

# 化工安全技术

## CHEMICAL ENGINEERING SAFETY TECHNOLOGY

Chief Editor ▶ FU Yong



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# Chemical Engineering Safety Technology

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## Preface

The chemical industry is a vital pillar of the national economy and occupies a central position in global economic development. However, chemical production is inherently associated with risks: production conditions are extreme, materials are hazardous, and processes are complex. With industrial upgrading, the requirements for safety management have become even more demanding.

This textbook has been compiled with the principles of “practicality first, concise logic, and standard orientation,” focusing on typical and frequent safety issues in the chemical industry. The content is organized around the main line of “theoretical analysis—case warnings—practical guidance.” The textbook adheres to the current national standards, integrates core requirements of international standards, and also incorporates some standards that are about to take effect.

The textbook consists of six chapters forming a system of “basic understanding—specialized skills—comprehensive application.” Each chapter is both independent and interconnected, covering topics such as fundamental knowledge of chemical safety, the application of safety protection and equipment, chemical operations safety procedures, emergency response and first aid skills, risk analysis and preventive measures, as well as comprehensive practice and advanced applications.

This textbook is suitable for teaching in higher vocational chemical engineering programs or as a reference book for pre-job training of chemical industry personnel. Through its study, learners can improve their critical thinking and predictive abilities, develop a safety-first mindset, and understand that safety is the guarantee of economic efficiency and enterprise development. Most of the cases in this textbook are derived from real chemical safety incidents; the authors hope that these examples will serve as warnings to raise awareness of the importance of safety. It is expected that everyone involved in safety will adhere to the principle of “safety first,” ensure their own safety, and make valuable contributions.

In compiling this textbook, the authors referred to online technical resources and industry practical experiences. Since the original sources of some information are difficult to trace, individual citations have not been provided. We extend our gratitude to the original authors, and apologize for any omissions or oversights; your understanding and correction would be greatly appreciated.

Special thanks are given to Mr. Fu Dayong and Mr. Yue Ruifeng from Henan Vocational University of Applied Technology for their professional guidance and meticulous review during the textbook’s preparation.

As national standards for chemical safety are numerous, complex, and subject to ongoing updates, the authors’ abilities are limited. There may be omissions or

deficiencies in the interpretation of standards, content organization, or case selection.  
We sincerely welcome criticism and suggestions from readers.

Editor  
2026, January

# 前 言

化学工业是国民经济重要支柱，在全球经济发展中居核心地位。然而，化工生产伴随固有风险，生产条件极端、物料危险，工艺复杂，且随着产业升级，对安全管理要求更高。

编写本教材秉持“实用为先、逻辑简洁、标准导向”原则，聚焦典型高频安全问题，按“理论解析—案例警示—实操指导”主线编写。教材遵循现行国标，融入国际标准核心要求，提前纳入部分即将生效的标准。

教材共六章，形成“基础认知—专项技能—综合应用”体系。各章既独立又衔接，包括化工安全基础认知、安全防护与装备应用、化工作业安全程序、应急处置与急救技能、风险分析与防范措施、综合实践与高阶应用等内容。

本教材适用于高职化工类专业教学，或作为化工行业人员岗前培训参考书。通过学习可提升思维和预判能力，帮助学习者树立安全生产意识，明确安全是经济效益和企业发展的保障。教材案例大多源于真实化工安全事故，编者希望通过案例警示，让人们认识安全的重要性。期盼安全参与者以“安全第一”为原则，保障自身安全并贡献力量。

编写教材时，编者参考了网络技术资料和行业实践经验，因部分资料原始来源难追溯，未逐一标注出处，在此向原始作者致谢，若引用有不周到之处，敬请谅解指正。

特别感谢河南应用技术职业学院的付大勇、岳瑞丰老师，他们在教材编写中给予专业指导和细致编审。

化工安全国家标准繁多复杂且动态更新，编者水平有限，在标准解读、内容组织、案例筛选等方面可能有疏漏不足。恳请读者提出批评指正。

编者

2026年1月

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# **Chapter I Fundamental Understanding of Chemical Industry Safety**

The chemical industry is a vital pillar of the national economy and occupies a prominent position worldwide. Its products are widely used in everyday life and industrial production. However, chemical manufacturing processes involve hazardous factors such as high temperatures and pressures, flammable and explosive substances, and toxic and harmful materials. Once an accident occurs, it may result in severe casualties, substantial property losses, and serious environmental pollution. According to statistics, losses caused globally by chemical accidents and chemical hazards exceed RMB 400 billion each year, drawing widespread attention from governments around the world. Against this backdrop, chemical process safety technology is essential to ensuring safe, stable, and sustainable development of the chemical industry.

This chapter provides a systematic introduction to the fundamentals of chemical production safety, including the identification of hazardous chemicals, the proper use of personal protective equipment, and the establishment of safety management systems. The objective is to cultivate students' core competencies in "risk identification - regulatory awareness - preliminary analysis," thereby laying a solid foundation for subsequent professional skill development.

## **1.1 Safety in the Chemical Industry**

### **1.1.1 Scope and Characteristics of the Chemical Industry**

The chemical industry encompasses multiple sectors, including petrochemicals, coal chemical engineering, fine chemicals, and biochemical engineering. Its main characteristics are as follows:

1. Complex production processes: Operations often involve extreme conditions such as high temperature, high pressure, low temperature, and vacuum. For example, ethylene cracking is carried out at temperatures around 800 °C, where side reactions can readily trigger process runaway.

2. High concentration of hazardous chemicals: toxic and harmful materials Large quantities of flammable, explosive, toxic, and harmful substances are used. A petrochemical industrial park may store up to 200 hazardous chemicals (classified

under the GHS), of which approximately 30% are flammable liquids (e.g., gasoline with a flash point below  $-20\text{ }^{\circ}\text{C}$ ).

3. Strong process continuity: Facilities are typically large in scale and highly automated. For instance, a coal chemical enterprise in Yongcheng, Henan Province, occupies an area of about 1,500 mu, with a total annual production capacity of 1.61 million tonnes of chemical products.

### **1.1.2 Importance of Chemical Safety**

1. Personal safety: Protecting employees from hazards such as poisoning and burns.
2. Corporate viability: Accidents may lead to production shutdowns, legal liability, and reputational damage.
3. Social stability and environmental protection: Major incidents can trigger public panic and long-term environmental crises.

Case: In 2016, an explosion in a certain country caused direct economic losses of EUR 230 million. In another country, a toxic gas leak resulted in 20,000 fatalities, and soil remediation has continued for more than 30 years.

## **1.2 Hazard Identification in Chemical Production**

### **1.2.1 Properties and Hazards of Dangerous Chemicals**

In accordance with the United Nations *Globally Harmonized System of Classification and Labelling of Chemicals* (GHS), as well as China's *Rules for Classification and Labelling of Chemicals - Part 1: General Rules* (GB 30000.1-2024, replacing GB 13690-2009) and *Classification and Code of Dangerous Goods* (GB 6944-2025), hazardous chemicals are classified into the following categories:

1. Physical hazards: such as explosives (e.g., TNT), flammable gases (e.g., hydrogen, with an explosive range of 4%-75%), flammable liquids (e.g., gasoline), oxidizing gases, and gases under pressure.
2. Health hazards: including acute toxicity (e.g., potassium cyanide, extremely toxic,  $\text{LD}_{50} = 6.4\text{ mg/kg}$ ), skin corrosion (e.g., concentrated sulfuric acid), serious eye damage/eye irritation, respiratory or skin sensitization, germ cell mutagenicity, carcinogenicity, and reproductive toxicity.
3. Environmental hazards: such as hazards to the aquatic environment (e.g., the Minamata disease caused by mercury contamination).

In summary, hazardous chemicals may exhibit properties such as explosiveness, flammability, toxicity, infectivity, corrosiveness, and radioactivity. During production, storage, transportation, use, and disposal, they can readily cause personal injury or fatalities, property damage, and environmental pollution.

### **Key Skills:**

Ability to rapidly extract key information (e.g., first-aid measures and protective requirements) from the *Safety Data Sheet* (SDS).

### **Classification of Common Industrial Toxicants and Toxicity Indicators**

According to the Classification for Hazards of Occupational Exposure to Toxicant (GBZ/T 230-2025), the toxicity assessment of industrial toxicants is based primarily on indicators such as acute toxicity ( $LD_{50}$ ,  $LC_{50}$ ), sensitization, reproductive toxicity, and carcinogenicity. These are combined with modifying factors such as dispersibility and bioaccumulation to determine the degree of hazard using the *Toxic Hazard Index* (THI). Hazard levels are classified as follows: Slight hazard (Class I,  $THI < 35$ ), Moderate hazard (Class II,  $35 \leq THI < 50$ ), High hazard (Class III,  $50 \leq THI < 65$ ), Extreme hazard (Class IV,  $THI \geq 65$ ) For acute oral toxicity, the core classification criteria are as follows: Category 1 ( $LD_{50} < 5$  mg/kg), Category 2 ( $5 \leq LD_{50} < 50$  mg/kg), Category 3 ( $50 \leq LD_{50} < 300$  mg/kg), Category 4 ( $300 \leq LD_{50} < 2000$  mg/kg), Category 5 ( $LD_{50} \geq 2000$  mg/kg).

Common types of industrial toxicants and their key characteristics are as follows:

**Irritant toxicants:** Such as chlorine gas (acute inhalation  $LC_{50}$  reaches 293 ppm; 1-hour inhalation in rats, equivalent to approximately  $820$  mg/m<sup>3</sup>), which falls under acute inhalation toxicity Category 1. Chlorine is highly corrosive and irritating, primarily causing burns to the respiratory tract, ocular mucosa, and skin. Under the relevant standards, its irritant and corrosive effects are classified as Category 1.

**Asphyxiant toxicants:** Such as carbon monoxide (a blood asphyxiant), which impairs oxygen transport by binding to hemoglobin. It has high dispersibility (gaseous form) and moderate bioaccumulation. Hydrogen sulfide (a chemical asphyxiant) inhibits cellular respiration by suppressing cytochrome oxidase and also exhibits both irritant and toxic effects. For both substances, actual hazard levels must be assessed in conjunction with exposure concentration.

**Narcotic toxicants:** Such as benzene (oral  $LD_{50} = 930$ - $1800$  mg/kg, classified as acute oral toxicity Category 4). Its principal hazards include: ① Acute poisoning that depresses the central nervous system, producing a “narcotic effect” manifested by dizziness, drowsiness, and coma. ② Benzene is classified by the IARC as a Group 1

human carcinogen; long-term exposure damages the hematopoietic system and can induce leukemia. Under GBZ/T 230-2025, benzene is classified as an extreme hazard (Class IV) due to its strong carcinogenicity and high overall hazard index.

Note: LD<sub>50</sub> (median lethal dose) refers to the dose that causes death in 50% of test animals (commonly determined via oral or dermal exposure, with rats or rabbits as preferred test species). LC<sub>50</sub> (median lethal concentration) refers to the concentration of a gas, vapor, or dust that causes death in 50% of test animals (with 4-hour inhalation exposure data commonly used). Lower LD<sub>50</sub> or LC<sub>50</sub> values indicate greater toxicity.

### 1.2.2 Classification of Hazardous Chemicals

At present, hazardous chemicals are classified mainly by the following approaches:

1. For chemicals already in use, their hazard classes and divisions shall be determined in accordance with the *China's Rules for Classification and Labelling of Chemicals - Part 1: General Rules* (GB 30000.1-2024) and the *Classification and Code of Dangerous Goods* (GB 6944-2025).

2. For new chemicals, relevant literature should first be reviewed, and available data used for a preliminary hazard assessment, followed by targeted experimental testing. For hazardous substances for which no literature data are available, comprehensive testing is required, covering physicochemical properties, toxicity, flammability and explosiveness, and environmental hazards. Final classification shall then be conducted in accordance with the above two latest national standards.

3. Data on fire and explosion hazards of mixtures can generally be obtained through testing. However, the acquisition of toxicity data is time-consuming and costly, making comprehensive testing impractical in many cases. In such situations, the “bridging principles” specified in GB 30000.2 to GB 30000.29 may be applied.

According to the *China's Rules for Classification and Labelling of Chemicals - Part 1: General Rules* (GB 30000.1-2024), chemicals are classified into 17 categories based on physical hazards: explosives, flammable gases, aerosols and pressurized chemicals, oxidizing gases, gases under pressure, gases under pressure, flammable solids, self-reactive substances and mixtures, pyrophoric liquids (self-igniting liquids), pyrophoric solids (self-igniting solids), self-heating substances and mixtures, substances and mixtures which, in contact with water, emit flammable gases, oxidizing liquids, oxidizing solids, organic peroxides, substances corrosive to metals, desensitized explosives (newly added category).

According to the *Classification and Code of Dangerous Goods* (GB 6944-2025), dangerous goods are divided into nine classes based on the nature of their hazards or principal risks, as shown in Table 1.1.

Table 1.1 Classification of Dangerous Goods

Category	Description
Class 1	Explosives (including six divisions, such as substances and articles with a mass explosion hazard)
Class 2	Gases (including flammable gases, non-flammable non-toxic gases, and toxic gases)
Class 3	Flammable Liquids
Class 4	Comprising three divisions: flammable solids, self-reactive substances, desensitized solid explosives and polymerizing substances; substances liable to spontaneous combustion; and substances which, in contact with water, emit flammable gases. Among these, polymerizing substances are a newly added item.
Class 5	Oxidizing substances and organic peroxides (organic peroxides are clearly classified into seven types according to their degree of hazard, ranging from Type A (transport not permitted in the packaging tested) to Type G (not subject to the provisions for organic peroxides). For Types B to F, classification is directly related to the maximum permitted packaging quantity.
Class 6	Toxic Substances and Infectious Substances
Class 7	Radioactive material
Class 8	Corrosive Substances
Class 9	Miscellaneous dangerous substances and articles, including environmentally hazardous substances. Newly added items include sodium-ion batteries, capacitors, and ammonium nitrate-based fertilizers.

It should be noted that the differences in classification between GB 30000.1-2024 (17 categories) and GB 6944-2025 (9 categories) arise from their different application scenarios. A comparison of the two standards is shown in Table 1.2.

Table 1.2 Differences in Classification Between the Two Standards

Standard	Number of Categories	Core Application Scenarios	Core Application Scenarios

GB 30000.1-2024	Class 17	Production and use	Includes more refined categories such as desensitized explosives
GB 6944-2025	Class 9	Transportation and storage	Emphasizes transport-related scenarios such as miscellaneous dangerous substances

Compared with the EU CLP Regulation, China’s GB standards differ from CLP in their underlying classification logic. The GB standards adopt separate, scenario-specific classification systems for production, transportation, and other stages, whereas the CLP Regulation places greater emphasis on a unified classification across the entire chemical supply chain. With respect to specific categories, the two systems show slight differences in toxicity threshold values for certain substances; however, the classification principles for core hazard categories (such as explosives and flammable liquids) are essentially consistent.

### 1.2.3 Main Characteristics of Common Hazardous Chemicals

The principal characteristics of common hazardous chemicals are summarized in Table 1.3.

Table 1.3 Main Characteristics of Common Hazardous Chemicals

No.	Category	Main Characteristics (Selected Examples)
1	Explosives	1. Explosiveness: Chemically unstable; can be triggered by mechanical impact, open flame, or static electricity, releasing large amounts of energy (heat and gas) instantaneously to produce high-pressure explosions (e.g., nitroglycerin detonation velocity exceeds 3,000 m/s).
		2. Sensitivity: Requires external initiation energy; the lower the required initiation energy, the higher the sensitivity (initiation energy is inversely proportional to sensitivity).
		3. Instability: Prone to decomposition when exposed to acids or light; may form unstable salts with metals, increasing reaction risk.
		4. New category - desensitized explosives: e.g., wet ammonium nitrate, which requires specific desensitization conditions (moisture content $\geq$ 10%); once the desensitizing agent fails, the substance remains highly hazardous.
2	Gases (compressed/liquefied gases)	1. Classification: Flammable gases (e.g., hydrogen, explosive limits 4.0%-75.6%); oxidizing gases (e.g., oxygen, which may ignite spontaneously on contact with oils and greases); toxic gases (e.g., ammonia, hydrogen sulfide); inert gases (e.g., nitrogen, argon).
		2. Compressibility: At constant temperature, volume decreases as pressure increases; continued pressurization may lead to liquefaction (e.g., CO <sub>2</sub> critical temperature: 31.2 °C).

		<p>3. Expansion: Exposure to light or heat causes volume expansion; in closed containers, higher temperatures result in higher pressures (e.g., hydrogen expansion coefficient: 0.00366/°C).</p> <p>4. Derived properties: Depending on type, gases may exhibit flammability, explosiveness, toxicity, oxidizing ability, or asphyxiation potential (e.g., chlorine possesses both oxidizing and toxic properties).</p>
3	Flammable Liquids	<p>1. Classification:</p> <p>(1) Low flash point (flash point &lt; 23 °C): For example, No. 92 gasoline has a flash point in the range of -50 °C to -20 °C; its vapors are extremely flammable. Ethanol, with a flash point of 13 °C, is also readily ignitable.</p> <p>(2) Medium flash point (23 °C ≤ flash point &lt; 60 °C): For example, light diesel fuel has a flash point of approximately 55 °C, and spill fires involving such liquids tend to burn for a prolonged duration.</p> <p>(3) High flash point / combustible liquids (60 °C ≤ flash point ≤ 93 °C): For example, certain lubricating oils. It should be noted that under some standards, liquids in this range are not classified as flammable liquids but rather as combustible liquids.</p> <p>2. High flammability: Low flash points make these liquids easy to ignite. For example, banana oil (isoamyl acetate) has a flash point of about 25 °C.</p> <p>3. Explosiveness: Due to high volatility, vapors can form explosive mixtures with air and may explode upon contact with an ignition source once the explosive limits are reached. For gasoline vapor, the explosive range is 1.4%-7.6% by volume.</p> <p>4. High fluidity and dispersibility: Low viscosity (e.g., diethyl ether has a viscosity of 0.233 mPa·s at 20 °C) allows leakage through even minor defects, resulting in rapid spreading and continuous vapor release.</p> <p>5. Thermal expansion: These liquids have relatively high coefficients of expansion (e.g., methanol: 0.00119/°C). In sealed storage containers, heating causes volume expansion and increased vapor pressure, which may lead to container rupture or explosion.</p>
4	Flammable solids, substances liable to spontaneous combustion, and substances which, in contact with water, emit flammable gases	<p>1. Flammable solids: Readily oxidized; may decompose or sublime when heated; sensitive to friction, impact, and vibration (e.g., the lower explosion limit of red phosphorus dust is 48-64 g/m<sup>3</sup>).</p> <p>2. Substances liable to spontaneous combustion: Easily oxidized or decomposed, with low ignition temperatures (e.g., white phosphorus has an ignition temperature of only 40 °C). Slow oxidation leads to heat accumulation, and once the self-ignition temperature is reached, spontaneous combustion occurs.</p> <p>3. Substances which, in contact with water, emit flammable gases: React violently with water or moist air to produce flammable gases and heat. For example, metallic sodium reacts instantaneously with water to generate hydrogen gas and ignite violently: <math>2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2\uparrow + \text{heat}</math>. Reactions with acids are even more vigorous, accelerating gas release and potentially causing explosions. For instance, the reaction rate of calcium carbide with hydrochloric acid increases by three to five times, with gas evolution reaching up to 300 L/kg.</p>
5	Oxidizing Substances and	<p>1. Classification: Oxidizing agents (e.g., potassium permanganate, a strong oxidizer that may self-ignite or even explode within seconds when mixed with glycerol) and organic peroxides (e.g., peracetic acid, which readily</p>

	Organic Peroxides	<p>decomposes at temperatures above 40 °C; di-tert-butyl peroxide, which decomposes at around 180 °C and may explode).</p> <p>2. Strong oxidizing properties: Inorganic peroxides contain peroxy groups (–O–O–), while other oxidizers contain elements in high oxidation states. They readily accept electrons and can react violently with combustible materials, leading to fire or explosion (e.g., potassium chlorate mixed with sucrose releases intense heat).</p> <p>3. Thermal instability: At elevated temperatures, these substances readily decompose, releasing oxygen and/or heat. Organic peroxides are particularly unstable due to the presence of the peroxy group (–O–O–).</p> <p>4. Mechanical sensitivity: Highly sensitive to friction, impact, and vibration; for example, ammonium perchlorate exhibits relatively high impact sensitivity.</p>
6	Toxic Substances and Infectious Substances	<p>1. Classification: (1) Toxic substances (Acute toxicity: short-term exposure to high doses leading to poisoning, e.g., sodium cyanide, where small amounts can cause respiratory failure within minutes. Chronic toxicity: long-term exposure to low doses with cumulative effects, e.g., prolonged exposure to benzene. Special hazards: teratogenicity, carcinogenicity, and mutagenicity, as observed with certain heavy metals. (2) Infectious substances: Contain pathogenic microorganisms such as bacteria and viruses. Category A: exposure following release can cause permanent disability or death; high risk; Category B: lower risk than Category A.</p> <p>2. Toxicity: Extremely toxic substances (e.g., sodium cyanide) can cause poisoning through ingestion, inhalation, or contact with damaged skin even in very small amounts. Substances of lower toxicity require larger doses to cause harm. Toxicity is generally assessed using LD<sub>50</sub>/LC<sub>50</sub> values.</p> <p>3. Solubility: Water-soluble substances (e.g., methanol) present higher risks as solubility increases; fat-soluble substances (e.g., benzene) readily penetrate through the lipid layers of the skin.</p> <p>4. Volatility: For liquid toxicants, higher volatility (i.e., higher vapor pressure) results in higher airborne concentrations. For example, formaldehyde has a vapor pressure of 13.3 kPa at 20 °C; although evaporation at room temperature is relatively slow, accumulation can occur.</p>
7	Radioactive Substances	<p>1. Radioactivity: Spontaneous emission of <math>\alpha</math>, <math>\beta</math>, and <math>\gamma</math> radiation (natural radionuclides such as radium-226 primarily emit such radiation) or neutron fluxes (mostly from artificial radionuclides, such as nuclear reactor products). When cumulative radiation doses to the human body exceed threshold levels, radiation sickness or even death may occur. Radium-226 has a half-life of 1,600 years and thus poses a long-term radiation hazard.</p> <p>2. Toxicity: Most radioactive substances are highly toxic. Their hazards include radiation toxicity (primary) and, in some cases, chemical toxicity. For example, plutonium-239 can cause severe poisoning when inhaled at doses as low as 0.6 <math>\mu\text{g}/\text{kg}</math>.</p>
8	Corrosive Substances	<p>1. Classification: Acidic corrosives, alkaline corrosives, and other corrosive substances.</p>

		2. Strong corrosivity: React with human tissue, equipment, and materials, causing severe corrosion. For example, hydrofluoric acid corrodes glass according to the reaction: $\text{SiO}_2 + 4\text{HF} \rightarrow \text{SiF}_4\uparrow + 2\text{H}_2\text{O}$ .
		3. Oxidizing properties: Some corrosive substances (e.g., concentrated sulfuric acid and nitric acid) also exhibit strong oxidizing properties. Their highly exothermic reactions with organic materials may lead to fires or explosions (e.g., the reaction between concentrated sulfuric acid and sucrose releases up to 1,500 kJ/mol of heat).
		4. Heat release upon dilution: Many corrosive substances release large amounts of heat when mixed with water. For example, the heat of dilution of concentrated sulfuric acid is approximately 75.3 kJ/mol, posing significant risks during dilution operations.

### 1.2.4 Risks in Chemical Process Operations

The hazards associated with chemical process operations arise primarily from the nature of chemical reactions, operating conditions, and material properties. Common risks include the following:

#### 1. Hazardous Chemical Reaction Processes

(1) Nitration reactions: These are strongly exothermic reactions. Loss of control over agitation, cooling, or feed rates can easily cause a rapid temperature rise and lead to explosions. Both raw materials and products are often flammable and toxic. Mixed acids (strongly oxidizing and highly corrosive) may undergo violent boiling and material ejection when exposed to water.

(2) Sulfonation reactions: Characterized by intense heat release. Incorrect charging sequence or insufficient cooling may trigger fires. Sulfonating agents (e.g., chlorosulfonic acid) release heat upon contact with water, potentially causing boil-over, and are also highly corrosive.

(3) Halogenation reactions: Exothermic processes involving flammable substances and strong oxidants. Loss of control over cooling or reactant ratios can result in overtemperature and explosions. Feedstocks such as liquid chlorine and bromine are highly toxic, and leaks may lead to poisoning incidents.

(4) Strong oxidation reactions: Highly exothermic, with accumulated reaction heat prone to runaway. Oxidants in contact with organic materials, or exposed to external stimuli (e.g., high temperature or impact), can readily cause fires or explosions. Unstable peroxide by-products may also be formed.

(5) Diazotization reactions: Diazonium salts readily decompose at elevated temperatures or under light exposure, and in the dry state may explode when subjected to external stimuli. Aromatic amine feedstocks are typically flammable, posing a fire hazard.

(6) Hydrogenation reactions: Commonly carried out under high temperature and high pressure. Hydrogen leaks present a high explosion risk. Hydrogen embrittlement can reduce equipment strength, and failures in recycle systems may trigger cascading incidents.

## 2. Hazards Associated with Extreme Operating Conditions

(1) High temperature ( $\geq 300$  °C): From a reaction perspective, elevated temperatures accelerate reaction rates and increase material volatility, thereby raising the risk of fire and explosion. From an equipment perspective, high temperatures reduce mechanical strength (e.g., creep deformation), increasing the likelihood of leaks.

(2) High pressure ( $\geq 10$  MPa): From an equipment standpoint, high internal pressure imposes heavy loads on vessels and piping. In the presence of manufacturing defects (e.g., weld flaws) or fatigue damage, rupture or leakage can readily occur. From a reaction standpoint, high pressure can broaden the explosive limits of gases and intensify reaction severity, thereby elevating risk levels.

(3) Cryogenic conditions ( $\leq -100$  °C): From an equipment perspective, low temperatures increase the brittleness of materials such as carbon steel, causing a sharp loss of toughness and a higher likelihood of brittle fracture. From an operational perspective, leaks of cryogenic materials may cause frostbite, and can also impair the sealing performance and structural integrity of nearby piping, valves, and other components.

In addition to the above process-related risks, material transfer operations also pose hazards. Seal failures in pumps or rupture of corroded pipelines may result in leaks, potentially leading to major accidents.

**Case:** In 2003, a blowout occurred at a mine in a certain country. Natural gas mixed with highly toxic hydrogen sulfide was suddenly released, shooting up to a height of approximately 30 meters and rapidly spreading to surrounding areas. The accident resulted in more than 200 fatalities, hundreds of injuries of varying severity, and the emergency evacuation of tens of thousands of residents overnight. In 2013, a short circuit in part of the electrical wiring in the main plant building of an enterprise

ignited nearby combustible materials. The high temperatures generated by the fire caused an extremely severe fire and explosion involving ammonia equipment and pipelines, resulting in over 100 deaths, more than 70 injuries, and direct economic losses of RMB 182 million.

### 1.2.5 Safety Colors and Safety Signs

To ensure the safety and health of workers, colors and signs conveying safety information are widely used in production and operation areas. These colors and signs indicate prohibition, warning, mandatory instructions, and safety information, reminding workers to pay attention to hazards so that timely precautions can be taken to prevent accidents and occupational harm.

#### 1. Safety Colors

Safety colors are colors used to convey safety-related information. According to the national standard *Safety Colors and Safety Signs* (GB 2894-2025), four safety colors are specified in China: yellow, red, blue, and green.

Note: The standard *Safety Colors and Safety Signs* (GB 2894-2025) will fully replace *Safety Colors* (GB 2893-2008) and *Safety Signs and Guidelines for Their Use* (GB 2894-2008) as of March 1, 2026.

#### 2. Meanings and Applications of Safety Colors

The meanings and typical applications of the four safety colors - yellow, red, blue, and green - are shown in Table 1.4.

Table 1.4 Color Representation of Safety Colors

Color	Meaning	Typical Applications
Yellow	Conveys attention or warning information	Warning signs; e.g., guard lines around hazardous machinery and pits within plants, centerlines of roadways, safety helmets
Red	Conveys prohibition, stop signals, or indicates fire-fighting equipment and facilities	Prohibition signs; e.g., emergency stop handles or buttons on machinery and vehicles, and areas where personnel are prohibited from operating. Red also denotes fire protection.
Blue	Conveys mandatory instructions that must be followed	Mandatory signs; e.g., requirements to wear personal protective equipment, and instructions indicating the direction of travel for vehicles or pedestrians
Green	Conveys safety-related or safe-condition information	Safety signs; e.g., safe passageways within workshops, pedestrian and vehicle routes, and locations of fire-fighting equipment and other safety protective devices

### 3. Contrast Colors

Contrast colors are background colors that form a strong visual contrast with safety colors to enhance their visibility. They include black and white. Contrast colors are used in combination with safety colors as specified, as shown in Table 1.5.

Table 1.5 Contrast Colors





<b>Safety Color</b>	Yellow	Red	Blue	Green
<b>Corresponding Contrast Color</b>	Black	White	White	White

Black is used for text, graphic symbols, and the geometric borders of warning signs. White is used as the background color for red, blue, and green safety signs, as well as for text and graphic symbols on safety signs.

### 4. Safety Markings

Safety markings consist of alternating stripes of safety colors and contrast colors. The stripes shall be of equal width and inclined at an angle of 45°, with no fewer than two stripes of each color. Examples of safety markings are shown in Table 1.6.





Table 1.6 Examples of Safety Markings

Safety Marking Example	Information Conveyed
	Indicates hazardous locations
	Indicates prohibition or the location of fire-fighting equipment and facilities
	Indicates mandatory requirements that must be complied with
	Indicates a safe environment or safe condition

### 5. Safety Signs

Safety signs are signs used to convey specific safety information. They are composed of graphic symbols, safety colors, geometric shapes (borders), and text. According to *Safety Colors and Safety Signs* (GB 2894-2025), safety signs in China are classified into four types: warning signs, prohibition signs, mandatory signs, and informational signs. Their basic formats and examples are shown in Table 1.7.

Table 1.7 Basic Forms and Examples of Safety Signs

Safety Sign Type	Basic Form	Example Sign	Example Sign Name	Scope and Location of Installation
Warning Sign 标志	Equilateral triangle with a black border and yellow background		Caution: Safety Hazard	Locations and equipment that may cause personal injury
Prohibition Sign 标志	Circular shape with a diagonal slash; red border and red slash		No Open Flames	Areas where ignition sources are prohibited
Mandatory Sign 标志	Blue circular shape		Respirator Must Be Worn	Areas where gas masks or respirators are required, such as locations with toxic emissions
Informational Signs 标志	Green square		Emergency Exit	Emergency exits facilitating safe evacuation; installed together with directional arrows along evacuation routes, stairways, and access passages

## 6. Installation of Safety Signboards

Safety signboards shall be installed in conspicuous and clearly visible locations. In areas with poor lighting conditions, safety sign graphics shall be made of retroreflective or self-luminous materials to ensure adequate visibility.

Where multiple safety signs are installed at the same location, they shall be arranged in the following order by category: warning, prohibition, mandatory, and informational signs, positioned from left to right and from top to bottom. An example is shown in Figure 1.1.



Figure 1.1 Example of Multiple Safety Sign Installation

## 7. Comparison of International Safety Signs

There are both correspondences and differences between EU diamond-shaped hazard pictograms and China's GB 2894-2025 safety signs in terms of graphics, text labeling, and application scenarios:

Graphic correspondence: Core hazard categories use identical pictograms. For example, the symbol for “flammable gas” in both systems features a flame combined with a gas cylinder.

Textual differences: EU signs are labeled in English warning terms (e.g., “EXTREMELY FLAMMABLE GAS”), whereas Chinese signs use Chinese text (e.g., “易燃气体”).

Application scenarios: EU signs are mandatory in international trade and overseas manufacturing facilities, while Chinese signs are primarily applied in domestic production, storage, and operational settings.

In multinational operations, both local and internationally recognized safety signs should be posted simultaneously to ensure that personnel from different backgrounds can correctly identify hazards.

**Case:** At 07:20, a sand-mixing operator, Mr(s). Zhang, entered the foundry workshop and opened the access door of the sand mixer. He entered the mixer to carry out maintenance without hanging a “Personnel Working Do Not Energize” prohibition sign at the power switch. Concerned that the fully opened door might obstruct passage, he partially closed it, leaving a gap of approximately 150 mm. At around 7:50, another operator, Mr(s). Li, arrived for work. Without checking whether anyone was inside the mixer, he pushed the door closed and started the mixer for a trial run. Upon hearing shouts from inside the machine, Mr(s). Li immediately shut it down. After the mixer

came to a complete stop, Mr(s). Li and other workers rescued Mr(s). Zhang. However, due to severe head injuries, Mr(s). Zhang died despite emergency medical treatment. This incident exposed critical deficiencies, including the absence of a required prohibition sign and the failure to implement the work permit system.

The case further illustrates the close relationship between safety sign management and the safety responsibility system. The absence of a prohibition sign constitutes an unsafe condition of equipment, while the failure to enforce the work permit system represents a management deficiency. Together, these weaknesses form a vulnerable link in the safety management system. Subsequent study will show that the work safety responsibility system must cover all personnel and all operational processes.

**Practical Training Design:** Consult the national standard *Safety Colors and Safety Signs* (GB 2894-2025). In groups, introduce different types of safety signs and their application scenarios, and compare the differences between Chinese and European safety signage systems.

### **1.3 Basic Concepts and Documentation in Chemical Safety**

#### **1.3.1 Clarification of Core Concepts**

##### **1. Hazard Sources and Safety Hazards**

A hazard source refers to a source, condition, or act, with the potential to cause personal injury and/or adverse health effects, or a combination thereof. Examples include an “unsealed chlorine pipeline” and “a gasoline storage tank,” both of which constitute hazard sources.

Safety hazard: A safety hazard refers to unsafe conditions of equipment, unsafe human behaviors, or management deficiencies that may lead to accidents during production or business operations, arising from violations of laws, regulations, rules, standards, operating procedures, or safety management systems, or from other contributing factors. Examples include a loose valve on a chlorine pipeline and a malfunctioning level gauge on a gasoline storage tank.

Key distinction: A hazard source is an objectively existing carrier of risk, whereas a safety hazard represents a state of risk exposure resulting from the failure to effectively control a hazard source.

##### **2. Accident Causation Chain and Heinrich’s Law**

Accident causation chain: An accident results from the interaction of five elements - personnel, equipment, materials, methods, and environment - namely unsafe human behavior (e.g., improper operation), unsafe equipment conditions (e.g., aging equipment), hazardous material properties (e.g., flammability), deficiencies in procedures or management systems, and adverse environmental factors (e.g., high temperature and humidity). The combined effects of these elements ultimately lead to accidents.

Heinrich's Law: Heinrich's Law, also known as the 300:29:1 rule, is an empirical principle derived from occupational accident statistics. It indicates that among 300 near-miss incidents, there may be 29 minor injury accidents and 1 serious injury or fatal accident. This rule underscores that effective control of near-miss incidents is critical to preventing major accidents. For example, repeated near misses such as "failure to ground against static electricity" may eventually result in a "solvent storage tank explosion."

### **1.3.2 Requirements for Safety Documentation**

#### **1. Work Permit**

Key contents include the scope of work (e.g., *internal maintenance of a reactor vessel*), risk classification (e.g. *toxicity and asphyxiation-high risk*), safety attendant (required to hold a valid special operation certificate), gas detection results (e.g. oxygen concentration of 19.5%-23.5%), and validity period (e.g.  $\leq 8$  hours for special high-risk operations).

Documentation requirements: All information shall be truthful and accurate. Critical data must be double-checked by two persons, and the approval section shall be signed and confirmed by the responsible personnel.

#### **2. Accident Report**

The report shall include: Incident description (time, location, and sequence of events); cause analysis (both direct and root causes); corrective and preventive measures (targeted rectification actions); post-incident handling (casualty management and loss assessment).

Writing requirements: Reports shall be objective and neutral, avoiding subjective speculation. Cause analysis shall comprehensively cover the five dimensions of personnel, equipment, materials, methods, and environment.

#### **3. Document Management Requirements**

Approval process: Work permits shall be subject to tiered approval according to risk level (e.g., special high-risk operations require approval by the plant manager). Accident reports shall be reviewed by the safety management department and signed by the enterprise's responsible person.

Retention period: All categories of safety documents shall be retained for no less than one year and shall be linked to relevant work records and risk assessment reports.

**Case:** A chemical plant in the European Union was fined EUR 200,000 by regulatory authorities for failing to indicate gas detection results on a confined-space work permit, in violation of the SEVESO III Directive, which requires that work permits be accompanied by a documented risk assessment.

### **1.3.3 Risk Identification for Typical Positions**

#### **1. Intelligent Control Position**

Key risk points: DCS data distortion (sensor malfunction); failure of automatic interlocks (ESD not activated); delayed parameter adjustment (reactor temperature exceeding limits).

Identification techniques: Potential equipment failures can be anticipated through trend analysis, such as detecting abnormal flow variations preceding a sudden rise in pressure.

#### **2. Process Engineering Position**

Key risk points: Incorrect material ratios (e.g., excessive nitric acid in a nitration reaction); deviation of process parameters (pressure exceeding design limits); catalyst deactivation (decline in reaction rate).

Identification techniques: Regularly verify material charging records and continuously monitor process parameter trends in real time.

#### **3. Field Inspection Position**

Key risk points: Pipeline corrosion (wall thickness reduction exceeding 30%); internal valve leakage (wear of sealing surfaces); abnormal noise from rotating equipment (bearing damage).

Identification techniques: Adopt a combined "sensory inspection plus instrumentation" approach, such as visually examining flange sealing surfaces and using ultrasonic thickness gauges to measure pipe wall thickness.

**Case:** In one incident, a field inspection operator failed to detect corrosion-induced leakage at a pipeline flange, resulting in chlorine gas accumulation. The incident exposed operational weaknesses associated with insufficient inspection frequency and failure to use thickness measurement instruments.

## 1.4 Understanding Personal Protective Equipment (PPE)

### 1.4.1 Types of PPE and Selection Criteria

A wide range of personal protective equipment is used in chemical operations. Table 1.8 presents selected PPE types together with key considerations for their selection, while Table 1.9 shows photographs of representative PPE items.




Table 1.8 Selected Types of PPE and Selection Considerations

PPE Type	Typical Applications	Protective Function	Pre-use Safety Inspection Key Points
Safety helmet	Work at height; areas with risk of falling objects (e.g., equipment maintenance, material handling)	Protection against impact, penetration and crushing; anti-static types prevent electrostatic sparks	<ol style="list-style-type: none"> <li>1. No cracks or deformation; structure intact;</li> <li>2. Clearance between the shell and the head harness: 25-50 mm; chin strap secure;</li> <li>3. For anti-static helmets, surface resistance of <math>1 \times 10^5 \Omega</math> - <math>1 \times 10^{10} \Omega</math> (tested in accordance with GB/T 2812)</li> </ol>
Filtering respirator (gas mask)	Low-concentration toxic gases/vapours (e.g., laboratory solution preparation, storage areas for low-toxicity chemicals; $O_2 \geq 19.5\%$ )	Filters toxic gases/vapours to prevent inhalation poisoning	<ol style="list-style-type: none"> <li>1. Cartridge within validity period (check manufacturing date and shelf life);</li> <li>2. Facepiece fits tightly with no leakage;</li> <li>3. Cartridge type matched to the specific contaminant</li> </ol>
Self-contained breathing apparatus (SCBA)	Oxygen-deficient atmospheres ( $O_2 < 19.5\%$ ); high-concentration toxic gas environments (e.g., confined spaces, toxic gas leak response)	Supplies clean breathing air and isolates the wearer from toxic or oxygen-deficient atmospheres	<ol style="list-style-type: none"> <li>1. Storage pressure <math>\geq 90\%</math> of rated working pressure, ensuring <math>\geq 30</math> min service time;</li> <li>2. Pressure alarm functioning normally (alarm at <math>5.5 \pm 0.5</math> MPa);</li> <li>3. Good facepiece seal</li> </ol>

Safety goggles	Chemical splashing or airborne dust (e.g., acid and alkali preparation, sand-blasting)	Protects eyes from chemical burns and dust ingress	<ol style="list-style-type: none"> <li>1. Lenses free of scratches or cracks; clear, unobstructed field of vision, no fogging or glare;</li> <li>2. Sealing gasket fits the face securely;</li> <li>3. For corrosion-resistant types, verify acid and alkali resistance (GB/T 32166.2)</li> </ol>
Welding face shield	Arc welding, gas welding and other high-temperature operations with arc radiation and molten metal splash	Protection against UV/IR radiation and molten metal burns	<ol style="list-style-type: none"> <li>1. Filter lens' shade number appropriate to welding current (e.g., No. 10 filter for <math>\geq 100</math> A);</li> <li>2. Filter lens uniformly tinted, free from scratches, streaks, bubbles, mildew, orange peel, glare, or other optical defects;</li> <li>3. For auto-darkening types, switching time compliant with GB/T 3609.2-2009</li> </ol>
Earplugs	Areas with noise levels $\geq 85$ dB (e.g., compressor rooms, pump areas)	Noise attenuation and hearing protection	<ol style="list-style-type: none"> <li>1. No damage or deformation;</li> <li>2. Noise level reduced to below 85 dB after wearing (refer to GB/T 23466-2009)</li> </ol>
Acid- and alkali-resistant gloves	Handling strong acids or alkalis (e.g., electroplating, acid and alkali tank cleaning)	Prevents chemical corrosion of the hands	<ol style="list-style-type: none"> <li>1. Intact appearance; no tears, pinholes or damage, especially at fingers, palms and wrists; good airtightness;</li> <li>2. Where hydrofluoric acid is involved, verify HF resistance (in accordance with GB 28881-2023)</li> </ol>
Anti-static gloves	Flammable and explosive environments (e.g., solvent filling operations, handling of electrostatic-sensitive materials)	Dissipate static electricity from the human body to prevent explosions triggered by electrostatic sparks	<ol style="list-style-type: none"> <li>1. Surface resistance of <math>1 \times 10^6 \Omega</math> - <math>1 \times 10^9 \Omega</math>;</li> <li>2. No damage; conductive fibers intact.</li> </ol>
Chemical protective clothing	Chemical liquid splashes and vapour exposure (Type 6 for light splashing; Type 1 for high-concentration releases)	Prevent skin contact with toxic chemicals	<ol style="list-style-type: none"> <li>1. Fabric free from damage, pinholes, tears, coating delamination or ageing, with particular attention to high-stress areas such as the torso, cuffs and trouser legs;</li> <li>2. Seams free from unravelling, debonding or looseness; zippers, flaps and closures fully closed,</li> </ol>

			<p>operating smoothly without deformation;</p> <p>3. Air hoses, connectors and buckles free from blockage, looseness or damage;</p> <p>4. Visor functioning properly, ensuring clear visibility;</p> <p>5. For gas-tight suits, verify airtightness (refer to GB 24539-2021).</p>
Anti-static protective clothing	Flammable and explosive workshops (e.g., petrochemical cracking units, paint mixing rooms)	Eliminate static charge accumulation and prevent spark generation	<p>1. Surface resistance of <math>1 \times 10^5 \Omega</math>-<math>1 \times 10^{11} \Omega</math> (in accordance with GB 12014-2019);</p> <p>2. No damage; conductive strips securely connected.</p>
Safety footwear	Heavy material handling, exposure to acids and alkalis, and electrical work (impact-resistant, puncture-resistant, acid/alkali-resistant, insulating types)	Protect feet against impact, penetration, chemical corrosion and electric shock	<p>1. Toe cap impact resistance: under 200 J impact energy, residual clearance inside the shoe shall meet the requirement of a minimum toe clearance <math>\geq 15</math> mm (GB 21148-2020);</p> <p>2. Puncture-resistant midsole capable of withstanding <math>\geq 1100</math> N penetration force;</p> <p>3. Insulating footwear rated for a withstand voltage <math>\geq 5000</math> V.</p>
Full-body safety harness	Work at height (e.g., scaffolding, tank-top maintenance) and work at edges	Prevent falls from height and distribute fall arrest forces	<p>1. No abrasion or breakage of webbing; metal components free from corrosion;</p> <p>2. Breaking strength <math>\geq 22</math> kN (GB 6095-2021);</p> <p>3. Lanyard length <math>\leq 2</math> m.</p>

Table 1.9 Examples of PPE Appearance

			
Safety helmet	Filtering respirator (gas mask)	Self-contained breathing apparatus (SCBA)	Safety goggles

			
Welding face shield	Acid- and alkali-resistant gloves	Chemical protective clothing	Full-body safety harness

### 1.4.2 PPE Combinations for Operational Scenarios

Chemical operations are often comprehensive and complex, and in most cases require combined PPE protection. Examples of PPE combinations for selected work scenarios are shown in Table 1.10 (see GB 30871-2022).

Table 1.10 PPE Combinations by Work Scenario

Work Scenario	Core PPE Combination	Failure Case
Confined space	Supplied-air respirator + fall-arrest lifeline + safety helmet + chemical protective suit + explosion-proof intercom	In one enterprise, failure to check storage pressure resulted in insufficient air supply after entry, causing asphyxiation
Hot work	Flame-retardant clothing + explosion-proof face shield + welding gloves + impact-resistant safety footwear	During hot work, failure to wear flame-retardant clothing allowed sparks to ignite synthetic garments, causing burns
Work at height	Full-body safety harness + safety helmet + self-retracting lifeline + slip-resistant safety footwear + explosion-proof intercom	A maintenance worker used an expired harness with an aged lanyard, which failed during climbing and resulted in a fall

### 1.4.3 Inspection, Maintenance and Retirement Criteria for PPE

#### 1. Routine Inspection

Key inspection items: Safety helmets free from cracks; safety goggles free from scratches; gloves free from damage; respirator cylinder pressure within the normal range; safety harnesses free from abrasion or wear.

Inspection frequency: Mandatory before each work shift, to be carried out by the

operator and recorded accordingly.

## 2. Periodic Testing

Safety lifelines: Tensile testing every two years; residual strength shall be  $\geq 80\%$  of the rated value.

Insulating gloves: Power-frequency withstand voltage testing every six months, in compliance with EN 60903.

Self-contained breathing apparatus (SCBA): Comprehensive performance testing annually, including airtightness and functionality of alarm devices.

## 3. Maintenance Requirements

Storage conditions: Dry and well ventilated (relative humidity  $\leq 60\%$ ), protected from light (avoid direct sunlight on cylinders), and stored at ambient temperature ( $-10^{\circ}\text{C}$  to  $30^{\circ}\text{C}$ ).

Segregated storage: Respiratory protective equipment shall be stored separately from chemicals. In-use, standby and expired PPE shall be segregated and clearly labelled as “In Use / Standby / Expired,” together with the storage date.

Cleaning and care: Respirators shall be cleaned and dried after use; protective clothing shall be stored on hangers; filter canisters shall be sealed during storage.

## 4. Retirement Criteria

Damage-related retirement: PPE exhibiting physical damage such as cracks, holes or tears, e.g., cracked helmet shells or damaged chemical protective suit fabrics.

Expiry-related retirement: PPE exceeding its shelf life or recommended service life, e.g., filter canisters expired by more than three months.

Performance-related retirement: PPE failing to meet performance requirements upon testing, such as safety lifelines with breaking strength below 22 kN, or insulating gloves with degraded dielectric performance.

**Case: In one enterprise, failure to implement filter canister retirement criteria resulted in the use of canisters expired by three months, causing chlorine inhalation poisoning among employees and constituting a violation of “periodic inspection and retirement” management requirements.**

## Practical Training Design

Example: Confined space operations

1. Equipment integrity check: Verify SCBA cylinder pressure ( $\geq 27$  MPa), the external condition of chemical protective clothing, and the breaking strength of safety lifelines ( $\geq 22$  kN). Record any abnormalities.

2. Donning sequence: Chemical protective suit (zip fully closed and secure hook-and-loop fasteners) → SCBA (adjust shoulder straps for snug chest fit) → safety lifeline (anchor high, use low; lanyard length  $\leq 2$  m) → safety helmet (suspension clearance 25-50 mm) → final check of facepiece seal (positive-pressure test with no leakage).

3. Emergency simulation: Simulate a scenario in which the facepiece is damaged by impact; require switching to a spare facepiece within 30 seconds, assessing both operational speed and absence of secondary exposure.

## **1.5 Safety Management System for Hazardous Chemicals**

### **1.5.1 Objectives and Policy of Safety Management**

Objective: To prevent accidents and ensure the safety of personnel, property and the environment.

Approach: Safety first, prevention-oriented, and comprehensive management.

### **1.5.2 Current Status and Outlook of Hazardous Chemicals Safety Management in China**

Safety management of hazardous chemicals spans six stages - production, storage, transportation, distribution, use, and disposal. It is a matter of public concern involving the state, enterprises, and individuals alike, and requires coordinated governance across society as a whole. At present, pronounced disparities exist across different levels of management capacity. Relatively speaking, large state-owned enterprises generally have sound management systems, sufficient investment in safety technologies, and comparatively low accident rates. In contrast, small- and medium-sized enterprises, especially those at lower regulatory tiers, commonly suffer from incomplete management systems, insufficient investment in safety technologies, weakened organizational structures, inadequate supervision, limited technical capability, and delayed equipment maintenance. These deficiencies have become major sources of latent hazards and accident-prone areas. Despite ongoing efforts, systemic risks have not been fundamentally eliminated, and serious production safety accidents with significant casualties still occur.

Through legislative improvements, technological empowerment, and targeted

rectification campaigns, the state is striving to keep the overall number of chemical accidents nationwide within a relatively low range. The *Hazardous Chemicals Safety Law (Draft)*, adopted in November 2024, clearly establishes “people first, life first” as its fundamental principle, adheres to the policy of “safety first, prevention-oriented, and comprehensive governance,” and accelerates the establishment of a dual prevention mechanism integrating safety risk classification and control with hazard identification and remediation. It further strengthens corporate primary responsibility and government regulatory accountability, and prevents major and extraordinarily serious accidents through joint law enforcement across departments and regions.

At the local level, Henan Province issued a *Catalogue of Prohibited, Restricted and Controlled Industries* (Henan Development and Reform Industrial [2022] No. 610) in July 2022 to regulate industrial relocation. The provincial emergency management authority, in collaboration with chemical enterprises, has promoted the development of intelligent safety risk management and control platforms. A total of 344 enterprises with major hazardous chemical installations invested RMB 240 million, establishing six core functions, including special operations management and intelligent inspection, as well as advanced applications such as electronic geofencing. Enterprises employing five high-risk processes but not classified as major hazard installations were connected to the provincial dual prevention system, achieving a performance evaluation excellence rate approaching 100%. Following these upgrades, system stability and product qualification rates improved significantly, while on-site staffing levels were substantially reduced. By March 2025, 177 enterprises in Henan had invested RMB 1.72 billion in full-process automation upgrades. On average, each enterprise reduced staffing by 12 employees, achieved expected annual returns exceeding RMB 2.5 million, and is projected to recover investment costs within four years, thereby reducing safety risks at the source.

### **1.5.3 Significance of Effective Hazardous Chemicals Safety Management**

1. Industrial Development Perspective: Effective safety management ensures production continuity, reduces losses caused by accident-related shutdowns, and safeguards the stability of industrial and supply chains. For example, a large petrochemical enterprise reduced its equipment failure rate by 40% through improved management systems, raising annual capacity utilization to 95%.

2. Personal Safety Perspective: Proper management significantly reduces casualties from poisoning, burns, explosions, and other incidents, thereby protecting

the lives and health of workers. Statistics show that enterprises with standardized safety management report accident casualty rates only one-tenth of those observed in poorly managed enterprises.

3. Social Stability Perspective: Sound safety management mitigates public safety risks and environmental crises triggered by major accidents, helping to prevent social panic and maintain overall social stability.

#### **1.5.4 Development Trends in Chemical Safety Management**

The future governance of chemical safety can be advanced from five aspects.

1. Deepening digital transformation: shifting from “reactive response” to “proactive prevention and control.” By leveraging the industrial internet, AI algorithms, and big data analytics, a full-chain risk monitoring system covering production, storage, transportation, and waste disposal should be established. Key priorities include: real-time sensing of major hazard installations (e.g., dynamic monitoring of equipment temperature and pressure); AI-based identification of unsafe human behaviors (such as unlicensed operations or deviations from operating procedures); and intelligent early warning of risks and hidden hazards (e.g., predicting equipment failures based on historical data). This enables the early identification, early warning, and early mitigation of risks.

2. Strengthening regional coordination and talent development to address “fragmented efforts” and “skills gaps.” Cross-regional joint prevention and control mechanisms should be established to promote equipment sharing, expert exchanges, and joint emergency drills between technologically advanced eastern regions and chemical industry clusters in central and western China. Talent development should be enhanced through university-enterprise joint training programs and on-the-job practical training. For small and medium-sized enterprises (SMEs), targeted apprenticeship schemes should be implemented, and safety skills assessments should be incorporated into corporate credit evaluation systems.

3. Promoting the integration of regulation and technology to create a dual-engine model of “hard constraints” and “soft capabilities.” The legislative process for the *Hazardous Chemicals Safety Law* should be accelerated, with more detailed safety standards specified for each stage of the lifecycle. Research, development, and deployment of inherently safer technologies, such as microchannel reactors and intelligent monitoring sensors, should be encouraged. Enterprises using high-risk processes should be guided to complete technical upgrades aimed at “two reductions

and one enhancement”: reducing personnel, reducing inventories, and enhancing automation.

4. Advancing public participation and emergency capacity building to form a system of “co-governance” and “rapid response.” A coordinated mechanism involving government, enterprises, and the public should be established, including anonymous reporting platforms and incentive channels. Public risk awareness should be enhanced through science-based outreach formats such as short videos and VR safety experiences. At the same time, professional emergency response teams should be strengthened, regional emergency supplies depots established, and a model of “enterprise self-rescue plus regional mutual aid” promoted, supported by regular, unscripted field exercises.

5. Enhancing targeted support for SMEs to address the imbalance of “strong leaders and weak followers.” Provincial-level funds for chemical safety technology upgrades should be set up, providing tax incentives or retrofit subsidies to enterprises adopting inherently safer equipment. Industry associations should be encouraged to establish shared expert pools to offer SMEs free risk assessments and low-cost technical consulting services.

### **1.5.5 Safety Production Responsibility System**

The safety production responsibility system is the cornerstone of chemical safety management. It establishes a comprehensive framework encompassing legal requirements, organizational accountability, and clearly defined rights and obligations of personnel.

1. Legal basis: In China, the system is grounded in the *Law of the People’s Republic of China on Work Safety* and the *Law of the People’s Republic of China on the Prevention and Control of Occupational Diseases*, and is supplemented by sector-specific regulations for the chemical industry, including the *Regulations on the Safety Management of Hazardous Chemicals* and the *Standards for Determining the Potential Risks of Major Accidents in Chemical and Hazardous Chemical Manufacturing and Operating Units*. Together, these laws and regulations standardize the conduct of enterprises and personnel, safeguarding safe production and workers’ health.

2. Responsibilities of production and operating entities: Enterprises are required to fulfill their primary responsibility for safety, including conducting monitoring of occupational disease hazards and organizing occupational health examinations, as well as rectifying identified safety hazards. Failure to do so may result in administrative penalties or, in serious cases, criminal liability.

### 3. Rights and obligations of employees

(1) Obligations: Employees must comply with chemical safety operating procedures (such as gas testing prior to confined space operations and regulations for loading and unloading hazardous chemicals); participate in specialized safety training (including the properties of hazardous chemicals and emergency response measures); promptly report safety hazards (such as equipment leaks or failure of protective devices); and correctly use personal protective equipment (PPE) and safety devices (e.g., respirators, chemical protective suits).

(2) Rights: ① In the field of occupational disease prevention and control: the right to require labor contracts to specify occupational hazards, protective measures, and related benefits; the right to obtain copies of the *Occupational Health Surveillance Records* after health examinations; and the right to request such records upon termination of employment. ② In the field of work safety: the right to be informed of workplace risks; the right to make suggestions for safety improvements; the right to criticize, report, or expose illegal commands; the right to refuse hazardous operations; the right to take emergency evasive actions in dangerous situations; the right to claim compensation for work-related injuries in accordance with the law; the right to receive safety training; and the right to obtain, free of charge, standard-compliant PPE (such as chemical-resistant boots and safety goggles).

4. Accident handling: In accordance with the *Regulations on Reporting, Investigation and Handling of the Production Safety Accidents*, accidents are classified by severity. On-site personnel and the responsible persons of the enterprise must report accidents as required, cooperate with investigation and handling, and implement the principle of the “Four No-Pass” criteria.

5. Management principles: Centered on the entire lifecycle of chemical production, safety management shall adhere to the following principles: ① Core principles: “Those who manage production must also manage safety” (integrated control of production and safety), and “full-coverage safety training for all employees,” from senior management to frontline operators. ② Foundational principles: the “Three Simultaneities” (safety facilities designed, constructed, and commissioned simultaneously with the main project); the “Three Synchronizations” (safety production planned, developed, and implemented in step with economic development, enterprise reform, and technological upgrading); and the “Five Simultaneities” (safety work carried out concurrently with planning, deployment, inspection, review, and performance appraisal of production

activities). ③ Operational principles: the “Four No-Harms” (do not harm oneself, do not harm others, do not be harmed by others, and protect others from harm), and “strengthening labor protection and improving working conditions,” with particular emphasis on hazardous chemical operations and confined space work. ④ Accident management principle: the “Four No-Pass” principle, as stated above.

#### **Practical Training Design:**

① Document review: Collect and study the *Safety Regulations for Confined Space Operations in the Chemical Industry* and the *Safety Specifications of Special Work in Hazardous Chemicals Enterprises*.

② Simulated operation: Simulate the issuance of a *Confined Space Entry Permit*, with clear specification of: Work location (e.g. inside a reactor vessel); Risk level (e.g. poisoning, asphyxiation); Pre-entry gas testing requirements (oxygen concentration 19.5%-23.5%, toxic gases below permissible exposure limits); On-site attendant person (must hold a valid special operations certificate); Emergency measures (e.g. standby respirators, rescue lifelines, emergency communication methods).

③ Summary and output: Map out the responsibility chain (enterprise principal → safety management department → workshop director → team leader → operators → attendant) and clarify responsibility implementation measures, including: signing company-wide safety responsibility agreements; conducting monthly responsibility assessments (linked to performance evaluation); establishing responsibility traceability records (e.g. filing signed work permits); and carrying out regular special inspections on responsibility implementation, with a focus on preventing “responsibility gaps” in small and medium-sized enterprises.

### **1.5.6 Safety Education and Training**

The safety education and training system focuses on building personnel safety competence and is implemented in a tiered and categorized manner.

#### **1. Core-tier Training (Three-Level Safety Education)**

Plant-level training: (1) Regulatory dimension: Interpretation of key provisions of the *Law of the People’s Republic of China on Work Safety* and the *Law of the People’s Republic of China on the Prevention and Control of Occupational Diseases* (e.g. employer responsibilities for occupational disease prevention, employees’ rights and obligations); (2) Macro-level awareness: The company’s safety policy, overall risk map