be investigated for necessary changes to fire alarm or fire suppression systems.

5.6 SPECIAL CONSIDERATIONS

5.6.1 Seismic induced fires

This section focuses on the fire’s hazards linked to earthquake events, and the various issues concerning fire protection and prevention when dealing with earthquake conditions. After giving an overview of the operational experience for industry, it reminds us about the main aspects of the seismic design of each NPP, and the specific operational experience for the nuclear power industry. Different stress tests performed are recalled, some of them performed after the accident at the Fukushima-Daiichi NPP in 2011, following the great earthquake and tsunami. Recommendations are given on the necessary organizations, maintenance, control, trainings, drills, etc., to be made by the utility operators, and the main aspects of the management of the fire risk in earthquake situations.

5.6.1.1 Seismic hazards, generality

Earthquake events present a very low probability of occurrence during a plant life, but their effect may be significant. They are external hazards which present characteristics that profoundly challenge nuclear safety: they concern all the plant equipment and structures at the same time — potentially several plants — and their effect concerns both the outside and the inside of buildings, including the surrounding areas, which might make it difficult to provide external supplies.

Earthquake induced fires may potentially happen at the same time at different places inside the plant. Nuclear fire safety management principles being based on the occurrence of one independent fire event (rarely 2 or more), the main issue for fire protection in case of earthquakes is to prevent or avoid seismic damage induced fires (a secondary issue being to manage independent fires occurring in the long-term after an earthquake).

Consequences of an earthquake

- Mechanical damage to structures and plant equipment due to the initial effect of earthquakes (some plant equipment is more rugged in comparison with others: e.g. electrical cabinets);
- Effect on soil;
- Falling material (anchorage failure or non-anchored devices);
- Displacement of material (e.g. non-anchored vertical tank displacement);
- Cables and electrical connections (flexibility of connections, falling of cable trays);
- Seismic interaction in control room or other essential buildings;
- Some interactions have been noticed concerning fire protection devices:
  - Spurious smoke detection due to dust (including sensor-controlled spurious activation);
  - Spurious activation of sprinkling systems resulting from falls;
  - Mechanical damage to the fire barriers, depending on their robustness: doors, valves, penetration seals, cable wrapping, etc.

Seismically induced fires in the industry

A recent study in the USA Ref. [20] indicates that similar to statistics gleaned from the 1994 Northridge earthquake (mostly domestic fires), half of all seismic induced fire ignitions are typically electrically related, a quarter are linked to gas leakage, and the others stem from a variety of causes, including chemical reactions. The report mentions that the Japanese gas industry planned to move to shut-off valves after the Kobe earthquake.

The USA's department of energy's seismic evaluation procedure Ref. [21] provides a list of the potential seismic-induced spray, flood and fire interactions that ought to be evaluated:

- Hazardous/flammable material stored with inadequate clearance in unanchored shelves, or unlocked cabinets;
- Non-ductile fluid-carrying pipes (such as cast-iron or pvc pipes);

- Natural gas lines and their attachment to equipment or buildings;
- Acetylene bottles;
- Mechanical and threaded piping couplings can fail and lead to pipe deflection and falling and impact on equipment. Grooved type coupling used in the fire protection piping are one example of this type of mechanical coupling;
- Sheetrock falling and impact on equipment if it was previously water-damaged or if there is severe distortion of the building;
- Unanchored room heaters, air conditioning units, sinks and water fountains may fall or slide into equipment.

5.6.1.2 NPP seismic design approach

In practical terms, the main part of the protection against earthquake effects is based on the seismic design of the plant structure and equipment.

As required in the IAEA seismic design standards Ref. [22], NPP focus is based on a classification process. Equipment important to safety is designed for a seismic level agreed by the authorities, and their fire protection too (if any). The component design is completed by the so-called “seismic interaction” approach which aims to avoid impacting of seismically designed components by non-seismic designed ones (mechanical impacts, falls, etc.). This approach is mostly based on walk-downs and periodic updates and close management of the modification process and other permit of work risk analysis (seismic housekeeping and management of transient equipment). Nevertheless, this kind of approach is focusing on the falling of structures, fixed components or transient material, but not on induced fires.

From an overall point of view, structures and significant material for nuclear safety are designed inside the nuclear island for the design basis earthquake (DBE), in order to maintain their functional requirement.

The fire prevention/protection SSCs are generally designed to resist a certain seismic load, in some cases less than the DBE.

Fires inside the nuclear island (at least inside seismically classified buildings) are generally expected to be unlikely to happen and the seismic design of the fire protection devices appears as a supplementary robustness.

Outside the nuclear island, induced fires are likely to happen from an earthquake of medium magnitude. Fire ignition is thus postulated, but it is required that those fires may not jeopardize classified buildings or safety targets.

In non-seismic-classified parts of the plant, the fire-water network is generally not designed for the DBE. Commonly, the main water supply may also play a role as an alternative water source for SSD issues. Therefore, the design of this system is robust in the areas where needed.

Manual or automatic valves ought to be provided to isolate the seismic designed part of the fire water supply from the non-seismic one, in the case of an earthquake. The actuation of those valves may be controlled by earthquake sensors. Otherwise, specific procedures are necessary to guarantee a quick shutdown of those valves in case of a significant earthquake by operator actions.

The seismic design of the plant is in most cases verified with a PSA study. It is to be noted that these studies generally do not take into account potential induced fire aspects.

International feedback on NPP fires caused by a seismic incident followed a survey of over 100 plant and industrial facilities after 18 major earthquakes. The study was conducted by EPRI in 1990 Ref. [23]. At that date, no incidence of a post-earthquake fire impacting an NPP had been documented. Such events are rare. Following the earthquake of 11 March 2011 in Japan, recent seismic events causing earthquake-induced fires have been reviewed by EPRI Ref. [24].

Onagawa (Japan 2011)

During the 2011 Great East Earthquake, the heavy breakers hanging in switchgear cabinets swung wildly, causing arcs where the 6.9kV switchgear bushings are mated with the insulation bushings, or HEAFs. As a result, an arcing fault appeared in the switchgear cabinet. This short circuit, or arcing, resulted in a fire in the cabinet. Due to the difficulties to ingress in the compartment, the fire lasted 7 hours. The countermeasures against these HEAFs have been implemented across all Japanese utilities, including the installation of digital protective relays with appropriately set values for coordination protection. See Ref. [11] for more details.

Fukushima Daiichi (Japan, 2011)

No seismically induced fire occurred at the Fukushima-Daiichi NPP, as a direct result of the earthquake or the ensuing tsunami. Nevertheless, the plant suffered from hydrogen explosions, linked to the difficulty in implementing the severe accident management by the operators, and other support organizations. Even though the Fukushima Daiichi NPP was not directly damaged by the impact of internal fires (other than the hydrogen explosion consequences), the design base for many kinds of internal and external hazards, including fire hazards, were upgraded by new regulations.

Kashiwazaki Kariwa (Japan, 2007)

A fire caused by an earthquake started in an electrical transformer and was extinguished in two hours. The earthquake caused damage to the fire water piping (leakage). The operators did not have adequate firefighting preparedness for this situation and the arrival of the off-site fire department was delayed. The lessons learned included deploying additional qualified on-site fire brigade personnel, adding fire engines, and replacement of the fire water piping system to withstand projected seismic events. No significant safety issues resulted from this fire event.

Maanshan NPP (Taiwan, 2007)

During and following an earthquake, dust accumulated in the ventilation pipe of the main control room, and when floating down from the ceiling, it was interpreted as a fire. The operators conservatively decided to trip one of the reactors as a safety precaution.

US Individual Plant Examination of External Events

The USA's individual plant examination of external events (IPEEE) Ref. [25] programme provided the verification of a large population of external hazards including seismically induced fires. The main issues regarding these topics were the following:

- Examinations included the potential for seismic initiated fire, degradation and/or spurious actuation of fire suppression systems;
- For most of the submittal, seismic-fire considerations were included in the scope of the overall walk-down effort;
- Identification and vulnerability of combustion sources (e.g., hydrogen lines, oil tanks, fuel lines, unanchored electrical panels);
- Fire interaction evaluations which led to a number of fixes: relocation of fire sources far from safety equipment, restraining gas cylinders, strengthening anchorages for fuel oil tanks;
- Inadvertent actuation of fire suppression system and interaction with important to safety equipment was one of the most consistent strong points.

French stress tests (post Fukushima-Daiichi NPP event)

(i) SOER WANO

In the days following the accident at the Fukushima-Daiichi NPP, the world association of nuclear operators (WANO) published recommendations for the utilities Ref. [26], in particular:

"Point 4. Perform walk-downs and inspections of important equipment needed to mitigate fire and flood events to identify the potential that the equipment's function could be lost during seismic events appropriate for the site. Develop mitigating strategies for identified vulnerabilities. As a minimum, perform walk-downs and inspection of important equipment (permanent and temporary) such as storage tanks, plant water intake structures, and fire and flood response equipment; and develop mitigating strategies to cope with the loss of that important function."

This action was completed in May 2011. French NPP learnings from the walk-downs were as follows:

- Need to enhance the accessibility of the isolating valves on the main water supply duct and clarify the operator procedures relative to their activation in case of earthquake;
- Need to enhance the control of the seismic design of the fire hose cabinets due to the detection of some non-conformity (these components are not designed to resist DBE, but they are studied in a seismic interaction approach: no damage of the fire water supply piping and no damage of safety components in case of the hose cabinet falling down);
- Need to enhance the seismic information and training of the plant operators.

(ii) Complementary safety studies (ECS France)

Following the SOER WANO stress test, the French authority asked in its decision of 5 May 2011, to proceed to a deeper stress test in each French NPP relative to large earthquake and external flooding hazard events, taking into account the Fukushima-Daiichi operational experience.

This stress test, including supplementary walk-downs, was performed during the summer of 2011 (e.g. Gravelines plant ECS report Ref. [27]) for each existing or planned French EDF reactor (59). The analysis included a conformity check relative to the existing safety requirements for these hazards, and a complementary qualitative analysis considering the recent operational experience.

Concerning fire and explosion, dedicated chapters consider the available risk and answers concerning internal or external (environmental) fires and explosions. These reports detail the strategy in a nuclear island where induced fires are considered avoided in design basis conditions. Internal explosions are regarded since the nineties through a specific detailed safety assessment progressively applied to the different plant types.

The main decisions made during the process concerned enhancement of some component seismic design criteria and creation of a national nuclear rapid intervention force (FARN) dedicated to the supporting the plant operator in case of a major event, see Ref. [28]. This force relies on complementary mobile equipment and plug-in components being worked out. It has to be understood that the objective of this force is to operate the plant and not specifically to fight potential fires.

5.6.1.3 Earthquake hazard prevention

The earthquake hazard prevention during the plant operation, depending on the seismic design of the plant, consists of:

— Organizing and applying control of the seismic design fire safety management devices:

  - By maintenance of designed components;
  - By application of housekeeping programmes, including control and prevention of the possible seismic interactions linked to transient equipment or storage;

— Organizing the recovery from significant seismic events, in terms of actions and controls during and after the event:

  - By the activation of seismic/non seismic isolation valves on water supply circuit;
  - By the control of the fire safety management for any possible device damage, etc.;

— Preparing and implementing training and drills taking into account the global potential effect of an earthquake, inside the design basis assumption (and beyond, see section 5.6.2):

  - By identifying the main fire scenario;

- By ensuring recurrent drills including, if necessary, internal and external firefighting for each scenario.

5.6.2 Beyond design basis fires

This section focuses on the new considerations in terms of external hazards prevention that appeared following the accident at the Fukushima-Daiichi NPP in 2011. It gives some overall idea of the approaches developed for beyond design basis hazards assessments in NPP, that will likely continue to evolve.

5.6.2.1 Post-Fukushima issues

The Japanese earthquake in March 2011 and its consequences on the Fukushima-Daiichi NPP has prompted a significant process in the international community concerning the BDBA. New considerations are being worked out not only on earthquake and flooding but also on the other external hazards (and/or hazard combinations) like tornado and other extreme weather conditions.

Even while the related programmes are still being developed, significant modifications have begun in different countries concerning plant design and organization. In the scope of fire protection, the main issues have been specific analysis and walk-down controls performed in the years following the accident (for instance, the SOER WANO stress test, French complementary safety studies (ECS), American diverse and flexible coping strategies (FLEX), etc.). They have demonstrated the necessity to develop new rules concerning environmentally induced fire or explosions in BDBA and the general availability of the fire protection people and devices. Responses are coming from a reinforced design safety analysis adapted to this kind of situation (graduated approach on the minimum safety functions to preserve the hardened safety core (HSC) based on risk importance) and from organizational response to extreme external hazard scenario (drills, complementary equipment, supplementary external intervention teams, etc.).

5.6.2.2 Earthquakes

The tendency is to strengthen the fire protection devices, other safety devices, with all remaining at a design basis level. Beyond those design considerations, the problem is focused on the HSC and its potential damage by induced fires.

Studies focus on the risk of seismic induced fires and their potential impact on the HSC components and functions:

- Identify the potential risk sources in the surrounding area of the HSC components and supports;
- Control them through walk-downs, for instance, and when a risk is confirmed for the HSC and supports, settle corrective actions like removing, replacing with resistant component, strengthening, etc.;
- Develop plans for staging support equipment nearby, or options to have it brought in expeditiously with agreements documented and maintain the options throughout the life of the plant.

5.6.2.3 Seasonal impacts

Weather

Safety-related fire protection equipment is generally protected against extreme temperature design conditions, cold or hot.

Specific weather phenomena as exceptional rain, hailstorms, snow, tornado, hurricanes, etc., are generally covered through the design rules. The main concern is for the external parts of the plant, where the fire protection components may have to be protected.

Floods

The risk of external flooding concerns including tsunami, as appropriate, or nearby rivers or lakes for the external areas of the plant, as the design normally prevents water entering inside the safety classified parts. The BDBA flooding is focused on the protection of the HSC. Generally, the rooms containing the HSC components will be designed to avoid flooding.

Tornadoes

Protection against extreme wind conditions such as tornado events depends on specific missile and wind protection inside tornado designed buildings of the HSC, and thus their specific fire protection systems.

Environmental or other external events

Catastrophic impacts linked to the other nearby industry establishments or pipelines surrounding the plant is one of the issues regarded in the BDBA. In addition, transportation vehicles like trucks, trains or airplanes near or over the plant add to the issues to be considered. External fires and explosion, toxic gas, chemicals or smoke clouds are considered as the most probable hazards.

6 EMERGENCY RESPONSE

Emergency response issues for fires need to be addressed as part of a facility's fire protection strategy. Emergency response is defined as the efforts made by a coordinated group of personnel to assess, control and mitigate hazardous events.

Emergency response issues can be complicated to manage and often require significant training and equipment. Emergency response organizations must also meet government regulatory and company requirements.

Emergency response capabilities have a significant impact on a fire protection and response strategy. One primary question that must be addressed is whether to fight or not to fight fires (other than incipient ones). Emergency response is one of the last layers of protection at a facility that often uses off-site support personnel.

6.1 ORGANIZATION

6.1.1 On-site fire brigade vs. outside responders

The organization of fire brigade requires that effective measures be implemented to ensure the proper execution of fire fighting with the proper organization, training, and equipment facilities for on-site fire brigades at NPP sites.

An effective fire brigade training programme ought to be implemented to establish and maintain the capability to fight credible and challenging fires. The brigade is headed by a brigade chief, preferably a member of the operations department to better understand the significance of the equipment involved in the fire emergency. A shift fire brigade leader or shift chief may also be assigned to each shift. During a fire incident, the shift chief is in charge of the incident until the local municipal fire department arrives. The officer in charge of the municipal fire department and the shift chief will establish a joint incident command. The fire brigade, for example, typically consists of at least five members including the shift chief on each shift.

6.1.2 Off-site fire department interface

On-site fire brigades respond first to any plant fire emergency, since they are part of the plant staff, and assess whether additional off-site fire response is needed. Often a mutual aid agreement is established with a local fire department(s) to provided additional support if the fire size or complexity exceeds the capabilities of the limited staff available from the on-site fire brigade.

Periodic plant training is needed to ensure the off-site response personnel have the appropriate equipment to interface with site equipment, they know the site characteristics (fire pre-plans and FHA), and appropriate communications for command control with the plant control room personnel.

The off-site or local fire department(s) that provide backup firefighting support ought to have the following:

— Personnel and support equipment consistent with what are assumed in the plant's FHA and fire pre-plans;
— Threads compatible with those used by local fire departments may be provided on all hydrants, hose couplings, and standpipe risers. Alternatively, a sufficient number of hose thread adapters may be provided;
— Fire hoses need to be hydrostatically tested according to adequate standards such as NFPA;
— Fire hoses stored in outside hose houses need to be tested periodically (i.e., annually).

FIG. 8 presents an example of organization of fire brigade during normal operation.

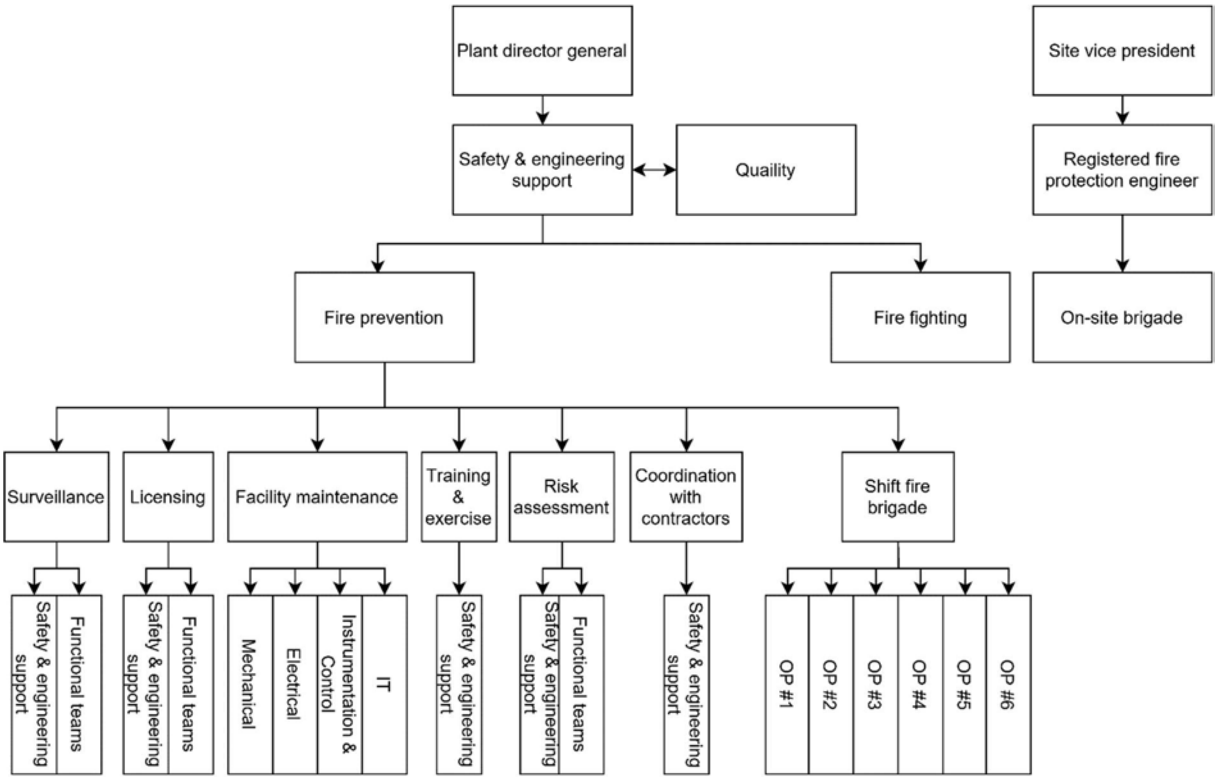

FIG. 8. An organization example during normal operation (Source: KHNP)

FIG. 9 presents an example of organization of fire brigade during emergency operation.

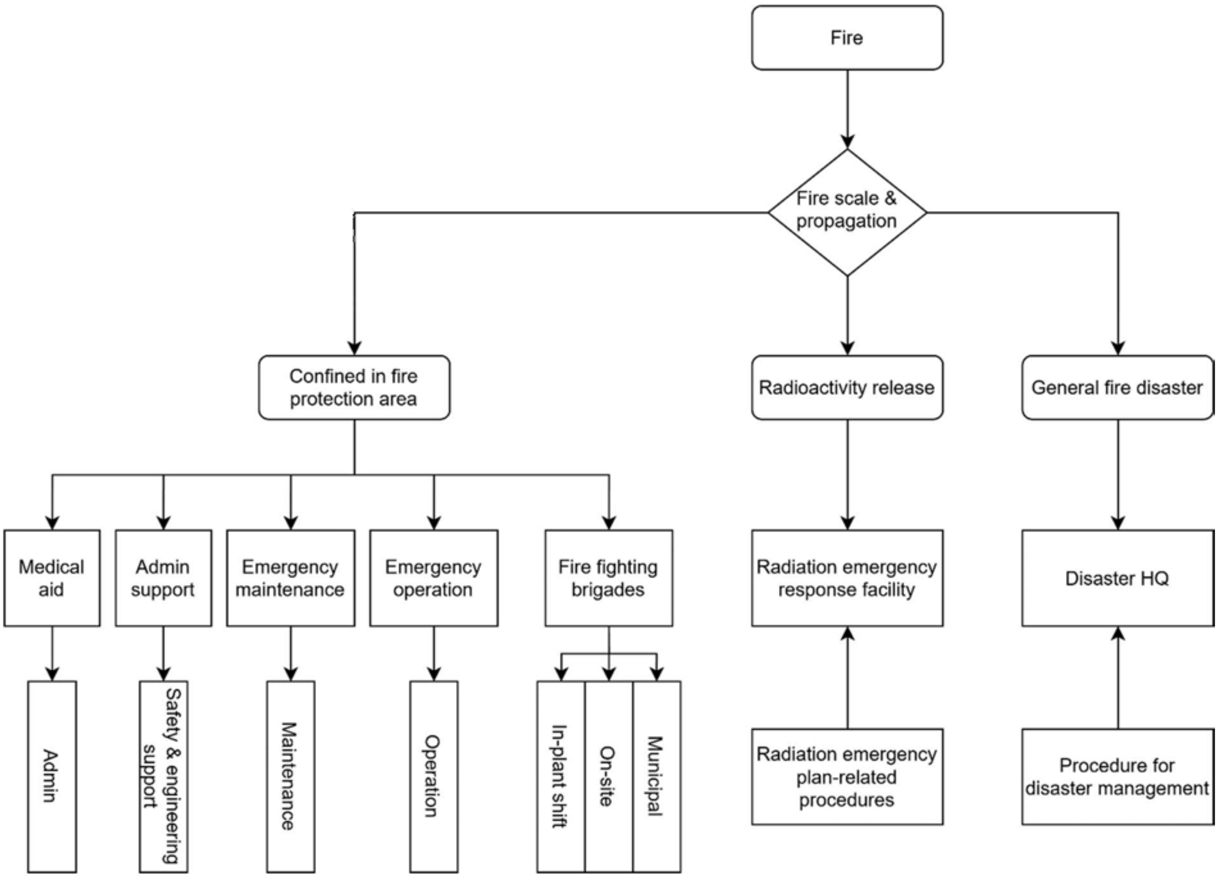

FIG. 9. An organization example during emergency operation (Source: KHNP)

6.2 MANUAL FIREFIGHTING CAPABILITIES

The provision of manual firefighting and emergency response capabilities at an NPP facility is a foundational element of fire protection DID, ensuring the protection of personnel, plant equipment, and nuclear safety. Manual fire response and intervention is always required to mitigate fire events, provide for the safety of lives and is assumed to be present for nuclear facility design and construction standards. The recommendations in this chapter are based upon industry best practices and operational experience from international best performing plants. Several good practices have been identified from member states in Ref. [19].

6.2.1 Fire pre-plan

6.2.1.1 Fire response needs analysis

Fire and emergency response equipment and resource needs at an NPP facility are determined from the following:

- Regulatory requirements (which may contain prescriptive, deterministic, or performance-based requirements);
- Implementation of applicable codes and standards (which may contain prescriptive, deterministic, or performance-based requirements);
- Corporate loss prevention requirements;
- Requirements determined from a systematic assessment of hazards, risks and fire protection goals in consideration of the physical design features of the facility and operational practices.

These requirements are demonstrated to be met in a documented fire response needs analysis (FRNA) which identifies the minimum human resources, equipment and intervention timelines required at the facility.

The FRNA systematically analyses postulated fires or scenarios at the facility, on a hazard-by-hazard basis. This analysis incorporates information from FHA, fire safe shutdown analysis and combustible control requirements (CCR) in analyzing fuel packages, the potential for impact to safety-related structures, systems and components, safety of the responders, effects of the fire and effects of firefighting activities.

Postulated fires are assessed for equipment and human resource needs based upon planned response strategies and required intervention timelines (determined from sources such as the fire safe shutdown analysis, safety analysis report, and loss prevention assessments).

At the end of the systematic assessment, the minimum staffing levels are determined for the facility based on the analysis. Minimum response equipment and their staged location, if not centrally provided, are also documented. This assessment and its output form the basis of fire pre-planning and equipment staging in the field.

Experience from conducting FRNA have shown that the minimum resource requirements for a nuclear facility are typically not determined from single large “design basis” fire events but from the most demanding needs from multiple individually assessed events depending on the size of the postulated fire, ability to access the fire, intervention timelines and protection requirements for the emergency responders for each scenario.

The FRNA is typically performed prior to initial construction and revised (which may require updating or simple confirmation) at any point where there are major changes in hazards, changes in physical design or operational state (e.g., changing from an operating plant to decommissioning). The FRNA ought to be performed by a multi-disciplinary team including representatives from emergency response, fire protection, engineering, operations, and safety analysis. The FRNA incorporates information from supporting analysis such as fire pre-plans, FSAR, FHA, fire safe shutdown analysis and CCR to document response objectives, intervention timeline targets and resource requirements.

6.2.1.2 Fire pre-plans

Each plant fire compartment needs to be documented in a format to support training of personnel for fire response. The fire pre-plans provide a summary of where nuclear safety-related equipment and post-fire SSD components are located in relation to potential fire hazards and what installed plant equipment is available to support firefighting activities. Typically fire pre-plans include:

- Fire compartment equipment layout, potential fire hazards, important to safety components or post-fire SSD equipment, and any fire protection features (detection and suppression related) that may be present. Any impairments that are long-term ought to be identified as appropriate;
- Fire pre-plans may include:

  - Strategy for pre-planned responses to fire alarms;
  - Options for notification to emergency response teams (e.g., on-site fire brigade, off-site fire department, emergency planning organization);
  - Coordination needs for operations and security personnel to support firefighting activities;
  - Firefighting techniques for each fire compartment;
  - Identification to allow appropriate response to potential radiological hazards.

Fire pre-plans ought to be available in the main control room and with the site fire brigade assembly area(s). Plans ought to be reviewed and updated after significant plant changes or periodically, as an example, every two years.

General example of fire pre-plans may be found in APPENDIX II.

6.2.1.3 Access and egress routes, lighting and communication

Paths to and from each fire compartment must be designed into the plant layout such that both firefighting personnel as well as operations personnel involved with the safe shutdown will be able to perform their separate functions for a single fire in any fire compartment. Multiple access/egress paths, with adequate emergency lighting, and consideration for security locking devices must be evaluated. The products of combustion will also need to be addressed since personnel habitability issues or visibility concerns may delay operations personnel involved with safe shutdown activities near the fire location. All potential delays in operations personnel activities will need to be addressed to ensure post-fire SSD activities are successful.

Emergency lighting, in either the fixed positions where needed, or portable to be used by plant personnel in SSD activities established by plant procedures must be provided. The locations include access/egress routes, as well as locations where the actions are to be performed on SSD equipment. This lighting will require illumination checks, maintenance and testing to ensure availability at all times. Plant communications, in the form of fixed local, or portable radio systems to support both the on-site fire brigade and operations personnel involved in SSD activities must be provided. These systems ought to be independent of normal plant communication systems, powered such that nearby fires will not affect them, tested for interference with other plant equipment (i.e., protective relays), and suitable for communication with off-site local fire departments, when needed. These systems will need to be tested for adequacy, and always maintained and inspected to be available when needed.

6.2.1.4 *Notification*

A procedure must be established and included in the emergency response plan (ERP) for notification of an emergency situation to:

- Other personnel on-site;
- On-site emergency response team;
- The surrounding community;
- Outside emergency response teams, community, or mutual aid;
- Regulatory agencies.

6.2.2 Firefighting response

6.2.2.1 *Incident command equipment*

Effective incident management requires command and control of the responders, equipment and documentation to support an effective response. The FRNA identifies equipment and resources to manage the control and response to an incident. Equipment required for the response, including incident management, is required to be available and functioning when demanded for the incident commander (IC) to effectively manage the emergency. effective response requires clear two-way communications with the various response organizations and their responders, including plant staff, mutual aid organizations, security and emergency preparedness groups.

The required equipment at a minimum may include:

- Radio communications between the command post - IC and emergency responders with the ability to utilize multiple channels simultaneously for effective command and control of parallel response activities, including security;
- Radio communications with mutual aid organizations;
- Radio communications with the emergency operations center and control rooms (main and secondary);
- Fire preplans in a suitable format to aid the IC in the field (an example of a fire preplan is provided in APPENDIX II);
- Provisions to record actions and conditions;
- Tactical worksheets;
- Response procedures or guidelines;
- Readily identifiable, sheltered and environmentally controlled (heat, ventilation, etc.) Command Post which is protected from the effects of the incident and equipped with light, heat and electrical power such as an Incident Command vehicle.

6.2.2.2 *Response equipment*

The minimum required number of responders and equipment are determined through the FRNA. The fire response organization and FPP ensures the following:

- The aggregate response capability of on-site emergency response and off-site mutual aid meets the minimum resource and intervention timeline needs as determined by the FRNA;
- On-site and off-site equipment and their deployment procedures are compatible and interoperable;
- Off-site responders from mutual aid organizations are familiar with the hazards and risks at the nuclear facility, their role in a response and the operation of emergency response equipment at the facility.

To ensure an effective and timely intervention, emergency response equipment is provided to the responders, including firefighting personal protective clothing, respiratory protective equipment, personal or team radios, flashlights, radiation monitoring equipment, personal dosimeters, and firefighting and emergency response equipment (such as hoses, nozzles and fire extinguishers, rescue tools, ladders, forcible entry tools, smoke removal equipment and foam generating equipment). Additional equipment and resources for emergency medical care, responder rest and rehabilitation during the incident (shelter, water, etc.), environmental protection (e.g. spill control) and property conservation are provided.

All personal response equipment (such as firefighter bunker gear, breathing apparatus, flashlights, etc.), is inspected periodically, such as at the beginning of each shift, to ensure it is in a state of readiness. All emergency response equipment, including personal response equipment is maintained under a documented ITM programme.

It is important to take balance between rapid / timely intervention and reliability. Indeed, “false” alarms might have an impact on reliability and therefore impact the response time, as indicated in TABLE 6.

6.2.3 Consideration for emergency response

6.2.3.1 Incident command system

A plan to integrate the facility firefighting team, local community fire response organization, and/or mutual aid firefighting group incident command system must be included in the ERP.

Where the community response organization supplies the incident command system, the role of the facility employees does not need to be defined. The answers to the following questions must be prepared:

- Who will represent the company and in what role in the Incident Command (IC) System?
- Who will be the IC before and after the arrival of the external fire department?
- Who will be the official spokesperson?
- Who will be responsible for taking over the plant situation after the external fire department arrival?
- Will employees simply evacuate after shutting down operating units to a preplanned location?
- Will some employees remain to provide advice to the IC or operations officer?
- Will trained and qualified employees assist the community fire brigade in suppression activities?

— Who will decide when it is safe to return control of the emergency site to the owner?

6.2.3.2 Examples of response effectiveness factors

Examples of response effectiveness factors can be found in TABLE 6.

TABLE 6. EXAMPLES OF RESPONSE EFFECTIVENESS FACTORS (adapted from Ref. [29])

Factor	Considerations
Response time	Faster response times done in a safe manner better ensure a higher probability to limit the consequences of an incident. Note that “false” alarms may occur and a timely way to validate the significance of each alarm may need to be considered.
Existing on-duty personnel	Ensure an appropriate number of qualified individuals are on-duty each shift to effectively respond to an incident.
Existing qualifications/training	Verify the existence of qualified and trained individuals in the organization to minimize additional personnel being needed.
Site-specific knowledge	Ensure on-site personnel used in responses are aware of the site-specific layout and equipment/materials involved.
Existing off-duty personnel	Should on-duty staff be unable to support the response needs, ensure off-duty or mutual aid support personnel are available, and can respond in a timely manner.
Availability of response team	Contingency plans must be developed to address multiple emergencies that could overburden the projected response needs.
Exposure to fire hazards	Adequate personnel response protective equipment must be made available in a known location to minimize exposure to fire-fighting personnel from heat and toxic smoke from a fire.
Environmental concerns	Controls must be provided to ensure contaminated fire-fighting water run-off is directed so as to protect water supplies (drinking water, lakes, rivers, etc.) from contamination.
Existing equipment	Ensure the existing plant fire-fighting equipment is suitable for the hazards at that location. This includes both fixed and portable/mobile fire suppression equipment and any special needs response equipment.

6.2.3.3 Example of management considerations for determining the emergency response organization

An example of management considerations for determining the emergency response organization can be found in TABLE 7.

TABLE 7. EXAMPLE OF MANAGEMENT CONSIDERATIONS FOR DETERMINING THE EMERGENCY RESPONSE ORGANIZATION (adapted from Ref. [29])

Factor	Considerations
Control of plant emergency	NPP emergency plans are essential to properly plan for unusual events including fires. Coordination with local agencies, such as fire departments, are needed to address who is responsible for the different aspects of an emergency to avoid conflicts of authority at a stressful time.
Ongoing commitment	Periodic plant training, plant equipment surveillance/maintenance, and ongoing interface with local fire department(s) personnel are essential.
Community relations	Communication with the community, such as the local fire department, about the unique hazards at the NPP facility and what plans are in place in the event of a fire situation.

Ongoing management/administration	Administrative oversight is necessary for appropriate emergency response management.

6.2.3.4 *Example of description of key sections of a comprehensive ERP*

An example of description of key sections of a comprehensive ERP can be found in TABLE 8.

TABLE 8. EXAMPLE OF DESCRIPTION OF KEY SECTIONS OF A COMPREHENSIVE ERP (adapted from Ref. [29])

Title	Description
Basic plan or executive summary	This should include a listing of potential emergencies including assumptions, organization structure, group responsibilities, emergency action levels, maintenance of the ERP and distribution plans.
Prevention procedures	Based on industry experience and regulatory guidance the NPP should have procedures in place to prevent fire hazards or ignition sources as much as possible. These would support the ERP and could be referenced versus reproduced.
Preparedness procedures	These procedures should include how to prepare for any emergency, which includes a discussion of training plans, drills and exercises planned, equipment acquisition options, mutual aid agreement(s) with off-site fire department(s), community relations plans, annual reviews/audits, and equipment testing needs, for example.
General response procedures	These procedures should provide details of the appropriate actions to be taken by the NPP site personnel and organizations, equipment that could be used, and the operation/interface of the site organizations.
Team procedures	These procedures should detail responsibilities and duties of each emergency response team (ERT) member.
Hazard-specific procedures	These procedures should explain the actions necessary in response to a specific emergency, such as credible incidents (fire, chemical spill, steam leaks, etc.) and natural disasters.
Recovery procedures	These procedures should explain the necessary actions for recovery from an emergency. These should include incident investigation, employee support, community coordination, critiques and decontamination operations.
Appendices	Useful reference materials including site maps, fire water system layout diagrams, critical utility emergency shut off points, and names and contacts for service providers should be included.

6.3 TRAINING AND DRILLS

6.3.1 Considerations for emergency responder training

- The nature of the processes and materials involved in an emergency situation;
- The appropriate procedures for safely handling emergency scenarios;
- The proper use and limitations of emergency response equipment;
- The function of the incident command system and how to work within it;
- Appropriate rescue procedures;
- Procedures regarding blood-borne pathogens;
- Respiratory protection procedures;
- Decontamination procedures;
- Personal protective equipment (PPE).

6.3.2 Facility and operations personnel

- Fire behaviour;
- The phases of a fire;
- How, when, where and what to report on emergencies;
- How to use communication tools;
- Evacuation procedures;
- Shelter-in-place procedures;
- How to use portable fire extinguishers;
- Classes of fire (A, b, C and D);
- Fire Control Equipment;
- Techniques used to control fires and emergencies (fires, spills, leaks, etc.);
- Alarm notification systems;
- Special hazards that may be encountered;
- Hazardous/toxic materials;
- Radiation sources;
- Electrical storage and location of flammable liquids and gases;
- Storage of combustibles;
- Hot work activities;
- Control of ignition sources;
- Housekeeping;
- Emergency shutdown and isolation.

These training, drills and exercises are systematically organized and effectively implemented by the operating organizations and the external organizations such as the regional fire departments. Use of actual fire, mock-up facilities or smoke making equipment can contribute to enhancing the effectiveness. Several good practices have been identified from member states in Ref. [19].

6.3.3 Incipient fire brigades (on-site)

- Fire behavior;
- The phases of a fire;
- Use of portable fire extinguishers;
- Classes of fire (A, B, C and D);
- Fire control equipment;
- Techniques used to control fires and emergencies (fires, spills, leaks);
- Alarm notification systems;
- Special hazards that may be encountered;
- Hazardous/toxic materials;
- Radiation sources;
- Electrical storage and use of flammable liquids and gases.

6.3.4 Examples of on-site training

Examples of on-site training for on-site firefighting personnel can be found in TABLE 9.

TABLE 9. EXAMPLES OF ON-SITE TRAINING (Ref. [14])

Target	Training name	Training description	Frequency
Shift personnel (Management personnel)	Field guiding training	- Conduct field layout training (dangerous material facilities, access control centers, access control rooms); - Inform the locations of equipment for public fire brigades.	Once a year per shift
On-site fire brigade	Field layout training Firefighting equipment arrangement training	- Conduct field layout training (on-site field training, system training); - Inform the locations of equipment for fire brigades.	Once a year per team
On-site fire brigade	Radiation control training	- Conduct radiation control knowledge training and radiation control skill training.	Once a year per team
Personnel of the plant manager's office	Satellite telephone call exercise	- Conduct an exercise to call the competent fire department using satellite phones.	Once a year
Shift supervisor Shift managers	Notification exercise	- Conduct an exercise to call over the dedicated firefighting line.	Five times a year
Shift supervisors and personnel On-site fire brigade On-site security guards	Coordinated exercise with contract fire brigade	- Conduct an exercise based on the firefighting plan (Fire drills using smoke extraction systems); - Conduct an exercise on initial firefighting, notification, room access within the controlled area anticipating a fire within the controlled area.	Five times a year

TABLE 9. EXAMPLES OF ON-SITE TRAINING (Ref. [14])

Target	Training name	Training description	Frequency
Shift personnel (Management personnel)	Firefighting equipment handling exercise	- Conduct an exercise to handle extinguishers, fireplugs, and simplified fire suits. (Actual fire shall be used for extinguisher handling exercises).	Once a year per shift
On-site fire brigade	External training	- Conduct an exercise using external organization (and actual fire) (in cooperation with Maritime force).	Once a year
Shift supervisors and personnel On-site fire brigade On-site security guards	Comprehensive firefighting exercise (Firefighting model exercise)	- Conduct external notification (including dedicated lines), initial firefighting, evacuation and guiding, coordination with public fire brigades, and more.	Once a year
On-site fire brigade	Firefighting equipment handling exercise	- Conduct an exercise on the handling of outdoor fireplugs, heatproof suits, respirators, portable compact fire pumps, and fire trucks.	Once a month per team
		- Conduct an exercise on the handling of chemical solution makeup pumps and line proportioners.	Once per six months per team
		- Conduct an exercise on the handling of extinguishers and indoor fireplugs.	Once per six months per team

7 CONCLUSION

The overall lessons learned from experience in NPP operation and recent fire protection risk assessments indicate the potential for nuclear fuel damage and the resulting potential for off-site dose implications is higher than for other postulated plant events. Fires in NPPs pose a real threat to nuclear safety and their significance extends beyond the scope of past conventional fire hazard analyses. The point of this publication is to help explain the broad range of experiences for a consistent example of what insights to address to better ensure DID practices are consistently applied.

As described in chapters 1 and 2, the basic principles of fire protection and range of DID issues are described. As noted in these chapters: (a) the need to compensate for potential human and equipment failures must be addressed; (b) the need to provide margin for the design of the fire barriers and their protection systems (suppression/detection) must also be addressed, so that previously unexpected issues can be addressed by this bounding approach; and finally, (c) the last stage of DID is to assure that should the previous defences be inadequate an alternative is assured to minimize the potential for radiation exposure to the public. This may be assured via redundant, or even a third option for post-fire safe shutdown systems being protected from the worst-case fire considerations.

The various fire protection systems are discussed in chapter 3 to provide a consistent base for consideration. The range includes passive, active, and inspection and maintenance for these systems. Passive systems also range from separation distances, fire barriers, structural, electrical, ventilation, lighting and communications needs. Active systems are needed to quickly detect fire development, suppress fires in the early stages of development, and provide manual suppression capabilities to ensure firefighting capabilities once fire brigade personnel arrive. Inspection, testing, and maintenance for each of these fire protection systems is described to address the functionality for each of these components.

A foundation is needed to reduce the likelihood for fires to occur and this is discussed in chapter 4 through fire prevention activities. These include organizational and management issues, fire prevention issues, and QA issues. The organizational and management section covers the roles, responsibilities, fire safety management training, and performance as well as assessment of these personnel activities. The physical aspects of fire prevention that are discussed include controls on combustible materials, ignition sources, housekeeping practices, plant modification controls, and efforts during fire protection systems maintenance and impairments. Finally, the QA and audits for these fire prevention activities are addressed.

Plant analyses to predict the postulated fire damage consequences and ability to assure post-fire safe shutdown are discussed in chapter 5 on fire risk analysis. This information provides plant knowledge of where fires are more likely to occur. Postulated fire impact on structures, systems, and components important to safety so that pre-fire planning can be established based on plant specific information. Documents such as the FHA, post-fire safe shutdown procedures, and plant modification packages can be more efficiently and consistently developed. Issues may be identified where a fire is postulated to occur when other unrelated, or possibly related, events occur including seismic and beyond design basis fire (BDBF) events.

The need for pre-fire planning is covered in chapter 6 on emergency response activities. Both an on-site fire brigade supported by off-site responders must be organized, maintained, and the interface activities established. The potential damage from postulated fires in all areas of the plant must be pre-planned and documented to assure more efficient response to actual events. Finally, the general plant staff, on-site fire brigade, off-site responders, and operations personnel must be trained and drilled to assure success during actual fire events.

Each of these areas provides lessons learned from past NPP experiences in the interest of improving fire safety in both new and existing operating NPPs.

APPENDIX I.
GENERAL EXAMPLE DATA FOR FIRE SUPPRESSION SYSTEMS

I.1. ADVANTAGES AND LIMITATIONS OF VARIOUS EXTINGUISHING AGENTS [29]

The center for chemical process safety provided the information for TABLE 10 below in Ref. [29].

TABLE 10. EXAMPLE OF ADVANTAGES AND LIMITATIONS OF VARIOUS EXTINGUISHING AGENTS

Agent	Type Extinguishment	Advantages	Limitation
Water	Cooling Smothering Dilution Exposure	Available Very low cost	Not for Class C electrical fires Freezes at 32^0F (0^0C) Reactive with some material, e.g., sodium, magnesium Cannot extinguish low flash point materials
Foam	Smothering	Best for Class B Pool Fires (Two-dimensional fires)	Not for electrical fires Foam blanket may break-up Not applicable for LPG
CO_2	Smothering Reduction Some cooling	Nonreactive No residue Class C	Reduces O_2 level Toxic to people (asphyxiant) Not applicable for oxidizers
Dry Chemical	Chain breaking	Class B & C	Fire reflashes if not completely extinguished or surfaces are present (especially flammable/combustible liquids)
Clean Agent	Chain breaking Inerting	Good for Class A, B, C	Not for outdoors May produce toxic gases

I.2. SELECTED EQUIPMENT WATER SPRAY APPLICATION RATES (API 2030) [30]

The American petroleum institute provided the information for TABLE 11 below in Ref. [30].

TABLE 11. EXAMPLE OF SELECTED EQUIPMENT WATER SPRAY APPLICATION RATES

Item	$L \cdot m^2/min$
Air-cooled fin-tube heat exchangers	10.2
Cable trays	12.2
Compressors	10.2
Exposure protection	10.2
Fired heaters	10.2
LPG loading racks	10.2
Motors	10.2

Pipe racks	10.2
Pressurized storage tanks	10.2
Pumps	8.1–20.4
Electrical switchgear	10.2
Towers	10.2
Transformers	10.2
Turbines and related gear boxes	10.2
Vessels and heat exchanges	10.2

I.3. SPRINKLER PROTECTION FOR MEDIUM TO SMALL PROCESSING FACILITIES [31]

The factory mutual insurance company provided the information for TABLE 12 below in Ref. [31].

TABLE 12. EXAMPLE OF SPRINKLER PROTECTION FOR MEDIUM TO SMALL PROCESSING FACILITIES

Flash Point	Heated To/Above Flash Point	Room or Equipment Explosion Hazard	Sprinkler Density (L·m^2/min)	Sprinkler Temp. Rating ^{0}F (^{0}C)	Area of Demand m^2	Manual Hose Streams L·m^2	Duration min
Any liquid presenting explosion hazard			12	286 (141)	560	3 800	120
				165 (74)	740		
< 100^{0}F (38^{0}C)	Does Not Apply	No	12	286 (141)	370	1 900	60
				165 (74)	560		
100–200^{0}F (38–93^{0}C)	Yes	No	12	286 (141)	370		
				165 (74)	560		
	Yes	No	10	286 (141)	370		
				165 (74)	560		
> 200^{0}F (93^{0}C)	Yes	No	10	286 (141)	370		
				165 (74)	560		
	Yes	No	8	286 (141)	280		
				165 (74)	370		

I.4. SPRINKLER COLOUR CODING AND TEMPERATURE RATING [29]

The center for chemical process safety provided the information for TABLE 13 below in Ref. [29].

TABLE 13. EXAMPLE OF SPRINKLER COLOUR CODING AND TEMPERATURE RATING

Rating	Maximum temperature at sprinkler level ^{0}F (^{0}C)	Rated temperature of sprinkler ^{0}F (^{0}C)	Frame color	Glass bulb colour
Ordinary	100 (38)	135–170 (57–77)	Uncolored	Orange/Red
Intermediate	150 (66)	175–225 (79–107)	White	Yellow/Green
High	225 (107)	250–300 (121–149)	Blue	Blue
Extra high	300 (149)	325–375 (163–191)	Red	Purple
Very extra high	375 (191)	400–475 (204–246)	Green	Black
Ultra-high	475 (246)	500–575 (260–302)	Orange	Black

I.5. WATER SPRAY AND FIREPROOFING FOR STRUCTURAL STEEL PROTECTION [32]

The U.S. national fire protection association provided the information for TABLE 14 below in Ref. [32].

TABLE 14. EXAMPLE OF WATER SPRAY AND FIREPROOFING FOR STRUCTURAL STEEL PROTECTION

Type protection	Vertical structural steelwork	Horizontal structural steelwork	Comments
Water spray only	10.2 L·m^2/min of wetted surface	4.1 L·m^2/min Of wetted surface	This provides active protection that depends on fire detection to actuate enough water spray to the structural member for protection.
Fire-resistive insulating material only	2 to 3–hour rated fireproofing	2 to 3–hour rated fireproofing	This provides passive protection, but unseen corrosion beneath the material should be considered.
Combination water spray with fire-resistive insulating material	1 to 1 1/2–hour rated fireproofing plus water spray (as above)	1 to 1 1/2–hour rated fireproofing plus water spray (as above)	This provides both active and passive protection should the water spray fail.

APPENDIX II.
EXAMPLE OF FIRE PREPLANS

II.1. FIRE PREPLAN EXAMPLE FOR ROOM LAYOUT INFORMATION

FIG. 10 below presents a fire preplan example for room layout information. Many other pieces of information can be added to such a fire preplan such as exits, fire lockers, fire alarm panel, etc…

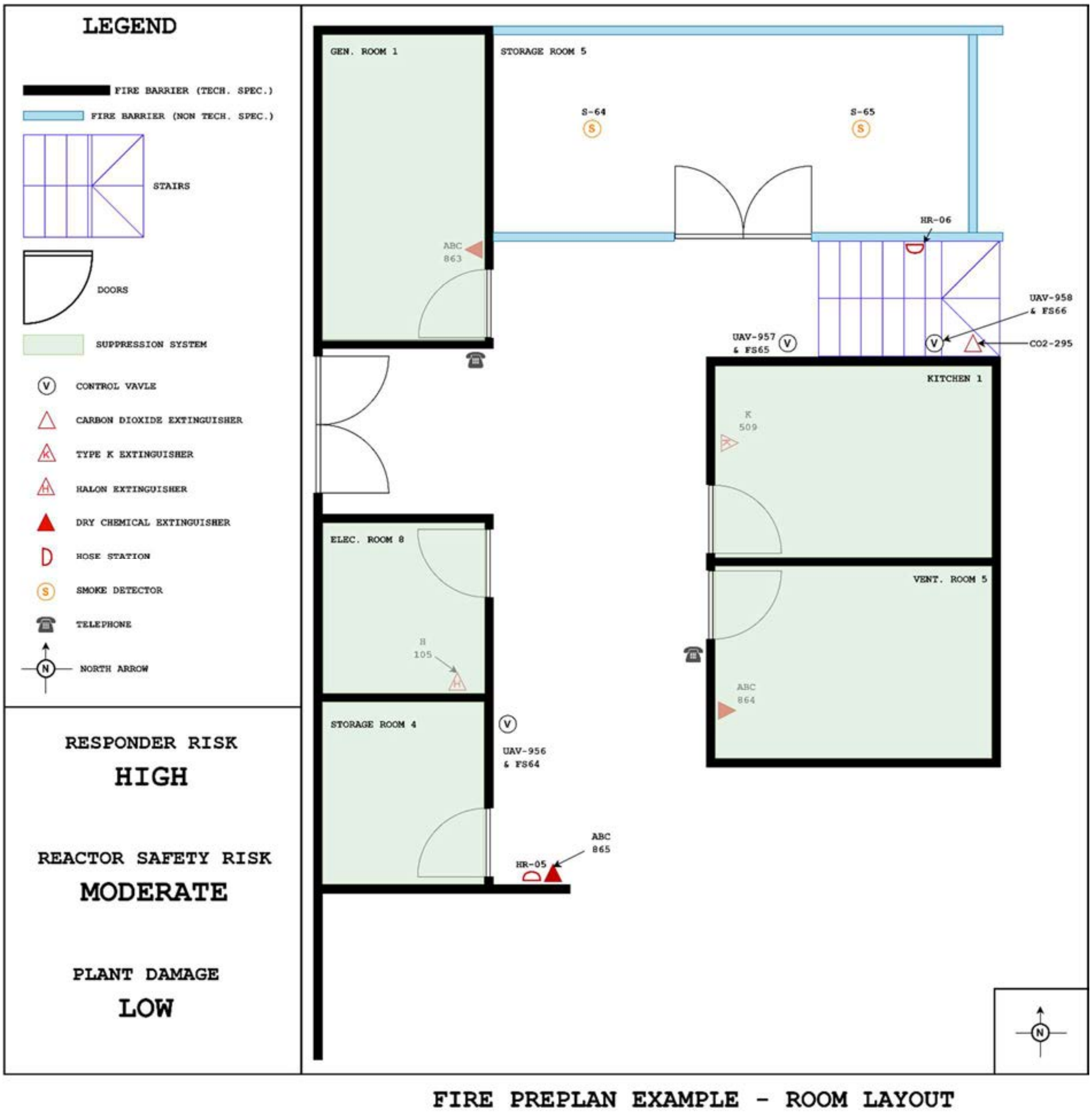

FIG. 10. Fire preplan example room layout

II.2. FIRE PREPLAN EXAMPLE FOR ROOM DETAILED INFORMATION

FIG. 11 below presents a fire preplan example for room detailed information.

FIRE LOAD	**HIGH**	**SUPPRESSION AND CONTROL**			**REACTOR SAFETY**	**MODERATE**
ADD A DESCRIPTION OF THE DIFFERENT FIRE CLASSES PRESENT (A, B, C, …)		DESCRIBE THE DIFFERENT EXISTING SUPPRESSION AND CONTROL ITEMS			ADD A DESCRIPTION OF HOW THE DESCRIBED ROOM(S) PARTICIPATE TO THE FIRE SAFE SHUTDOWN	
RADIOLOGICAL	**HIGH**				**VENTILATION**	
ADD A DESCRIPTION OF THE RADIOLOGICAL RISK		**ELECTRICAL MAX VOLTAGE:** XXX			ADD A DESCRIPTION OF THE PRESENT VENTILATION	
CHEMICAL	**MODERATE**	**CONTACT CONTROL ROOM PRIOR TO ATTEMPTING ANY ELECTRICAL ISOLATION**			**PLANT DAMAGE**	
ADD A DESCRIPTION OF THE CHEMICAL RISK		**EQUIPMENT**	**POWER SUPPLY**	**LOCATION**	N/A	
EXPLOSIVE	**LOW**	ADD TECHNICAL DATA	ADD TECHNICAL DATA	ADD LOCATION	**EFFLUENT CONTROL**	
ADD A DESCRIPTION OF THE EXPLOSION RISK					ADD A DESCRIPTION OF THE EFFLUENT CONTROL (ACTIVE SUMPS, AUTOMATIC OR NOT, ETC…)	
PRESSURE VESSELS	**MODERATE**				**AREA OCCUPANCY**	
ADD A DESCRIPTION OF THE PRESSURE VESSELS (LOCATION, …)					**DAYS:** XX **– NIGHTS:** XX	
		PREPARED BY: (SIGNATURE/DATE)	FIELD CHECKED BY: (SIGNATURE/DATE)	VERIFIED BY: (SIGNATURE/DATE)	APPROVED BY: (SIGNATURE/DATE)	FIELD RESERVED FOR ADMIN.NUMBER

FIG. 11. Fire preplan example room detailed information

APPENDIX III.
EXAMPLE PROCESS OF FIRE SAFE SHUTDOWN

III.1. DETERMINISTIC SAFE SHUTDOWN ANALYSIS

III.1.1. Methodology overview

The nuclear energy institute provided the information for FIG. 12 below in Ref. [18].

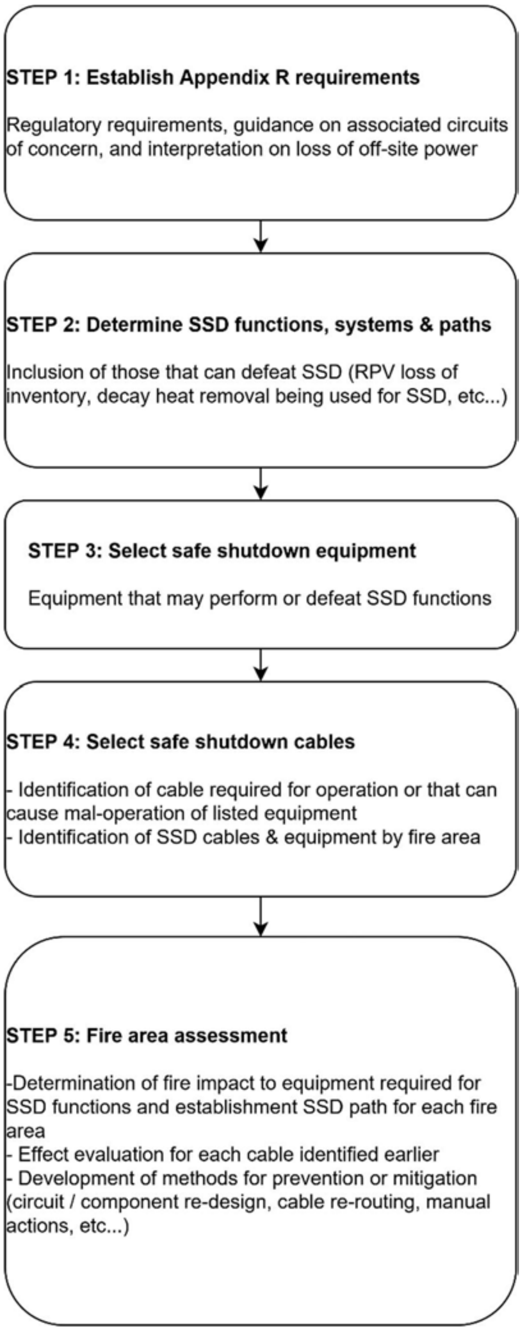

FIG. 12. Deterministic methodology overview (adapted from Ref. [18])

III.1.2. Safe shutdown functions

The nuclear energy institute provided the information for FIG. 13 below in Ref. [18].

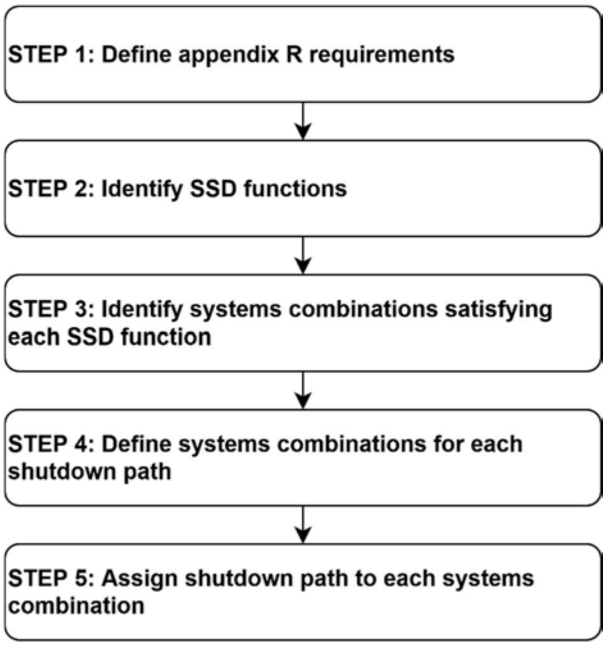

FIG. 13. Safe shutdown system selection and path development (adapted from Ref. [18])

III.1.3. Safe shutdown equipment selection

The nuclear energy institute provided the information for FIG. 14 below in Ref. [18].

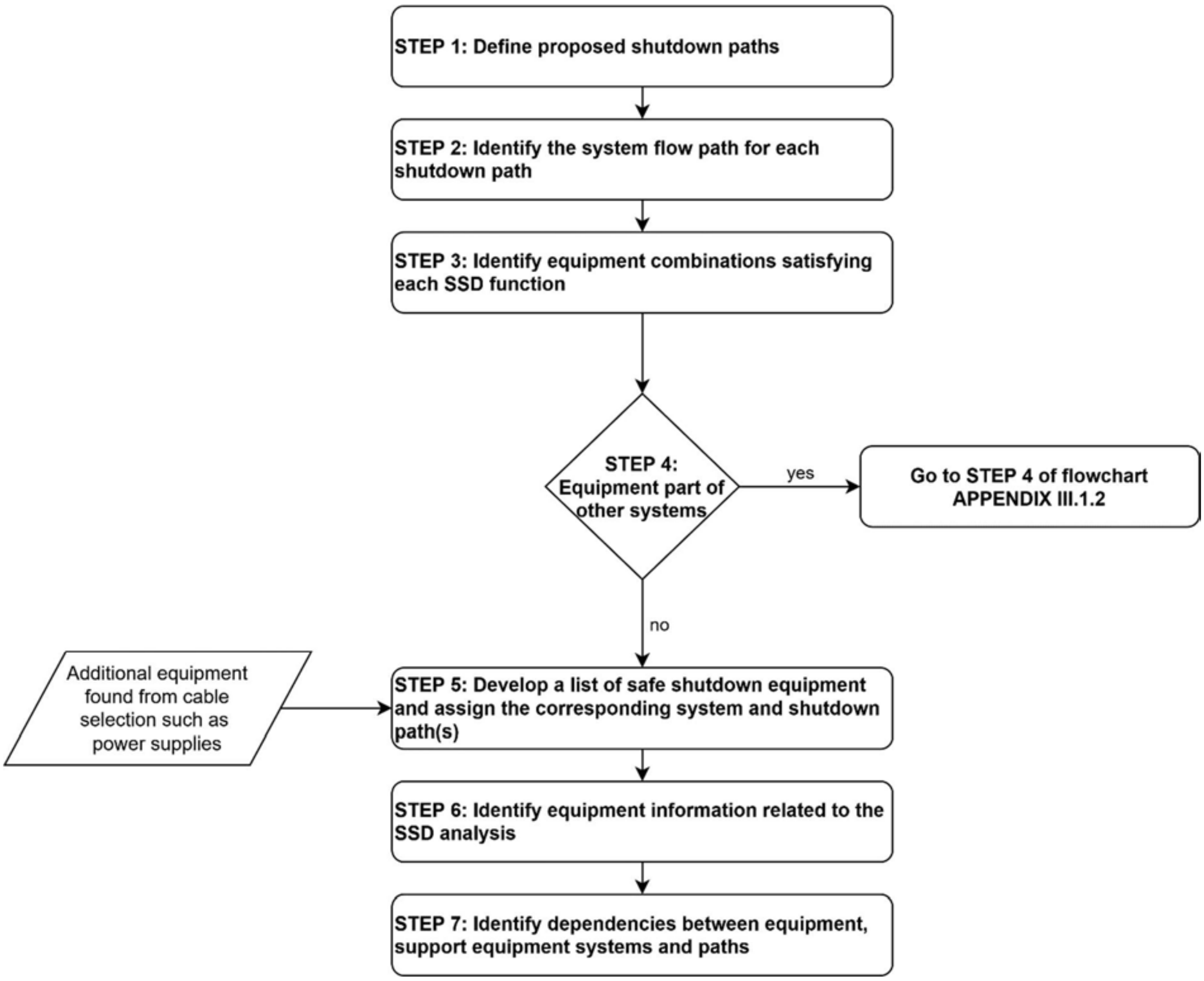

FIG. 14. Safe shutdown equipment selection (adapted from Ref. [18])

III.1.4. Safe shutdown cable selection

The nuclear energy institute provided the information for FIG. 15 below in Ref. [18].

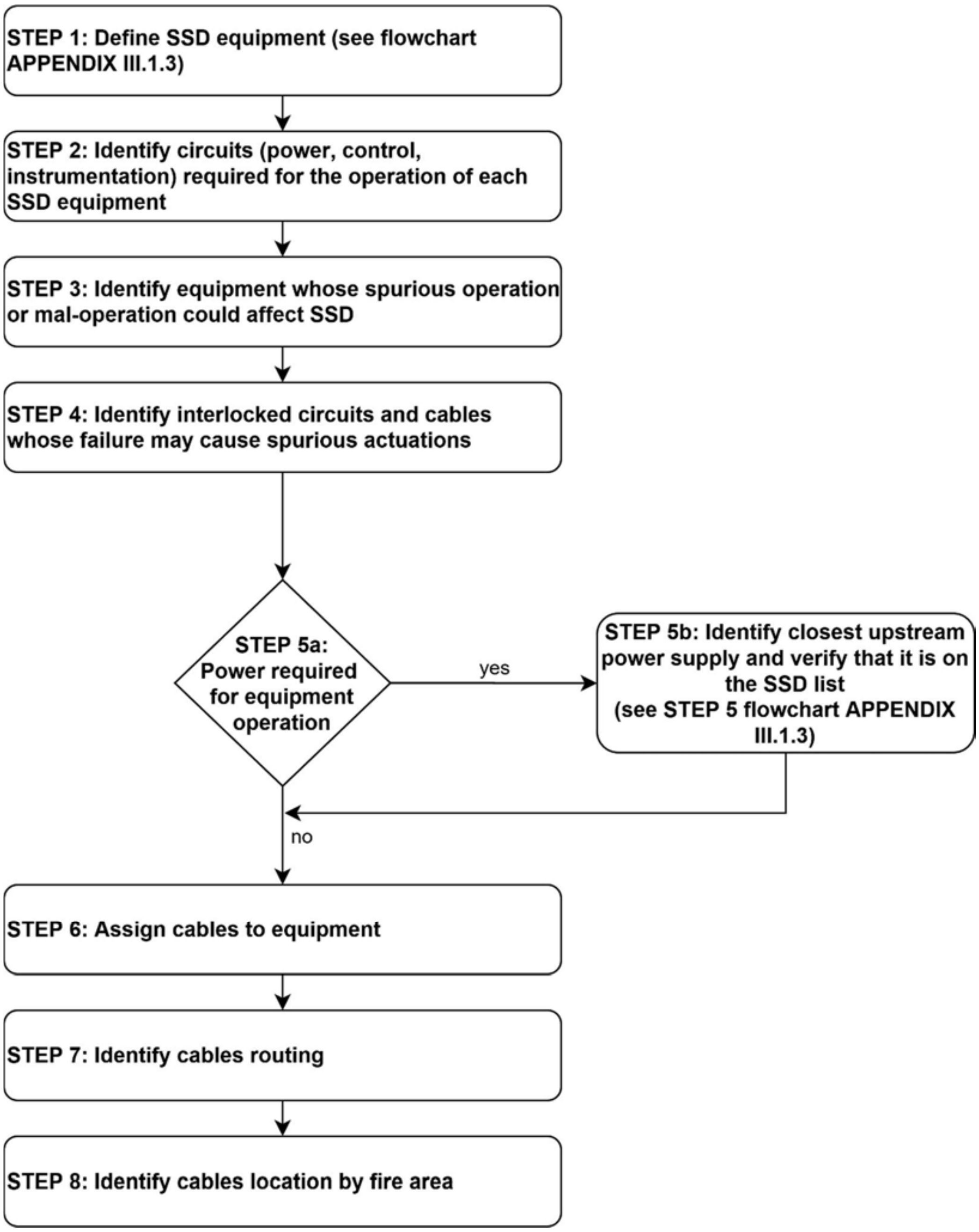

FIG. 15. Safe shutdown cable selection (adapted from Ref. [18])

III.2. FIRE AREA ANALYSIS – ASSESSMENT FLOWCHART

The nuclear energy institute provided the information for FIG. 16 below in Ref. [18].

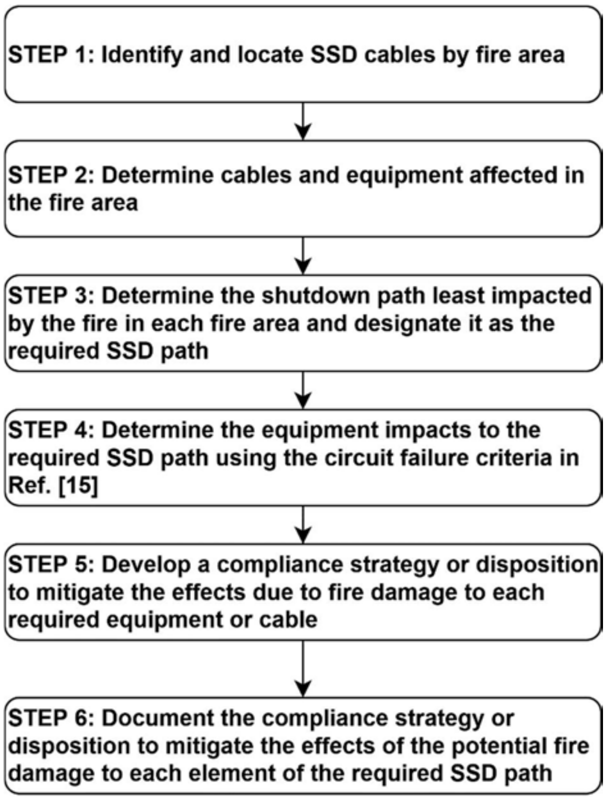

FIG. 16. Fire area assessment flowchart (adapted from Ref. [18])

APPENDIX IV.
FIRE HAZARD REPORT ANALYSIS FORMAT

Below is a generic example of the type information generally provided in an FHA.

COMPARTMENT NUMBER		COMPARTMENT NAME	
I. AREA BOUNDARY DESCRIPTION			
CONFIGURATION			
VOLUME			FLOOR AREA
L:	W:	H:	
FIRE RESISTANCE RATING			
North		South	
East		West	
Floor		Ceiling	
PENETRATION SUMMARY			
HVAC			
Electrical			
Mechanical			
Architectural			
II. MAJOR EQUIPMENT			
III. EQUIPMENT CONTAINING RADIOACTIVE MATERIALS			
IV. COMBUSTIBLES AND FIRE LOADING			
IN-SITU COMBUSTIBLES		TRANSIENT COMBUSTIBLES	
Items (Quantity)	Heat Load	Items (Quantity)	Heat Load
-		-	
-		-	

Floor Area		Total Heat Load	
Fire Load		Fire Severity	
V. FIRE PROTECTION MEASURES			
Detection system		Suppression system	
Drains/Curbs		Hose Stations	
Portable Fire Extinguishers		Smoke Removal Provision	
DESIGN BASIS FIRE			
VI. INADVERTENT ACTUATION EFFECT OF SUPPRESSION SYSTEM			
REMARKS:			

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Fires and Explosions in the Design of Nuclear Power Plants, Safety Guide No. NS-G-1.7, IAEA, Vienna (2004).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Fire Safety in the Operation of Nuclear Power Plants, Safety Guide No. NS-G-2.1, Vienna (2000).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Fundamental Safety Principles, Safety Standard Series No. SF-1, IAEA, Vienna (2006).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Defence in Depth in Nuclear Safety, Safety Series No. INSAG-10, IAEA, Vienna (1996).

[5] U.S. NUCLEAR REGULATORY COMMISSION, Fire Protection for Nuclear Power Plants, Regulatory Guide 1.189, Revision 3, February (2018).

[6] U.S. NUCLEAR REGULATORY COMMISSION, Fire Dynamics Tools (FDTs): Quantitative Fire Hazard Analysis Methods, NUREG-1805, December (2004).

[7] U.S. NUCLEAR REGULATORY COMMISSION, Fire Dynamics Tools (FDTs) Quantitative Fire Hazard Analysis Methods, NUREG-1805 Supplement 1, Vol. 1 and 2, July (2013).

[8] U.S. NUCLEAR REGULATORY COMMISSION, Fire Endurance Test Acceptance Criteria for Fire Barrier Systems Used to Separate Redundant Safe Shutdown Trains Within the Same Fire Area (Supplement 1 to Generic Letter 86-10, Implementation of Fire Protection Requirements), March (1994).

[9] NFPA FIRE PROTECTION HANDBOOK, 20th Edition.

[10] U.S. NUCLEAR REGULATORY COMMISSION, Fire Barrier Penetration Seals in Nuclear Power Plants, NUREG-1552, Supplement 1, January (1999).

[11] U.S. NUCLEAR REGULATORY COMISSION, Nuclear Regulatory Authority Experimental Program to Characterize and Understand High Energy Arcing Fault (HEAF) Phenomena, NUREG/IA-0470, August (2016).

[12] U.S. NATIONAL FIRE PROTECTION ASSOCIATION, Standard for Portable Fire Extinguishers, NFPA 10, (2006).

[13] U.S. NATIONAL FIRE PROTECTION ASSOCIATION, Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems, NFPA 25, (2011).

[14] THE KANSAI ELECTRIC POWER CO., INC., The Examples of the Operational Practices for Fire Protection of Japanese NPP (excerpt), (2020).

[15] U.S. NUCLEAR REGULATORY COMMISSION, Fire Protection, 10 CFR 50.48, August (2007).

[16] NUCLEAR ENERGY INSTITUTE, Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c), NEI 04-02, Rev. 2, April (2008).

[17] U.S. NUCLEAR REGULATORY COMMISSION, Fire Protection for Nuclear Power Facilities Operating Prior to January 1, 1979, Appendix R to 10 CFR 50, July (2012).

[18] NUCLEAR ENERGY INSTITUTE, Guidance for Post-Fire Safe Shutdown Circuit Analysis, NEI-00-01, Washington D.C, (2011).

[19] OSART GOOD PRACTICES, 03 Operations, 3.6. Fire Prevention and Protection Programme, April (2020), https://www.iaea.org/sites/default/files/20/04/osart_good_practices_3.6.pdf

[20] UNITED STATES GEOLOGICAL SURVEY AND CALIFORNIA GEOLOGICAL SURVEY, Fire following earthquake, (2008).

[21] UNITED STATES DEPARTMENT OF ENERGY, Seismic Evaluation Procedure for Equipment in US Department of Energy Facilities, Rep. DOE/EH-0545, (1997).

[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Design and Qualification for Nuclear Power Plants, Safety Standards Series No. NS-G-1.6, IAEA, Vienna (2003).

[23] ELECTRIC POWER RESEARCH INSTITUTE, EPRI NP 6989, Survey of Earthquake-Induced Fires in Electric Power and Industrial Facilities, (1990).

[24] U.S. NUCLEAR REGULATORY COMMISSION, ML121450226, Plan for the Development of a Methodology for Seismically Induced Fires and Floods, (2012).

[25] U.S. NUCLEAR REGULATORY COMMISSION, NUREG 1742, Perspectives gained from Individual Plant Examination of External Events (IPEEE) Program, Final report, (2002).

[26] WANO SOER, Significant Operating Experience Report WANO SOER 2011–12 Fukushima Daiichi Nuclear Station Fuel Damage Caused by Earthquake and Tsunami, March (2011).

[27] RECS Gravelines « Rapport d'évaluation complémentaire de la sûreté des installations nucléaires au regard de l'accident de Fukushima du CNPE de GRAVELINES » September 15th (2011).

[28] SEVENTH FRENCH REPORT UNDER THE CONVENTION ON NUCLEAR SAFETY, August (2016).

[29] CENTER FOR CHEMICAL PROCESS SAFETY, Guidelines for Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities, CCPS, New York, (2003).

[30] AMERICAN PETROLEUM INSTITUTE, Guidelines for Application of Water spray systems for Fire Protection in the Petroleum Industry, API 2030, (1998).

[31] FACTORY MUTUAL INSURANCE COMPANY (FM Global), Ignitable Liquid Operations, Property Loss Prevention Data Sheets. 7-32, (2014).

[32] U.S. NATIONAL FIRE PROTECTION ASSOCIATION, Standard for Water Spray Fixed Systems for Fire Protection, NFPA 15, (2012).

GLOSSARY

closure. Includes a device or assembly for closing an opening through a fire separation or an exterior wall, such as a door, a shutter, a fire damper, wired glass or glass block, and includes all components such as hardware, closing devices, frames and anchors. (2010 NBC)

combustible liquid. A liquid that has a closed-cup flash point at or above 37.8°C. (NFPA 804)

combustible material. A material in solid, liquid or gaseous state capable of igniting, burning, supporting combustion or releasing flammable vapour when subject to specific conditions such as fire or heat. (IAEA NS-G-2.1)

fire. A process of combustion characterized by heat emission and accompanied by smoke or flame, or both. (IAEA Safety Series 50-SG-D2)

fire barrier. Wall, floor, ceiling or device for closing a passage such as a door, a hatch, a penetration or a ventilation system to limit the consequences of a fire. A fire barrier is characterized by a fire resistance rating. (IAEA NS-G-2.1)

fire brigade. An organized group of employees at a facility who are knowledgeable, trained and skilled in at least basic firefighting operations, and whose full-time occupation may or may not be the provision of fire suppression and related activities for their employer. (NFPA 600)

fire compartment. A building or part of a building comprising one or more rooms or spaces, constructed to prevent the spread of the fire to or from the remainder of the building for a given period of time. A fire compartment is completely surrounded by a fire barrier. (IAEA NS-G-2.1)

fire damper. A device designed to prevent by automatic operation the passage of fire through a duct under given conditions. (IAEA NS-G-2.1)

fire hazards. Condition that involve the necessary elements to initiate and support combustion, including in situ or transient combustible materials, ignition sources (e.g., heat, sparks, open flames), and an oxygen environment. (RG 1.189)

fire load. The sum of the calorific energies calculated to be released by the complete combustion of all the combustible materials in a space, including the facings of the walls, partitions, floors and ceiling. (IAEA NS-G-2.1)

fire protection rating. The time in minutes or hours that a closure will withstand the passage of flame when exposed to fire under specified conditions of test and performance criteria. (2010 NBC)

fire resistance. The ability of an element of a building construction, component or structure to perform, for a stated period of time, the required loadbearing function, integrity and/or thermal insulation, and/or other expected function specified in a standard fire resistance test. (IAEA NS-G-2.1)

fire retardant. The quality of a substance of suppressing, reducing or delaying markedly the combustion of certain materials. (IAEA NS-G-2.1)

fire safe shutdown. Actions, components, capabilities, and design features necessary to achieve and maintain safe shutdown of the reactor after a fire in a specific fire area. (NFPA 804)

fire stop. The physical barrier designed to restrict the spread of fire in cavities within and between building construction elements. (IAEA NS-G-2.1)

fire watch. One or more persons responsible for providing additional (e.g. during hot work) or compensatory (e.g. for system impairments) coverage of plant activities or areas for the purpose of detecting fires or identifying activities and conditions that present a potential fire hazard. These people should be trained in identifying conditions or activities that present potential fire hazards, as well as in the use of firefighting equipment and the proper fire notification procedures. (IAEA NS-G-2.1)

flammable liquid. A liquid that has a closed-cup flash point that is below 37.8°C and a maximum vapour pressure of 40 psia at 37.8°C. (NFPA 804)

hot work. Work having the potential for causing fire, particularly work involving the use of open flames, soldering, welding, flame cutting, grinding or disk cutting. (IAEA NS-G-2.1)

ignition source. An applied (external) source of heat which is used to ignite combustible materials (IAEA NS-G-2.1)

impairment. The degradation of a fire protection system or features that adversely affects the ability of the system or feature to perform its intended function. (RG 1.189)

non-combustible. A material meets the acceptance criteria of CAN/ULC-S114, "Test for Determination of Non-Combustibility in Building Materials." (2010 NBC)

ABBREVIATIONS

AHJ	authority having jurisdiction
BDBA	beyond design basis accident
BDBF	beyond design basis fire
CCR	combustible control requirements
DBE	design basis earthquake
DID	defence in depth
ECS	études complémentaires de sûreté (complementary nuclear safety studies)
EDF	électricité de France
EME	emergency mitigation equipment
EPRI	electric power research institute
FARN	force d'action rapide du nucléaire (national nuclear rapid intervention force)
FHA	fire hazard analysis
FPE	fire protection engineer
FPO	fire prevention officer
FPP	fire protection programme
FPPE	fire protection programme engineer
FPSRE	fire protection system responsible engineer
FRNA	fire response needs analysis
FSI	fire service instructor
FSAR	final safety analysis report
FSSA	fire safety shutdown analysis
FTO	fire technical officer
HSC	hardened safety core
HEPA	high efficiency particulate air
HEAF	High energy arcing fault
HVAC	heating, ventilation and air conditioning
IC	incident commander
IFB	industrial fire brigade
INSAG	international nuclear safety group
IPEEE	individual plant examination of external events
ITM	inspection, testing and maintenance
MSDS	material safety data sheet
MSO	multiple spurious operations
NFPA	national fire protection association
NPP	nuclear power plant
NRC	nuclear regulatory commission
PSA	probabilistic safety assessment
PVC	poly vinyl chloride
QA	quality assurance

QA/QC	quality assurance/quality control
SAT	systematic approach to training
SATM	space allocation and transient material
SFPE	society of fire protection engineers
SOER	significant operating experience report
SOP	standard operating procedures
SPOC	single point of contact
SSC	structures, systems and components
SSD	safe shutdown
TNA	training needs analysis
UV	ultraviolet
WANO	world association of nuclear operators

CONTRIBUTORS TO DRAFTING AND REVIEW

Bokor, L.	Paks Nuclear Power Plant, Hungary
Brown, R.G.	Randal Brown & Associates Engineering Ltd, Canada
Gautier, B.	Électricité de France, France
Kang, K.S.	IAEA
Kim, E.S.	KHNP, Republic of Korea
Kim, K.Y.	KHNP, Republic of Korea
Kleinsorg, E.A.	Jensen Hughes, USA
Magnusson, T	Ringhals AB, Sweden
Roué, V.	IAEA
Song, B.S.	IAEA
Trylinski, D.	Ontario Power Generation, Canada
Young, L.D.	Arkansas Nuclear One, USA

Consultancy meetings

3-6 September 2013, 5-7 March 2014, Vienna, Austria

24-26 March 2015, 15-18 March 2016, Vienna, Austria

Technical Meeting

27-29 May 2015 Vienna, Austria

IAEA
International Atomic Energy Agency

No. 26

ORDERING LOCALLY

IAEA priced publications may be purchased from the sources listed below or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

NORTH AMERICA

Bernan / Rowman & Littlefield

15250 NBN Way, Blue Ridge Summit, PA 17214, USA
Telephone: +1 800 462 6420 • Fax: +1 800 338 4550
Email: orders@rowman.com • Web site: www.rowman.com/bernan

REST OF WORLD

Please contact your preferred local supplier, or our lead distributor:

Eurospan Group

Gray's Inn House
127 Clerkenwell Road
London EC1R 5DB
United Kingdom

Trade orders and enquiries:

Telephone: +44 (0)176 760 4972 • Fax: +44 (0)176 760 1640
Email: eurospan@turpin-distribution.com

Individual orders:

www.eurospanbookstore.com/iaea

For further information:

Telephone: +44 (0)207 240 0856 • Fax: +44 (0)207 379 0609
Email: info@eurospangroup.com • Web site: www.eurospangroup.com

Orders for both priced and unpriced publications may be addressed directly to:

Marketing and Sales Unit
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530 • Fax: +43 1 26007 22529
Email: sales.publications@iaea.org • Web site: www.iaea.org/publications

21-00125E

International Atomic Energy Agency
Vienna