Fire Engineering Series — Volume 1

A Practitioner's Reference for Greenfield and Brownfield Projects

FIRE ENGINEERING FOR INDUSTRIES

For Engineers, Senior Engineers, and EHS Professionals in Oil & Gas, Petrochemical, and Manufacturing

sparrow

Standards covered: NBC 2016 · IS Codes · OISD STDs · TAC · CEA · NFPA · IFC · FM Global · (API STDs)

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Important Notice

This reference book is intended as a practitioner's guide and does not constitute a substitute for professional engineering judgement, site-specific hazard assessment, or compliance verification against the latest editions of applicable standards and regulations. **The authors and publisher make no warranties, express or implied, regarding the completeness or accuracy of the information contained herein.**

Always consult the latest published editions of Indian and international standards. Where this guide references specific clause numbers or threshold values, verify against the current edition before applying them in a design or audit context. Regulatory requirements may differ by State, facility classification, and process type.

Fire engineering is a life-safety discipline. All designs, assessments, and recommendations must be reviewed and certified by a competent fire protection engineer with appropriate qualifications and professional indemnity insurance.

About Sparrow

Sparrow Risk Management Solutions operates as a dynamic umbrella organization, integrating a comprehensive portfolio of critical disciplines that span in Manufacturing Excellence, Optimization fire and life safety engineering, Operation & Quality Optimization, electrical reliability, process safety, complex engineering, and advanced technological innovation. By synthesizing deep industry knowledge with cutting-edge digitalization tools like IndustryOS®, the firm establishes the gold standard for robust risk mitigation and manufacturing excellence.

This reference manual is authored specifically within the context of Sparrow RMS's Fire Engineering function, distilling specialized field expertise into a definitive guide for high-hazard sectors. Beyond advanced fire protection, Sparrow stands as a leader in comprehensive Environmental, Health, and Safety (EHS) and ESG solutions. The firm delivers uncompromising precision across a diverse portfolio, executing rigorous electrical and arc flash studies, resilient process safety management, mechanical design, and proprietary software integration. Through seamless execution and objective analysis, Sparrow RMS transforms compliance into a strategic advantage, engineering safer, highly resilient, and future-ready operational environments worldwide.

How to Use This Book

This volume is structured as a working reference, not a textbook to be read sequentially from cover to cover. Engineers facing a greenfield project will find Part II the primary resource; those conducting brownfield assessments will anchor in Part III. Part I provides the foundational science and regulatory context that underpins both. Parts IV and V give sector-specific and technical-discipline depth respectively.

Icons and Call-outs

Throughout this book, shaded boxes signal specific content types:

- NOTE — Contextual clarification, interpretation nuance, or common misapplication of a standard
- KEY POINT — Critical principles that must not be overlooked in design or assessment
- WARNING — Conditions where errors have historically caused fatalities or major loss events
- FORMULA — Referenced calculation methodology with source standard

Standards Notation

Where standards are cited in the text, they appear as [Standard – Clause]. For example: [NBC 2016 Part 4 – Cl. 4.4.2] or [NFPA 13:2022 – Cl. 8.1.1.1]. The full standards matrix is in Appendix A.

Abbreviations & Acronyms

Abbreviation	Full Form
ASET	Available Safe Egress Time
BLEVE	Boiling Liquid Expanding Vapour Explosion
BMS	Building Management System
CFD	Computational Fluid Dynamics
CEA	Central Electricity Authority
DFT	Dry Film Thickness (passive fire protection coatings)
ERP	Emergency Response Plan
FERA	Fire and Explosion Risk Assessment / Hazard Assessment
FHC	Fire Hydrant Cabinet
FM	Factory Mutual (now FM Approvals)
FMC	Fire Main Cabinet
FOG	Foot on the Ground — Sparrow philosophy of on-site verification
FPE	Fire Protection Engineer
FREAP™	Fire Risk Engineering Assessment Programme (Sparrow proprietary)
GOR	Gas-to-Oil Ratio
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability Study
HRR	Heat Release Rate (kW or MW)
IFC	International Fire Code
IS	Indian Standard (Bureau of Indian Standards)
LEL	Lower Explosive Limit

LFL	Lower Flammable Limit (same as LEL in common use)
MoC	Management of Change
NBC	National Building Code of India
NFPA	National Fire Protection Association (USA)
OISD	Oil Industry Safety Directorate (India)
PFD	Process Flow Diagram
PFP	Passive Fire Protection
P&ID	Piping and Instrumentation Diagram
PPE	Personal Protective Equipment
PSSR	Pre-Startup Safety Review
QRA	Quantitative Risk Assessment
RSET	Required Safe Egress Time
SIL	Safety Integrity Level (IEC 61511)
SLD	Single Line Diagram
TAC	Tariff Advisory Committee (India – insurance underwriting)
UEL	Upper Explosive Limit
VCE	Vapour Cloud Explosion
VESDA	Very Early Smoke Detection Apparatus

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PART I

Fundamentals of Fire Engineering

Science, regulation, and methodology — the foundation before design begins

Chapter 1: The Science of Fire and Industrial Hazard Mechanisms

Before any engineering can be done, the engineer must understand fire as a physical and chemical phenomenon. Many fire safety failures in industry trace back not to a lack of systems, but to an incorrect understanding of how fire behaves in the specific geometry and process environment of the facility. This chapter establishes the physical science that governs all subsequent design and assessment work.

1.1 The Fire Tetrahedron

Classical fire science describes combustion through the fire triangle — fuel, oxygen, and heat. The modern model, the fire tetrahedron, adds a fourth element: the uninhibited chemical chain reaction. Effective fire suppression can interrupt any one of the four sides:

- Fuel removal: isolation of the fuel source (emergency shut-off valves, blow-down)
- Oxygen exclusion: inerting with nitrogen, CO_2, or halogenated clean agents; foam blanketing of liquid spills
- Cooling: water application to reduce temperature below the fire point
- Chain reaction interruption: dry chemical powder and halon-replacement clean agents act here

Understanding which mechanism is appropriate for a given fuel type drives the selection of suppression agent. A CO_2 system on a three-dimensional deep-seated cellulosic fire (e.g., cable trays) will suppress momentarily but reignite — because it cools and excludes oxygen but does not eliminate the fuel or quench deeply. Similarly, water on Class D metals (magnesium, sodium) can accelerate reaction rather than suppress it.

Note:

IS 2190:2024 – Cl. 3.4 classifies fires by class: Class A (ordinary combustibles), Class B (flammable liquids/gases), Class C (live electrical equipment), Class D (combustible metals), Class F (cooking oils/fats). Every suppression agent specification must reference the class of fire it is designed to control.

1.2 Combustion Chemistry — Industrial Fuels

The dominant fuel types in oil & gas and manufacturing environments differ substantially from ordinary building fires. Engineers must understand the specific combustion behaviour of the fuels on site.

1.2.1 Hydrocarbon Pool Fires

A pool fire occurs when a flammable liquid spills and ignites on a bund floor or open surface. The mass burning rate (m'', $kg/m^2 \cdot s$) is fuel-dependent and controls the heat release rate per unit pool area. Key relationships:

Formula: $$Q = m'' \times A\_pool \times \Delta H\_c \text{ [Heat Release Rate, kW]}$$

where: m'' = mass burning rate per unit area ($kg/m^2 \cdot s$); A_pool = pool area (m^2); ΔH_c = net (lower) heat of combustion (kJ/kg)

Note: for pool diameter D < 0.2 m, apply correction: $m'' = m''\infty \times (1 - e\hat{}(-k\beta D))$

Reference: SFPE Handbook, 5th Edition, Chapter 26

Typical specific burning rates: LPG ≈ 0.099 $kg/m^2 \cdot s$; Crude oil ≈ 0.035 $kg/m^2 \cdot s$; Diesel ≈ 0.035 $kg/m^2 \cdot s$; Petrol (gasoline) ≈ 0.055 $kg/m^2 \cdot s$. Larger pools exhibit reduced burning rates due to oxygen starvation at the base; the asymptotic burning rate is reached when pool diameter exceeds approximately 1–2 m for most hydrocarbons.

1.2.2 Jet Fires

A jet fire occurs when pressurised gas or two-phase fluid releases and ignites immediately. Unlike pool fires, jet fires are momentum-dominated and can impinge directly on process equipment, vessel walls, or structural steel. Flame lengths from sonic releases can extend 10–60 m. Jet fire heat fluxes at the impingement point can exceed 200–350 kW/m^2, which will fail un-protected structural steel within 2–4 minutes. This is the primary hazard driving passive fire protection (PFP) requirements on offshore platforms and process plants.

WARNING

Jet fire impingement on pressure vessels can rapidly heat vapour spaces and may lead to BLEVE-type failures. OISD-STD-116 – Cl.4.2.4 mandates automatic water spray protection for pressure vessels. IS 13039:2014 – Cl.5.1.4.4 permits reduction of water spray density from 10.2 to 5 lpm/m^2 where a minimum 2-hour passive fireproofing coating is provided. A jet fire resistance rating of about 350 kW/m^2 is considered a recognized global engineering practice, but it is not a statutory OISD requirement.

1.2.3 Flash Fires and Vapour Cloud Explosions

When flammable vapour disperses into the atmosphere before igniting, it forms a flammable cloud. If the cloud ignites with a weak ignition source (e.g., a spark), the result is a flash fire — a rapid flame propagation that does not produce significant overpressure. If the cloud is large, confined, or obstructed (by pipe racks, vessels, or congested process areas), turbulence can accelerate flame speed past the speed of sound, producing a deflagration-to-detonation transition (DDT) and the Vapour Cloud Explosion (VCE). The overpressure generated by a VCE is the dominant cause of structural damage in major refinery and chemical plant incidents. Key parameters for consequence modelling are described in Chapter 16. Require site-specific VCE consequence modeling? Connect with our analytical team.

1.3 Heat Transfer Modes and Thermal Injury Thresholds

Fire engineers use heat flux (kW/m²) as the primary metric for assessing impact on people and structures. Three mechanisms transfer heat from a fire to its surroundings:

- Radiation: dominant mechanism for large pool fires and fireballs. Follows the inverse-square law with distance.
- Convection: dominant for jet fires and fully-developed compartment fires. Forces hot gases onto surfaces.
- Conduction: governs heat transfer through structural elements and fireproofing.

The following threshold values are used in consequence modelling and siting studies — they are referenced in the SFPE Handbook, and DNV PHAST documentation:

Heat Flux (kW/m²)	Effect on People	Effect on Structures
1.6	Threshold of pain after 60 seconds (no injury)	—
4	Pain threshold; 2nd degree burn within 60 s	Ignition of wood (long exposure)
12.5	1% fatality probability within 30 s	Ignition of wood (10 s exposure)
25	50% fatality probability within 30 s	Piloted ignition of most materials
37.5	Near-certain fatality (unprotected)	Steel structural failure within 5–10 min (unprotected)
>200	—	Jet fire impingement (BLEVE risk zone)

NOTE

Industry practice uses 4 kW/m² as the exclusion zone boundary for occupied areas and 12.5 kW/m² for uninhabited process areas when evaluating minimum separation distances for storage tanks and process equipment, NFPA 30 itself does not set these figures as exclusion limits

1.4 Fire Development in Buildings and Enclosures

For manufacturing facilities and warehouses, fire development in an enclosure differs fundamentally from open-air scenarios. The classical enclosure fire progresses through four stages:

1. Ignition and incipient growth: the fire is fuel-controlled, growing approximately as a t-squared (t^2) fire. The rate of growth depends on the fuel's surface-to-mass ratio and heat of combustion. Sprinkler system response time is measured in this phase.
2. Growth phase: hot gas layer descends. Smoke detectors activate. Flashover potential builds as the upper layer temperature approaches 600°C.
3. Flashover: the transition to a fully developed fire — all exposed combustible surfaces ignite simultaneously. Beyond this point, active firefighting inside the compartment is not survivable.
4. Decay: fuel consumption reduces the HRR. Structural elements may fail in this phase due to prolonged exposure.

The fire growth coefficient (α, kW/s²) categorises industrial fuel loads for sprinkler response and smoke management design. NFPA 204:2024–Cl. Annex F and NFPA 72:2025 – Cl. B.2.3.2.3.6 references the following classifications:

Growth Class	α (kW/s²)	t_2 (s)	Representative Occupancy
Slow	0.00293	600	Densely stacked solid wood products
Medium	0.01172	300	General warehousing, office occupancies
Fast	0.04689	150	Light warehousing, foam rubber, rolled paper
Ultra-fast	0.1875	75	Flammable liquids in open containers, cotton

Formula: $$Q(t) = \alpha \times t^2 \ [kW]$$

where: t = time from effective ignition (seconds)
t_2 = time to reach Q = 1055 kW (1000 BTU/s threshold, indicating well-established fire)

1.5 Industrial Dust Explosion Hazards

Manufacturing environments handling food-grade powders (flour, sugar, starch, spices), pharmaceutical materials, wood dust, or metal fines face a distinct explosion hazard not addressed in the standard NBC framework. Dust explosions require five elements (the dust explosion pentagon): dispersed combustible dust, oxidiser (air), ignition source, dispersion (dust cloud), and confinement.

The severity of a dust explosion is characterised by KSt (bar·m/s) and Pmax (bar). These values determine explosion vent sizing to IS 3103 and NFPA 68. The St classification used in Indian practice follows IEC/EN 14034:

St Class	KSt (bar·m/s)	Hazard Level	Examples
St 0	0	No explosion	Sand, cement, minerals
St 1	1–200	Moderate	Grain flour, wood dust, milk powder, polyethylene powder, sugar
St 2	201–300	Strong	Coal dust, cellulose
St 3	>300	Very strong	Aluminium, magnesium

WARNING

Hybrid mixtures (flammable gas + combustible dust) can detonate at concentrations below the LEL of the gas alone. FMCG facilities handling flavour concentrates or solvent-based coatings with concurrent dust operations must assess hybrid mixture risk under ATEX Directive 2014/34/EU and IS 5572.

1.6 Thermal and Structural Response of Materials

Understanding how structural materials behave under fire exposure is fundamental to both passive fire protection design and post-fire structural assessment.

1.6.1 Structural Steel

Unprotected structural steel begins to lose strength appreciably above 400°C and retains only 60% of its ambient-temperature yield strength at 550°C. Indian standard IS 800:2007 – Cl.16.5 defines the critical temperature as the temperature at which the member can no longer carry its design loads under fire conditions. For most steel members carrying standard imposed loads, the critical temperature is in the range 510–580°C. Passive fire protection (intumescent coatings, mineral wool wraps, or spray-applied cementitious materials) must maintain the steel below this critical temperature for the required fire resistance period.

1.6.2 Reinforced Concrete

Concrete is a poor conductor of heat and provides inherent fire resistance. The failure mode in reinforced concrete is loss of bond between reinforcement and concrete, and spalling of the concrete cover. Siliceous aggregates (granite, quartzite) suffer more explosive spalling than calcareous aggregates (limestone). High-strength concrete (fck > 55 MPa) and self-compacting concrete are particularly susceptible to explosive spalling in the first 30 minutes of fire exposure.

1.6.3 Passive Fire Protection Materials

PFP materials are assessed against the standard ISO 834 time-temperature curve (cellulosic fire) for building applications, and against the hydrocarbon fire curve (HC curve, ISO 22899) for process plant applications. The HC curve reaches 950°C within 5 minutes, compared to 945°C at 60 minutes for ISO 834. All PFP specified on oil & gas plant must be qualified to the HC curve, not the cellulosic curve.

KEY POINT

The single most important lesson from major industrial fire incidents (Texas City 2005, Buncefield 2005, Vizag 2020) is that consequence scenarios must be site-specific. Never apply generic separation distances from standards without validating them against a consequence model tuned to your actual fuel inventory, release rates, and layout.

Chapter 2: Indian Regulatory and Standards Framework

Indian fire engineering operates under a layered framework of mandatory regulations, advisory standards, and insurance requirements. Understanding the hierarchy — what is legally enforceable, what is mandatory by reference, what is advisory but industry-expected, and what international codes fill gaps where Indian codes are silent — is essential for every practising engineer. Failure to distinguish between these tiers has led to both over-specification (costly) and under-specification (unsafe) in Indian industrial projects.

2.1 The Regulatory Hierarchy

Indian fire safety regulation operates through the following hierarchy:

Tier	Instrument	Authority	Status
1 — Statute	Factories Act 1948 + State Rules	State Govt / Labour Dept	Legally binding on all factories
1 — Statute	Petroleum Act 1934 + Petroleum Rules 2002	PESO	Mandatory for petroleum storage
1 — Statute	Indian Electricity Rules 1956 / CEA 2010	CEA / State DISCOM	Mandatory for electrical infrastructure
2 — Regulation	OISD Standards (STD, GDN, RP)	OISD (MoPNG)	Mandatory for O&G sector by DGH/PESO
2 — Regulation	NBC 2016 Part 4	BIS / Local Authority	Mandatory via Building Bye-laws (State-specific)
3 — IS Code	Bureau of Indian Standards (BIS) IS Codes	BIS	Mandatory where cited by NBC or regulation
4 — Insurance	TAC Rules (Tariff Advisory Committee)	IRDAI	Required for industrial risk insurance cover
5 — Gap-fill	NFPA, IFC, FM Global, EN, ISO	Various	Used where Indian codes are silent; accepted by regulators

2.2 National Building Code 2016 — Part 4: Fire and Life Safety

NBC 2016 Part 4 is the primary fire and life safety code for buildings in India. It applies to all new constructions and major modifications requiring a building permit. Key aspects relevant to industrial fire engineering:

2.2.1 Occupancy Classification

NBC Part 4, Section 3 classifies buildings into 9 occupancy groups (A through I). Industrial and manufacturing occupancies fall under:

- Group F: Mercantile — shops, departmental stores (for warehousing with public access)
- Group G: Industrial — factories, workshops, power plants
- Group H: Storage — warehouses, godowns, cold storage

The occupancy group determines minimum fire resistance ratings of structural elements, means of egress requirements, fire compartment sizes, and sprinkler mandate thresholds.

2.2.2 Fire Resistance Ratings

NBC 2016 Part 4 – Cl.3.3.1 & Table 1specify the minimum fire resistance rating (FRR) of structural elements based on the Type of Construction (Types 1 to 4) and the specific structural element. Industrial occupancies (Group G) typically require 2-hour FRR for load-bearing elements up to 4 floors, and 4-hour for high-rise or high-hazard facilities. These ratings must be achieved by the structural element alone or in combination with applied PFP, tested to IS 3809.

2.2.3 Sprinkler Requirements

NBC 2016 Part 4 – Section 5 mandates automatic sprinkler systems for Group G (Industrial) buildings exceeding 500 m² in covered area, and for all high-hazard occupancies irrespective of area. The design standard referenced is IS 12835 for foam and IS 15105 for water sprinklers. Where IS codes are silent on occupancy-specific design criteria, NFPA 13 is accepted by most State authorities as the reference standard.

2.3 IS Codes — Fire Protection Systems

The following IS codes are the primary design standards for fire protection systems in Indian industrial facilities. Engineers must use current editions, as revisions occur periodically.

IS Code	Title	Key Application
IS 2189:2026	Selection, Installation & Maintenance of Automatic Fire Detection & Alarm	Fire alarm system design
IS 15105:2021	Automatic Sprinkler Installations	Wet pipe, dry pipe, pre-action, deluge sprinkler design
IS 15325:2020	Fixed Automatic Water Spraying Systems (Water Spray Systems)	Deluge and medium velocity water spray for vessels, transformers
IS 12835:2021	Fixed Firefighting System — Foam Extinguishing Systems	Low, medium and high expansion foam systems for tank farms, aircraft hangars
IS 15528:2004	Fixed CO2 Firefighting Systems	Total flooding and local application CO2 systems
IS 12469:2019	Specification for Pumps for Fire Fighting	Fire pump selection, testing and installation
IS 1642:2013	Fire Safety of Buildings (General): Details of Construction — Code of Practice	Classification and fire resistance requirements for building elements
IS 5572:2009	Classification of Hazardous Areas (other than mines) for Electrical Installations	Hazardous area classification for electrical equipment selection
IS 3103:1975	Code of Practice for Industrial Ventilation	Design requirements for ventilation systems in industrial buildings and hazardous areas
IS 15519:2020	Water Mist Fire Suppression Systems	Water mist system design for machinery spaces, turbine enclosures
IS 1239(Part 2):2011	Mild Steel Tubes, Tubulars & Other Wrought Steel Fittings	Pipe specification for fire water distribution systems

2.4 OISD Standards — Oil Industry Safety Directorate

OISD standards are the primary regulatory instrument for fire safety in oil & gas, refining, and petrochemical facilities in India. They are developed by the Oil Industry Safety Directorate, a body under the Ministry of Petroleum and Natural Gas, and are enforced by the Directorate General of Hydrocarbons (DGH) and PESO (Petroleum and Explosives Safety Organisation).

2.4.1 Key OISD Standards for Fire Engineering

OISD Standard	Title	Relevance
OISD-STD-116	Fire Protection Facilities for Petroleum Refineries and Oil/Gas processing plants	Refinery-specific fire water network, FHC spacing, foam systems, fireproofing
OISD-STD-117	Fire Protection Facilities for Petroleum Depots and Terminals	Tank farm firefighting, hydrant systems, foam systems, firewater storage
OISD-STD-118	Layout for Oil and Gas Installations	Minimum separation distances for process equipment, vessels, and facilities
OISD-STD-119	Selection, Operation and Maintenance of Pump	Pump selection, operation, and maintenance in petroleum installations
OISD-STD-150	Design and Safety Requirements for LPG Mounded Storage Facility	LPG storage facilities, mounded bullets, bottling plants
OISD-STD-194	Storage and Handling of Liquefied Natural Gas (LNG)	LNG import terminals, cryogenic safety, vapour dispersion
OISD-GDN-145	Guidelines on Internal Safety Audits in Petroleum Industry	Audit framework, checklist structure, rectification timelines
OISD-RP-147	Inspection and Safe Practices during Electrical installation	Electrical fire hazard management
OISD-STD-155	Personal Protective Equipment	Selection and use of PPE in petroleum industry installations

2.4.2 OISD Separation Distances — Key Principles

OISD-STD-118 is one of the most referenced documents in petroleum installation design. It provides minimum safe distances between storage tanks, process units, utilities, and occupied buildings. Key principles:

- Distances are minimum values — the engineer must verify against a site-specific consequence model where the hazard profile differs from the standard assumption
- Distances apply to above-ground storage. Mounded storage (earthen bund) benefits from shielding and attracts reduced separation distances per OISD-STD-150
- Occupied buildings (control rooms, administration, substations) must be sited outside the 4 kW/m² radiation contour from the worst credible fire scenario
- The standard does not account for explosion overpressure. Where VCE risk is credible, a QRA must supplement OISD-STD-118 siting

2.5 Tariff Advisory Committee (TAC) Requirements

The Tariff Advisory Committee (now the General Insurance Council) sets minimum fire protection requirements for industrial properties to qualify for industrial insurance. TAC requirements in India are generally influenced by international frameworks such as NFPA standards and FM Global FM Global Data Sheets, with modifications to suit Indian regulatory practices, climatic conditions, infrastructure limitations, and local risk philosophies. Key points:

- TAC requires certified fire pumps, tested hydrant systems, and valid maintenance contracts for sprinkler systems as conditions for policy validity
- TAC occupancy classification (light, ordinary, extra hazard — Groups I, II, III) governs the sprinkler density and water supply demand required
- Non-compliance with TAC requirements may invalidate an insurance claim, even if all regulatory requirements are met
- The EHS engineer should obtain the TAC rating for the facility and ensure the fire protection system design meets or exceeds that rating

2.6 Integration with International Standards

India's IS codes have significant gaps, particularly in areas such as foam system design for three-dimensional fires, explosion-resistant construction, deluge system design density for specific occupancies, and fire modelling methodologies. In these areas, NFPA codes, FM Global Data Sheets, and ISO standards are routinely referenced in Indian engineering practice. The following principles govern their use:

- NFPA codes are treated as supplementary standards where IS codes are silent. Most Indian State authorities and OISD accept NFPA as the reference in the absence of a specific IS code clause.
- •FM Global Data Sheets (FM DS) are particularly relevant for facilities with FM-insured assets or multinational owners with FM insurance. FM DS 4-9N (Halon Alternatives), FM DS 7-76N (Fire Protection for Combustible Dust), and FM DS 10-3 (Cutting and Welding) are commonly referenced.
- ISO 834 (cellulosic fire curve) and ISO 22899 (hydrocarbon fire curve) are the reference test standards for passive fire protection qualification.

NOTE

When Indian and international standards conflict, Indian standards and regulations take precedence for domestic projects. However, when an Indian client has a multinational parent or seeks international insurance, the more conservative of the two standards is typically applied.

2.7 Regulatory Approvals and Interfaces

Fire engineering deliverables must interact with a range of regulatory bodies depending on the facility type and location. The following table summarises the key approval interfaces:

Facility Type	Primary Regulatory Body	Key Approval Document
All buildings	State Fire Department (via building permit)	Fire NOC (No Objection Certificate)
Petroleum storage (> 30 kL)	PESO (Petroleum and Explosives Safety Organisation)	PESO licence under Petroleum Rules 2002
O&G upstream and refining	DGH (Directorate General of Hydrocarbons) / PESO	HSE case / Safety report
Chemical manufacturing	State Environment Department + Factory Inspectorate / OSHA	Environmental clearance + Factory licence
Major Accident Hazard sites (> Schedule 1 thresholds)	Factory Inspectorate (State) / OSHA	Major Accident Prevention Policy (MAPP) / Safety Report
All facilities with insurance	Insurance company / TAC / FM	FM approval or TAC rating compliance

Chapter 3: Fire Engineering Methodology — Process and Approach

Fire engineering is not a lookup exercise. It is a structured, iterative process of hazard identification, consequence assessment, protection design, and verification. This chapter describes the methodology that underpins both greenfield and brownfield work — the difference lies in when and how the methodology is applied in the project or asset lifecycle.

3.1 Prescriptive vs. Performance-Based Engineering

Most Indian fire regulations and standards are prescriptive: they specify what must be installed (e.g., sprinkler density of X mm/min over area Y) without requiring the engineer to demonstrate that the specification achieves a quantified safety outcome. Prescriptive compliance is generally faster to design, easier to approve, and appropriate for standard occupancies.

Performance-based fire engineering (PBFE) develops a fire safety strategy from defined objectives — typically life safety and property protection — and demonstrates through analysis that the design achieves those objectives. PBFE is mandatory when:

- The building or facility type is not addressed by the prescriptive code (e.g., large-volume atria, complex process plant geometries)
- The designer wishes to deviate from a prescriptive requirement and achieve equivalent safety by other means
- The risk profile justifies quantified analysis (major accident hazard sites, critical infrastructure)
- An insurer or Authority Having Jurisdiction (AHJ) specifically requires a fire engineering report

Need to demonstrate equivalent safety to regulators for a complex facility? Contact our Fire Protection Engineers to develop a robust Performance-Based design strategy.

NOTE

NFPA 72:2025– Cl.17.3 and Annex B.2–B.4 explicitly permit performance-based design as an alternative to prescriptive compliance, subject to defined fire scenarios, design fire parameters, engineering justification, and approval by the AHJ. The NBC Foreword similarly encourages a holistic engineering design approach under qualified fire protection engineers, provided the proposed design achieves safety levels exceeding the prescribed minimum requirements.

3.2 The Fire Engineering Process

Whether prescriptive or performance-based, fire engineering follows a logical sequence. The following process applies to both greenfield design and brownfield assessment, with the brownfield process starting at step 2 (existing conditions audit) rather than a blank sheet.

Step 1: Scope Definition and Information Gathering

- Define the scope of the fire safety strategy: occupancy, process fluids, inventory, building configuration, number of occupants, operational philosophy
- Obtain all relevant plot plans, P&IDs, PFDs, building layouts, and material safety data sheets
- Identify the applicable regulatory framework (see Chapter 2) and obtain the project fire safety standards matrix
- Establish fire safety objectives (life safety, property protection, business continuity, environmental protection, regulatory compliance)

Step 2: Hazard Identification

- Conduct a structured fire and explosion hazard identification (HAZID) for all credible ignition sources, fuel types, and release scenarios
- For process plant: use HAZOP study results as input to fire scenario development
- For storage facilities: reference OISD-STD-108 / OISD-STD-244 scenario matrices
- Output: a ranked hazard register with scenario descriptions, frequency estimates, and consequence categories

Step 3: Consequence Assessment

- Develop design fire scenarios: worst-credible, credible worst-case, and selected intermediate scenarios
- For open-air plant: radiation contour modelling for pool fire, jet fire, and fireball scenarios
- For enclosed buildings: smoke and fire development modelling (hand-calculation or CFD as warranted)
- Determine: radiation exclusion zones, smoke/toxicity threat zones, evacuation time requirements, structural exposure

Step 4: Protection Strategy Development

- For each hazard/scenario: select the combination of prevention, detection, active protection, passive protection, and emergency response that achieves the defined fire safety objectives
- Document the Fire Protection Philosophy (FPP) — the master document that governs all system design
- Develop the Fire Safety Concept or Fire and Gas Detection Philosophy as sub-documents

Step 5: Detailed Design

- Design each system (sprinklers, foam, hydrants, detection, passive protection) to the applicable standard.
- Hydraulic calculations, detector spacing calculations, PFP thickness calculations as required.
- Prepare design drawings: layout, schematic, isometric, and calculation sheets.

Step 6: Verification and Review

- Peer review of the fire engineering strategy and detailed system designs by an independent FPE
- Authority review: submit fire safety drawings for building permit / Fire NOC / PESO licence
- Factory Acceptance Test (FAT) for major systems (fire alarm, suppression, fire pumps)

Step 7: Installation and Commissioning

- Inspection of installation against approved drawings: as-built verification
- Commissioning tests: hydrostatic test of pipework, trip test of suppression systems, functional test of detection system
- PSSR (Pre-Startup Safety Review) sign-off before energisation or process start-up

Step 8: Operation and Maintenance

- Establish the preventive maintenance schedule per IS 2189 (detection), IS 15105 (sprinklers), IS 12469 (fire pumps)
- Annual fire safety audit against OISD-GDN-145 for petroleum facilities; NBC 2016 Part 4 for industrial buildings
- Management of Change (MoC) review for any process, layout, or inventory change affecting fire scenarios

3.3 The Design Fire

The design fire is the quantified fire scenario used to size fire protection systems and evaluate structural performance. It is characterised by heat release rate (kW), fire area (m^2), growth rate (α), and duration (minutes). Selection of the design fire is one of the most consequential decisions in the fire engineering process.

For prescriptive sprinkler design, the design fire is implicit in the density-area method (e.g., IS 15105:2021–Cl.8.0. gives design density for each hazard class). For performance-based design, the engineer must explicitly define the design fire for each scenario.

NOTE

A common error is selecting a design fire that is too small to be conservative, based on the "credible worst case" being defined too narrowly. The SFPE Handbook Engineering Guide to Performance-Based Fire Protection recommends selecting design fires that produce results slightly more severe than the expected worst case, to provide a margin against uncertainty in fire growth modelling.

3.4 ASET/RSET Analysis

For life safety verification in occupied facilities, the engineer demonstrates that the Available Safe Egress Time (ASET) exceeds the Required Safe Egress Time (RSET) with adequate margin (typically a factor of 2 or greater).

Formula:	***ASET = time from ignition to untenable conditions in the evacuation route*** ***RSET = detection time + alarm response time + pre-movement time + travel time*** ***Criterion: ASET > 2 × RSET (per BS PD 7974-6 and SFPE guidance)*** ***Untenable condition: CO > 1400 ppm; CO_2 > 5%; temperature > 60°C at 2 m height; visibility < 5 m***

ASET is determined by smoke management modelling (hand calculation for simple geometries, CFD for complex atria, large warehouses, or high-rack storage). RSET is calculated from occupancy data, detection system response times, and exit capacity analysis.

3.5 Interaction with Other Engineering Disciplines

- Structural engineering: fire resistance requirements, fireproofing specification, blast-resistant construction where VCE risk exists
- Process engineering: identification of flammable inventories, emergency shutdown (ESD) philosophy, blow-down and depressurisation design
- Electrical engineering: area classification (IS 5572 / IEC 60079), uninterruptible power for fire systems, lightning protection
- Mechanical engineering: firewater pump specifications, suppression system pipeline design, vessel pressure relief sizing
- HVAC/MEP: smoke management, fire damper location, pressurisation of escape routes, fire stopping of ductwork penetrations
- Civil/architectural: bund sizing (OISD/TAC), fire wall construction, exit door sizing and travel distance compliance
- Safety/process safety: HAZOP interface, SIL assignment for fire and gas detection, QRA and risk-based layout decisions

KEY POINT

The Fire Protection Philosophy (FPP) document is the single most important document in a fire engineering project. It describes the fire scenarios, protection strategies, system responsibilities, and verification requirements. All other fire engineering deliverables are derived from the FPP. On brownfield projects, the absence of a current FPP is itself a significant finding.

PART II

Greenfield Fire Engineering

Designing fire safety into new facilities from first principles — before the concrete is poured

Chapter 4: Site Planning and Layout for Fire Safety

Fire safety begins at the site planning stage, not at the system design stage. The single greatest opportunity to reduce fire risk in a new facility is in the layout — the separation distances between ignition sources and fuel inventories, the routing of escape paths, the placement of the control room, the orientation of occupied buildings relative to prevailing wind and dominant hazard zones. Once the layout is frozen, many design decisions are locked in, often for the life of the plant.

4.1 Site Layout Principles

4.1.1 Wind Direction and Dominant Hazard Orientation

All flammable material handling areas (tank farms, loading gantries, process units with large inventories) should be located downwind of occupied buildings and ignition sources in the prevailing wind direction. The dominant wind rose for the site should be obtained from meteorological data and used to orient the plot so that the occupied facilities (control room, administration, laboratory) are upwind of the main hazard areas. This principle is embedded in OISD-STD-118 – Cl.4.0.

4.1.2 Zoning by Hazard Category

Divide the site into hazard zones based on the nature and quantity of flammable inventory:

Zone	Description	Examples	Separation Principle
Zone 1 — High Hazard	Large inventory of Class A/B liquids or pressurised gases	Crude/product tank farm, LPG sphere farm, process reactors	OISD-STD-118 minimum distances; consequence model overlay required
Zone 2 — Medium Hazard	Smaller inventories, secondary containment, active suppression	Truck loading/unloading, day tanks, utilities with diesel	Min 45m from Zone 1 per OISD-STD-118 Table 1
Zone 3 — Low Hazard	Non-process, no significant flammable inventory	Warehouses, workshops, administration, car parking	Occupied buildings: outside 4 kW/m² radiation contour

Zone 4 — Utility and Support	Fire station, water tanks, instrument air, electrical substation	Fire water pump house, control room, substation	Locate upwind; min 30 m from Zone 1

4.1.3 Road and Access Planning

Emergency vehicle access is a fundamental layout requirement. NBC 2016 Part 4 – Cl. 3.4.4.1 and IS 3594:2024–Cl. 5.2 specify:

- Minimum 6-m wide access roads around all major process units and tank farms
- Two independent access/egress routes to all major areas, oriented in different compass directions to ensure at least one route is accessible regardless of incident location
- Access roads to all fire hydrant points and monitor positions — maximum 30-m travel distance from access road to any FHC
- Turning radius for fire appliances: minimum 9 m inside, 15 m outside for 19-m aerial ladders
- No dead-end roads without a turning area; road gradients not exceeding 1:20 in areas where heavy firefighting appliances are required

4.2 OISD-STD-118 Separation Distances — Practical Application

OISD-STD-118 Table 1 provides minimum distances between process units, storage tanks, utilities, and occupied buildings for petroleum installations. The distances are floor values — site-specific consequence modelling may indicate a need for greater separation. The following are key extract values (distances in metres, from centre-to-centre or boundary as specified in the standard):

From / To	Storage Tanks	LPG / Gas Spheres	Process Unit	Occupied Building / Control Room	Flare / Loading Area
Storage Tanks	Min. larger tank dia. or 30 m between	30 m	30 m	30–60 m	90 m flare / 30 m loading
LPG / Gas Spheres	30 m	Min. 1.5D or 30 m	60 m	30–90 m	90 m flare / 30–50 m loading
Process Unit	30 m	60 m	36 m	Min. 30 m (16 m if attached blast-resistant CR)	90 m flare / 45 m loading
Occupied Building / Control Room	30–60 m	30–90 m	Min. 30 m	As per OISD-STD-163	90 m flare / 30–60 m loading
Flare / Loading Area	90 m flare / 30–45 m loading	90 m flare / 30–50 m loading	90 m flare / 45 m	90 m flare / 30–60 m loading	90 m flare / 50 m between gantries

D = diameter of the tank. All values are minima per OISD-STD-118:2004. Verify against the current edition before applying in a design.

WARNING

These distances do not account for VCE overpressure. Where large flammable gas inventories exist (LPG spheres > 500 m³, process units with significant vapour cloud potential), the layout must be verified by a VCE consequence model. Distances required for overpressure protection (to avoid structural damage to control rooms at >0.03 bar) may exceed the OISD-STD-118 minimums by a factor of 2 to 4.

4.3 Bund and Containment Design

Bunds (dikes) provide secondary containment for liquid spills, limiting the pool area and reducing the pool fire hazard. OISD-STD-118 – Cl.7.1 and IS 10987 or NFPA 30 specify bunding requirements for petroleum storage. Key design rules:

- Bund capacity: minimum 110% of the capacity of the largest tank within the bund (some jurisdictions require 100% of all tanks as per FM Global DS 7-88)
- Bund wall height: 1.0 m minimum; maximum height that can be safely vaulted by firefighters (typically 1.8 m for Class A/B products)
- Bund floor: impermeable to hydrocarbons; sloped to a sump or low point where runoff can be collected or pumped
- No stairways or ladders penetrating the bund wall — all access via steps over the bund wall
- •Aggregate tank capacity within a dyke enclosure is limited to 60,000 m^3 for fixed roof tanks and 120,000 m^3 for floating roof tanks (OISD-STD-118 – Cl.7.1.1)
- Drainage from bunds must pass through an oil interceptor — no direct discharge to stormwater system

Formula: ***Minimum bund capacity = 1.1 × V_max [m^3]***
where V_max = volume of the largest tank in the bund
Bund area must be < 60,000 m^3 for fixed roof and < 1,20,000 for floating roof tank (OISD-STD-118 – Cl. 7.1.1) to limit pool fire extent.

4.4 Escape Route Planning

Escape route design must be integrated from the earliest plot plan stage. The following principles govern industrial escape route design under NBC Part 4 and Factory Rules:

- Minimum two means of escape from all areas, including elevated platforms and mezzanines.
- Maximum travel distance: 45 m to the nearest exit in industrial occupancies (NBC 2016 Part 4 –Table 5); 22.5 m in high-hazard areas.

- Muster points located outside the radiation exclusion zone (>4 kW/m²) from the worst credible fire scenario, upwind of the main hazard areas
- Escape routes must not pass through hazardous areas (classified zones per IS 5572) unless there is no alternative — in which case the route must be marked and maintained as a defined 'hazardous route' with signage
- Assembly points must be accessible by emergency response vehicles and must have communications equipment

KEY POINT

In tank farms and process plants, the direction of escape must be modelled for all dominant wind directions. A muster point downwind of a LPG sphere farm is unsafe in a gas cloud scenario regardless of normal site orientation rules.

4.5 Control Room and Occupied Building Siting

NBC Part 4 and API RP 752 provide guidance on the siting of occupied buildings relative to process plant. API RP 752 is the reference document for quantitative siting assessment of occupied buildings in petroleum and chemical facilities, and is widely used in India for major process plant projects.

The key principle is that any occupied building must be able to withstand the worst credible overpressure event without structural collapse (to allow occupants to shelter in place) and must be outside the thermal radiation hazard zone for the duration required for evacuation. Where blast-resistant construction is required, buildings should be designed to API 752 Category C blast resistance (overpressure < 0.03 bar) or greater.

NOTE

Control rooms on major process plants are typically designed to 0.07–0.14 bar blast resistance (Category A per API 752) and are positioned upwind at a distance that limits radiation below 4 kW/m² from pool fire scenarios. Blast relief panels or blast-resistant windows are specified where conventional construction cannot achieve the required resistance.

Chapter 5: Fire and Explosion Hazard Assessment (FERA)

Fire safety begins at the site planning stage, not at the system design stage. The single greatest opportunity to reduce fire risk in a new facility is in the layout — the separation distances between ignition sources and fuel inventories, the routing of escape paths, the placement of the control room, the orientation of occupied buildings relative to prevailing wind and dominant hazard zones. Once the layout is frozen, many design decisions are locked in, often for the life of the plant.

5.1 FERA Scope and Objectives

A complete FERA addresses:

1. Hazard identification: systematic identification of all credible fire and explosion scenarios
2. Consequence assessment: quantification of fire and explosion effects (radiation, thermal dose, overpressure)
3. Risk evaluation: comparison of risk against criteria (individual risk, societal risk, asset risk)
4. Protection strategy: identification of risk reduction measures to reduce risk to ALARP
5. Residual risk statement: documented acceptance of residual risk by facility management

5.2 Fire Scenarios — Classification and Characterisation

The following fire scenario types are assessed in a FERA for oil & gas and petrochemical facilities:

5.2.1 Pool Fire

A pool fire occurs when a flammable liquid spill ignites and burns on a confined or unconfined surface. Thermal radiation is the primary consequence. The pool area is constrained by bund size (confined spill) or topography (unconfined spill). Key parameters: pool diameter, burning rate (m″), flame height, radiation fraction (χ_r).

Formula:

Radiation Intensity at distance r: $E_r = \tau \times F \times Q_r / (4\pi r^2)$ *[kW/m²]*

where: τ *= atmospheric transmissivity; F = view factor;* Q_r *= total radiated power (kW); r = distance (m)*

$Q_r = \chi_r \times m'' \times A_{pool} \times \Delta H_c$

Tool: Phast (DNV), SAFETI, ALOHA (US EPA) – all accepted by OISD for consequence modelling

5.2.2 Jet Fire

A jet fire results from the ignition of a pressurised release from a pipe, fitting, or vessel. Consequence is a combination of thermal radiation (same radiation model as pool fire but with directional flame) and direct flame impingement on adjacent equipment. Jet fire flame length is modelled by Chamberlain (1987) correlation, implemented in all major consequence modelling tools. For structural fire protection design, the critical parameter is the heat flux at the impingement point: typically 200–350 kW/m² for sonic releases of light hydrocarbons.

5.2.3 Flash Fire

A flash fire results from the delayed ignition of a dispersed vapour cloud. Consequence is thermal: persons within the cloud boundary (LFL contour) suffer severe or fatal burns. The flash fire engulfs everything within the flammable envelope but generates negligible overpressure (insufficient to cause structural damage). Key parameter: cloud extent at LFL and 0.5×LFL concentrations from dispersion modelling.

5.2.4 Fireball (BLEVE)

A Boiling Liquid Expanding Vapour Explosion (BLEVE) occurs when a pressure vessel containing a superheated liquid (LPG, propane) fails catastrophically. The result is a fireball — a burning, expanding sphere of fuel. The fireball radiates intense heat for a short duration (seconds). Thermal dose (kJ/m²) rather than steady-state flux (kW/m²) governs the hazard zone calculation.

Formula:

Fireball diameter: $D = 5.8 \times M^{0.333}$ *[m]*

Fireball duration: $t = 0.45 \times M^{0.333}$ *[s] (for M < 30,000 kg)*

where: M = mass of flammable material in the vessel (kg)

Thermal dose at distance r: $TDU = [E \times F_{eff} \times \tau] / r^2$ *[kJ/m²]*

Source: Roberts (1982), as implemented in SFPE Handbook Chapter 71 and PHAST

5.2.5 Vapour Cloud Explosion (VCE)

A VCE occurs when a large vapour cloud ignites and the deflagration or detonation generates damaging overpressure. The TNT equivalency method and the Baker-Strehlow-Tang (BST) method are the most widely used consequence models. Overpressure is the primary consequence metric; it determines structural damage levels and safe standoff distances for occupied buildings.

Overpressure (bar)	Structural Damage Level	Personnel Impact
0.007	Glass breakage	Injury from flying glass; no structural injury
0.014	Partial wall collapse (lightweight)	Injury from debris
0.035	Serious structural damage to unreinforced masonry	Eardrum rupture; flying debris injury
0.07	Severe damage to most buildings	Lung damage; potentially fatal in some cases
0.14–0.20	Collapse of most structures	Highly fatal for unprotected personnel
>0.35	Total destruction	Near-certain fatality

5.3 Dispersion Modelling

Before a flash fire or VCE can be assessed, the cloud size must be determined by atmospheric dispersion modelling. The engineer must characterise:

- Release source: hole size (mm), fluid phase (gas, liquid, two-phase), pressure, temperature, inventory
- Atmospheric conditions: Pasquill-Gifford stability class (D5 weather: neutral stability, 5 m/s wind is the standard for worst-case cloud extent; F2 weather: stable, 2 m/s for worst-case onsite exposure)
- Terrain: flat open ground (conservative), elevated release point (stack/flare reduces ground-level concentration)

Gaussian dispersion models are used for passive (non-buoyant, non-heavy) gases. Dense gas dispersion (LPG, LNG, heavy hydrocarbons) requires a dense gas model (DEGADIS, SLAB, PHAST UDM) as the cloud hugs the ground and travels further downwind.

NOTE

OISD-STD-118 separation distances are derived from specific release scenarios and atmospheric conditions. When a site's inventory or release potential differs from the OISD base case, site-specific dispersion modelling is required. This is particularly important for LNG facilities (OISD-STD-194) where vapour dispersion from a major spill can extend to 500 m+ in stable atmospheric conditions.

5.4 Risk Criteria and ALARP

FERA findings must be evaluated against risk acceptance criteria. In Indian practice, the following criteria are referenced:

- Individual risk: < 1×10^{-6}/year for members of the public; < 1×10^{-5}/year for workers in process areas; < 1×10^{-4}/year for workers in high-hazard areas (on the ALARP boundary)
- Societal risk: FN curve (frequency vs. number of fatalities) should fall below the 'broadly acceptable' line where practicable; ALARP principles apply in the 'tolerable' region
- Asset risk: typically defined by the client's own risk appetite, calibrated by insurance requirements

Where risk exceeds criteria, risk reduction measures must be implemented in order of preference: eliminate the hazard (change process), reduce inventory, increase separation, then add protective systems (detection, active suppression, PFP, ESD). This hierarchy is the ALARP framework — As Low As Reasonably Practicable. Ensure your facility is as low as reasonably practicable in terms of risk. Consult our regulatory experts.

Chapter 6: Active Fire Protection Systems Design

Active fire protection systems require energy or mechanical action to operate — they must detect the fire and apply suppression agent. This chapter covers the design principles and key parameters for the main system types used in Indian industrial facilities. For each system, the primary Indian standard is cited alongside the NFPA reference where it provides supplementary guidance.

6.1 Fire Water Demand and Storage

The firewater system is the backbone of fire protection in almost all industrial facilities. The design basis begins with calculating the total fire water demand — the flow rate and duration that must be sustained for simultaneous firefighting operations.

6.1.1 Design Basis

OISD-STD-116 and OISD-STD-117 specify that the fire water system must be designed to handle the single largest foreseeable fire scenario — typically either a full tank fire with cooling of adjacent tanks, or a major process unit fire. Simultaneous demand from the following must be added:

1. Fixed suppression system demand (e.g., foam monitor covering the burning tank): per OISD foam application rate for the tank class
2. Cooling water for adjacent exposed tanks or vessels: tanks within an (R+30) m radius of the burning tank shall be cooled at 3 lpm/m² of shell area, while tanks outside this radius but within the same dike may be cooled at 1 lpm/m². [OISD-STD-116 – Cl. 5.2]
3. Hydrant demand for manual firefighting: 4 hydrant streams plus 1 HVLR monitor, totaling 372 m³/hr Hydraulic calculations consider one operating monitor, while minimum two monitors are required in the facility layout, from OISD-STD-117

Formula: ***Total demand Q_total = Q_foam + Q_cooling + Q_hydrants + Q_fixed [L/min]***
Storage = Q_total × duration [L]; minimum duration: 4 hours per OISD-STD-116 – Cl. 6.1
Foam concentrate storage = Q_foam × 3% or 6% (type-specific) × duration

6.1.2 Fire Water Pump Selection

OISD-STD-116 – Cl.5.5 requires:

- At least two fire water pumps, each sized for 100% of total demand (not 50%+50%)
- At least one electric pump and one diesel-driven pump. Both must be able to start automatically on system pressure drop
- Pumps to be certified to IS 12469 and tested to NFPA 20 acceptance criteria
- Minimum pump pressure: sufficient to deliver 7 bar at the most remote hydrant with simultaneous demand
- Jockey (pressure maintenance) pump sized for approximately 10% of total demand to maintain system pressure without starting main pumps

NOTE

NFPA 20:2022 – Cl.4.7.4 requires that fire pump drivers not be used for any purpose other than driving the fire pump. This is commonly violated on Indian industrial sites where the diesel-driven pump driver is connected to a dual-purpose generator. This configuration is not accepted by TAC or OISD.

6.2 Hydrant and Monitor Systems

The fire hydrant and monitor network is designed to IS 15105 Part 2 and OISD-STD-116 Annex D. Key design parameters:

- •Hydrant spacing: maximum 45 m in non-hazardous areas; 30 m in process and tank farm areas [OISD-STD-116 – Cl. 5.7.1(i) / OISD-STD-117 – Cl. 4.3.6]
- Landing valve pressure: 3.5 bar at remote hydrant but strictly capped at a maximum of 7.0 bar [NBC 2016 Part 4]
- Portable monitors (mobile): minimum 2 HVLR monitors of 1000 GPM (≈3,785 L/min) capacity, scalable to 1500 or 2000 GPM based on aggregate storage capacity [OISD-STD-116 – Cl. 12.2 / OISD-STD-117 – Cl. 4.4.11(iii)]
- Fixed monitors (water/foam): minimum 2 HVLR monitors of 1000 GPM (≈3,785 L/min) capacity per tank/cluster, positioned to achieve the required foam application rate for full surface tank fires [OISD-STD-116 – Cl. 5.7.4 / OISD-STD-117 – Cl. 4.3.6(vii)]
- Ring main sizing: velocity not exceeding 3.5 m/s under simultaneous demand to limit pressure loss
- All sections of the ring main must be capable of isolation without deactivating more than 25% of the system at once

6.3 Automatic Sprinkler Systems

Automatic sprinkler systems are the most effective and cost-efficient fire suppression technology for occupied industrial buildings, warehouses, and manufacturing areas. Design to IS 15105, with NFPA 13 referenced where IS 15105 is silent.

6.3.1 Hazard Classification

IS 3844 classifies occupancies into three categories for sprinkler design:

Class	IS 15105 Hazard	Design Density (lpm/m2)	Design Area (m^2)	Typical Occupancy
I	Light Hazard	2.25	84–139	Offices, showrooms, schools
II	Ordinary Hazard	5	360	Factories, warehouses, light mfg
IV	Extra Hazard	12.2	260	Flammable liquid handling, foamed plastic

6.3.2 Sprinkler Selection and Response

Key sprinkler parameters for industrial applications:

- Response index: Standard Response (RTI > 80 m^0.5·s^0.5) or Quick Response (RTI ⩽ 50 m^0.5·s^0.5). Quick Response (QR) sprinklers significantly improve life safety by activating earlier in the fire growth phase.
- Temperature rating: select based on maximum ceiling temperature. Most industrial applications use 68°C or 79°C rated heads. Unventilated boiler rooms, sterilisation areas: use 141°C.
- K-factor: standard K=80 (K=5.6 in US units). Large-drop and ESFR (Early Suppression Fast Response) heads with K=115 to K=320 are used for high-challenge storage where ceiling-only sprinklers must penetrate high-velocity fire plumes.

Formula:

Minimum design flow at sprinkler: $q = K \times \sqrt{P}$ ***[L/min]***
where: K = orifice coefficient (L/min / bar^0.5); P = inlet pressure (bar)
Design density check: density = q / A_coverage [mm/min]
where: A_coverage = area per sprinkler (m²), from IS 15105:2021 – Cl. 9.17.1 (max 21 m² light, 12 m² ordinary, 9 m² high)

6.3.3 Hydraulic Calculation

IS 15105 describes the hydraulic calculation method (Hazen-Williams). Modern practice uses proprietary software (SprinkCAD, HydraCalc, AutoSPRINK) calibrated to IS 15105. All calculations must be verified by an independent check calculation and submitted to the Fire NOC authority and TAC.

6.4 Foam Systems

Foam fire suppression is the standard protection method for flammable liquid storage tanks and processing areas. Design is generally based on IS 12835:Part1 and NFPA 11. Foam extinguishes by blanketing the liquid surface to exclude oxygen and cool the fuel.

6.4.1 Foam Agent Selection

Foam Type	Application Rate	Best Application	Indian Standard
AFFF (3%)	5 L/min/m²	Hydrocarbon pool fires, tank fires	IS 12835; NFPA 11
FFFP (3%)	5 L/min/m²	Hydrocarbon and polar solvents	IS 12835; NFPA 11
AR-AFFF (3%)	5 L/min/m²	Both hydrocarbons and alcohol/polar solvents	NFPA 11
Protein Foam (6%)	6.5 L/min/m²	Crude oil tank fires (high heat)	IS 12835
FFFP (6%)	6.5 L/min/m²	Crude storage, high-viscosity oils	IS 12835; NFPA 11

6.4.2 Fixed Foam System Design for Storage Tanks

OISD-STD-116 Section 6 and NFPA 11 Chapter 5 govern fixed foam systems for petroleum storage tanks. Critical design requirements:

- Cone roof tanks: sub-surface injection (below the floating seal) or top-side pouring via fixed foam chambers at the tank shell are both acceptable for fixed roof tanks
- Fixed (cone) roof tanks: minimum 2 foam chambers for tanks > 15 m diameter; foam injection point must be at the liquid level for sub-surface type [NFPA 11:2024 – Cl. 5.2]
- Floating roof tanks: foam dams with foam pourer systems at the seal area; foam rate for the seal area only, not the full tank surface
- Minimum application time: 65 minutes for Class 'A' and 'B' petroleum tanks; foam application rates include 5 lpm/m² for cone roof tanks, 12 lpm/m² for floating roof rim seals, and 8.1 lpm/m² for sunken floating roof tanks [OISD-STD-116 – Cl. 6.9(ii)]

Formula:

Foam concentrate required = Application rate × Tank area × Application time × % concentration

= 5 L/min/m² × A [m²] × 65 min × 0.03 (3% AFFF)

Water required = Total solution required × (1 - foam concentration)

Add 25% safety factor to both foam concentrate and water storage

6.5 Gaseous Suppression Systems

Gaseous suppression (CO_2, clean agents) is used for enclosure protection of high-value equipment where water or foam would cause damage and where the space can be effectively sealed. Typical applications: generator rooms, turbine enclosures, electrical switchrooms, UPS rooms, computer rooms.

6.5.1 CO_2 Systems

Design to IS 15528 and NFPA 12. CO_2 total flooding uses a concentration of 34% for surface fires and 50% for deep-seated fires (Class A). Critical design considerations:

- CO_2 is immediately life-threatening above 10% concentration. A CO_2 system must have a pre-discharge alarm with sufficient evacuation time (minimum 30 seconds) before discharge
- Room integrity must be maintained to hold the design concentration for the soak period (10 minutes for electrical fires, 20 minutes for deep-seated fires)
- Holding time must be verified by door fan test to NFPA 2001 Annex D methodology
- CO_2 is not accepted in rooms that are permanently occupied. It is progressively being replaced by clean agents for this reason

WARNING

CO_2 has caused multiple operator fatalities on process plants. NFPA 12 and IS 15528 require mechanical lockouts on system discharge connections during maintenance. Every CO_2 protected space must have audible and visual pre-discharge alarms and clearly signed emergency egress routes. Safety-related documentation (emergency procedures, lockout keys) must be posted at every access point.

6.5.2 Clean Agent Systems

Clean agents (FK-5-1-12, HFC-227ea, IG-541, IG-100) are zero-ozone-depletion alternatives to halon, designed to IS 15493 and NFPA 2001. They operate by heat absorption (chemical agents) or oxygen dilution (inert gas agents). Clean agents are preferred over CO_2 where:

- The protected space may be occupied during discharge (clean agents are physiologically safe at design concentration; CO_2 is not)
- The space is small (< 500 m^3) and can be made leaktight
- Equipment is high-value and sensitive to water, foam, or dry chemical damage

6.6 Water Spray and Deluge Systems

Water spray (medium-velocity deluge) systems apply water at 10–12 L/min/m^2 to exposed surfaces for cooling and fire control, rather than suppression by surface coverage. They are the standard protection method for pressure vessels, heat exchangers, loading arms, and transformers in Indian process plant, per IS 15325 and NFPA 15.

- Design density for vessel cooling: 10.2 L/min/m^2 of wetted surface [NFPA 15:2027 – Cl. 7.4.2.1; IS 15325]
- Design density for cooling of structural steel: 12.2 L/min/m^2 of projected horizontal area
- Deluge valve actuated by pneumatic or electric signal from fire detector; fail-safe open design required
- All nozzles must be open-orifice (not automatic), sized to provide uniform coverage over the protected surface
- Hydraulic calculation must account for simultaneous operation of all nozzles in one deluge zone

NOTE

Water spray over LPG or other pressurised gas vessels can cause rapid vapour generation and ice formation at rupture points. The primary objective is to keep the vessel wall below the metal temperature at which BLEVE becomes imminent (approximately 200°C for carbon steel). The spray must completely wet the exposed vessel surface at all orientations relative to the fire scenario.

Chapter 7: Passive Fire Protection Design

Passive Fire Protection (PFP) provides fire resistance without requiring activation — it is always in place, requires no power, and works regardless of whether detection systems function. In oil & gas and process plant, PFP is the last line of defence between a fire and a structural collapse or BLEVE escalation. It must be designed, specified, installed, and maintained with the same rigour as active systems.

7.1 PFP Strategy and Philosophy

The PFP strategy must be developed as part of the Fire Protection Philosophy and must address three questions for every structure and equipment item:

- What is the fire scenario and heat flux the item may be exposed to? (Pool fire, jet fire, or hydrocarbon fire curve)
- What is the critical temperature of the item (i.e., at what temperature does it fail)? (Structural steel: typically 510–580°C; pressure vessel: 200–300°C for BLEVE prevention)
- How long must protection be maintained? (Sufficient for detection, activation of ESD, blow-down, and/or evacuation — typically 1–4 hours)

The answer to these three questions defines the required PFP specification: the fire rating (hours), the fire curve (cellulosic or hydrocarbon), and the applied thickness of material needed to limit the substrate temperature.

7.2 What Requires PFP in Process Plant?

Item	PFP Requirement	Typical Rating	Standard / Basis
Structural steel in hazardous area	Full encapsulation or board	1.5–3 hr HC curve	API RP 2218, UL 1709
Supports of pressure vessels containing flammables	Full encapsulation	1.5 hr HC curve	API RP 2218, UL 1709
LPG sphere legs and supporting skirts	Full encapsulation to crown of sphere	1.5 hr HC curve	API RP 2218, UL 1709

Pipe racks above hazardous areas	Fireproofing of structural elements only (not pipes)	1.5 hr HC curve	API RP 2218, UL 1709
Firewall / blast wall	Specific rating from structural analysis	2–4 hr — by design	IS 1642
Cable trays in safety-critical circuits	Intumescent coating or mineral wool wrap	15-30 min HC curve	API RP 2218, UL 1709
Drainage channels and bund walls	Not typically fireproofed unless adjacent to LPG	By risk assessment	OISD-STD-116

7.3 PFP Materials — Selection and Specification

7.3.1 Intumescent Coatings

Intumescent coatings are thin-film epoxy or water-based materials that expand 20–50 times their original thickness when exposed to heat, forming a low-conductivity char that insulates the substrate. They are applied by spray or roller to a dry film thickness (DFT) of 1–10 mm depending on the required fire rating and the steel's profile section factor (Hp/A, m^{-1} — the ratio of heated perimeter to cross-sectional area).

- Advantages: thin application, aesthetically acceptable, available in various colours, amenable to inspection of substrate after removal
- Limitations: all intumescent products are HC-curve rated only if specifically tested to ISO 22899. Many commercial products are tested only to ISO 834 (cellulosic). Never use cellulosic-rated intumescent on process plant without verification.
- In practice, an independent third-party DFT survey (measured with an electromagnetic gauge after each coat) is the minimum quality assurance step. A full holiday test (pinhole detection) survey is strongly recommended for assets with extended design life or inaccessible locations.

7.3.2 Cementitious Spray (Lightweight Fireproofing)

Cementitious (Portland cement-based) spray-applied fireproofing (e.g., Fendolite, Cafco) provides HC-curve fire resistance when applied at 20–60 mm thickness. It is the most common material for large structure PFP in Indian refineries and petrochemical plants because of its durability, thermal mass, and relatively low cost. Specification per API RP 2218 and IS 1661 (cement).

7.3.3 Mineral Wool and Blanket Systems

Mineral wool (rockwool or glasswool) encapsulation systems provide fire ratings up to 4 hours HC curve. They are used where the structural shape makes spray application difficult (complex nodes, stiffened plate structures), and for cable circuit protection. Thickness for H-section steel: typically 50–100 mm rockwool at density 100 kg/m^3.

7.3.4 Ablative and Epoxy Materials

Ablative materials (e.g., Chartek series) are epoxy intumescents specifically engineered for the hydrocarbon fire curve and jet fire impingement. They expand to 30–60 mm of high-performance char. They are specified for jet fire scenarios where flux levels > 150 kW/m^2 are expected. More expensive than cementitious, but resistant to mechanical damage and require less thickness for equivalent rating.

7.4 Compartmentation and Firewall Design

Fire compartmentation limits the spread of fire and products of combustion within a building by subdividing it with fire-rated walls, floors, and doors. As per IS 3594 – Cl.6.2.2 for storage and warehouse occupancies:

- Normal risk: maximum floor area 2,000 m^2 per compartment; no sprinklers
- High hazard goods storage: maximum compartment size 750 m^2
- Fully sprinklered buildings designed to IS 15105: maximum compartment size may be increased to 5,000 m^2
- 12,000 m^2 represents the maximum floor area controlled by a single sprinkler alarm valve, not a fire compartment size
- Fire walls between compartments must be 2-hour FRR minimum for industrial occupancies, continuous from foundation to roof, and without openings except protected doorways
- Every opening in a fire wall requires a self-closing fire door or rolling fire shutter rated to the wall's FRR. Check that the door FRR is tested to the same fire curve as the wall — many steel fire doors in India are tested only to EN 1634 (cellulosic). For process plant firewall doors, test to ISO 22899 is required.

7.5 Firestopping — Penetrations and Gaps

A firewall is only as effective as the weakest penetration through it. Every pipe, cable tray, duct, conduit, or structural member that penetrates a rated wall or floor creates a pathway for fire and smoke to bypass the compartmentation. Firestopping must restore the compartment's fire resistance at every penetration.

- All penetration seals must be certified to IS 12458 or EN 1366-3 for the same rating as the element penetrated
- Common firestopping products: intumescent sealant, intumescent collars, mineral wool plug and intumescent sealant, fire-rated pillows for temporary openings
- A penetration register must be maintained, recording every penetration, the product used, and the installer's certificate. This is a key inspection item in brownfield assessments.

KEY POINT

A single unsealed cable tray penetration through a 4-hour fire wall can reduce the effective separation to 20 minutes. On most Indian industrial sites, the penetration sealing register does not exist, and inspection of existing penetrations in brownfield assessments consistently reveals unsealed or partially sealed openings. This is a 'high priority' finding in every category of fire audit.

Suspect your fire compartmentation has been compromised by plant modifications? Contact us to schedule a comprehensive Passive Fire Protection (PFP) integrity survey.

Chapter 8: Fire Detection, Gas Detection, and Alarm Systems

Early and reliable detection is the trigger for all downstream fire response: suppression system activation, emergency shutdown, alarm notification, and evacuation. An undersized, poorly specified, or incorrectly placed detection system will delay response and allow fire to grow beyond the capacity of the protection system. This chapter covers both fire and gas detection, as the two systems are integrated in process plant.

8.1 Fire Alarm System Design — IS 2189

The fire alarm system (FAS) is designed to IS 2189:2026 and NFPA 72:2025. Key design elements:

8.1.1 System Architecture

Modern industrial fire alarm systems are based on analogue-addressable (intelligent) technology. Each detector has a unique address and reports smoke or heat concentration as a continuous analogue signal to the Fire Alarm Control Panel (FACP). This allows alarm decisions (pre-alarm, alarm, fault) to be programmed based on the signal level and pattern from multiple detectors, reducing false alarms significantly compared to conventional threshold-based systems.

- Panel: certified to EN 54-2 (Control Equipment) or UL 864. All panels must have battery standby power for minimum 24 hours (non-fire) and 30 minutes (alarm) [IS 2189:2026 – Cl. 3.37(d)]
- Wiring: minimum 6-core for loop wiring (IS 2189:2026 – Cl. 4.4.4.2); fire-resistant cable (850°C / 30 min minimum per IEC 60331-1) in hazardous areas and escape routes
- Zones: each zone must be physically identifiable from the FACP location; maximum 40 detectors or 2,000 m² per zone for conventional systems [IS 2189:2026 – Cl. 4.4.2 (a)]
- For addressable systems: a single spur fault must not disable more than one zone; Class B (supervised) wiring is minimum requirement for industrial systems

8.1.2 Detector Selection by Environment

8.1.2 Detector Selection by Environment

Detector Type	Best Application	Avoid in	Standard
Optical smoke (point)	Clean environments; slow smouldering fires	Dusty, high humidity, oily atmospheres	IS 2189:2026 – Cl. 5.1.22; EN 54-7
Ionisation smoke (point)	Flaming fires; invisible aerosols; clean rooms	Dusty, dirty, radiation-restricted areas	IS 2189; being phased out — radioactive source
Heat detector (fixed temp or ROR)	Kitchens, engine rooms, dirty environments	Large open areas (slow response)	IS 2189:2026 – Cl. 5.1.1; EN 54-5
Linear beam smoke (optical)	Large open areas: warehouses, atriums	Environments with vibration, mist, fog	EN 54-12; IS 2189
Aspirating smoke (VESDA)	High-value spaces, early warning critical	Very dirty air; fibrous environments	EN 54-20; NFPA 72 Cl. 17.7
UV/IR flame	Hydrocarbons and flammable liquids; indoor/outdoor	Dusty, obstructed sight lines	EN 54-10; NFPA 72:2025 – Cl. A.17.8.2
UV only flame	Fast-flaming fires; alcohols; unobstructed view	Solar radiation interference outdoors	EN 54-10
Multi-spectrum IR flame	Outdoors; hydrogen and CO fires (no UV)	Very high dust attenuation	EN 54-10; NFPA 72:2025 – Cl. A.17.8.2

8.1.3 Detector Spacing

IS 2189 Table 2 provides maximum spacing and coverage area for point detectors in ceiling-mounted configuration. Key values:

- Heat detector: for heights between 5 m and 7 m - 3.5 m spacing; Beyond 7 m height - Not allowed to install heat detectors
- Smoke detector: Ceiling heights between 7 m and 10 m; maximum detector spacing 5 m
- For ceiling heights > 10 m: only beam detectors or aspirating type detection systems shall be used
- Obstructed ceilings (beams > 250 mm deep): each beam bay treated as a separate detector zone

8.2 Gas Detection Systems

Gas detection is a critical safety system on any facility handling flammable gases or volatile liquids. It provides early warning of gas releases before ignition, enabling ESD activation and personnel evacuation before a hazardous vapour cloud forms. Gas detection systems are designed to SIL requirements per IEC 61511, with the SIL rating driving the requirements for detector redundancy, voting, and proof testing.

8.2.1 Detector Types

IS 2189 Table 2 provides maximum spacing and coverage area for point detectors in ceiling-mounted configuration. Key values:

- Catalytic bead (pellistor): measures combustible gas as a percentage of LEL. Operating range 0–100% LEL. Accurate, low cost. Inhibited by silicone compounds; fails safe on loss of power.
- Infrared (IR point): non-contact, non-consuming; suitable for hydrocarbons. Immune to poisoning. Higher cost than pellistor. Does not detect hydrogen (H2 has no IR absorption band).
- Open-path IR (OPGD): measures average gas concentration along a beam up to 200 m. Detects clouds that might miss point detectors; cannot pinpoint source. Required for large open areas (tank farms, pipe racks).
- Electrochemical: for toxic gases (H2S, CO, Cl2, SO2). Specific to a single gas. Accurate at low ppm levels relevant to toxic threshold.
- Ultrasonic: detects the acoustic signature of high-pressure gas leaks. Not concentration-based; detects leaks below LEL. Used as an early warning of pressurised release (jet release) independent of gas type.

8.2.2 Voting and SIL Philosophy

A gas detection signal is typically voted before triggering safety-critical actions (ESD, deluge, ventilation):

- 1oo1 (1 out of 1): single detector; alarm and early warning actions only. Not acceptable for SIL-rated actions.
- 1oo2 (1 out of 2): first detection from either detector triggers alarm. High availability, low spurious trip rate. Used for pre-alarm and ventilation actions.
- 2oo3 (2 out of 3): two detectors must agree before triggering major ESD actions. Used for SIL 2 safety functions (major plant shutdown, deluge activation). Standard configuration in OISD-STD-117 for refinery process areas.

NOTE

IS/IEC 60079: Part 29 requires gas detectors to be positioned at a spacing not exceeding the detection radius of the detector for the expected gas cloud size. The spacing must be determined by gas cloud consequence modelling, not by rule of thumb. Detector spacing can be derived from cloud size analysis.

8.3 System Integration – Fire and Gas

On process plants, the fire and gas (F&G) detection system is a safety instrumented system (SIS) with defined safety functions. It must be integrated with:

- Emergency shutdown (ESD) system: gas detection triggers ESD isolation and blow-down per a predefined cause-and-effect matrix
- Public address and general alarm (PAGA): confirmed fire or gas triggers audible and visual alarm throughout the facility
- Suppression systems: fire detection (confirmed by 2oo3 or specific detector logic) releases deluge or gaseous suppression
- Building management system: smoke detection triggers fire damper closure, pressurisation of stairwells, elevator recall
- Emergency response: the fire and gas system feeds the Emergency Control Room for manual override capability during incident management

The cause-and-effect matrix (F&G C&E) is the defining document for this integration. It must be developed by the process safety engineer and fire engineer jointly, reviewed against the HAZOP study output, and approved before construction drawings are issued.

Complex facilities require more than just standalone fire systems—they demand seamless integration. Let our cross-functional experts bridge the gap between process safety and fire engineering to guarantee your plant's resilience.

Chapter 9: Greenfield Fire Engineering Deliverables and Documentation

Completeness of fire engineering documentation is not an administrative requirement — it is the mechanism by which the engineering design is communicated to installers, maintained by operators, verified by regulators, and audited by insurers. Incomplete documentation is the primary cause of installation errors and of failures to update the protection system when the facility changes.

9.1 Document Hierarchy

Document	Stage	Approving Authority	Primary Content
Fire Safety Concept (FSC)	Concept / FEED	Client / Regulator	Fire safety objectives, scope, design basis
Fire Protection Philosophy (FPP)	FEED / Basic design	Client / Insurer / Regulator	Fire scenarios, protection strategy for each area, system responsibilities
Fire and Gas Detection Philosophy	Basic design	Client / SIS engineer	Detection strategy, voting logic, C&E matrix basis
FERA Report	FEED / Basic design	Independent FPE / Client	Consequence modelling, risk evaluation, ALARP demonstration
Fire Water Demand Study	Basic design	Client / OISD / Fire Dept	Total demand, storage, pump sizing basis
Fire Protection Drawings (layouts, schematics)	Detailed design	Fire Dept (NOC) / PESO	All system layout, pipe routing, equipment data

Hydraulic Calculations	Detailed design	Client / TAC	Sprinkler or hydrant system hydraulic proof
Passive Fire Protection Schedule	Detailed design	Client / Structural engr	All fireproofed items, material, thickness, rating
Factory Acceptance Test (FAT) Reports	Procurement	Client / Third party	Pre-shipment testing of major systems
Commissioning and Test Records	Construction	Regulator / Client	As-installed verification, functional test results
Operating and Maintenance Manual	Handover	Client / Operator	System description, preventive maintenance schedule, emergency procedures

9.2 Fire Protection Philosophy — Minimum Content

The FPP is the master fire engineering document. At minimum it must contain:

1. Executive summary of fire safety objectives and strategy
2. Regulatory framework — all applicable standards, codes, and regulations
3. Facility description — process overview, fluids, inventories, personnel numbers
4. Hazard identification summary — fire and explosion scenario register
5. Area classification — fire zone plan (plan drawing and written description)
6. Active protection strategy — system type, coverage, design standard, design basis per zone
7. Passive fire protection strategy — FPP schedule basis and design fire curve
8. Detection and alarm philosophy — detector types, spacing basis, voting logic
9. Emergency response interface — ESD philosophy, muster points, evacuation strategy
10. Firewater supply and demand summary — demand calculation, storage, pump philosophy
11. Regulatory approval status — NOC applications, outstanding items, PESO licence status
12. Document history and revision control

The FPP must be reviewed and approved by a competent fire protection engineer. It must be a living document — updated at every MoC review and at every major modification or process change.

9.3 Pre-Startup Safety Review (PSSR) — Fire Safety Elements

Before any new facility or modified system is started up, a PSSR must be completed. The fire safety elements of the PSSR include:

- All fire and gas detection systems functionally tested and alarm set-points verified
- All suppression systems commissioned: hydrostatic test complete, deluge valves functional, foam proportioning verified, gaseous system cylinder weights confirmed
- All fire doors, fire dampers, and smoke control systems tested
- Fire pump diesel engine commissioned: fuel level, battery condition, auto-start tested from system pressure drop
- Emergency lighting and exit signage energised and tested
- Evacuation plan posted; muster points established and communicated to all personnel
- F&G cause and effect matrix verified against design C&E by function test of each input-output pair
- Fire NOC issued by State Fire Department for the facility
- PESO licence current for petroleum storage quantities
- TAC inspection completed and any punch-list items closed

KEY POINT

The most common gap at greenfield PSSR is incomplete functional testing of the F&G cause-and-effect matrix. Individual detectors are tested, but the integrated response (detector signal → ESD → deluge → PAGA) is not verified end-to-end. Require an integrated PSSR test plan that exercises every cause-and-effect row in the C&E matrix.. Let Sparrow RMS validate your fire safety systems end-to-end for a flawless, risk-free handover.

PART III

Brownfield Fire Engineering

Assessing, prioritising, and upgrading fire safety in existing and ageing industrial facilities

Chapter 10: Brownfield Site Assessment — Methodology and Process

Brownfield fire engineering is fundamentally different from greenfield design. The engineer arrives at a facility that already exists, is typically operating (or recently operational), and has accumulated decades of modifications, repairs, deferred maintenance, and regulatory non-compliances that have been normalised into the operating culture. The task is not to design from first principles — it is to objectively measure where the facility stands against the risk it faces, identify the gaps, and create a structured programme to close them.

The most important quality the brownfield fire engineer brings is independent, objective assessment — the ability to see what the site team has stopped seeing. This requires a systematic methodology, thorough documentation, and the willingness to call out findings that the client may not want to hear.

10.1 The Brownfield Assessment Framework (FREAP)

Sparrow RMS's Fire Risk Engineering Assessment Programme (FREAP) is a six-phase structured audit framework developed over 13 years of industrial fire safety assessment across oil & gas, petrochemical, and manufacturing facilities in India. The six phases ensure that no element of fire safety is overlooked and that findings are structured for action:

Phase	Activity	Output
Phase 1: Pre-Audit Assessment	Information gathering; document review; scope definition; prior audit review	Audit scope document; pre-audit gap list; site briefing pack
Phase 2: Data Collection	Detailed site walkdown; photographic evidence; system testing; record collection	Field data sheets; photographic register; as-found test results

Phase 3: Strategy Development	Gap analysis; risk ranking; compliance matrix; consequence review	Gap register; risk-ranked finding list; compliance matrix
Phase 4: Client Collaboration	Findings presentation; client discussion; prioritisation workshop	Agreed priority list; client annotation on findings; provisional timeline
Phase 5: Engineering Report	Detailed audit report with recommendations; cost-indicative remediation schedule	FREAP audit report; engineering drawings (where required); executive summary
Phase 6: Support and Close-out	Design review of remediation work; re-inspection; closure certificates	Closure report; updated compliance matrix; revised Fire Protection Philosophy

10.2 Phase 1: Pre-Audit Assessment

The pre-audit phase is the most under-resourced and most important phase. The quality of the site walkdown depends entirely on how well the engineer understands the facility before arriving.

10.2.1 Document Request List

The following documents must be requested from the client before the site visit:

- Plot plan and facility layout drawings (latest revision)
- Piping and instrumentation diagrams (P&IDs) — current issued-for-operation (IFO) revision
- Fire Protection Philosophy or equivalent (if it exists)
- Fire water demand calculation and single-line diagram for the fire water network
- Fire and gas detection system as-built drawings and cause-and-effect matrix
- Last fire pump test records (NFPA 25 or IS 12469 acceptance criteria)
- Fire system maintenance logs for the past three years (sprinklers, detection, suppression)
- PESO licence (petroleum facilities), Factory licence, and any pending regulatory notices
- Previous fire safety audit reports and outstanding action trackers
- Incident log: any fire-related incidents, near misses, or unwanted actuations in the past five years
- Electrical area classification drawing (IS 5572 / IEC 60079)
- Insurance survey report (TAC or FM Global, if available)

10.2.2 Pre-Audit Gap Screening

Review the available documents to identify the most significant likely gaps before the site visit. Arrive with a preliminary hypothesis about the highest-risk areas — this focuses the walkdown time and ensures critical areas are inspected in depth even if the on-site schedule is compressed.

10.3 Phase 2: Site Data Collection (Walkdown)

10.3.1 Walkdown Structure

The site walkdown must be structured by fire protection element, not by geography. Walking through the plant area by area risks missing systematic deficiencies that span multiple areas. The recommended walkdown structure:

- Fire water supply: pump house, diesel engine condition, tank levels, jockey pump operation, ring main condition (visible corrosion, valve positions, pressure gauge readings)
- Hydrant network: valve positions (normally open valves confirmed open), hydrant box condition, branch pipe and landing valve operability, monitor nozzle condition, hose reel condition
- Fixed suppression: deluge valve rooms (alarm valve condition, pressure gauges, corrosion, test facilities), sprinkler head condition (painted/corroded heads), foam concentrate condition and quantity
- Detection and alarm: panel condition, alarm zones, battery test results, detector condition (dust accumulation, mechanical damage), notification appliance condition
- Passive fire protection: inspection of structural fireproofing (hollow-sounding, cracked, disbonded, water-ingress damage), penetration seals, fire door condition and self-closing integrity
- Active protection maintenance: annual test records, evidence of corroded or blocked nozzles, suppression system inspection tags
- Life safety: exit door operability (not locked or obstructed), exit signage illumination, emergency lighting testing, muster point accessibility
- Housekeeping: combustible material accumulation, waste disposal, vegetation control around hazardous areas, smoking controls in classified zones

10.3.2 Evidence Standards

10.4 Common Brownfield Findings — Ranked by Risk

The following table summarises the most commonly identified high-severity brownfield findings across Indian industrial facilities, based on Sparrow RMS field experience across 400+ fire safety audits:

Finding	Risk Level	Root Cause	Typical Regulatory Ref.
Fire water pump not starting automatically on pressure drop	CRITICAL	Deferred maintenance; auto-start isolation left in manual after last test	OISD-STD-116 – Cl. 16.2; NFPA 25:2026 – Cl. 8.3.7
Deluge valve room flooded or in poor condition — valve not operable	CRITICAL	Maintenance neglect; corrosion of valves and trim	IS 15325; NFPA 25:2026 – Cl. 13.4.4
Diesel engine fire pump — fuel tank empty or engine seized	CRITICAL	Maintenance neglect; no operational ownership	IS 15301:2003 – Cl. 7.3.2
F&G cause-and-effect not tested in 3+ years	CRITICAL	No test programme; no operational ownership	IS 2189 Table 4
Passive fire protection — large areas disbonded or missing	HIGH	Age, corrosion, mechanical damage, no PFP inspection programme	OISD-STD-116 – Cl. 22.0; API RP 2218
Sprinkler heads painted over by maintenance painting programmes	HIGH	No co-ordination with fire system; no permit required	IS 15105:2021 – Cl. 7.1; NFPA 13:2021 – Cl. 16.2.3.1
Fire doors wedged open permanently	HIGH	Operational convenience; no training	NBC Part 4 Cl. 9.2.3
Penetrations in fire walls unsealed — cable trays and pipes	HIGH	No penetration control process at construction or modification stage	NBC Part 4; IS 3809

Foam concentrate below minimum level or past shelf life	HIGH	No stock management; no maintenance ownership	OISD-STD-116 – Cl. 6.11; NFPA 11:2024 – Cl. 4.3.2
Hazardous area lighting with non-ATEX fixtures following lamp replacement	MEDIUM-HIGH	Maintenance replacement with non-approved items	IS 5572; IEC 60079-14
Expired fire extinguishers; wrong type for hazard	MEDIUM	No maintenance contract; wrong selection at installation	IS 2190; NBC Part 4 Cl. 14.2

WARNING

The single most dangerous finding in any brownfield audit is a non-functional fire water pump – either the electric pump with a deactivated auto-start, or a diesel pump with a discharged battery, empty fuel tank, or seized engine. On multiple sites, a fire has occurred and the pump could not be started. If the pump auto-start test is not scheduled as a monthly routine with signed records, treat this as a critical finding regardless of other evidence.

Chapter 11: Gap Analysis and Risk Prioritisation

The gap analysis converts field observations into an engineering-grade risk register that can drive investment decisions. Raw audit findings without risk context are ignored. A well-structured gap register with risk-ranked findings, cost estimates, and regulatory linkage becomes a capital investment case that finance and senior management can act on.

11.1 Gap Classification Framework

Gaps are classified on two dimensions: severity (the consequence if the gap leads to an incident) and likelihood (the probability that the gap will be exploited in a real fire scenario). The combination of severity and likelihood yields a risk priority number (RPN) used to rank and sequence remediation.

Severity Rating	Description	Examples
S1 — Critical	Failure could result in multiple fatalities or catastrophic asset loss during a fire	Non-functional fire pump; failed deluge system; missing PFP on LPG sphere support
S2 — High	Failure significantly impairs fire control or life safety	Painted sprinkler heads; unsealed major penetrations; non-functional F&G detection zone
S3 — Medium	Failure reduces system effectiveness but does not eliminate it	Corroded hydrant valve (still operable); single defective smoke detector; foam concentrate below 10% of design
S4 — Low	Housekeeping, administrative, or minor technical deficiency	Signage missing; extinguisher inspection record not displayed; minor foam concentrate shortfall

Likelihood Rating	Description
L1 — Certain to fail	The system or component will fail on demand with near certainty based on observed condition
L2 — Likely to fail	High probability of failure on demand — significant doubt about operability
L3 — Possible failure	Intermittent or partial functionality; may operate in some demand scenarios
L4 — Unlikely to fail	Condition that reduces effectiveness but is unlikely to cause failure on demand

The Risk Priority Number is calculated as RPN = S × L (1–4 × 1–4 = 1–16 scale). Findings with RPN ⩾ 8 are 'critical'; 4–7 are 'high'; 1–3 are 'medium/low'. Sequence remediation from highest RPN downward.

11.2 Compliance Matrix

Alongside the risk ranking, a compliance matrix maps each finding against the regulatory requirement it breaches. This serves two purposes: it provides the legal basis for requiring remediation (regulators and insurers cannot mandate action without a regulatory reference), and it allows the client to understand their regulatory exposure in prioritising the work.
The compliance matrix format: Finding ID | Finding Description | Location | Standard / Clause | Non-compliance Nature | RPN | Recommended Action | Target Date | Status.

11.3 Remediation Prioritisation

A practical remediation programme must recognise that not all gaps can be closed simultaneously. The following framework prioritises the sequence:

Priority 1 — Immediate Action (within 30 days)

S1/L1 or S1/L2 findings that represent an immediate life safety risk if a fire occurs tomorrow. These must be resolved before normal operations continue, or interim risk controls must be implemented (increased patrol frequency, temporary suppression, process rate reduction).

Priority 2 — Short-term (30–90 days)

S1/L3 or S1/L4 findings, and S2/L1–L2 findings. These require capital expenditure or significant maintenance intervention. They should be designed, procured, and implemented on an accelerated schedule.

Priority 3 — Medium-term (90 days–1 year)

S2/L3–L4 and S3/L1–L2 findings. These are planned as part of the annual capital programme or major maintenance shutdown. Each finding should have a named owner and a scheduled completion date.

Priority 4 — Long-term (1–3 years)

S3/L3–L4 and S4 findings. Administrative, housekeeping, and minor technical improvements that can be incorporated into routine maintenance cycles.

KEY POINT

Brownfield clients frequently resist Priority 1 findings because they imply immediate disruption and cost. The fire engineer's obligation is to document the finding clearly, state the recommended action and the consequence of not acting, and obtain the client's written acknowledgement. If the risk is immediately life-threatening and the client refuses to act, the engineer must consider the limits of professional liability and the obligation to notify the relevant authority.

Hidden compliance gaps don't just threaten life safety—they expose your business to massive legal and financial liability. Partner with Sparrow RMS for an independent, engineering-grade fire safety audit and secure your facility's blind spots.

Chapter 12: Upgrade Design and Retrofit Fire Engineering

Once the gap analysis is complete and remediation priorities are set, the fire engineer transitions from audit mode to design mode. Brownfield retrofit engineering is technically more challenging than greenfield design — the engineer must fit new systems into existing structures, interface with live process systems, and work around operational constraints that a greenfield designer never faces.

12.1 Design Constraints in Brownfield Retrofit

- Existing pipe routing: retrofitting a sprinkler system into an existing building requires routing supply pipes through structural members, above ceiling tiles, and around electrical services — the full hydraulic calculation must account for the actual (not idealised) pipe routing
- Structural loading: additional weight of fire water pipework (full of water) must be verified against the existing slab and structural frame capacity. A structural check by a civil engineer is required before routing new 100 mm+ bore fire water mains over existing floors.
- Interface with live systems: any tie-in to an existing fire water ring main requires isolation of a section under pressure, with temporary fire cover for the isolated zone during the tie-in period
- Operational availability windows: many brownfield facilities can only allow intrusive work during planned shutdowns. The fire engineer must sequence the retrofit design to maximise progress within the available shutdown window and maintain minimum fire cover during construction. Avoid costly shutdowns and integration failures. Leverage our brownfield retrofit engineering services for seamless fire system upgrades
- As-built vs. drawing discrepancy: existing facilities almost never match their design drawings exactly. Every critical dimension must be field-verified before fabrication, particularly for pipe spool fabrication and PFP material ordering

12.2 Retrofitting Sprinkler Systems

Adding sprinkler protection to an existing unprotected building is one of the most common brownfield fire engineering assignments. The design sequence:

1. Confirm hazard class for the occupancy per IS 15105 / NFPA 13
2. Establish the available firewater supply pressure and flow at the connection point (conduct a flow test per NFPA 291 methodology — static and residual pressure at the tie-in point)
3. Design the system within the available supply, optimising the pipe layout to minimise pressure demand at the connection
4. Verify structural slab capacity for pipe and water weight loading
5. Issue design for building permit / Fire NOC amendment
6. During installation: verify all penetrations through walls, floors, and roofs are firestopped with approved materials
7. Commission and test: flush, hydrostatic test at 200 psi (14 bar) or 50 psi (3.4 bar) above system working pressure, whichever is greater, for 2 hours with no pressure loss, and conduct main drain test to verify supply flow per NFPA 13:2025 – Cl. 29.2.1.1 / 6.11.2.2.1.

12.3 Passive Fire Protection Upgrades

Upgrading PFP on an operational facility is one of the most operationally disruptive brownfield activities, because it requires direct access to structural steel and equipment that may be hot, under pressure, or in a classified hazardous area.

12.3.1 PFP Condition Survey

Before specifying a PFP upgrade, conduct a systematic condition survey of all existing fireproofing:

- Visual inspection: disbonding, cracking, hollow sound on tapping (tap test), water ingress, vegetation growth in cementitious fireproofing
- Thickness measurement: core samples at representative locations to verify residual thickness against the design PFP schedule. Minimum 3 cores per 10 m² for cementitious; DFT gauge readings at 1 m² intervals for intumescent coatings
- Bond strength test: pull-off adhesion test per ASTM D4541 or BS EN ISO 4624 for epoxy intumescent. Minimum acceptance criterion per manufacturer's data sheet.
- Substrate condition: if substrate corrosion is suspected (from inspection of areas where coating is removed), abrasive blast and visual assessment per SSPC-SP10.

12.3.2 Repair vs. Replace Decision

Where existing PFP is partially defective:

- If > 30% of the surface is disbonded, hollow, or missing: full strip and reapplication. Patch repairs of degraded cementitious PFP rarely achieve the original fire rating at the repair boundary.
- If < 30% isolated areas: spot repair is acceptable, but the repair must be feathered to maintain a continuous, monolithic surface with no exposed substrate at repair edges.
- For intumescent coating in poor condition: full strip to bare metal and reapply. The original DFT schedule applies — there is no credit for partially intact existing coating.

12.4 Working Safely in Hazardous Areas During Retrofit

Retrofit work in operating petroleum facilities and chemical plants introduces unique hazards that require a robust permit-to-work (PTW) system and specific safe work procedures:

1. Hot work permit: required for any welding, grinding, or flame cutting within a classified hazardous area (IS 5572 Zone 0, Zone 1, Zone 2). Hot work must be preceded by gas testing, provision of a fire watch, and preparation of a fire extinguisher rated for the specific fuel type on site
2. Line break permit: required before disconnecting any section of the fire water ring main or suppression system piping. Obtain a written statement of temporary fire cover arrangements from the site fire safety manager before isolation
3. Confined space entry: water tanks, deluge valve rooms, and firewater underground sumps may be classified confined spaces under IS 17893. A confined space entry permit is required, with atmospheric testing and rescue capability in place
4. Simultaneous operations (SIMOPS): agree a SIMOPS plan with the operations team before retrofit work commences, defining which process operations are excluded during which construction activities (e.g., no solvent transfers during hot work windows within 30 m)

Chapter 13: Management of Change and Pre-Startup Safety Review

Process safety statistics consistently show that a significant proportion of major industrial incidents occur within 12 months of a plant modification, expansion, or turnaround maintenance activity. The common thread is that changes to the facility alter the fire and explosion risk profile without a corresponding update to the fire protection system or the fire safety documentation. Management of Change (MoC) and Pre-Startup Safety Review (PSSR) are the two process safety tools that prevent this failure mode.

13.1 Management of Change — Fire Safety Scope

An MoC process must capture any change that could affect fire safety. Engineers frequently underestimate this scope. The following changes always require a fire safety review as part of the MoC:

- Process changes: new fluid introduced, increase in inventory, change in operating temperature or pressure (affects fire scenario consequence)
- Equipment replacement: larger vessel, different material, change from double to single containment
- Layout changes: new structure, wall removed, access road modified, new building within existing plot
- Utilities changes: fire water supply pressure changed, connection to ring main modified, fire pump replaced
- Detection system changes: detector type changed, new zone added, detector removed or relocated
- PFP changes: sections of fireproofing stripped for inspection and not reinstated, new penetration through fire wall
- Personnel changes: occupancy of a previously unoccupied area (e.g., a warehouse converted to an office)

The MoC trigger question for any proposed change is: 'Does this change alter the fire hazard inventory, the consequence of a fire, or the capability of the fire protection system to respond?' If any element of this answer is yes, a fire safety MoC review is required.

13.2 Fire Safety MoC Review Process

1. Describe the proposed change — written description with P&ID markup and layout drawing revision
2. Identify all fire safety elements affected — use the Fire Protection Philosophy as the reference document
3. Assess the change in fire risk — has the fire scenario changed? Has the detection or suppression coverage been affected?
4. Define required modifications to fire protection — updated system, drawing revision, FPP update
5. Obtain independent review — for major changes: peer review by a fire protection engineer not involved in the original MoC
6. Update documentation — FPP, system drawings, as-built records, and the fire safety risk register
7. PSSR before restart — verify all fire safety modifications are complete before the changed system is commissioned

13.3 PSSR — Fire Safety Verification Checklist

The following checklist covers the minimum fire safety verification items for a PSSR on any new or modified facility. Each item must be signed off by the responsible engineer with documentary evidence:

PSSR Item	Verification Method	Acceptance Criterion
Fire water supply — pressure and flow	Flow test at nearest FHC to modified area	Min 7 bar at FHC with full system demand
Fire pump auto-start test	Simulate pressure drop; observe auto-start time	Electric: < 10 s; Diesel: < 30 s per NFPA 20
Deluge system functional test	Activate by detector signal AND manual call point	Valve opens; full coverage confirmed; alarm to panel
Sprinkler system hydrostatic test	Pressure to 200 psi above working pressure for 2 hours	No leakage at any joint or fitting per NFPA 13
F&G detection — all new detectors tested	Functional test with test gas / heat source	Correct response at panel; alarm within response time
F&G cause-and-effect — all rows tested	Inject signal from each input; verify output	All C&E rows verify per approved matrix

Passive fire protection — visual inspection	Inspector walk with PFP schedule in hand	No areas below minimum thickness; no disbonding
Penetration seals — penetration register	Review register against as-built drawings	All penetrations sealed; product certified for rating
Emergency lighting — full discharge test	Disconnect mains; test for 3 hours	All emergency lights illuminated for full 3-hour period
Exit signage — all signs illuminated	Visual inspection with mains off	All exit signs illuminated; not obstructed
Fire extinguisher — types, locations, dates	Physical inspection	All extinguishers correctly typed, located, and in date
Evacuation plan — updated and communicated	Check posted copies; conduct drill	All staff aware of muster point and evacuation route
Fire NOC — valid for modified facility	Review NOC document scope	NOC covers the modified facility and occupancy

KEY POINT

The PSSR is a gating activity — the modified facility should not be operational until every PSSR item is closed. In practice, 'conditional start-up' with outstanding items is often agreed under pressure from operations. If conditional start-up is agreed, the outstanding fire safety items must have a defined close-out date (not 'as soon as possible'), a named owner, and an interim risk control that mitigates the gap. Any conditional start-up with a critical fire safety gap outstanding must be approved by the most senior responsible person at the site.

PART IV

Sector-Specific Guidance

Oil & Gas, Petrochemical, and Manufacturing & FMCG

Chapter 14: Oil, Gas and Petrochemical Facilities — Sector Guidance

Oil & gas and petrochemical facilities represent the highest fire and explosion risk category in Indian industry. The combination of large inventories of flammable and toxic substances, high operating pressures and temperatures, continuous ignition source proximity, and significant public consequence exposure demands the most rigorous fire engineering approach. This chapter provides sector-specific guidance supplementing the generic methodology in Parts I–III.

14.1 Facility Types and Risk Profiles

Facility Type	Primary Fire Hazard	Key OISD Standard	Dominant Scenario
Petroleum storage depot / terminal	Large pool fire from tank overflow or seal fire	OISD-STD-117	Full surface tank fire + adjacent tank cooling
Petroleum refinery	Process unit fire; hydrogen system fires; crude unit fire	OISD-STD-116	Jet fire from pressurised release; pool fire in crude unit
LPG bottling plant / storage	BLEVE; flash fire from cylinder damage	OISD-STD-150, OISD-STD-169	BLEVE from mounded bullet; flash fire from gantry release
Natural gas processing	VCE; hydrogen sulfide toxic release	OISD-STD-179; OISD-GDN-139	VCE in compression area; H2S cloud dispersion
Petrochemical plant	Pool fire; reactor fire; polymerisation runaway	OISD-STD-116;	Flash fire from ethylene/propylene release; reactor fire
LNG import terminal	Vapour cloud from LNG spill; rapid phase transition	OISD-STD-194	Large LNG spill; flash fire; rapid phase transition explosion

14.2 Petroleum Tank Farm — Fire Engineering

14.2.1 Tank Types and Fire Characteristics

The fire engineering design for a tank farm is driven primarily by the tank type, as the fire scenario and foam application method differ fundamentally:

- Fixed (cone) roof tank: burns as a full surface fire. Cooling of the burning tank shell required at 3.0 L/min/m² as per OISD-STD-117; adjacent tanks outside the (R+30) m radius require 1.0 L/min/m². Foam application via fixed foam chambers at the shell or by sub-surface injection as per IS 12835 (Part 1), provided the stored product is not a polar solvent or high-viscosity fuel.
- Internal floating roof (IFR) tank: the primary fire scenario is a seal fire — the area between the floating deck and the fixed roof, at the deck periphery. Foam application via a foam dam and pourer system at the seal. Full surface fire is a secondary scenario if the floating deck sinks.
- External floating roof (EFR) tank: the primary scenario is a seal fire, with no fixed roof. Foam dam and pourer system directly on the deck rim. Wind deflection of foam must be considered in exposed locations.
- Pressurised tanks (bullets, spheres): LPG, propane, butane. The primary scenario is BLEVE, which is prevented by cooling (water spray deluge) and pressure relief. Foam is not applicable — the fuel is a gas when released. Fire scenario is a fireball (BLEVE) or jet fire from PRV.

14.2.2 Firewater Demand Calculation for Tank Farm

OISD-STD-117 Clause 4.2.2 specifies the firewater demand for a tank farm fire scenario. The demand is the sum of:

Formula:

Q_total = Q_foam_attack + Q_foam_protect + Q_cooling_adj + Q_hydrant
Q_foam_attack = Application rate × Tank area × 1.25 (safety factor)
For AFFF 3%: Q_foam_attack = 5 L/min/m² × π(D/2)² × 1.25
Q_cooling_adj = 3.0 L/min/m² × Wetted area of all adjacent tanks within 30 m
Wetted area = π × D × H (height to product level)
Q_hydrant = 6200 L/min (for large facilities).
Duration: 65 min (foam attack) + 60 min (cooling) = 115 min minimum
OISD-STD-116 requires 4 hours total firewater storage

14.3 Process Plant — Key Differences from Storage Facilities

Process plants (refineries, petrochemical units) present more complex fire engineering challenges than storage facilities because:

- Multiple simultaneous scenarios are credible (a release in the crude unit can propagate to the adjacent vacuum unit within the same fire event)• Managing fire risks in dynamic process environments requires advanced safety engineering. Contact Sparrow RMS to define your facility's design scenario envelope.
- Process streams change composition during operations, and the fire scenario must account for the full range of operating compositions
- Equipment inventories and operating conditions are not static — the fire engineer must define a design scenario envelope that covers normal operations, startup, shutdown, and upset conditions
- Hydrogen fires are essentially invisible in daylight — UV/IR multi-spectrum flame detectors are required in hydrogen service areas (hydrotreaters, reformers, hydrogen headers)
- Corrosion under fireproofing (CUF) is the dominant PFP degradation mechanism in process plants — condensation under cementitious fireproofing in tropical climates causes severe substrate corrosion that is invisible from the outside. PFP inspection intervals of 3–5 years are required per API RP 583.

14.4 Key OISD Compliance Checks — Field Checklist

The following are the most commonly non-compliant items when OISD-STD-116 and OISD-STD-117 are audited in the field:

- Foam concentrate: incorrect specification (protein foam instead of AFFF), expired material, insufficient quantity, or incorrect proportioner setting (set to 3% when 6% required for high-viscosity crude)
- Monitor position and coverage: monitors that cannot reach the burning tank surface at design flow rate due to obstructions added after original installation
- Ring main isolation valves: multiple valves found closed without documentation; ring main effectively not a ring (single feed point)
- Fire pump room: heat build-up in the pump room causing diesel pump heat soak failure on auto-start; no ventilation to maintain pump room temperature below 45°C
- PFP — sphere legs: cementitious PFP on LPG sphere legs found with hollow sections (loss of material integrity) that would fail within 5–10 minutes of HC curve fire exposure
- F&G voting — bypasses left in: gas detector zones found bypassed in the fire alarm panel after hot work or detector replacement, with bypass not reinstated

Chapter 15: Manufacturing and FMCG Facilities — Sector Guidance

Manufacturing and FMCG facilities present a different risk profile from oil & gas. The individual scenarios are generally lower consequence (smaller fuel inventories, lower operating pressures), but the occupancy levels are typically much higher (hundreds to thousands of workers on a single shift), and the diversity of hazards is greater — a single FMCG factory may handle flammable solvents, combustible dusts, compressed gases, and high-rack storage in the same facility.

15.1 Manufacturing Facility Hazard Profile

Process Area	Primary Hazard	Fire Class	Priority Protection
Solvent handling and mixing	Pool fire; flash fire from vapour release	Class B	Foam deluge or sprinkler; ATEX ventilation; gas detection
High-rack warehouse (> 8 m)	High-challenge storage fire; fast fire growth	Class A	In-rack sprinklers + ceiling sprinklers (ESFR); VESDA detection
Flammable solvent storage (> 500 L)	Pool fire; flash fire	Class B	Bunded storage; sprinklers or CO_2 (if enclosed); foam
Electrical switchroom / MCC	Electrical fire; arc flash	Class C	Gaseous suppression (clean agent or CO_2); FM200 typical
Powder handling (dusty operations)	Dust explosion; dust fire	Class A/D	Explosion venting (NFPA 68); earthing and bonding; non-sparking equipment

Cold storage (-20°C to +4°C)	Insulation fire; high polyurethane foam load	Class A	Early detection (VESDA); fire compartmentation; sprinklers (antifreeze or dry pipe)
Boiler room / thermal oil heater	Thermal oil fire (flash point 100–300°C)	Class B	Fixed suppression; thermal oil spill containment; auto-shutdown
Generator room	Diesel pool fire; fuel system fire	Class B	CO2 or clean agent; automatic generator shutdown on fire detection

15.2 High-Rack Warehouse Fire Engineering

High-rack storage (pallet racking above 4 m, commonly up to 15 m in modern cold-chain logistics) is one of the most challenging fire protection scenarios. The fire grows extremely rapidly in the rack flue spaces (the vertical channels between pallets), accelerating the fire plume and producing ceiling gas temperatures that can activate hundreds of sprinkler heads before the fire is suppressed.

15.2.1 Sprinkler Selection for High-Rack Storage

Two approaches are accepted by IS 15105, NFPA 13, and FM DS 2-0:

- ESFR (Early Suppression Fast Response) ceiling sprinklers: large K-factor (K=202 or K=242) high-flow heads that suppress the fire at the ceiling level before it can grow beyond the rack. Used for Class I–IV commodities (no high-hazard commodity or on-floor foam plastics above 1.8 m). No in-rack sprinklers required when ESFR is used correctly.
- In-rack sprinklers + ceiling CMSA (Control Mode Specific Application): intermediate rack levels have additional sprinkler heads every 3 m of rack height. Ceiling sprinklers are smaller and control rather than suppress the fire. Required for commodities exceeding ESFR limits (e.g., aerosol storage, expanded plastic, roll paper).

WARNING

ESFR sprinklers require a specific minimum water supply (typically 12–15 bar at the most remote head) and will not perform as designed if the firewater supply is inadequate. Before specifying ESFR, conduct a detailed water supply analysis. A flow test at the fire water connection point is mandatory – do not rely on design drawings alone. An ESFR system installed on an inadequate water supply is more dangerous than no sprinkler – operators assume they have protection when they do not.

15.3 Flammable Solvent Handling — FMCG Facilities

FMCG facilities (personal care products, food flavourings, pharmaceuticals, cleaning products) routinely handle Class IB and IC flammable solvents (ethanol, IPA, acetone, MEK, hexane) in production. Key fire engineering requirements:

- Hazardous area classification per IS 5572: solvent handling areas are typically Zone 2 (IEC 60079-10 equivalent) for normal operations, with Zone 1 around open transfer points and tank vents. All electrical equipment must be ATEX-certified for the appropriate zone.
- Ventilation: LEV (local exhaust ventilation) at all open solvent handling points; minimum 10 ACH general ventilation in solvent storage and mixing rooms. Gas detection at 10% LEL to confirm ventilation effectiveness.
- Sprinkler density: •Extra Hazard Group 1 per NFPA 13 (12.2 mm/min over 230 m²) as a minimum for production areas handling Class IB solvents above flash point. Where solvents are stored in quantities > 950 L: Extra Hazard Group 2.
- Containment: all flammable liquid transfers must occur within bunded areas. Bund capacity to hold 110% of the largest vessel. Drainage from bunds must not enter the main site drain without an oil interceptor.

15.4 Combustible Dust — Recognition and Control

Dust explosion is the most underrecognised fire and explosion hazard in Indian FMCG and food manufacturing. Facilities producing or handling powdered materials (flour, sugar, spice, starch, milk powder, coffee, pharmaceutical excipients) have all the conditions for a catastrophic dust explosion, yet many have never had a formal dust hazard assessment.

The dust explosion pentagon requires all five conditions simultaneously. Eliminating any one element prevents an explosion:

1. Dust cloud: minimise airborne dust through enclosed processing, LEV, and cleaning programmes. Any surface accumulation > 1 mm depth of combustible dust over a significant area represents a potential secondary explosion fuel source — cleaning frequency must prevent accumulation above this threshold
2. Oxidiser (air): provide inert atmospheres (nitrogen blanketing) for the most hazardous processes (metal powder handling, fine pharmaceutical powder milling); not practical for all operations
3. Ignition source: eliminate all ignition sources within dust cloud zones — no open flames, hot surfaces, sparks from mechanical friction or conveyor belt slip, static discharge (earthing and bonding of all conductive equipment and containers)

1. Dispersion: ensure that conveying, pneumatic transport, and classifier design prevents dust accumulation in dead zones that can be dislodged by vibration or pressure wave from a primary explosion
2. Confinement: vent explosions by installing explosion vents (burst panels) per IS 60079 and NFPA 68 on all dust collectors, silos, and enclosures in dust-handling areas

NOTE

The deadliest dust explosions are typically secondary events – a small primary explosion disperses surface dust deposits throughout the building and the secondary explosion destroys the entire structure. This is why cleaning frequency (preventing surface accumulation) is as important as explosion venting of equipment. A single ATEX-compliant dust collector with properly designed explosion vents will not protect a building where surface dust accumulation is allowed to build up on horizontal surfaces.

15.5 Cold Storage Facilities

Cold storage facilities (blast freezers, chilled storage, controlled atmosphere rooms) present specific fire engineering challenges:

- Insulation: polyisocyanurate (PIR) and polystyrene insulation panels have very high fire loads and flame spread characteristics. NBC Part 4 requires that insulated panel systems in food storage are tested to demonstrate limited fire spread to EN 14509 or equivalent. The 'sandwich panel' fire scenario has caused multiple total-loss incidents globally where sprinkler systems were ineffective due to the burning panels dripping molten polymer onto the water spray.
- Sprinkler design: dry-pipe or pre-action systems are required where ambient temperatures are below 4°C. Dry-pipe systems have a delayed response time (water must travel from the dry valve to the activated head) — this additional travel distance must be included in the hydraulic calculation. Antifreeze systems are an alternative for moderately chilled areas (0 to 4°C).
- Detection: smoke detectors are unreliable in high-humidity, cold environments. Multi-spectrum infrared flame detectors or linear heat detection cable (rated to -40°C for blast freezer environments) are preferred.
- Access for firefighting: emergency access to all cold store areas must be maintained (unlockable from inside, even if external keypad entry). Firefighters must have access to emergency egress for any worker accidentally locked in.

PART V

Technical Reference

Advanced analytical disciplines for senior fire engineers and specialists

Chapter 16: Consequence Modelling and Fire and Explosion Studies

Consequence modelling is the quantitative backbone of performance-based fire engineering. It converts a hazardous scenario (a hole in a pipe, a tank overflow, a vessel failure) into measurable physical consequences — radiation contours, overpressure fields, vapour cloud extents — that can be compared against injury and damage thresholds to define exclusion zones and protection requirements.

16.1 Modelling Tools and Their Limitations

Tool	Developer	Models Covered	Application in Indian Practice
Phast (SAFETI)	DNV GL	Dispersion, pool fire, jet fire, flash fire, BLEVE, VCE (BST)	Standard tool for major FERA studies; accepted by OISD and PESO
ALOHA	US EPA / NOAA	Dispersion, pool fire, BLEVE, VCE (TNT equivalent)	Free tool; used for first-pass screening and emergency response planning
FLACS	Gexcon (DNV)	CFD-based VCE (best method for congested areas); gas dispersion	High-end studies; required for high-congestion VCE scenarios where BST method is non-conservative
FDS (Fire Dynamics Simulator)	NIST (USA)	CFD fire; smoke transport; sprinkler response	Smoke management in buildings; atrium fire; performance-based smoke modelling

FRED / SteadyState	Shell / Various	Jet fire; pool fire; BLEVE	Shell-licensed facilities; highly accurate for large jet fire scenarios
Custom spreadsheets	Engineer	Point source radiation; simple pool fire	First-pass only; not accepted as primary FERA methodology by OISD

WARNING

Consequence modelling tools are only as accurate as the input data. The quality of a FERA study is determined by the correctness of the release hole sizes, fluid properties, operating conditions, and meteorological data used as inputs – not by the sophistication of the tool. A Phast model run with incorrect fluid properties or unrealistic release rates will produce misleading results that may give false confidence. Every FERA study should include a sensitivity analysis on key input parameters. Ensure your FERA study is built on accurate, validated inputs. Partner with Sparrow RMS for expert Phast and FLACS consequence modeling.

16.2 Reporting Requirements for FERA Studies

A FERA study submitted to a regulator or insurer must include:

1. Executive summary: key findings, highest-risk scenarios, protection recommendations
2. Facility description and inventory: all relevant chemicals/hydrocarbons with quantities, operating conditions, physical properties
3. Methodology: tool selected, version, validation basis, assumptions
4. Hazard identification: scenario descriptions with frequency estimates
5. Consequence modelling results: tables and plots of radiation contours, overpressure fields, and vapour cloud extents for each scenario
6. Risk evaluation: individual and societal risk results against acceptance criteria
7. Sensitivity analysis: variation of key parameters to demonstrate robustness of results
8. Recommendations: risk reduction measures with residual risk statement after implementation
9. Appendices: detailed calculation outputs from modelling tool.

Chapter 17: Structural Fire Engineering

Structural fire engineering is the quantitative assessment of how a structure behaves when exposed to fire, and the design of that structure (or its protection) to ensure it does not collapse before its occupants have evacuated and firefighters have contained the fire. In Indian practice, most structural fire engineering is prescriptive — specify PFP to achieve a tabulated fire resistance rating. Performance-based structural fire engineering (advanced analysis) is used only for complex, non-standard structures or where prescriptive solutions are impractical.

17.1 Prescriptive Structural Fire Engineering

IS 800:2007 – Cl.16 Section 16 provides the prescriptive approach to structural fire design for steel structures. Key steps:

1. Determine the required fire resistance period (FRP) from NBC Part 4 Table 1 based on occupancy and building height
2. Calculate the section factor (Hp/A, m^{-1}) for each structural member: the ratio of the heated perimeter to the cross-sectional area. Higher Hp/A = faster heating = more PFP required
3. Using the PFP manufacturer's published data (tested to IS 15103 or EN 13381), determine the required material thickness to achieve the design FRP at the calculated Hp/A
4. Specify the thickness on the PFP schedule for each member

Section factor (box protection): Hp/A = 4 / d[m^{-1}] for square hollow sections
Section factor (contour protection): Hp/A = (2b + 2d) / (b × d) [m^{-1}]for I-sections
where: b = flange width, d = section depth (metres)

Formula: ***For a typical 254×146×37 UB (Hp/A ≈ 180 m^{-1}), a 1-hour cellulosic fire rating requires***
approximately 8 mm DFT of a standard intumescent coating (product-specific – verify with manufacturer).
For the HC curve: the same rating requires 12–18 mm DFT or 20–25 mm cementitious spray.

17.2 Performance-Based Structural Fire Engineering

For structures that cannot be designed prescriptively (curved roofs, complex frames, structures with unconventional occupancy patterns), advanced fire analysis is used. The approach follows Eurocode 1 Part 1-2 (EN 1991-1-2) and Eurocode 3 Part 1-2 (EN 1993-1-2), referenced alongside IS 800:2007 in Indian practice for complex structures:

- Natural fire modelling: instead of the standard fire curve, a parametric fire based on the actual fuel load density, ventilation conditions, and compartment geometry is used
- Structural analysis: finite element analysis of the structure under the natural fire temperature-time history, accounting for thermal expansion, loss of stiffness at elevated temperature, and catenary action in composite floors
- Failure criterion: the structure must not collapse within the required evacuation time (RSET). Partial collapse (one floor) is acceptable if it does not trigger progressive collapse of the whole structure

NOTE

Performance-based structural fire engineering typically reduces the required PFP significantly compared to the prescriptive approach – by 30–60% in many cases. For major greenfield projects with large quantities of structural steel, the savings in PFP material and application cost can justify the additional engineering cost of the advanced analysis several times over. Want to optimize your structural steel fireproofing and reduce capital costs? Ask us about Performance-Based Structural Fire Engineering.

Chapter 18: Fire Safety Management System

A fire safety management system (FSMS) provides the organisational framework that ensures fire engineering hardware (detection systems, suppression systems, passive protection) remains effective throughout the life of the facility. The best-designed fire protection system will fail if the FSMS that maintains, tests, and updates it does not function. This chapter describes the essential elements of an FSMS for an industrial facility.

18.1 FSMS Framework

The FSMS must address eight core elements:

FSMS Element	Key Activities	Minimum Frequency
Fire risk assessment	Site-wide hazard and risk assessment; scenario review	Annual review; immediate update after MoC
Legal and regulatory compliance	Tracking of applicable regulations; audit against IS codes, OISD, NBC	Semi-annual; immediate on regulatory change
Preventive maintenance — fire systems	PM schedules for all fire protection systems per applicable standard	Per IS 2189, IS 3844, IS 12469, NFPA 25 schedules
Inspection and testing — F&G systems	Functional test of all detectors, suppression systems, and fire pumps	Monthly (pumps); quarterly (detectors); annual (full functional test)
Hot work and permit-to-work	Issuance, monitoring, and close-out of hot work permits	Every instance of hot work activity
Emergency response preparedness	Drills; equipment readiness; mutual aid agreements	Quarterly drill; annual full-scale exercise
Incident investigation and learning	Root cause analysis; sharing lessons across sites	After every fire, near-miss, or unwanted actuation
Management of Change	MoC review for all changes affecting fire risk	Every proposed change to process, equipment, or layout

18.2 Fire Prevention Programme

Prevention reduces the probability of ignition — the first cause in the fire triangle. The fire prevention programme must address:

- Ignition source control: hot work permit system; no smoking and no open flame policy in classified zones; monthly inspection of electrical equipment for overheating, loose connections, or improper replacement
- Housekeeping: defined maximum combustible material quantities in process areas; waste collection schedule; vegetation control around bunds and process areas
- Electrical maintenance: thermographic survey of all electrical panels, connections, and motor terminals annually — identify hot spots before they become ignition sources
- Static electricity and earthing: monthly verification of earthing continuity for all tanks, vessels, and road tanker earthing points; calibration check for earthing continuity test instruments

18.3 Preventive Maintenance Schedule Reference

System	Task	Frequency	Standard Reference
Fire pumps	Auto-start test; pressure and flow verification at churn and rated conditions	Monthly auto-start; annual flow test	NFPA 25:2026 – Cl. 8.3; IS 12469
Sprinkler system	Main drain test; inspector's test; heat detector test	Quarterly main drain; annual inspector's test	IS 15105; NFPA 25:2026 – Cl. 5
Fire alarm (FAS)	Functional test of each detector; sounders and visual alarms; battery capacity test	Annual (per detector); monthly (system alarm test)	IS 2189; NFPA 72
Gas detection system	Bump test (gas exposure check) for all pellistor/IR detectors; sensor calibration	Monthly bump test; 6-monthly calibration	EN 60079-29-2; IEC 61511
Deluge/foam system	Valve trip test; foam proportioner test; foam concentrate sample and analysis	Annual valve trip; 2-yearly foam sample	NFPA 25; IS 12835
CO2 / clean agent	Cylinder weight check; nozzle inspection; integrity test (door fan)	Semi-annual weight check; 5-yearly integrity test	IS 15493; NFPA 12

Passive fire protection	Visual inspection; tap test for hollow areas; DFT check	Annual visual; 3-year full inspection	API RP 2218
Fire extinguishers	Visual inspection; weight check; 5-year overhaul	Monthly visual; annual weight; 5-year overhaul	IS 2190; NBC Part 4
Emergency lighting	Function test (mains off); 3-hour discharge test	Monthly function; annual 3-hour test	IS 10322; NBC 2016 Part 4 – Cl. 3.4.73

KEY POINT

The most common FSMS failure mode is not the absence of a maintenance schedule – it is the absence of accountable ownership. Each fire safety system must have a named owner (not a department – an individual) who is accountable for the maintenance schedule being executed and records being maintained. Audits consistently find that facilities with documented PM schedules but no named owner have the same rate of non-functional systems as facilities with no schedule at all.

APPENDICES

Appendix A: Standards and Codes Reference Matrix

This matrix provides a quick-reference guide to the primary standard governing each fire protection discipline. Verify edition currency before applying in a project.

Discipline	Primary Indian Standard	Primary NFPA / International	Notes
Fire alarm and detection	IS 2189:2026	NFPA 72:2025	IS 2189 under revision — monitor BIS for update
Sprinkler systems	IS 15105:2021	NFPA 13:2025	NFPA 13 used for high-challenge occupancies
Foam systems	IS 12835: Part1:2021; IS 4989:2018	NFPA 11:2024	NFPA 11 used for specific foam type selection
CO2 systems	IS 15528:2004	NFPA 12:2025	—
Clean agent systems	IS 15493:2021	NFPA 2001:2025	—
Water spray / deluge	IS 15325:2020	NFPA 15:2027	IS 13039 largely superseded by NFPA 15 in practice
Water mist	IS 15519:2020	NFPA 750:2027	—
Fire pumps	IS 12469:2019	NFPA 20:2025	NFPA 20 used for acceptance test criteria
Fire extinguishers	IS 2190:2024	NFPA 10:2026	—

Passive fire protection (test)	IS 1642:2013	EN 13381; ISO 22899	ISO 22899 for HC curve (process plant)
Structural fire (steel)	IS 800:2007 Sec.16	EN 1993-1-2	Eurocode used for advanced analysis
Hazardous area classification	IS 5572:2009	IEC 60079-10; EN 60079-10	IEC 60079 supersedes in practice
Dust explosion venting	IS 3103:1975	NFPA 68:2023	—
Building fire and life safety	NBC 2016 Part 4	NFPA 101:2021; IFC 2021	NBC is primary; NFPA 101 fills gaps
Tank farm fire protection	—	OISD-STD-117; NFPA 11	OISD-STD-116 is primary for petroleum in India
Petroleum layout / siting	—	OISD-STD-118; API RP 752	—
Refinery fire protection	—	OISD-STD-116; NFPA 30	—
LPG storage	—	OISD-STD-150; NFPA 58	—
Fire water supply	IS 13039:2014	NFPA 24:2025; FM DS 3-10	—
FERA methodology	—	SFPE Handbook; API RP 752; BS PD 7974	No Indian standard — international methods used

Appendix B: Greenfield Fire Engineering Checklist

Use this checklist during design review at each project stage to confirm fire engineering completeness.

FEED Stage

- Fire safety objectives defined and documented
- Applicable regulatory framework established (State, PESO, OISD, NBC, TAC)
- Fire hazard classification of all process areas confirmed
- Site layout reviewed for OISD-STD-118 separation compliance
- Bund design checked for capacity and drainage requirements
- Occupied buildings sited outside 4 kW/m^2 radiation zone
- Control room blast and radiation assessment complete (API RP 752)
- Fire Protection Philosophy first draft issued for client review

Basic Engineering / Detailed Design

- FERA study complete; scenarios documented; protection strategy confirmed
- Fire water demand calculation complete; storage and pumps sized
- Hydrant and monitor network layout issued
- Sprinkler system hazard class confirmed; density-area design basis confirmed
- Foam system design complete: agent type, application rate, concentrate quantity
- Gaseous suppression systems designed and room integrity confirmed
- Passive fire protection schedule complete: all items listed, material, thickness, fire curve
- Fire and gas detection philosophy issued; C&E matrix complete and approved
- Emergency response plan drafted; muster points located and communicated
- Fire NOC application submitted with design drawings

Construction and Commissioning

- As-built survey confirms installation matches approved drawings
- Penetration register maintained and all penetrations sealed
- Hydrostatic test of all pipework complete with records
- All fire and gas detectors functionally tested; panel programmed and verified
- Fire pump auto-start and flow tests complete with records
- F&G cause-and-effect matrix fully tested row by row
- PSSR sign-off obtained; all outstanding items closed or formally accepted
- Operating and maintenance manual issued to site team

Appendix C: Brownfield Assessment Checklist

Use this checklist during brownfield fire safety audits. Annotate each item with status (Compliant / Non-compliant / Not Applicable / Not Inspected) and reference the relevant finding number in the audit report.

Fire Water Supply

- Fire pump auto-start tested within 30 days — records available
- Diesel pump fuel level > 75% of tank capacity
- Diesel pump engine: oil level, coolant level, battery voltage verified
- Fire water tank level > 90% of design capacity
- Ring main pressure gauge reading at design pressure (typically 7–9 bar)
- All isolation valves on ring main confirmed open and locked/chained

Hydrant and Monitor System

- All hydrant box covers operable; no locked, painted, or seized landing valves
- Hose reels/hoses in place, rolled, and in serviceable condition
- Fixed monitors: rotation free; nozzle set to correct angle; no corrosion at base
- Last hydrant flow test records available (annual minimum)

Fixed Suppression Systems

- All deluge valves in automatic (not manual) position
- Deluge valve room dry, ventilated, and accessible
- Foam concentrate level, type, and expiry date confirmed
- Proportioner setting verified against design concentration (3% or 6%)
- Sprinkler heads: no painted, corroded, or mechanically damaged heads in any zone

Fire and Gas Detection

- Fire alarm panel: no active faults; battery capacity tested within 12 months
- All gas detector zones: no bypasses active without written authorisation
- Last full functional test of C&E matrix: records show all rows tested
- Detectors: visual inspection shows no mechanical damage, accumulation, or corrosion

Passive Fire Protection

- Structural PFP: tap test of all visible cementitious PFP; no hollow areas found
- PFP: no areas where PFP is missing, stripped, or damaged to bare steel
- Fire walls: all penetrations sealed; penetration register available
- Fire doors: self-closing; not wedged open; door closer functional

Life Safety

- All exit doors unlocked from inside; no blocked or obstructed exits
- Exit signage illuminated; emergency lighting functional
- Muster point accessible and communicated to all site personnel
- Last evacuation drill within 6 months; records available
- All fire extinguishers in date; correct type for each fire hazard in area

Appendix D: Fire Load Density Reference Values

The following fire load density values are used for compartment fire design and FERA study. Source: SFPE Handbook, 5th Edition, Table 35.3; Eurocode 1 Part 1-2.

Occupancy / Content	Fire Load Density (MJ/m²) — 80th Percentile
Office (general)	420
Office (paper-heavy / legal)	800–1200
Hotel bedroom	310
Retail (general merchandise)	600–900
Warehouse — general storage (1.5 m high)	730
Warehouse — general storage (3 m high)	1460
Warehouse — high rack storage (6 m+)	3000–6000 (use t² fire model — not tabulated value)

Workshop / light manufacturing	600–800
Library (bookshelves)	1500–2000
Pharmaceutical manufacturing	300–600
FMCG — solvent-based products	1200–2000 (includes liquid fuel energy)
Cold store — PIR/polyurethane insulation dominant	800–1500 (insulation contributes significantly)

NOTE

for high-rack storage and any scenario where fire load > 1500 MJ/m², a t² fire model with site-specific fuel type and arrangement is more appropriate than a single fire load density value. Consult a fire dynamics specialist.

Appendix E: Glossary of Key Fire Engineering Terms

Term	Definition
ALARP	As Low As Reasonably Practicable — the principle that risk must be reduced to the lowest level achievable, unless the cost of further reduction is grossly disproportionate to the benefit
Autoignition Temperature (AIT)	The steel temperature at which a member can no longer carry its design load under fire conditions. Typically 510–580°C for lightly loaded members; higher load ratios produce lower critical temperatures.
Critical temperature	The steel temperature at which a member can no longer carry its design load under fire conditions. Typically 510–580°C for lightly loaded members; higher load ratios produce lower critical temperatures.

Design fire	A quantified fire scenario used as the basis for fire protection system design and structural fire analysis. Characterised by heat release rate (kW), fire area (m^2), growth rate (α), and duration.
Fire resistance period (FRP)	The duration for which a structural element or assembly maintains its load-bearing, integrity, and insulation performance when exposed to the standard fire test per IS 3809 or EN 1363.
Flash point	The minimum liquid temperature at which sufficient vapour is generated to form an ignitable mixture with air. Class IA: < 22.8°C; Class IB: 22.8–37.8°C; Class IC: 37.8–60°C; Class II: 60–93°C; Class IIIA: 93–149°C.
Flammable range	The range of vapour concentrations in air between the LEL and UEL within which ignition can occur.
Heat release rate (HRR)	The rate at which thermal energy is released by a fire. Measured in kW or MW. The fundamental quantity that drives all fire consequence (sprinkler response, structural damage, smoke production, evacuation impact).
Hydrocarbon fire curve	A standardised time-temperature relationship for testing passive fire protection materials in process plant environments (reaches 1100°C within 5 minutes). More severe than the cellulosic (ISO 834) curve used for building structures.
K-factor	Sprinkler orifice constant. Defines the flow rate at a given pressure: $Q = K\sqrt{P}$. Standard K=80 (L/min/bar^0.5). Large-drop and ESFR heads: K=115 to K=320.
Section factor (Hp/A)	The ratio of the heated perimeter to the cross-sectional area of a structural steel member (m^{-1}). Higher values indicate faster heating and require more passive fire protection.
Thermal dose	The time-integrated heat flux received by a surface. Used for fireball and flash fire scenarios where the exposure is brief. Units: kJ/m^2 or (kW/m^2)^(4/3)·s. Threshold for 1% fatality: approximately 1000 (kW/m^2)^(4/3)·s.
t^2 fire (t-squared fire)	A fire growth model where the heat release rate increases as the square of time from ignition. $Q = \alpha \times t^2$. Used in sprinkler design, smoke management, and evacuation time analysis.

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