CHAPTER - 20

Safety in Engineering Industry

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1 NEED OF SAFETY IN ENGINEERING INDUSTRY

Man and Machine are two important ingredients of Industrial Safety. Man needs machines which many times bring hazards and accidents. This has created the need of industrial safety. It is most important to eliminate or minimise the contact between men and machines. Machines are the product of engineering and therefore engineering occupies the pioneering place in industrial safety. Without engineering industries, no machine, no guard and no mass production is possible. The history of machine is old and interesting. In Chapter-7, Part-1, old engineering branches of India are mentioned and another historical part is given in Chapter-33. Weapons and vehicles expected by *Yajurveda* and fixed and movable machines in *Kautilya's times* were not possible without engineering industry. Modern engineering technology is much advanced and many other industries are dependent on it.

In 2005 (Table 5.4, Chapter 5) out of 7179848 workers employed in all factories in India, workers employed in engineering factories (i.e. in NIC group No. 27 to 29) were 1276277 i.e. 17.77% Thus about 20% labour force is employed in engineering industry in our country.

In USA, deaths due to machinery are reported, by Accidents Facts, 1997, as under :

Year	1992	1993	1994
Out of	86777	90523	91437
Deaths due to machinery	1037	999	970
Percentage	1.19%	1.10%	1.06%

Table 5.8, chapter-5, causes 1 to 3 state that there were 17.62% and 17.48% injuries in engineering industry in 2004 and 2005 respectively.

From Table 5.8, it can be concluded that 15.06% fatal and 17.58% non fatal injuries in India, in 2005, were in engineering processes.

Table 5.22, last row Causation No. 101 to 112 and 122 give total 5008 accidents out of 15683 i.e. 31.93% accidents due to machinery, in 1994, in Gujarat.

Table 5.20 shows fatal accidents as 11.71% in 2007 and non-fatal accidents as 4.1% in 2007 in engineering industry in Gujarat. Dangerous occurrences with or without injuries were 4.34% in 2007.

Thus a share of accidents in engineering industry is about 17 to 30% which needs attention.

2 STATUTORY PROVISIONS

Sections 14, 21 to 26, 28 to 35, 87, 88 and Chapter IV-A (Sections 41A to 41H) of the Factories Act 1948 and rules made under these sections by the Gujarat Factories Rules provide safety measures for engineering machinery, processes and accidents. Their details are readily available from the statute book and therefore they are not reproduced here. In short, these provisions are for the safety from dust, machinery in motion, power cutting devices, self-acting machines, casing of new machinery, hoists and lifts, lifting machines, revolving machinery, pressure plant, floors, stairs, means of access, pits, sumps, floor openings, excessive weights, protection of eyes and hazardous processes in ferrous and non-ferrous metallurgical industries and foundries, coal industries, grinding or glazing of metals, electroplating of metals, sand or shot blasting and stone or silica processes. Provisions of Rules 54 and 102, GFR are also important.

Under rule 54, schedule 5 for centrifugal machines, schedule 6 for power presses and schedule 7 for shears, slitters and guillotine machines are important. See Part 4.4 of Chapter-14 for details.

Under rule 102, Sch. 24, 25 and 26 provide detailed safety measures for welding/cutting, pottery and foundry operations.

See Part 5.1.3 for Sch. 26, and Part 7.1.3 for Sch. 24 for gas welding and cutting.

3 INDIAN STANDARDS

There are numerous IS for various metallurgical and foundry operations, hand tools, portable power tools, machines, machine tools etc. A few are mentioned below :

Abrasive wheels 10489
Agitator equipment 9522
Air compressor, 6430, selection 6206, testing 5456
Air conditioning, Safety code 659, terminology 3615
Alloy brazing 2927, steel casting grinding media 6079
Aluminium forging 734, heat treatment of 8860
Aluminising hot dip coating 6697,8508
Anodising 7088
Arc welding 8804

Bag filling machines 9776
Ball mill 4642
Band saw for metal cutting 5030
Belt for pulleys 8531,V- belt 2494,10022, drives 2122, 7923
Blast furnace 8953, 9959
Blasting drilling safety code 4081

C- hook 4164, 3813
Chain driving 1927
Chimney design 6533,1649,4998
Chipping hammer 4915, chisel 402
Coal cutting m/c 3869, cutting tools 5775, Pulverisers fire safety 2595
Cold forming 5986
Compressed air safety code 4138, air receivers 7938 steel cylinders 8198
Coolant for machine tools 2161
Cooling forging 6272, towers 8581
Copper forging 6912
Corrosion of metals 3531, protection 8062,8629
Cutting tools 10412

Die castings 1655, die forging 9684, die sets press working 10068, dies cutting 1859, rolling 8405, 5702
Drawing office layout and planning 5197, engineering drawing practice 696
Drilling machines portable 5441, bench type 2426, pillar type 2425, radial 6893
Drop forging 5518

Electroplating 3658, 2679,1986,7453
Engineering table hand book SP-6 and 8
Erection of steel work, safety 7205
Ergonomics 10224

Fabrication 7215, 6916
Fan, ventilating 2312, pedestal 1169
Feed for machine tools 2219

Ferrous castings 4843, 7001
Film safety 5431
Flour mills 9374, 10520
Foundry- chaplets 5904, sand 6788, cleaner 6443, dextrin 4269, pin for moulding boxes 4982, ladle 4475, 4476, lancets 5824, lifter 6443, oven design 10298, pattern equipment 1513, lifting pin hook and plate 6376, 6378
Furnace - blast 7189, 9959, cupola 5032, forging 9977, induction 8992, open Hearth 6727, 8506

Galvanised coatings 4826, 6159, 2629,8917
Gas cylinder for welding and cutting 6901, hand trolley 8016, safety devices 5903, technology 7241
Gas industry 7062, marks 8523, safety lamp 7577
Gauge glass for pressure vessels and boilers 5428
Gearing worm 3734, cutter 5996, gearbox selection 7403
Girder plate handbook SP-6
Grinding machines 2368, 10352, 2743, grinding wheel 551, safety code 1991
Guard for power driver 8265.

Hammer - hand 841 mill 10444
Hand lamp 1415
Hardware glossary 7881
Helical gear box, selection 7403
Hydrology 4410

Lathe 2932

Machine driving and driven shaft height 2031, foundation 2974, noise measurement 4758 metal forming 6652, reamer 5918, working level height 7229

Machine tools - controls and operation 2987, speeds 2218, testing code 2063
Manhole 1726, 5455, 3133
Manual on quality assurance systems 10201
Mechanical testing 5069
Metal cutting - glossary 812, band saw blade 5030, 5031, shears 6087, tools 10097
Metal forming machine and tool 6652
Milling cutter - carbide-tipped 9322, concave 6322, convex 6323, cylindrical 6309, interlocked 2671, other 6325, 6255, 6256, 6326,5698, 6355, 6308, 9325, 2668, 6352 etc.
Milling machines - 6893, 7765

Nickel coating 4827, 4828,1068, 4942

Oil hydraulic system 10481
Oven - electric 8985, gas 4473, 7342

Pneumatic chippers 7446, 7605, drilling m/c 5441, grinding m/c 7157, rivet cutter 7978, hammer 7979, wrencher 8067, sander 9828

Press - 8064, 10068 test for power take-off (PTO) drive shaft guard 8265

Reamer - chucking 5446, machine 5918, 5919, 6091
Refrigeration 660, 3615, 5111
Rubber belting 1370, 1891

Scrap classification 2549, 2066, scraper 8646, 6861
Screw conveyor 5563, machine 2255
Screw bolts and nuts 3139
Screw driver 844, 9707
Seam welding 1261
Sanitation 1172, 10446
Sieving 1607, 5421
Silver Electroplating 1067, 6267
Sliding door 281, 2681
Slotting machine 2308
Soldering 959, 999
Spanners - box 2030, hook 90632, open jaw 2028, 4508, 5167, ring 2029, 4509, square 6130, requirements 6131

Spittoons 3996
Spot welding machine 4804
Spur gears 3681, 7504, 4460
Stainless steel sheet arc welding 2811
Standard colours for building SP 1650
Steel drop, upset and press forging 3479
Steel forging - alloy, tool and alloy for pressure vessels 9683, hard chromium plating 1337, hard drawn wire 432
Steel plates for boilers 2002, for pressure vessels 2041, radiographic examination of welded joints 1182, ultrasonic testing 4225, tensile test 1608, protection against corrosion 3618, 4777, Rockwell hardness test 1586
Steel tool and die for cold work 3749, hot work 3748, tool high speed 7291
Steel tubes in building construction 806
Stone dressing 1129, facing 4101, glossary 1805
Structure design for corrosion prevention 9172
Structures clay products glossary 2248
Structures blast resistant 4991, earthquake resistant 1893, fire resistant 3809, subject to dynamic loading 1024
Submersible Pump sets 8034,9283

Tap for pipe threads 6172, 7796, wrench 4914, 4917
Test chart for - cutter grinder 2368, drilling m/c 2367, 2199, gear hobbling m/c 8407, gear shaping m/c 6679, milling m/c 2200, 2201, planning m/c 2877, power hacksaw m/c 3405, precision lathes 6040, shaping m/c 2308, shearing and guillotines 2515, universal tool 3080, boring and turning mills 6197
Test probes 1401
Testing of metal, mechanical, glossary 5069

Thread milling cutter 2670

Tool - assembly nomenclature 6293, flat faced 5770, parrot beak 5772, 5855, radial 5775,5854, tungsten carbide tipped 3820, non - sparking 4595, planing 6075, 8842, pneumatic 5651, portable motor operated 4665.

Toothed gearing 2458, 2467

Transmission belting, friction surface 1370

Turning - mandrel 7262, mill 6197 tools 2162, 2163, 3019.

Twist drill for jig boring machine 7766

Ultrasonic testing glossary 2417, Industrial radiographic practice, safety 2598

Unfired pressure vessels 2825

Vibration machine 10080

Vice - 2586, 2588

Warehousing fire safety 3594.

Water - for industry, tests 1622, 3025, 3550, for boilers 10390, 1680, 1813

Weigh bridges for bulk handling 9777

Weighing machine - automatic 1437, platform 1435, electronic 9281, totalizing 3960

Welding - electrical and gas cutting, safety 818, resistance spot welding 819, fire precaution 3016, procedure approval 7307, 7310, 7318, arc rectifier type 4559, electric 2641 and cutting 812, 6016 arc 6008, cables 9857, welding equipment for eye and face protection 1179, oxyacetylene 1323, protective filter 5983, welder's handbook SP - 12

Wire - drawing 1137, 4913, 9888,

Worm gears - glossary 2567, selection 7403

Zinc alloy die castings 742, electroplating 1073

website : http://www.hse.gov.uk/engineering

4 INTRODUCTION TO HOT AND COLD PROCESSES :

4.1 Types of Hot and Cold Processes :

Metallurgical processes are of two types : Hot and Cold processes.

Hot processes are employed to melt ore to make metal, to refine metal and to mould metal in the required shape, section or grade, to make alloy, to weld or cut metal parts and to make tools, equipment, building materials, machine parts, structural parts etc. Fuel-fired or electric furnaces are used for these purposes. Chemical energy of fuel (gas, furnace oil, LDO, wood, coal, lignite, waste etc.) or electric energy is converted into heat in such furnaces. Hot processes include melting, refining, smelting, moulding, forging, hot rolling, welding and cutting, brazing and soldering operations.

See Part 5 for hot working of matal.

Cold processes are employed to further reduce or change the shape, size or section of the hot rolled, forged or moulded metal parts, cut into pieces, drill, bore or grind surfaces, press, punch slot, shear, cut, bend or shape the metal parts. A variety of machines and machine tools are used for these purposes. Hand and foot operated presses, power presses, hydraulic or pneumatic presses, shearing machines, press brakes, cold rolling mills, forming rolls, wire drawing machines and various machine tools like lathe, boring m/c, grinding m/c and modern computerised controlled machines are used in engineering industry.

See Part 6 for cold working of Metal.

4.2 Types of Furnaces, Uses and Safety Measures :

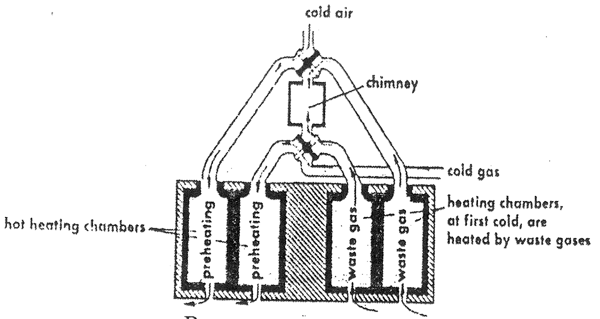
They are classified as under-

(1) Classification based on Structure :

Technologically metallurgical furnaces are classified as *melting* or *heating* furnaces.

Melting furnaces are employed to make metals from ores and remelt metals for obtaining the desired properties. Materials processed in melting furnaces *change* their state of aggregation.

Heating furnaces are employed to heat materials for roasting (limestone, magnesite, refractories, potteries etc.) or drying (foundry moulds, ore, sand etc.) and also for increasing the plasticity of metals before plastic working. They are also used for heat treatment of metals to change the metal structure. Materials processed in heating furnaces *remain* in the same state of aggregation.



Regenerative Heating

Furnaces may be regenerative or recuperative according to the method the heat of waste gases is utilised.

(2) Classification based on Heat Generation :

Furnaces are also classified according to the principle of heat generation i.e. either *fuel-fired furnaces* where heat is generated from chemical energy of fuel or *electric furnaces* where heat is generated from electric energy.

In **fuel-fired furnaces** heat is generated by burning fuel on the furnace hearth. They are of two types : *flame furnaces* and *shaft furnaces*. In flame (reverberatory) furnaces, the material to be burnt occupies only a small portion of the reaction chamber volume, the rest being occupied by flames and combustion products. In shaft furnaces, all the space is filled with loose charge materials which include lumpy solid fuel.

In steelmaking furnaces (converters), the chemical energy of molten metal is also converted into heat through combustion of impurities present in them. The heat evolved is evenly distributed over the whole mass of the molten metal.

Heat for refining the bath to produce steel is derived from the oxidation of carbon and other elements and no external source of heat is required.

In oxygen process steelmaking furnace, initially oxygen is blown on to the surface of a bath of molten pig iron and steel scrap.

Types of **electric furnaces** are : (a) Electric-arc and plasma furnaces, single, two or three phase furnaces (b) Induction furnaces (c) Dielectric heating plants (d) Resistance furnaces and (e) Electron-beam furnaces, i.e. micro-wave and infra-red.

(3) Classification based on Operating Mode:

Heat transfer from a heat carrier (flame, electric arc) to the surface of material is mainly through thermal radiation and convection.

Heat transfer from the surface of material into the depth of material occurs predominantly by conduction. But with heated liquids, convective heat transfer is also possible.

Convective mode is typical of low-temperature heat-treatment and drying furnaces. This mode is also employed in heating baths in which a hot liquid is the heat carrier.

Layer wise mode is used in the processing of lumpy materials mostly in shaft furnaces. In such layer wise mode, all three kinds of heat transfer - radiation, convection and conduction - are interlinked so closely that practically cannot be separated from one another. There are three types of layer - dense (filtering) layer, fluidised bed layer and suspended layer of the processed material.

Modern complex thermal plants are usually composed of furnace proper (reaction chamber, burners, electrodes or resistors) and auxiliary equipment (waste gas heater, ventilator, exhauster, stack, valves, gates etc.).

Others :

So far we have discussed the types and uses of *furnaces.* It is relevant to consider **kiln** used for cement, lime, ceramic (brick, tile, refractory) and drying purposes and **ovens** for drying (moisture removal), curing, baking, decorating and solvent evaporation (paint drying).

Hazards and Safety Precautions :

Main hazards while working with furnaces, kilns and ovens are as under :

1. Burns due to contact with hot surfaces.
2. Burns due to contact with hot product, fuel or electricity.
3. Splashing or bubbling of molten metal.
4. Contact of cooling water with the molten metal or slag (e.g. induction furnace) and explosion due to sudden steam generation.
5. Fire or explosion due to leakage of fuel.
6. Carbon monoxide from fuel gas or products of combustion.
7. Explosion due to hydrogen.

Precautions to be followed are as under :

1. Good insulation over hot metal surfaces.
2. Protective clothing for head, face, hands and feet.
3. Respirators, safety eye glass (plain or tinted) for protection against dust, fumes, toxic gases and glare.
4. Exhaust hoods and fans to draw dusts, fumes, gases etc.
5. Good ventilation to vent off hazardous waste generated from scrap charged, alloys and fluxes.
6. Hot work permit before allowing any worker to enter any hot chamber. Ensurance of cooling, fresh air ventilation and lighting necessary.
7. Interlocking to cut off fuel supply in case of flame failure.
8. Precautions while lighting fuel or burner to prevent flash back, fire or explosion.
9. Training and awareness programmes for workers.
10. Provisions of drinking water and shielding to avoid heat disorders.
11. Flameproof electric fitting with solvent drying ovens. PPE against eye and skin irritation or respiratory disorders.
12. Precautions against free silica, asbestos etc., while cleaning and maintaining furnaces. Area monitoring and medical surveillance of such hazardous exposures.

4.3 Steel Manufacture, Hazards and Safety Measures :

Iron occurs very abundantly constituting about 4.7% of the earth's crust. It is the fourth in abundance (first three are oxygen, silicon and aluminium) amongst all the elements. Amongst metals, its abundance is second only to aluminium.

The most important iron ores are iron oxides, carbonates and sulphides.

Three commercial varieties of iron are cast iron, wrought iron and steel. They differ in their carbon and phosphorous content.

Cast iron is the least pure form of iron containing 2.5 to 4.5% carbon with some sulphur, phosphorous, silicon and manganese.

CHAPTER - 2

Philosophy of Safety

THEME

1. *What is Philosophy?*
2. *Philosophy of Safety*
   2.1 *Need of Safety Philosophy*
   2.2 *Nature and Subjects of Safety Philosophy*
3. *Safety Terminology (100 terms defined)*
4. *Message of the word "SAFETY'*
5. *Philosophy of Accident Causation*
6. *Philosophy of Total Safety Concept*

What is stated in Chapter-1 about the Concept of Safety falls within the scope of philosophy of safety which we will see, now, in further detail.

1 WHAT IS PHILOSOPHY?

Philosophy is originally an Indian branch of knowledge. It had existence in our country before the English word 'philosophy' came into existence.

Thousands years ago our profound Rushies and great thinkers told about 'तत्त्व' (element) and search for its 'तत्त्वज्ञान ' (knowledge). This 'तत्त्वज्ञान ' is our oldest and current synonym for the English word 'philosophy'. It has its origin in Vedas, Smruties, Shruties, Upnishads, Ramayana, Shrimat Bhagwat and other Purans, Mahabharat, Gita and many old and modern Indian literatures. Gita explains it as follows:

तद्विद्धि प्रणिपातेन, परिप्रश्नेन सेवया।

उपदेक्ष्यन्ति ते ज्ञानं, ज्ञानिनस्तत्त्वदर्शिन: ॥

Know that knowledge by leaning down, interrogating and serving the philosophers who will teach that knowledge to you.

Our concept of philosophy is a branch of knowledge searching for basic elements, origin, source, causation, effect, reality and means to achieve and apply them to various fields. It includes science, which is a specific branch of knowledge having some characteristics like verifiability by experiments, definiteness, objectivity, certainty, predictability etc.

The philosophy is older and wider than the science, as it is in existence since centuries and has wide coverage of knowledge of all branches including that of science. To study the nature and origin of science, its branches, utility, applications etc. is philosophy. It also studies art, sculpture, धर्म (which has no synonym in English and which does not mean religion only), psychology, history of universe and its cause and effect.

Our old concept of philosophy was more concerned with 'धर्म, अध्यात्म ', search of God, universe, its elements, realities, causes and effects. As the scientific rules were invented gradually, science (विज्ञान) was separated as a special branch of philosophy.

The western concepts of philosophy are defined by Plato, Aristotle, Hegal, Bredle, Comte, Bartrand Russell, Dr. Brod, Kent, Fichte, Democritics, Marx, Burgsan etc. They have also explained the philosophy of science and the difference between the philosophy and science. Their concepts are criticized and counter argued by other philosophers. Their views in brief are as follows:

Philosophy is a study of true realities and of appearances. It is the super science. It analyses and examines original or fundamental concepts of science or assumptions. It coordinates the scientific results with religions and moral experience of man. It studies the language and meanings. It visualises or assesses the knowledge, its root, measure and limitations.

Philosophy has three original branches:

1. **Ontology** searching the root cause or fundamental element(s) in the creation of world.
2. **Cosmology** searching how this visible world is developed from the final element.
3. **Epistemology** discussing the forms, types, tests and limitations of the knowledge.

There are three conceptions about philosophy of science -

1. Its purpose is to think about the line of thinking and logic of science, and
2. Its function is to coordinate various kinds of knowledge, and
3. Its specific work is to analyse the methodology and problems of science.

Major problems of philosophy of science are the problems of reductionism, technological explanation, causation and induction.

Difference between Science and Philosophy

The **science** has specific subjects and divisions, it rests upon experience, observation, experiment and examinations, its rules are universal, unaltered and unchangeable. It has no two opposite statements or opinions and it does not recognize religion.

The **philosophy** has no specific subject, it interprets facts and findings, it searches for common principles lying at the root of facts, it finds generality of totality, it does not need experience or experiment, though it recognises them, its attitude is intellectual and logical, it includes theories of opposite opinions also viz. reality and ideology, spiritualism and materialism, द्वैत-अद्वैत, नास्तिक -आस्तिक theistic and atheistic, free behaviour and morality etc. It recognises the religion and always looks for the final truth.

2 PHILOSOPHY OF SAFETY

After understanding the nature of philosophy in general, let us be precise over the philosophy of safety.

2.1 Need of Safety Philosophy:

The objectives of philosophy of safety are to-

1. Think about what is safety, what is its need, where it is required, what are its types and applications etc
2. Protect and serve the mankind, to search, suggest and apply
   (a) the safe ways of behaviour (action),
   (b) the safe working conditions and
   (c) the safe environment for the safety, health and welfare of all people.

This shows the highest importance of the subject of safety, as it has started from the age-old need of safety and has to last for continuous and permanent need forever. This is the supreme significance of the philosophy of safety.

2.2 Nature and Subjects of Safety Philosophy:

Safety is directly connected with science, technology, engineering, health, hygiene, toxicology, psychology, management and law. It has specific rules or principles on specific safety subjects. The philosophy of safety tries to search and coordinate the common causes and remedial measures for general as well as specific safety problems. It begins with the basic need or requirement of safety, its fundamentals, causation analysis and consequence, methods of detection of unsafe condition, unsafe action and reason and sequence of accident occurrence. It searches for the principles and methods of accident prevention and speedy control after the happening, safety devices, fittings, techniques and measures, factors impeding and approving safety, safety responsibility and roles of various agencies; terminology, theories and mysteries of accident causation, prevention and control. It studies for physical, physiological, psychological and other factors affecting and strengthening safety. It studies costs and types of accidents and their significance, type of safety management necessary and ways and means of providing and maintaining safe working conditions and human actions affecting health and safety of people and the safety of environment. It touches the origin, development and amendment of safety law and its innovation and all safety needs in the areas of industrial and environmental safety including safety at home, road, rail, water and air. Thus the field of safety philosophy is unlimited, its scope is very wide to include the entire subjects of safety from origin to the research, the latest development and from causation and behavioural analysis to the modern concept of design, testing, reliability, hazard control technology, risk analysis, assessment and audit, emergency planning, public awareness and involvement programmes and all future developments.

3 SAFETY TERMINOLOGY

Like other branches of science, many *words* and *terms* are now well defined in *safety science*. Some terms are defined by statutes from legal point of view. Some commonly used safety terminology is given below. It is most important to understand these words as they clarify many concepts of safety philosophy, safety science and safety law. Other terms are defined in respective chapters. For terminology of MSDS, see part 7.2 of Chapter -18. For terminology of Risk Management, see Part 4.3 of Chapter -19.

3.1 Accident:

An accident is defined in different ways -

Dictionary meaning of 'accident' is an unexpected event or mishap. It is defined as an event that is not expected, intended or imagined. It refers the **event** not the result or effect.

An accident is an unplanned event that interrupts the completion of an activity and that may (or may not) cause damage to person, property or environment.

An accident is that occurrence in a sequence of events, which produces *unintended injury*, death or property damage. An accident refers to the event, not to the result of the event.

Unintentional injury is the preferred term for accidental injury in the public health community. It refers to the result of an accident.

An accident is unintended, unplanned event or its sequence caused by unsafe condition(s) or/and unsafe act(s) and may result in immediate or delayed undesirable effects.

An accident is an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof.

It is also defined as an unexpected, unintended or unforeseen event that causes injury, loss or damage

An accident is any unplanned, sudden event, which causes or is liable to cause an injury to man, materials (including plant) or environment.

An accident is any occurrence that interrupts or interferes with the orderly progress of the activity and which causes or likely to cause injury with or without damage to property or environment.

An accident is the result of carelessness, casualness or any fault known or unknown.

An accident is an unwanted transfer of energy beyond the threshold limits. In case of accident to a person, physiological energy loss is an accident while in other cases it may be an energy loss from material.

It is an event, which is unexpected, unavoidable and unintended - *Suchman*

An accident is an unexpected, unavoidable, unintentional act resulting from the interaction of host (accident victim), agent (injury deliverer) and environmental factors within situations, which involve risk taking and perception of danger - *Suchman*.

An accident is an unplanned event, which has a probability of causing personal injury or property damage or both. It may result in physical harm (injury or disease) to person(s), damage to property, loss to the company, a near miss or any combination of these effects including delayed effect.

An accident is an unexpected, unplanned event in a sequence of events, that occurs through a combination of causes, it results in physical harm (injury or disease) to an individual, damage to property, equipment, building etc., a near miss, loss to the company, or any combination of these effects.

An accident is an unplanned, not necessarily injurious or damaging event that interrupts the completion of an activity. It is invariably preceded by an unsafe act or an unsafe condition or their combination.

An industrial (occupational) accident is also defined as an undesirable event that results in a certain length of disability and stoppage of work and time loss due to the effect of a production-related dangerous factor or a combination of such factors.

An occupational accident is presently regarded as an index or a symptom of dysfunction in a system formed by a production unit, such as a factory, a workshop, a shift or a workplace.

Occupational accident is also defined as "any organic or functional injury or damage to body, limbs or health or psychic disorder due to an external, sudden or violent cause occurring during work or due to work itself and resulting in death or total or partial, permanent or temporary incapacity for work".

Fatal accident or death from accident is an accident that results in one or more deaths within one year from the date of accident.

Philosophy of Accident: It should be noted from above definitions of 'accident' that -

1. In accident phenomenon, which includes event and its effect, 'event' is more important then its 'effect'. Effect or consequence may or may not be there. For example, a person getting chemical splash (exposure), struck by falling body, striking against object, falling from height, getting electric shock or meeting with road accident may not get any injury or his normal activity may not be interrupted. Here event has taken place but it has not a notable effect. Even then this is an accident for the purpose of finding the 'cause' of event and remedial measures to prevent its recurrence.
2. Event may be one or more. One thing falls or many things fall one by one, only fire takes place or explosion follows the fire, events of primary and secondary explosion, collision of many vehicles, one person dies or more persons die in a sequence or due to different injuries in one accident may constitute one accident.
3. Idea of 'accident by chance' is not acceptable in safety philosophy. Each accident has its 'cause' or 'causes' that need inquiry, investigation and efforts to remove them. Considering accident as chance or fate does not help to prevent the accident and may result in another accident. Even if it is considered as chance, the 'causes' of that chance occurrence are important.
4. There may not be immediacy between event and effect. For example, pain or symptom may appear after repeated actions or few hours or days after the accident, cancer may occur after years from the exposure of a toxic substance. This delay or 'latency period' hides the effect for some time. However such accident of *delayed effect* may prove most serious and needs thorough investigation and effective control measures viz. pesticide poisoning and control.
5. Duration or span of event may be short or long. Span of event should be considered from its beginning to the end of the effect or consequence. Therefore when effect occurs just after the event begins, duration of event is short and when effect occurs after a long time (i.e. delayed effect) from the beginning of the event, duration of the event is long. Therefore in definition of accident, immediate or delayed, both the effects are included. Chronic disease (effect) requires events of long duration.

Legal definition of 'nonfatal injury accident' or 'dangerous occurrence' makes it reportable after the duration of 48 hours from the time of accident. Thus legal definition of accident has considered 48 hours duration of event to notice any harmful effect. Accident causing death or possibility of death is to be reported immediately (Sec. 88 & 88A, the Factories Act).

See Chapter-4 for further details about 'accident', its causation and prevention and Chapters-28 & 29 for legal definitions.

3.2 Accident Consequence Analysis:

Consequence means effect or result of a specific event.

Accident Consequence Analysis is an analysis of the expected effects of an accident, independent of frequency and probability.

Mostly this is carried out after the completion of Risk Assessment to predict the consequences i.e. severity of the effects due to the assumed worst or maximum credible accident scenarios. See part 3.100.

With accident consequence analysis, the Vulnerability Analysis may be carried out of the persons, property and environment adversely affected or likely to be affected.

Computer software is useful in carrying out consequence analysis and vulnerability analysis.

In such type of analyses, determination of following things is important –

1. Type of substance being released e.g. gas, liquid or liquid with vapour etc.
2. Type of release i.e. instantaneous, continuous, intermittent etc.
3. Leak rate or outflow volume and rate of evaporation in case of liquid pool.
4. Dispersion calculation of the released mass. Parameters of atmospheric conditions are also considered e.g. wind speed, weather condition (stability class), cloudiness, terrain conditions and sinking mechanism and absorbtion (influence of trees, houses etc as obstruction of toxic gases).
5. Damage distances i.e. damaging concentration or effect of fire or explosion at different distances in the direction of wind or other directions. Plotting of footprint or counter showing these distances and effects.
6. Severity of the effect i.e. vulnerability in terms of possible deaths, injuries, destruction of buildings or damage to environment. Use of Probit equation.
7. Plotting of 'risk counters' on the area map of place of release and vicinity. Counters should indicate low, medium and high risk areas.

3.3 Accident Prevention:

Accident prevention is both science and art. It represents, above all other things, control i.e. the control of human performance, machine or equipment performance and physical environment.

The word 'control' connotes prevention as well as correction of unsafe conditions and actions. Prevention is the first step of control.

To control unsafe human actions, knowledge of psychology, philosophy and management are necessary. To control unsafe conditions, knowledge of engineering, health effects, industrial hygiene, ergonomics etc. are necessary.

Accident prevention requires five steps: organisation, fact-finding, analysis of the facts found, selection of remedy and application of the remedy. Sixth step of **monitoring** should be considered. It includes measurement of result, assessment i.e. comparing measured value with legal criteria or standard, feedback and further improvement if necessary. See Chapter – 4 for details.

3.4 Air Pollution:

In short it means contamination of air by harmful substances like toxic gas, dust, vapour, acid fumes, flue gases, fuel gases etc. When it exceeds legal permissible limit, it is considered legally harmful.

It is also called presence of air pollutants (including noise) in air.

In its broad meaning it includes detection, monitoring and chemical analysis of air pollutants, air pollution control equipment and engineering measurements and standards of industrial and automotive emissions and common air quality parameters, odours, acid rains, thermal discharge, gas and particulate emission, climate change, greenhouse effect, ozone depletion, chemical and biological aspects of air pollution, radioactive fall out, radiation levels and their effects; and effects of air pollutants on soil, plants and animals.

3.5 APELL:

It means 'Awareness and Preparedness for Emergencies at Local Level'. It is a co-operative programme of the United Nations Environment Programme (UNEP), Industry and Environment Office prepared in June 1987, and was started in late 1988.

APELL's main goals are to prevent technological accidents (disasters) and, failing this, to minimise their impacts. This is achieved by assisting decision-makers and technical personnel to increase community awareness of hazardous installations and to prepare coordinated response plans involving industry, government and the local community, in case unexpected events at these installations should endanger life, property or the environment.

Thus APELL consists two parts (1) Provision of information to the community, which is called 'Community Awareness' and (2) Formulation of a plan to protect the public, which is called 'Emergency Response'. (On-site and off-site Emergency plans are legally suggested).

3.6 Care and Types of Care:

Every person has a moral and legal duty to exercise *due care* for the safety of others and to avoid injury to others if possible. Common carriers must exercise *great care*.

Reasonable care is that degree of care exercised by a prudent man in observance of his legal duties toward others.

Responsible care is the safety duty towards society. Now this has developed as a systematic approach.

Responsible care is a chemical industry initiative, which started in Canada in the late 1970s and is slowly gaining worldwide momentum. It is voluntary and the willing company has to demonstrate its commitment to improve all aspects of performance relating to safety, health & environment. This helps, in turn, to develop and maintain public acceptability of that industry.

In India, ICMA (Indian Chemical Manufacturers' Association) has adopted six codes of management practices for responsible care as under:

1. The Process Safety Code.
2. The Employee Health & Safety Code.
3. The Pollution Prevention Code.
4. The Community Awareness & Emergency Response Code.
5. The Distribution Code, and
6. The Product Stewardship Code.

3.7 CASH:

This means Change Agents for Safety & Health. This is a term used for Occupational Health and Safety program where different agents like noise, dust, heat-stress, injures, chemical exposures, PPE, light, ventilation etc are considered as targets (agents) for necessary change to get desired improvement at the work place.

3.8 Chemical Accident:

As defined u/r 2(a) of the Chemical Accidents (Emergency Planning, Preparedness, and Response) Rules, 1996, it means an accident involving a fortuitous or sudden or unintended occurrence while handling any hazardous chemicals [defined in rule 2(b)] resulting in continuous, intermittent or repeated exposure to death or injury to any person or damage to any property but does not include an accident by reason only of war or radioactivity.

3.9 Chemical Safety:

It means 'safety' from hazards of chemical. See definition of 'safety' at Sr. No. 3.80 following.

3.10 Code of Practice:

It is a document offering practical guidance on the policy, standard-setting and practice in occupational and general public safety and health for use by governments, employers and employees in order to promote safety and health at the national level and at the level of the installation. A code of practice is not necessarily a substitute for existing national legislation, regulations and safety standards.

3.11 Confined Space:

Confined space as defined in clause (o) of Part-1, Schedule-19, Rule-102, Gujarat Factories Rules, means any space by reason of its construction as well as in relation to the nature of the work carried therein and where hazards to the persons entering into working inside exist or are likely to develop during working.

Normally a confined space is enclosed from all sides except one for entering inside and coming out from the same e.g. manhole or open top. It is not a normal place for working. **Inside risks** include - possibility of toxic gas or dust, oxygen deficiency, fire, explosion, high temperature, sudden flow or pressure, accidental starting of stirrer etc., burying (engulfment) under free flowing solid e.g. grain, cement, sugar, drowning in liquid at bottom and similar causes.

NIOSH, USA describes 'confined space' as a space which has any one of the following characteristics:

1. Limited opening for entry and exit.
2. Unfavourable natural ventilation, or
3. Not designated for continuous worker occupancy.

Confined space is also classified as that -

- has vertical or maze exit, or
- contains loose dust, fluidised materials or unstable solids.

Examples of confined spaces are - tank, pit, sump, vat, duct, gutter, tunnel, sewer, drain, trench, pipe, reaction or utility vessel, boiler, chimney, flue, furnace, oven, ceiling voids, enclosed room, basement etc.

Proper safety work permit, work place monitoring, use of self breathing apparatus and safety belt, rescuer standing outside and holding life line are the important **safety measures**.

See Part 2.1 of Chapter 16 also.

3.12 COSHH:

It means 'Control Of Substances Hazardous to Health' Regulations 1994, published by the Health and Safety Executive (HSE), UK. It is a **guideline, not** compulsory but helpful. Its **compliance requires -**

1. Assessing the risks to health arising from the work.
2. Deciding what precautions are needed.
3. Preventing or controlling exposures.
4. Ensuring that control measures are used and maintained.
5. Monitoring exposures of workers to hazardous substances and carrying out appropriate health surveillance, and
6. Ensuring that employees are properly informed, trained and supervised.

3.13 Damage Control:

It is directly concerned with the protection of machinery, materials and manufactured goods assets from accidental loss within the factory. Indirectly it is concerned with money asset and manpower asset.

Damage can be defined as severity of injury or the physical, functional or monetary loss that could result if control of a hazard is lost.

3.14 Danger:

It expresses degree of exposure to a hazard. By taking suitable precautions, the danger is reduced. Machine guarding or safety device reduces the danger of a particular hazard.

3.15 Dangerous Occurrences:

Dangerous occurrences are mentioned u/s 88-A of the Factories Act 1948 and u/r 103 of the Gujarat Factories Rules 1963. They include:

1. Bursting of a steam plant under pressure.
2. Collapse or failure of lifting appliances or overturning of a crane.
3. Fire, explosion, escape of molten metal, hot liquor, gas etc.
4. Explosion of a pressure vessel.
5. Collapse or subsidence of a structure.

For Dangerous Chemical Reaction see Part 3.39.

3.16 Disaster:

Disaster is a catastrophic situation in which the day-to-day patterns of life are, in many instances, suddenly disrupted and people are plunged into helplessness and suffering and as a result need protection, clothing, shelter, medical and social care and other necessities of life, such as-

1. Disasters resulting from natural phenomena like earthquakes, volcanic eruptions, storm, surges, cyclones, tropical storms, floods, landslides, forest fires and massive insect infestation. Also in this group, violent draught, which will cause a creeping disaster leading to famine, disease and death are included.
2. **Second group** includes disastrous events occasioned by man, or by man's impact upon the environment, such as armed conflict, industrial accidents, factory fires, explosions and escape of toxic gases or chemical substances, river pollution, mining or other structural collapses, air, sea, rail and road transport accidents, aircraft crashes, collisions of vehicles carrying inflammable materials, oil spills at sea, dam failures etc.

3.17 Disaster Management Plan (DMP):

This is the requirement of Government Dept. (MoEF, GPCB, Factory Inspectorate, Collectorate etc.) under various Acts and Rules.

It includes On-site emergency plan and Off-site emergency plan. Its key elements are –

1. **Basis of the plan or risk assessment.** Hazards and emergency situations are determined with their possible effects. Typical scenarios and consequences are outlined for the purpose of off-site emergency plan (see part 3.2).
2. **Accident prevention procedures and control measures.** Organisational set-up and division of responsibility. It includes listing of control measures provided in the factory and to be managed from outside if not available in the factory. Help from outside agencies.
3. **Emergency response procedures.** It includes emergency control centre, communication system and description of roles to be played by plant people and outside agencies.
4. **Recovery procedures.** It includes safe shut down or flow restriction procedure, evacuation and restoring of normal condition.

See Part - 7 of Chapter - 19 for details.

3.18 Ecology:

It includes interaction between microbes, plants and animals and their environment, which are primarily affected by climate, water resources, soil and man, ecosystem studies, ecology of grasslands, woodlands and wetlands, arid zones and high altitude environments, coastal ecosystem, mangroves, aquatic ecosystem, fresh water, river basins, brackish water, marine, estuarine and soil ecology.

3.19 Emergency:

Emergency could be defined as any situation, which presents a threat to safety of person or/and property or environment. It may require outside help also.

As defined in clause 2(j) of Schedule 19 of Chemical Works u/r 102 of the Gujarat Factories Rules

(GFR), **emergency** means a situation leading to a circumstance or set of circumstances in which there is a danger to the life or health of persons or which could result in big fire or explosion or pollution to the work and outside environment, affecting the workers or neighbourhood in a serious manner, demanding immediate action.

It is also defined as, 'a dynamic incident in which there is continuing potential for major injury, ill health, damage to property, to the process or to the environment.'

3.20 Emergency Plan:

Emergency plan is a formal written plan, which on the basis of identified potential hazards at the installation together with their consequences, describes how such hazards and their consequences should be handled either on-site or off-site. See DMP at Sr. No. 3.17.

See Part 7 of Chapter - 19 for details.

3.21 Emergency Services:

Emergency services mean external bodies which are available to handle major accidents and their consequences both on-site and off-site, e.g. fire authorities, police, health services etc.

3.22 Environment:

As defined u/s 2(a) of the Environment (Protection) Act, 1986, it includes water, air, land and the inter relationship which exists among and between water, air and land, and human beings, other living creatures, plants, micro-organisms and property.

3.23 Environmental Management:

In its broad meaning it includes Government policies, planning, programmes, regulations and legislations, international agreements, environmental impact assessments(EIA), environmental education, environmental law and legal actions, sustainable development, siting of industries, clean technologies, eco-development and ecosystem management, managerial aspects of forestry, biosphere, conservation, waste and wildlife.

3.24 Environment Management Plan (EMP):

After identification and assessment of adverse impacts on environment due to proposed activity of a new plant or expansion of existing plant and after preparation of Environment Impact Assessment (EIA) document, Environment Management Plan (EMP) becomes necessary.

The EMP describes general good practice measures and site-specific measures to mitigate potential impacts due to the proposed industrial activities. The EMP provides mechanism to address potential adverse impacts, to instruct contractors and to introduce standards of good practice to be adopted for all project works.

For each stage of the programme, the EMP suggests effective mitigation of every potential biophysical and socio-economic impact identified in the EIA. It presents following information:

1. A list of mitigation measures or action plan.
2. Parameters to be monitored to ensure effective implementation of the action.
3. Time schedule to implement actions to ensure that the objectives are fully met.

3.25 Environmental Pollutant:

Defined u/s 2(b) of the Environment (Protection) Act 1986, it means any solid, liquid or gaseous substance present in such *concentration* as may be, or tend to be, injurious to environment.

Environmental Pollution means the presence of environmental pollutant in environment.

3.26 Error:

Errors are of different types, viz. human error, design error; planning, production, operation and maintenance error etc.

Human error can be defined as a human's action, which differs from or is inconsistent with prescribed or established behaviours or procedures. It may be of two types: predictable or random.

Predictable error occurs under similar conditions and can be foreseen because it has occurred more than once.

Random error is non-predictable and unique in nature. For example, all of a sudden a fly or insect enters in eye due to which a worker may throw away a tool or lose his balance and cause error. But if flies become common phenomena i.e. predictable, the error becomes predictable one and remedial measures are required.

Human error takes place due to omission (failure to perform a required function) or commission (performing a function not required), failure to recognise hazard, poor response, poor timing, wrong decision, sudden disturbance etc.

3.27 Evacuation:

It means to move all people from a threatened area to a safer area. It is required as a function of Onsite or Offsite Emergency Plan.

3.28 Fire Prevention and Control:

It is a special aspect of damage control. It protects machinery, materials, manufactured goods, money assets and manpower from damage due to fire.

See Chapter - 13 for details.

3.29 Flash fire and Jet fire:

A **flash fire** is the non-explosive combustion of a vapour cloud resulting from a release of flammable material into the open and which after mixing with air, ignites. A flash fire results from the ignition of a released flammable cloud in which there is essentially no increase in combustion rate. The ignition source could be electric spark, a hot surface and friction between moving parts of a machine or an open fire.

Thus flash fire means a release of flammable gas under unconfined condition in the presence of air and ignition source. Dispersion process occurs between LEL and UEL with no increase in combustion rate.

A **jet fire** occurs when flammable gas releases from the pipeline (or hole) and the released gas ignites immediately. Damage distance depends on the operating pressure, the diameter of the hole or opening flow rate and the air resistance.

3.30 Foresee-ability:

A man may be held liable for actions that result in injury or damage only when he was able to foresee dangers and risks that could be reasonably anticipated.

3.31 Forestry:

It includes afforestation including social forestry and energy plantation, deforestation, ecology and management of forests, influence of forest on the physical environment, protection of forests, soil conservation and erosion of forests, watershed / catchments management, endangered and threatened plant species.

3.32 Handling of a Substance:

As defined u/s 2(d) of the Environment (Protection) Act, it means the manufacture, processing, treatment, package, storage, transportation, use, collection, destruction, conversion, offering for sale, transfer or the like of such substance.

3.33 Harmful Element:

It means a substance, which in contact with the human body is likely to cause, during employment and long after, identifiable by modern methods, injuries and diseases or likely damage to the health of the present and future generations. Harmful elements may be injurious, toxic, corrosive or irritating.

3.34 Hazards:

Hazard means existing unsafe condition or action or situation or event or their combination which has potential to cause accident. Thus hazard can become a cause of accident or risk and it can exist without accident or risk. When due to hazard, accident happens, it is converted into accident. If hazard still exists, accident may happen again. viz. flammable atmosphere.

The causes of accidents generally remain latent for some time before an accident occurs. These latent or potential causes are hazards. Hazards are sometimes referred to synonymously with accident causes, but there is a clear distinction that a *hazard* can exist without an accident whereas an *accident cause* without an accident is an absurdity. Hazard recognition, diagnosis and elimination are essential to any successful safety programme.

Hazard is an inherent property of a substance, agent, a source of energy or situation having the potential of causing undesirable consequences.

Hazard means an intrinsic capacity associated with an agent or process capable of causing harm.

Hazard is defined as, 'any event with the potential to cause harm, ill health, injury, damage to property, plant, products or the environment, production losses or increased liabilities.'

Hazard is a condition with the potential of causing injury to personnel, damage to equipment or structures, loss of material, or lessening of the ability to perform a prescribed function. When hazard is present, the possibility exists of these adverse effects occurring.

Chemical Hazard is a hazard due to chemical (including its property, storage, process, handling, effect etc.) and it is realised by fire, explosion, toxicity, corrosion, radiation etc.

Major Hazard is a large-scale chemical hazard, especially one, which may be realised through an acute event.

For Major Accident Hazard (MAH) see part 3.55 following.

Occupational hazards are the hazards arising in course of and out of occupation or employment. They include physical, chemical, biological, mechanical, electrical, psychological and all occupational health hazards, diseases and poisoning.

Rapid ranking method is a means of classifying the hazards of separate elements of plant within an industrial complex, to enable areas for priority attention to be quickly established.

3.35 Hazards Analysis:

In simple term, hazard analysis means classification of hazards, eg. chemical hazards, mechanical hazards, electrical hazards, fall hazards, day and night wise hazards etc. *In this way it is qualitative analysis.*

Hazard Analysis is (i) Analysis of mechanism of hazard occurrence and (ii) Analysis of terminal consequences of hazards which may include number of injury, fatality, property damage and other loses. In this way it is *quantitative analysis*. Its study is known as HAZAN (Hazard Analysis). It means *identification of* undesired events, which lead to the materialization of a hazard, *analysis of* the mechanism by which such undesired events could occur, and *estimation of* the extent, magnitude and likelihood of any harmful effects or consequences.

Preliminary Hazard Analysis (PHA) is a procedure for identifying hazards early in the design phase of project before the final design has been established. Its purpose is to identify opportunities for design modifications, which would reduce or eliminate hazards, mitigate the consequences of accidents or both.

HAZAN (**Hazard analysis**) is generally undertaken at the preliminary stage of determining the location, basic design principles and operational parameters to establish the adequacy of basic safety of design, operation and environmental control. It may be followed by an updated analysis to establish final risk levels. HAZAN exercise has to be undertaken by a professional team with expertise in failure mode and effect analysis, fault tree analysis, simulation and modelling, event tree and consequence analyses.

3.36 Hazard Assessment and Survey:

Hazard assessment is an evaluation of the results of a hazard analysis including judgments as to their acceptability and, as a guide, comparison with relevant codes, standards, laws and policies.

Hazard survey means the total efforts involved in an assessment of the hazards from installations and their means of control.

3.37 Hazard Identification:

It is an identification of sources of hazards and their causes. It is qualitative. Its study is known as HAZOP study.

Many methods and techniques are available to identify hazards. See Chapter -19.

In simple term, it means listing of unsafe conditions, actions, situations etc.

Hazard identification is the first and important step. If hazards are identified and removed, risks are prevented. If risks are prevented, accidents are prevented. If accidents are prevented, injuries and losses are prevented and that is the object of safety.

3.38 Hazardous chemical:

Hazardous chemical is defined u/s 2(e) of the Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989 as a listed chemical in Schedule 1, 2 and 3 therein. The same term is also similarly defined u/r 2(b) of the Chemical Accidents (Emergency Planning Preparedness and Response) Rules 1996 and u/r 68J(1)(a) of the Gujarat Factories Rules, 1963.

When threshold quantity of hazardous chemical listed in Sch. 2 or 3 exceeds in a plant it is identified or classified as a Major Accident Hazard (MAH) installation. See Part 3.55 also.

General meaning of hazardous chemical is that chemical which because of its properties, condition, concentration or method of handling or use can cause harm to environment (as defined in part 3.22)

3.39 Hazardous Substance, Process and Reaction:

Hazardous substance is defined u/s 2(e) of the Environment (Protection) Act 1986, as a substance or preparation which, by reason of its chemical or physico-chemical properties or handling, is liable to cause harm to human beings, other living creatures, plants, micro-organism, property or the environment.

It is an element, compound, mixture or preparation, which by virtue of chemical, physical or (eco) toxicological properties constitutes a hazard.

Toxic Substances as defined in clause (i), Schedule 19 on Chemical Works u/r 102 of the Gujarat Factories Rules, mean those substances which cause fatality or serious health effect and which exceed their TLV specified in the 2nd Schedule of the Factories Act (See Table 15 in Chapter-32).

Hazardous Process as defined u/s 2(cb) of the Factories Act, means any process or activity in relation to an industry specified in the First Schedule, where, unless special care is taken, raw materials used therein or the intermediate or finished products, bye-products, wastes or effluents thereof would -

1. cause material impairment to the health of the persons engaged in or connected therewith, or
2. result in the pollution of the general environment.

Dangerous Chemical Reactions as defined in clause (k) of Schedule 19 on Chemical Works u/r 102 of the Gujarat Factories Rules, mean high speed reactions, run-away reactions, delayed reactions etc. and are characterised by evolution of large quantities of heat, intense release of toxic or flammable gases or vapours, sudden pressure build-up etc.

Unit processes and operations mentioned in Sch. 4 u/r 68J of the Gujarat Factories Rules, when involve or likely to involve 'hazardous chemical' as defined in Part 3.38 above, activity in that installation or isolated storage is called **hazardous industrial activity**.

3.40 HOZOP:

Hazop (Hazard & operability) study is carried out by application of guidewords to identify all possible deviations from design intent having undesirable effects on safety or operability, with the aim of identifying potential hazards.

Hazop study is normally undertaken at an *advanced stage* of project implementation when the design criteria are well established. The study can be used for both new and working plants. They have to be carried out by multidisciplinary teams of experienced technical personnel having detailed knowledge of both the design and operation of a plant.

A preliminary Hazop study is intended to review the general parameters of materials processed, unit operations and layout of individual units and plant sub-units. A detailed Hazop study is required after the finalisation of the designs to identify the potentially hazardous situations and to arrive at agreeable options to rectify design deviations and anomalies.

See Part 4.6 of Chapter -19 for details.

3.41 Health and Toxicology:

In its broad meaning, it includes toxicology of pesticides, heavy metals, industrial and agricultural chemicals and other environmental contaminants, effects of toxic materials, fertilizers, pesticides etc. on human, animals, plants and soil, contaminants, measurement and methodology, occupational and public health, use and transportation of hazardous materials, industrial accidents and safety.

3.42 HSMD:

The Hazardous Substances Management Division (HSMD) is the nodal point within the Ministry for Management of Chemical Emergencies and Hazardous substances. The main objective of the Division is to promote safe management and use of hazardous substances including hazardous chemicals and hazardous wastes, in order to avoid damage to health and environment. The Division is also the nodal point for the following three International Conventions.

1. The Basel Convention on the Control of Transboundary Movement of Hazardous Waste and their Disposal.
2. The Rotterdam Convention on the Prior Informed Consent (PIC) procedure for certain hazardous chemicals and pesticides in International Trade.
3. The Stockholm Convention on Persistent Organic Pollutants (POPs).

The activities of the division are carried out under three main thrust areas, viz., Chemical Safety, Hazardous Waste Management and Solid Waste Management.

3.43 Incident:

An incident is any observable human activity sufficiently complete in itself to permit references and predictions to be made about the persons performing the act viz. cleaning an unguarded machine, failing to wear PPE, using compressed air on body, raising pressure or temperature unnecessarily.

It may result in accident or a near miss.

Incident for accident is defined as, 'an unplanned event or series of events that has or could have, caused injury to people and / or damage to assets and / or damage to the environment and / or loss of reputation.

3.44 Industrial Health & Hygiene:

This is connected with the protection of the manpower asset from industrial hazards, illnesses, diseases and other long-term accidental effects caused by industrial environment on human bodies. Indirectly it protects money asset.

Specific areas for consideration include: noise, dusts, gases, vapours, corrosives, toxic materials, ventilation, heating, lighting, humidity, environmental monitoring, biological monitoring, health checks, general and personal hygiene and counselling, health education, employee screening, placement and medical antidotes.

Occupational Hygiene Practice includes:

(a) Anticipation or Identification and Recognition of the possible health hazards in the work environment.

(b) Evaluation of hazards, i.e. the process of assessing exposure (comparing with standard) and reaching conclusion as to the level of risk to human health.

(c) Prevention and control of hazards, which is the process of developing and implementing strategies to eliminate/ reduce to acceptable levels, the occurrence of harmful agents and factors in the workplace. It will also account for environmental protection.

See Chapter -24 for details.

3.45 Industrial Hygiene Audit:

Its aim is to examine industrial hygiene practices with a view to establish their effectiveness in preventing occupational illness and their conformance with standards and regulations. Audit report should indicate whether key industrial hygiene programme elements (not necessarily degree of compliance) are present or absent. The presence of a particular element merely indicates that the organisation is capable of moving towards desirable preventing goals. Audit worksheets should include data gathering format and

CHAPTER - 19

Hazards and Risks Identification, Assessment and Control Techniques

THEME

1 *Safety Appraisal, Analysis and Control Techniques :*
- 1.1 Objectives
- 1.2 Safety Appraisal System
- 1.3 Damage Control
- 1.4 Total Loss Control (TLC)
- 1.5 Job Safety Analysis (JSA)
- 1.6 Safety Inventory System
- 1.7 Product Safety
- 1.8 Safety Work Permit.
- 1.9 Safety Tag System
- 1.10 Standard (Safe) Operating Procedure (SOP)
- 1.11 Incident Recall Technique
- 1.12 Critical Incident Review Technique
- 1.13 Procedures Analysis
- 1.14 Methodical Analysis
- 1.15 Technique for Human Error Rate Prediction (THERP)
- 1.16 PERT and CPM
- 1.17 Safety Codes and Standards Including ISO 14001 & OHSAS 18001
- 1.18 Safety Steward System
- 1.19 Circuit Approach to Safety

2 *Plant Safety Inspection :*
- 2.1 Definitions and Objectives
- 2.2 Types and procedures
- 2.3 Non Destructive Testing (NDT)
- 2.4 Safety Checklists
- 2.5 Safety Survey
- 2.6 Safety Study
- 2.7 Safety Tour
- 2.8 Safety Review
- 2.9 Safety Sampling
- 2.10 Contact Scheme
- 2.11 Good Manufacturing Practice (GMP)
- 2.12 Recommendations & Follow-up Actions (Compliance)
- 2.13 Responsibility for Inspections

3 *Accident Investigation, Analysis and Reporting :*
- 3.1 Philosophy
- 3.2 Purposes of Investigation and Report
- 3.3 Process and Types of Investigation
- 3.4 Agencies investigating Accidents
- 3.5 Accident Analysis (Classification) :
- 3.6 Industrial Classification (NIC, 1987)
- 3.7 Accident Investigation Report and its Content
- 3.8 Methods of Collating and Tabulating Data
- 3.9 Follow up for Corrective Action
- 3.10 Record Keeping

4 *Hazard and Risk Management Techniques*
- 4.1 Hazards, Risks & Detection Techniques
- 4.2 Hazard and Risk Progression Chart
- 4.3 Risk Analysis, Assessment and Management
- 4.4 Preliminary Hazard Analysis (PHA) & Hazard Analysis (HAZAN)
- 4.5 Failure Mode and Effect Analysis (FMEA)
- 4.6 Hazard and Operability (HAZOP)Study
- 4.7 Hazard Ranking (DOW and MOND Index)
- 4.8 Fault Tree Analysis (FTA)
- 4.9 Event Tree Analysis (ETA)
- 4.10 Accident or Cause Consequence Analysis
- 4.11 Maximum Credible Accident Assessment (MCAA)
- 4.12 Vulnerability Analysis
- 4.13 "What if" Analysis

5 *Reliability Engineering :*
- 5.1 Principles of Reliability Engineering
- 5.2 Application of Reliability Engineering
- 5.3 Concepts of Critical Equipment and Devices

6 *Major Accident Hazard (MAH) Control :*
- 6.1 Concept of MAH.
- 6.2 Types and Consequences of MAH including Discharges and Disperson Effects.
- 6.3 Criteria (Identification) for the Plant to become MAH unit :
- 6.4 Role of the Management
- 6.5 Role of the Government Authorities
- 6.6 Role of the Workers & Public
- 6.7 Role of the Public
- 6.8 Safety Report, Safety Audit Report & Risk Assessment Report.

7 *On-site and Off-site Emergency Plans :*
- 7.1 Need and Types of Emergency Plans
- 7.2 Statutory Provisions
- 7.3 On-site Emergency Plan
- 7.4 Off-site Emergency Plan

1 SAFETY APPRAISAL, ANALYSIS AND CONTROL TECHNIQUES

1.1 Objectives :

1 To appraise means to set a value on. Safety appraisal, therefore, includes all ways and means to measure and indicate the value of any plant, machinery, process, method, exposure etc. in terms of their individual and total safety effectiveness, performance, maintenance and control techniques. This is the first step of any safety organisation in its march toward accident or loss prevention programme.

2 Safety appraisal are of many types :

(A) *Qualitative appraisal* is carried out to find the area where safety improvement is necessary. It includes techniques of inspection, audit, review, analysis, study etc. for the exclusive purpose of safety. Previous approval of plant and building, machinery layout, safety measures provided and to be provided are required under the Factories Act and Rules for this objective.

(B) *Quantitative appraisal* is the method of computing accident frequency, severity, incidence and their index rate as we studied in Part 11.2 of Chapter-5. Frequency rate is useful in comparing safety performance of different units in a given time, while severity rate is useful in comparing safety performance of the same unit in different periods. Significance and utility of such injury rates are explained in details in Chapter-5.

(C) *Preventive appraisal* includes preventive maintenance before any accident occurs. Plant safety sampling, safety survey, fault tree analysis, risk analysis. HAZOP and HAZAN studies, safety inventory, system safety, safety standards, safety permit system, safety tag and lockout, safety steward etc. are used for this purpose. Inspections by the plant personnel, Safety Officer, safety expert and factory inspectors must be utilised for this objective.

(D) *Corrective appraisal* includes corrective maintenance after any accident takes place or any defect (crack, corrosion, wear & tear etc.) detected. If such damage/injury valuation and repairing is not carried out, it will continue the interruption of activity and ill-effect on health and safety. Accident investigation, analysis, identifying the key facts, accident potential and causes, application of the remedy (corrective action) are carried out for this objective.

3 Statutory appraisal tests and records are prescribed as a minimum measure necessary. Testing of boilers, pressure vessels, lifting machinery, fire safety, monitoring and analysis of toxic, flammable, explosive or harmful environment and medical health check-ups of workers are prescribed under the Factories Act and Rules. Water/Air Pollution Control Acts, Environment (Protection) Act & Rules and similar statutes are also for this objective.

4 Organised industrial safety is, now, recognised as an integral part of routine industrial operations. Inspections of plant, machinery, tools, equipment, premises, work practices, processes, procedures and general environment must be carried out for the health and safety of plant-people and surrounding. On-site and Off-site Emergency Plans are also useful in this regards.

5 To assess the overall standard of safety performance the concept of Safety Audit developed by Chemical Industries Association is also useful in non-chemical industry.

6 The concepts of Total Loss Control and Total Loss Prevention are also useful to measure and maintain the levels of safety.

7 As we have seen in Part 4 of Chapter-5, indirect cost of accident is more than the direct cost of compensation and medical expenses. Injured party can also sue the employer. Similarly compensation is also payable for breach of product safety. A manufacturer may be economically out due to such accident losses. Therefore he must seriously think to save such high costs and losses by adopting good safety appraisal systems.

1.2 Safety Appraisal System :

Safety appraisal system is a system, method, practice or procedure to measure the safety performance or standards for the purpose of evaluating its effectiveness and reliability, to find out drawbacks or deficiency if any and to suggest the safety measures to raise its safety value.

For this broad aspect, safety appraisal system includes many techniques of measurement and control. It is desirable to adopt it as a regular practice of plant safety inspection or safety auditing before any accident occurs. Measurement of injury frequency rate, severity rate, incidence rate, safety activity rate and total cost of accident is an quantitative appraisal system. The qualitative system includes statutory safety approval, inspection, checklists and follow up, design and construction safety, process & product safety, safety checks and standards, machine guarding, good house keeping and maintenance, chemical safety, engineering controls, use of safety devices and equipment, safety survey, safety sampling, hazard/risk detection, measurement, assessment and control techniques, safety study, safety tour ,safety training, safety observation plan, damage or loss control, job safety analysis, critical incidence technique, fault tree analysis, HAZOP and HAZAN, safe inventory, system safety, circuit approach to safety, safety permit system, total loss control, safety stewardship scheme, plant safety inspection, checklist and audit, safely recommendations and compliance, accident investigation, fact finding, analysis, selection and application of remedy, report writing and maintaining good safety records to check safety performance at any time. On-site and Off-site emergency plans are useful to plan and handle emergencies and control major hazards. All factories should prepare their on-site emergency plans from their own resources. This will be useful to minimise heavy accidental losses. All these systems are explained below in brief :

1.3 Damage Control :

Damage means severity of injury or physical, functional or monetary loss that could result if control of a hazard is lost.

Damage Control is directly concerned with the protection of machinery, materials and manufactured goods assets from accidental loss within the factory. Indirectly it is concerned with money asset and manpower asset.

The Problem of Damage Accident was highlighted by H. W. Heinrich some 75 years ago. He analysed 75000 accidents and concluded that an accident can result in human injury and damage to property or both and the causes of injury and damage are similar - lack of skill, knowledge, unsafe system etc. Frank Bird (USA)'s study of 90,000 accidents in 1959 revealed that damage accidents were 5 times more frequent than injury accidents. He concluded that for 145 disabling injuries there were 15000 other injuries and 75000 property damage accidents. He carried out second study in 1966 of 17,53,498 accidents of 297 industries employing 17,50,000 workers. He concluded that 30.2 property damage accidents were reported for each disabling injury. He pointed out the ratio 1-100-500 of disabling injury (1),to minor injuries (100),and incidents with no visible injury or damage (500). Similar other researches also conclude that damage accidents outnumber personal injuries and then account for greater loss then injury accidents. In spite of this fact, is it not strange that safety programmes are more oriented to injury prevention than damage prevention?

Impediment to damage control was due to old definition of accident considering personal injury only, and referring property damage accident as ' no injury accident '. The modern definition of accident is ' an unintended event that results in physical harm to a person or damage to property'. Un-reporting or underreporting of damage accidents, no statutory requirement (except dangerous occurrence) and failure to set up a realistic programme to damage control are other impediments.

Therefore damage control problem should be property recognised to prevent all accidents causing (a) damage to plant, machinery, equipment, tools, building and other property (b) loss of quantity or quality of materials during storage, handling and transport and (c) delay to process, function or activity due to need of repair or replacement.

Benefits of damage control scheme are :

1. Reduction in potential accidents and chance of injury accidents.
2. Reduction in severe injuries, production delay, and costs of maintenance, replacement and damaged materials.
3. Detection of unsafe conditions and unsafe actions which may contribute to injuries.
4. Increase of quality control, profit, importance and status of safety organisation, awareness of supervisors and management to control property damage.
5. Suggestion of remedial measures to prevent recurrence.

Steps to introduce good damage control programme are as follows :

1 **Spot checking :** Includes visiting repair centres, making observation and taking notes.

2 **Damage Reporting and Investigation :** All unplanned or unintended happenings likely to cause personal injury must be reported by workers and supervisors to management. Such cases should be property investigated and corrected.

3 **Damage Costing and Auditing :** Cost of repairs arising out of accidental damage must be marked by 'D', accounted for and their records must be maintained. A full time damage control inspector can audit all work orders, conduct regular inspections, spot checking of repair centres and analysing damage cost factors.

Computation of direct and indirect cost of damage accidents should be carried out as explained in Part 4 of Chapter-5. Another method is *Ledger cost concept* which is concerned with damage to machines, equipment, materials and loss of production time. Having worked out the damage cost for full year, the cost-severity rate can be evolved by the formula -

$$\text{Cost - severity Rate} = \frac{\text{Total cost of accidents} \times 10^6}{\text{Total production man - hours}}$$

This property damage severity rate can be compared from year to year.

4 **Remedial Engineering :** Collecting data of repetitive repairs to equipment and property from repair shop, redesign of equipment, revision of layout or work method and engineering controls should be implemented to prevent those damage accidents.

1.4 Total Loss Control (TLC)

The Concept clarified : The concept of Accident Prevention when applied to prevent human injuries only, it is called Injury Prevention or Control. When it is applied to control property (machinery, materials and manufactured goods) damage (losses) only, it is called Damage Control. When it is applied to control human injuries and property damage (losses) both, and also extended to include injuries and property damage to society or surrounding, it is called Total Loss Control (TLC), Total Accident Control (TAC) or Total Injury Control (TIC). When this concept of total loss control is applied or achieved by means of engineering controls, it is known as Total Loss Prevention (TLP).

The terms damage control, loss control, loss prevention and risk management are defined in Chapter-2 with other terms to realise the total concept of safety.

The concept of Total Loss Control is also defined as follows :

It is an evolution from injury prevention to the control of all business losses by the application of sound management principles.

It is a system of reporting and controlling all incidents, however small, whether the associated loss is small or large. All incidents are examined, potential losses estimated and recommendations are made and acted upon to avoid repetitions.

It is a programme to eliminate unnecessary costs by means of identification of down grading situations, measurement of the loss potential, selection of methods to control the situation and finally implementation of the methods within the industrial enterprise. A down grading incident could be defined as any deviation in accepted performance levels resulting in injury, occupational sickness or disease, property damage, fire or explosion, breaches of security, pollution or product liability and business interruption.

Development of the Concept : Historically, the concept evolved from H. W. Heinrich's ratio in 1931 that for one serious injury there may be 29 minor injuries and 300 no-injury accidents (Ratio 1-29-300). Frank E Bird, after intensive research in 1966, gave this ratio as 1-100-500, John A. Fletcher, after a world-wide survey in 1969, gave this ratio as 1-19-175.

Though this ratio differs because of different study conditions, it proves two important conclusions: (1) No injury accidents are far greater than the serious or major injury and (2) It is necessary to control or prevent large number of no - injury and minor injury accidents for controlling or preventing a major or disabling accident.

Thus increasing hazards to persons and property because of the industrial revolution in western countries has developed this TLC concept and now, many books are available on this subject.

Relevance of Total Loss Control to India: This concept of TLC has great relevance to India as every loss reduced or eliminated would help to conserve our limited resources and control prices.

Some Annual Indices of avoidable losses in India are estimated below:

1. Accidental deaths in industries and elsewhere 1,40,000.
2. Non-fatal injuries in factories, 5,00,000.
3. Workmen Compensation being paid Rs. 500 lakhs.
4. ESIC benefits being paid Rs. 20000 lakhs.
5. Loss due to deficiencies in packing, transportation and storage of commodities like food,cement fertilisers etc. Rs. 5000 crores.
6. Losses due to fire Rs. 2000 Crores.

These figures reveal great opportunity to prevent as many losses as possible by our collective efforts.

The Fundamentals of Loss Control : Some fundamental principles are given below :

1. Accidents, unsafe conditions and unsafe actions are symptoms of something wrong in the management system.
2. Certain sets of circumstances can be predicted to produce sever injuries, which can be identified and controlled.
3. Safety should be managed like any other company function. Management must direct the safety efforts by setting achievable goals by planning, organising, and controlling to achieve them.
4. The key to effective line safety performance is management procedures that fix responsibility and accountability.
5. The function of safety is to locate and define the operational errors that allow accidents to occur.

The functions of safety can be carried out in two ways :

1. By asking *why* i.e. searching for root causes and
2. By asking *whether or not* certain known effective controls are being utilised.

Management for Loss Control : Risks Department, Risk Manager and Departmental Heads should, first, formulate Total Loss Control Policy for the company. Loss Prevention Committee should be formed to execute the policy. Responsibility should be fixed. By special attention to employees selection, placement, training and participation and adopting safety in design, safety audits and checklists, the goals should be achieved.

Four Steps procedure is necessary :

1. Identification of hazards.
2. Evaluation of hazards and their detailed analysis.
3. Planning and implementing measures to reduce hazards and
4. Frequent review.

Application of this procedure brings following *benefits* :

(a) Minimising damage to men, machines materials (raw and finished) and methods.

(b) Saving on insurance or better insurance cover at lower cost.

Control measures monitored by the Loss Control Department are :

1. Rules and Regulations.
2. Traffic Laws.
3. Standard Procedure Instructions.
4. Measurement of safety performance by various ratings (Indices).
5. Occupational safety and health standards/ rules.
6. Investigation of Losses and
7. Summary Analysis.

Thus by adopting Total Loss Control we can render the workplace fully safe and efficient.

1.5 Job Safety Analysis (JSA) :

Purpose & Definition :

Job safety Analysis is a procedure of analysing job for the purpose of finding the hazards in each step and developing safety precautions to be adopted.

Though this technique can be applied at any stage, it is most useful at the stage of planning, design and starting the process.

It can be used to review job method and uncover hazards (a) that may have been overlooked at the design or planning stage of plant layout, building, machinery, equipment, tool, workstations, processes etc. (b) that were noticed subsequently (c) that were resulted from changes in work procedure or personnel. It is the first step in hazard or accident analysis and safety training.

It determines details of each job in terms of duties, skills, abilities, qualification, safety aspect, tools required, methods, sequence of operation and working condition. It is useful for routine or repetitive job as well as maintenance and short orders.

Advantages (Benefits)

1. It suggests what personal characteristics such as age, sex, qualification, skill, experience, abilities, physical standards etc. are necessary for selecting a right man for a right job.
2. The job breakdown sheets are useful to train new workers in proper sequence of doing the job safely and efficiently.
3. The hazards are noticed before they cause any accident.
4. It suggests preventive measures in advance to avoid accidents.
5. It helps for planned and effective safety inspection and accident investigation.
6. It suggests improved job methods, motions, positions, actions and work standards.
7. Proper organisation of methods consistent with accepted safe and efficient practices.
8. Preplanning, preparedness and proper performance can be started by executing properly the requirements of the operation.

Procedure : Four basic steps of simple procedure are:

1. Select the job.
2. Breakdown the job into successive steps.
3. Identify hazards and potential accidents in each step.
4. Develop safety measures to eliminate above hazards and consequential accidents. These steps are briefly explained below :

Jobs with potential for more frequent accidents, severe injuries and new jobs wherein hazards are unknown should be selected first.

The job should be broken down in proper sequence and steps. Operation, description, hazards (existing or potential) and precautions should be mentioned.

To identify hazards observe the operations as many times as necessary, ask the operator concerned or others having good knowledge of that job and list the hazards in each step. Consider all possibilities of accident, failure mode and effect etc.

The safety solution to the hazards noticed may be worked out by (a) finding a new method to do the job (b) changing the physical conditions creating hazards (c) eliminating hazards still present or changing the work procedure (d) reducing the need of doing that job or at least the frequency of the job and (e) suggesting personal protective equipment if any.

Everything of above findings should be recorded on Job Breakdown Sheet (Job sheet or Job instruction sheet) and it should be explained to operators and trainees to perform the job safely.

Job safety analysis should be carried out by a person well conversant with the job. The supervisor is well suited for this. Where safety officer is appointed he may carry out the analysis jointly with the supervisor.

Example :

The procedure of Job Safety Analysis is illustrated below.

In a factory rough castings of 15 Kg. are fettled by hand on a pedestal grinder (dia 12"). The castings are picked up from nearby store, fettled on the grinder and replaced on the floor on the other side of the machine. Carry out job safety analysis and prepare the job breakdown sheet.

Job Breakdown Sheet			
Operation Step	**Description**	**Hazards**	**Precautions/controls**
1.	Start the job.	1. Breakage of wheel 2. Contact with wheel 3. Flying particles	1. Check and adjust the Guard 2. Adjust tool rest 3. Get wheel dressed if necessary 4. Use goggles/shield
2.	Pick up the job.	1. Sharp edges 2. Unsafe gripping or lifting	1. Use hand gloves 2. Use safety shoes 3. Proper method of storing 4. Proper training in lifting
3.	Grind	1. Flying particles 2. Wheel breakage due to jamming etc. 3. Dust-Silicosis, nuisance	1. Use goggles/shield 2. Do not jam 3. Local exhaust for machine and respirator 4. Aprons 5. Gloves
4.	Replace the job.	1. Sharp edges 2. Fall of casting 3. Strain and sprain	1. Use hand gloves 2. Use safety shoes 3. Proper method of storing 4. Proper training in lifting

Further details may be written at the end of this sheet.

1.6 Safety Inventory System :

This method proceeds to analyse quantity of hazardous material and to reduce it to the minimum possible level, to find out its safe substitute if any, and to find out necessary control measures to prevent or contain any accident due to it.

See Part 10.8 of Chapter-28 for MSIHC Rules and Rule 68J of the Gujarat Factories Rules wherein threshold quantities of chemicals are stated in Schedule-2 and 3. In Sch-2 the quantity varies from 0.75 tonne (for Carbonyl chloride) to 15000 tonnes (for flammable liquids). In Sch-3 the quantities varies from 1 kg (for many chemicals) to 1250 tonnes (for Ammonium nitrate fertiliser) and 50000 tonnes (for flammable liquids). If the quantity exceeds this threshold limits, the unit is identified as MAH unit and specific safety rules are applicable. These rules include disclosure of safety information, notification of major accident, notification of industrial activity, safety reports and on-site and off-site emergency plan. Thus inventory plays now statutory role also.

Threshold Quantities are listed for -

1. Toxic chemicals up to 1 kg.
2. Toxic chemicals > 1 kg and up to 200t.
3. Highly reactive substances 2t to 1250t.
4. Explosive substances 100 kg to 50t.
5. Flammable substances 15t to 50000t.

Steps suggested by the World Bank and IFC Guidelines to prevent major accident and to limit their consequences are : Proper design, construction, inspection, maintenance and operation of storage vessels and process plants, alarms, trips, dump-tanks, scrubbers, water curtains, emergency procedures; information, training and protective equipment to workers, and on-site and off-site emergency plans.

It is also suggested that within 1 km radius of major hazard, no population should be allowed and within 1 to 2 km, limited development of low density such as warehouses and light industry may be allowed.

See Part 17 of Chapter-18 for some Committee Reports.

1.7 Product Safety :

It is a legal responsibility of every manufacturer, seller, agent or supplier of each product to render it safe (non-injurious), otherwise if any harm is caused to a consumer, buyer, user by that product, legal damages are payable over and above any statutory compensation, for accidental injuries.

Section 7B of the Factories Act imposes duty upon every designer, manufacturer, importer or supplier of any article and substance for use in any factory, to make that product safe and without risks to the health of the workers, to carry out necessary tests for this purpose and to supply safety information regarding safe use of that product. The product should conform to the Indian and Foreign (higher) standards.

Negligence or Breach of Warranty should proved to establish product liability.

The manufacturer is obliged to (1) exercise care planning, designing and producing his product sonably safe for all users and (2) provide adequate rning and precautions with the product for the safe .

Breach of warranty may be expressed (written) implied (oral). Advertising and sales literature also ount to warrantees to the ultimate consumer and remote consumer can recover damages for breach these warrantees. Product liability cases involve ivy direct and indirect costs.

In USA, National Commission on Product Safety imate that more than 20 million are injured and 00 deaths per year due to products. This lead to enactment of Consumer Product Safety Act there. Consumer Protection Act has also been enacted in country and Consumers' Councils and Courts rk at many places where complaints regarding oduct' can be launched.

Product safety programme should include r policy, duties and responsibilities of personnel in ign, manufacturing, quality control, marketing and vicing. The committee should include Chief gineer, Sales Manager, Service Manager and resentatives from other departments. The committee ll carry out various functions such as review of ign, change required, safety warning signs and rnings, review of accidents and claims and cation of engineers and operators.

Safety Work Permit:

Objects and Types : Some jobs in a factory dangerous to life and therefore well advanced cautions are necessary before their commencement till the completion. Hot work like welding and ing, entering any confined vessel, working at height on fragile roof, opening of dangerous pipelines, tric work and handling dangerous chemicals etc. some example. For the safety from such works, a k permit system is highly essential.

Work permit system requires that authorisation ssued and obtained before any work is performed process. Equipment or area and instruction ained therein must be strictly followed by the mitted workers till the time limits.

A work permit system should cover the wing points -

Who requires a work permit, e.g. contractors, engineers, maintenance workers, etc.

What jobs require a work permit, e.g. all maintenance work, tank cleaning, electrical inspections, etc.

What types of permit are available :

General Work Permit	For work of a non-hazardous or 'cold' work type.
Special Work Permit	For work on live equipment, or hot work.
Confined space entry permit	For work involving entry into confined spaces such as tanks, sewers, excavations where toxic or flammable vapours may be present.
Gas Test Certificate	This may form part of the above permits and specifies what gas tests are necessary at particular periods.
Electrical Isolation Certificate	Specifies what electrical isolations are required and whether locks, earths, notices are to be applied.
There will be occasions when the work to be done requires all the above permits and certificates to be issued.	

4. Who is responsible for issuing work permits - a list should be compiled by management authorising specific persons to be responsible.
5. Arrangements for recording the issue, revalidation and retention periods of permits.

Most Commonly used permits are fire or hot work permit, safe (vessel) entry permit, excavation permit, electrical work permit, chemical area work permit, high height or depth permit and so on.

Who Issues and to Whom : Work permit is issued by supervisor, safety officer or responsible officer of the area and equipment. It is generally issued in the name of a supervisor or technician who has to carry out the required job under his direct supervision.

Contents of the permit : Some contents may very according to the permit but generally the contents are : Name of the supervisor or person to whom it is issued, workplace, equipment, name of the work to be carried out, date and time of start and completion, personnel permitted, details of actions, conditions, equipment, procedure and precautions from the authority who issues it.

The elements of a permit to work system are :

1. Hazards of the plant, chemicals and work are fully explained to the workers involved.
2. Instructions are in details and fully understood by both the parties.
3. Work area should be clearly identified, made safe or the hazards highlighted.
4. In-charge of the area who issues the permit, should be competent and responsible and should sign the document stating that he is satisfied regarding necessary isolation, blanketing etc. completed and it is made safe for the workers to work in that area.

5. The in-charge of the team of workers, who receives the permit must sign the permit stating that he has fully understood the work to be carried out, the hazards potential, precautions, conditions and procedure and the PPE/FFE to be utilised.
6. Any monitoring including gas testing required before, during and after the work should be specified and the results noted on the document.
7. When the work is completed (after necessary extension of the permit if work continues), the work in-charge signs off the permit stating that the specified work has been completed and the plant is in a suitable state to return to operations.
8. The area in-charge signs to accept that the work has been completed and he now accepts the responsibility.

Formats : A format can be designed according to the work but it should cover above mentioned eight points. More care is required when the permit is to be given to a contractor's workers. Necessary equipment must be supplied to them. Some formats are given in Table 19.1 to 19.3.

Table 19.1 : General Format : Safety Work Permit

Permit to Work — Name & Address of the Factory: — Permit No.______ Date :

Date & Time of Issue ____________________
Date & Time of Extension if any ____________________
Date & Time of Validity ____________________
Date & Time of Work Completion and Return of the Permit ____________________

A. Issue

1. Location of work
2. Work to be done
3. Hazards involved
4. Precautions/conditions necessary
5. Equipment to be used
6. Procedure to be followed
7. Special instructions
8. Prior work done and certified.

Necessary isolation, cleaning, purging and testing/monitoring is done and reported below with results :

Name & Designation of the Area in-charge	*Signature Date Time*	*Validity Date Time*	*Ratification by the Safety Department*

B. Acceptance

I have read and understood this permit and will carry out the work as per directions stated above.

Name & Designation of the Work in-charge	*Signature Date Time*	*Completion or Extension required Till* ____________

C. Extension

I have re-examined the situation above and hereby extend this permit to expire at
Date ______ Time ______

Further instructions if any :

Signature	*Date*	*Time*

D. Completion and Cancellation

I certify that the work is completed and the plant can be put to its normal operation.

Signature *Date* *Time*
(By the person who accepted the permit)

I accept the above plant back into service. The permit is cancelled hereby. A new permit will be required if work is to be done again

Signature *Date* *Time*
(By the person who issued the permit)

N.B. : Detailed instructions shall be written in this document. Where possible, Part A shall be ratified by the Safety Department.

Table 19.2 : General Format : Safety Work Permit

Permit to Work

Permit No. ______

Date :

Procedure used shall be in accordance with safety instructions
(Give consideration to each word. Strike out those not applicable)

Name & Address of the Factory :

Plant__________Section/Equipment________Valid Until Date_______Time :_____Hrs.____

PART - A : Preparation

A-1 Following Hazards are possible

- ☐ Gas/Fume
- ☐ Corrosive, Hot & other Liquid
- ☐ Gas or liquid under Pressure
- ☐ Toxic Materials
- ☐ Dust
- ☐ Fire & Explosion
- ☐ Hot Metal
- ☐ Trace Heating
- ☐ Steam Condensate
- ☐ Falling Objects
- ☐ Electricity Mains/Static Electricity/Shock
- ☐ Moving Machinery
- ☐ Overhead Hazards, Cranes etc.
- ☐ Underground Service
- ☐ Traffic (Road & Rail)
- ☐ Radio active substances
- ☐ Noise
- ☐ Work at Height
- ☐ Other (Specify)

A-2 Physical Isolation

☐ Physical isolation is required/not required
The Equipment isolation permit No. ______________________

Method of Isolation

- ☐ Single/Double isolation. valve closed/blind/tagged (no.
- ☐ Lines slip plated Tag Nos.
- ☐ Physical disconnection : open and blanked off
- ☐ Vent. drain or blow off open

A-3 Precautions already taken : ______________________

____

A-4 Hotwork Permit :
☐ A hotwork permit is not necessary.
A hotwork permit is necessary. permit issued no.

A-5 Vessel Entry Permit :
☐ A vessel entry permit is not necessary
A vessel entry permit is necessary. permit issued no.

A-6 Installed Radioactive Source :

☐ There is no installed radioactive source

☐ There is an installed radioactive source and is made safe

I have made the installation safe for the duration of this permit.
By
Signature of qualified person

A-7 Electrical Isolation :

☐ Electrical isolation is not required

Electrical isolation is required and has been made by following methods and tagged (Tag No.)

☐ Fuse withdrawn

☐ Drive Unit Disconnected/Deenergised

☐ Racked out

☐ Locked out Name___________ Signed________

A-8 Other (e.g. Instrument, Cathodic Protection) :

☐ Isolation not required

Isolation required and has been done (Tag. No. ____________)
by (Name) ____________________ Signed ____

A-9 Preparation Completed :

Name________________________ Designation________________ Signature _______________

PART - B : Operation

B-1 Job to be done

B-2 Precautions to be taken.

☐ Wear PVC suit

☐ Wear PVC, Rubber, Leather, Asbestos etc. gloves

☐ Wear Ear Muff/Plugs

☐ Wear Helmet

☐ Wear Full face shield

☐ Wear Goggles

☐ Use Gas Mask for ______________ (gas)

☐ Use Dust mask

☐ Use self breathing apparatus

☐ Use air line respirator

☐ Wear a safety belt with life line

☐ Keep fire extinguisher ready

☐ Keep rescuer available

☐ Use only safety torch/hand lamp

☐ Use only 24 Volts inspection lamp

☐ Use ELCB

B-3 Removal of Equipment

☐ Removal of equipment from the site is not required

☐ Removal of the equipment from the site is required

☐ The equipment is cleaned

☐ The equipment is not clean. Take following precautions

____
____

B-4 Special Instruction

____
____
____

C-1 Issue and Acceptance

	Name	Signature	Date and Time
Issued by	________	________	________
I have read the conditions of this permit.			
Accepted by	________	________	________

C-2 Extension of Validity (Please see on the back)

C-3 Text/Rotation check required

Signature of person making request ________

Electricity restored by ________ Sign. ________

Test run completed/Rotation check correct Sign. ________

Electricity isolated by ________ Sign. ________

C-4 Completion of job

This job is completed : The job site is cleaned and material removed.

Returned by Name & Sign ________ Time and Date ________

C-5 In case of hot work permit/vessel entry permit

The Hotwork permit No. ________ is cancelled

The Vessel entry permit No. ________ is cancelled

Countersigning person have been informed

Sign. ________ Name ________

C-6 Cancellation

This permit is cancelled. Please restore electricity. Remove or restore radioactive source/others.

Name ________ Sign. ________ Date & Time ________

C-7 Installed radioactive sources

I have recommissioned the installation

Signature of qualified person ________

C-8 Electricity Restored

☐ Fuse replaced ☐ Racked in

☐ Drive unit reconnected ☐ Lock removed

Signature ________ Name ________

C-9 Other isolation (Specify) ________

Restored by ________

Sign ________ Name ________

C-10 Details of job done

____

____

____

____

(back page) Instructions (See Part C2)

1. The Permit to Work does not ensure that the job is safe but it tells you the exact state of the job, precautions already taken, precautions to be taken by the permittee and residual hazards associated with the job. Therefore the issuing authority must give consideration to each point/word and strikeout which is not applicable or marked ☐ in the appropriate box. The permittee must read the contents of the permit carefully and follow the instructions and precautions to be taken.

2. In case of any emergency in the plant, the job shall be stopped and the permit shall be treated as cancelled. The work can be restarted after the emergency is over but the permit to work shall be endorsed by the issuing authority before starting the work.

Extension of Validity

C-2 The job is not yet completed. Therefore this permit requires extension of validity.

Extension of validity requested by		Time & Date Up to Which the Validity is requested		Reasons for requesting Extension	The permit is extended i.e. revalidated UPTO :			
Name	Signature	Time	Date		Time	Date	Name	Signature

Table 19.3 : Hot Work Permit

Name & Address of the Factory	HOT WORK PERMIT	Permit No. : Date :

A. Job Details :

Requested by ____________________Dept./Plant____________________Section ____________________

Validity Date ____________________Time : From ______________Hrs. To ____________________Hrs.

Location Details ____

Description of Work :____

____

B. Precautions : Tick (√) in the relevant boxes where applicable and score out the others.

Already taken by operators

☐ Equipment has been properly - Tick (√) in the box

a) depressurised ☐ b) drained ☐ c) washed ☐

d) vented ☐ e) purged ☐ f) steamed ☐

g) gas freed ☐ h) isolated ☐ i) blinded ☐

☐ Surrounding area checked and protected against hazards of spark/fire.

☐ Sewer openings covered/protected.

☐ Frequent explosimeter monitoring required during continuation of job.

☐ Keep fire station informed.

☐ Standby man available for rescue.

☐ (Others) ______________________________

To be taken by Maintenance

☐ Sparks can ignite the material in the surrounding areas. Effectively protect process sewers/material/equipment in the vicinity from a potential fire hazard. Keep the area wet.

☐ Properly ground the equipment and use insulated welding cable.

☐ Keep escape route clear.

☐ Keep fire extinguisher ready

☐ Keep fire hose connected with nozzle for use (not charged)

☐ Use only fire proof gloves/suits.

☐ Make provision to contain the sparks by shielding the job location from all sides using fire blankets.

C. Initial Explosimeter Test : (Indicate the exact locations where the tests are carried out) -

Sr. No.	Location	Explosimeter (LEL) reading	Date	Time	Name	Signature

D. Authorisation :

Shri ______________________of **Dept. :** ___________ **Section** _________ is hereby given permission to carry out the above work. This permit expires at _____ hrs. on ______ unless extended. [see (E) below].

Signature of issuing authority_____________________ Date : __________ Time : __________Hr.

Approved by : ___________ Signature ___________ Date : __________ Time : __________Hr.

Signature of accepting authority _________________Date : __________ Time : __________Hr.

E. Extention of Validity (To be renewed after every shift, **maximum validity 24 hrs.**)

(I) Condition at the site checked and found OK. The Explosimeter reading _____%LEL

Time : _______ hr.

The validity of the above permit extended up to : _____ **hr. on** ___________ **(date).**

Signature (Shift-In-Charge) ________________ Time : ____________ hr. Date : _________

Approved by: Signature :

(II) Condition at the site checked and found OK. The Explosimeter reading _____%LEL

Time : _______ hr.

The validity of the above permit extended up to : _____ **hr. on** ___________ **(date).**

Signature (Shift-In-Charge) ________________ Time : ____________ hr. Date : _________

Approved by: Signature :

F. Work Compleion (By the Maintenance Group) :

The work is completed. Area cleaned up. The permit returned to the issuing authority at

_____ hr, date _______ **Name :** ________________________ **Signature :** ________________

G. Job Acceptance : (By Issuing Dept.) - The job has been completed and the work area has been restored in its original condition. Hence, **the permit is hereby cancelled.**

Name : _______________________Signature : ____________ Time : _______hr. Date : _______

The format of the permit to work should be designed by the safety officer, safety consultant or an experienced engineer of the company. Well thought precautions and safety measures can certainly minimise the accidents.

Vessel Entry Permit : Under section 36 (2) of the Factories Act 1948, no person in any factory shall be required or allowed to enter any confined space (chamber, tank, vat, pit, pipe, flue etc. having dangerous fumes likely to involve risk) until all practicable measures have been taken to remove any fumes which may be present and to prevent any ingress of fumes and unless a certificate in writing has been given by a competent person based on a test carried out by himself that the space is free from dangerous fumes and fit for persons to enter or such person is wearing suitable breathing apparatus and a safety belt securely attached to a rope (life line) the free end of which is held by a person outside the confined space.

Isolation of the vessel from sources of energy or harmful substance by way of cooling, disconnection, blinding, blanking etc., draining, cleaning, washing and purging to make free from toxic gases, testing the air for oxygen or toxicity content, opening top and bottom connections for good ventilation, lighting and exit, wearing safety belts, helmet and suitable breathing equipment, allowing low voltage (24 volts) light, standby arrangement etc. are essential requirements.

See Part 2.2 of Chapter 16 and Part 16.2 of Chapter-18 for safe entry procedure to confined spaces.

Hot work Permit : For welding and cutting, working with open flames or sparks due to grinding, chiselling etc. or where hot work is dangerous or may cause fire, Hot work or Fire Permit is necessary.

The area must, first, be made free from hazards of fire and explosion. Tests for explosive air mixture or possibility should be carried out. All lines to the vessel shall be blinded or disconnected. Sufficient vents and flameproof light shall be provided. Fire protection and alarm shall be kept ready. Dangerous work shall not be allowed in the vicinity. Water facility shall be used to extinguish sparks, hot slugs etc.

See Table 19.3 for a Hot Work Permit.

Electrical Work Permit : The model form of permit-to-work is given in IS:5216 (Part-I).

Department of power generation, distribution, control etc. issues permit in the name of Electrical recommendation or delays necessary to make changes should be explained. The accident causation should be applied to all identical cases in other departments also to prevent similar recurrences.

3.10 Record Keeping :

Record of accidents reported to the plant management and to the Government authorities, facts collected as a result of investigation, analysis of the facts, conclusion about remedial measures necessary and status of implementation of those measures must be kept in a well documented form. Computer is more useful in this regard. In DCS system, printouts of accident situations at the time of accident should be kept out and preserved.

Safety department should design formats of safety records applicable to the factory, train personnel to fill such records and maintain them.

Records keeping may be ordinary or computerised and in much details. Good record is always useful for-

1. Studying past accident causes and remedial measures concluded.
2. Monitoring status of implementation of safety measures.
3. Taking decisions regarding future action in the matters of safety.

Period of maintaining record should be decided depending on the utility of the subject matter.

4. HAZARD AND RISK MANAGEMENT TECHNIQUES:

This subject requires clear understanding of definitions and difference between hazard and risk, analysis and assessment etc.

4.1 Hazard, Risk & Detection Techniques:

For definitions of hazards and risks see parts 3.34 and 3.75 of Chapter 2.

Risk results from hazard i.e. an unsafe condition, action or situation. Risk is the probability or frequency of hazards during a certain period (e.g. 2 explosions per year, 20 fires per year, 5 accidents per month, 200 fatalities per year, 1 disaster per 10 years etc.). Therefore if hazard is identified and removed first, risk is automatically reduced.

Some definitions are as under:

Hazard is the inherent property of a substance or unsafe condition, unsafe action or situation to cause harm which may cause *human injury, damage to property* or the *environment* or some combination of these criteria.

Chemical Hazard is a hazard due to chemical (including its storage, process, handling etc.) and it is realised by fire, explosion, toxicity, radiation etc.

Risk is the likelihood, chance, frequency or probability of an undesired event (i.e. accident, injury or death) occurring within a specified period or under specified circumstances and its severity, effect or consequences.

As per example risk of death for a man aged 30 is 1×10^{-3} per annum and that for a man aged 60 is 1×10^{-2} per annum.

This means death possibility of a man aged 30 is 1 out of 1000 per year, while that of a man aged 60 is 1 out of 100 per year. Risk unit '1×10^{-n} means $1/10^n$ i.e. one time event out of 10^n such occurrences during a period (e.g. 1 year).

Individual Risk is the frequency at which an individual may be expected to sustain a given level of harm from the realisation of specific hazards.

Societal Risk is a measure of the chances of a number of people being affected by a single event or set of events and is often presented as f/n curves. (i.e. frequency v/s number of people affected).

Almost all human activities involve some risk and zero risk is not possible. Therefore the concept of **Acceptable risk** is developed and Fischoff defines it as 'the level which is good enough where the advantages of increased safety are not worth the extra costs of reducing risk'. Thus it indicates the balancing condition of accident costs v/s preventive costs.

Hazard and Risk distinguished:

For example, banana skin lying on the road is a hazard but 2 persons falling per hour due to that, is a risk. Non-provision of safe overflow pipe is a hazard but weekly overflowing of the tank due to that, is a risk. Process of sand blasting is a hazard but contracting of silicosis by a worker at any point of time, is a risk. Storage of toxic gas is a hazard but due to its escape and effects, probability of deaths of 100 persons per 10 years, is a risk. Not providing a safety valve is a hazard but bursting of vessel once in 5 years, is a risk. Bad housekeeping is hazard but 2 accidents per month or 20 workers leaving the job every year due to it, is a risk.

Thus identification, analysis and assessment of hazards are different than the identification, analysis and assessment of risks, though both are interrelated. Factors of time, frequency or ill effects (consequence) are added in 'risk' distinguishing it from 'hazard'.

Some definitions relevant to risks are as under :

1. **Exposure to Risk** : A situation created whenever an act or omission gives rise to possible gain or loss that cannot be predicted.
2. **Cost of Risk** : The cost imposed upon organisation because of the presence of risk. Its component parts are (1) the cost of losses that do occur and (2) the cost of uncertainty itself.
3. **Risk Management** : A general management function that seeks to identify, assess, address, control and review the causes and effects of uncertainty and risk on an organisation.
It includes assessment, control, financing and administration of risk as defined herein below.

4. **Risk Analysis :** Technical process of identifying, understanding and evaluating risk (analysing cause and effect wise).
5. **Risk Assessment :** It is a judgement of significance or activities that enable the risk manager to identify, evaluate and measure risk and uncertainty and their potential impact on the organisation.
   This judgement can be taken when the measured value of hazard or risk is compared with the value or standard legally or otherwise prescribed. This calls for an expertise of an industrial hygienist.
6. **Risk and Uncertainty Assessment :** All activities associated with identifying, analysing, measuring, comparing and concluding risk and uncertainty.
7. **Risk Control :** All activities associated with avoiding, preventing, reducing or otherwise controlling risks and uncertainties.
8. **Risk Financing :** Activities providing means of reimbursing losses (i.e. finance for the cost of risks and losses) that occur and that fund other programmes to reduce risks and uncertainties.
9. **Risk Administration :** Activities and strategies associated with the long-term and day-to-day operation of the risk management function.
10. **Risk Selection :** The control technique best described as the conscious acceptance of risk in accordance with an organisation's overall goals, objectives and risk taking philosophy.
11. **Risk Avoidance :** A risk control technique whereby a risk is proactively avoided or abandoned after rational consideration.
12. **Loss Prevention :** Those strategies and activities intended to reduce or eliminate the chance of loss.
13. **Loss Reduction :** Activities minimising the impact of losses that do occur.
14. **The Risk Chain :** Five elements or links connected with accident i.e. hazard, environment, interaction, outcome and consequence.
15. **Subrogation :** Risk transfer by legal document as a loss reduction tool.
16. **Risk Transfer :** If risks cannot be controlled, the last resort is to transfer the risk by contract of job, or property or insurance to pay for losses.
17. **Risk Retention :** A risk financing method in which the organisation experiencing a loss retains the risk by self financing or borrowed funds, or by a group to which the organisation belongs. Retention may be passive or active, unconscious or conscious, unplanned or planned.
18. **Information Management (as a risk reduction tool) :** The use of information for the express purpose of reducing uncertainty or for enhancing stakeholder awareness or knowledge of organisational risks.

Hazard detection techniques :

Unsafe acts and **unsafe conditions** must be observed to find out hazards. Statutory accidents reports (e.g. Form 21 & 29 GFR) should be seen to detect past accident causes. Unsafe acts due to psychological and physiological personal factors should be detected as explained in Chapters 3 and 4. Hazards of unsafe conditions are mechanical, electrical, chemical (including radiation) and environmental. Some hazards are visible and some invisible.

Visible hazards can be detected by various techniques such as (1) Plant inspection based on statutory requirement, checklist, safety survey, safety audit and safety sampling (2) Detection and monitoring systems (3) Functional test of machinery and equipment (4) Accident investigation (5) Repair shop (6) Store consumption and (7) Shop feed back etc.

Examples of visible hazards are unguarded machinery, bad housekeeping, wrong practices etc. To discover such hazards careful planning and inspecting system is necessary. Some steps are : (1) Make a list of all statutory applicable provisions of the Factories Act and other Acts, make a survey of the plant to compare the existing provisions and find out the missing provisions (hazards) for implementation (2) Make a list of materials, processes, operations, vessels, equipment, machinery and classify them as hazardous and non-hazardous. Chemicals should be classified according to their hazardous properties. (3) Prepare layout of plant, machinery, equipment, premises and utility services like power, water, air, gas and heating / cooling media. From these prepare a list of possible hazards. (4) By means different techniques mentioned in Part 1 and 2. Further details of the hazards should be detected and (5) By means of a detailed inspection report preventive measures should be suggested.

Invisible hazards like gas leaks, concentration of toxic and hazardous vapour, malfunction or failure of machinery, equipment, pressure plants and miscellaneous environmental factors may cause sudden accident and heavy damage. They must be detected and controlled by built in self corrective systems. The devices used are detectors, recorders, alarms, trips, probes, sensors, limit switches, meters, analysers, electronic or auto controls, scrubbers, incinerators etc.

In modern machines various automatic movements take place near and around point of operation. Feeding devices, clamping action and work head movements should be interlocked with each other. Each position of these elements must be sensed and linked with command controls. Any malfunction of moving elements is indicated on audio-visual panel and the machine stops.

Repair shop data reveals clues to unsafe conditions like poor design, defective material, poor construction, wear and tear etc. Repetitive repairs indicate major hazards. Similarly store consumption data also indicates some defects. There should be a regular feedback of information from repair shop, stores, operators and foremen to monitor hazards and to take corrective actions.

Heating equipment should have temperature controllers and additional thermostats for better protection and to give audio-visual signals and to cut off power supply or heat source. In furnaces using flammable fuel in sealed chamber, the components are charged through hydraulically operated carriages and such carriages, fuel flow and flame curtain are sensed by various gadgets like photo-sells, probes, limit switches etc. Failures are sensed and indicated on panel. Suitable corrective actions are automatically taken viz. purging nitrogen etc. Toxic exposures are neutralised by scrubbers. Flammable exposures are controlled by flameproof fittings, flare and vents. Effluents are treated in treatment plants to nullify their harmful effects.

1. Hazard Identification (Identify sources and causes of hazards).
2. Hazard Analysis (Analyse how hazards will occur and affect).
3. Risk Analysis (Estimate risk i.e. hazard occurring per unit time).
4. Risk Assessment (Compare the risk with acceptable criteria – legal, social or political – and decide whether the risk is lesser or higher than that criteria), and
5. Risk Management (Form organisation to carry out above exercises and to monitor, control, review and keep the risks within permissible limits).

A stage of '*Hazard Assessment*' is also possible after hazard analysis. When hazard is compared with its standard prescribed e.g. noise level, light, air flow or chemical exposure (TLV, STEL, LD/LC etc.) is compared with their statutory values or Indian Standards and inference is drawn about their difference (measured value- prescribed value), it is called hazard assessment.

4.2 Hazard and Risk Progression Chart :

Process of Risk Management in six stages is explained below in a progression chart -

Hazard and Risk Study Progression Chart

Stages of hazard and risk studies	Hazard identification	Hazard analysis	Risk analysis	Risk assessment	Risk management
1. Identification of source of hazards and their causes.	Qualitative (i.e. HAZOP)				
2. Analysis of mechanism of hazard occurrence. 3. Analysis of terminal consequences of hazards.		Qualitative (i.e. HAZOP)			
4. Probability or frequency of a hazard occurring and thence an estimation of risk.			Qualitative		
5. Judgement of acceptability of risk against social, political or local criteria.				Usually Quantitative	
6. Making decisions and establishing ownership of action and monitoring to contain within limits of criteria.					Mixture of Qualitative and Quantitative

4.3 Risk Analysis, Assessment and Management :

Procedure of Risk Management is Stated below which includes Risk Analysis and Assessment.

4.3.1. Five Steps as per HSE (U.K.) guidelines (Qualitative):

1. Look for the hazards.
2. Decide who might be harmed and how.
3. Evaluate the risk and decide whether the existing precautions are adequate or whether more should be done.
4. Record your findings.
5. Review your assessment and revise it if necessary.

These steps suggest simple method of Risk Assessment for any hazardous activity.

It is qualitative only. No factor is quantified. Effect of control measures is taken into account.

4.3.2. Five steps as per Risk Assessment Methodology (Qualitative and Quantitative):

1. Identification of sources of hazards and their causes. It is qualitative. e.g. HAZOP.

   This step is known as **"Hazard Identification"**.

2. Analysis of -

   (i) Mechanism of hazard occurrence and

   (ii) Terminal consequences of hazards.

   This is quantitative e.g. HAZAN. Consequence analysis quantifies concentration, deaths, injuries and damage. (e.g. damage distance and effect).

   This step is known as **"Hazard Analysis"**.

3. Probability, frequency or likelihood of hazard occurring and thence an estimation of risk.

   This is also quantitative as it depends on failure rates, number of chances or cycles and reliability engineering.

   This step is known as **"Risk Analysis"**.

4. Judgment of acceptability of risk against legal, social or political criteria.

   Here measured value of hazard or calculated risk is compared with permissible safe limit (e.g. Sch. 2, Factories Act, GPCB norms etc.) and then inference is drawn whether hazard or risk is higher or lower than the permissible safe limit or standard.

   Therefore, this is usually quantitative.

   This step is known as **"Risk Assessment"**.

5. Decision making and taking control measures to prevent, reduce or transfer the risks, by short and long term planning.

   This is a mixture of qualitative and quantitative criteria.

   This step is known as **"Risk Management"**.

   Risk or Safety Manager should assist the top management in this regard.

4.3.3. Types or Methods of Risk Assessment:

(1) Simple or Qualitative Risk Analysis:

It is an identification of hazards and taking appropriate control measures.

It is as per Five steps explained in para (A) above.

Here quantification of hazards and their terminal consequences (damage distances, severity of injury or loss etc.) are not worked out.

It is sufficient to think about the adequacy of existing control measures vis-à-vis hazards identified and to adopt more safety measures if necessary.

Its important aspect is to consider the effect of control measures provided (in place) and to think for the 'Residual Risk' and 'Residual Control Measures' only.

(2) Quantitative Risk Assessment (QRA):

Here hazard potential is quantified, possible risk is also determined if failure rate data available and then it is **compared with** the 'permissible standard'. This will indicate whether calculated risk is lower or higher than the permissible limit. Based on this, new control measures or modification in existing control measures can be decided.

Generally theree methods of QRA are in practice as under.

Method 1 : Matrix using Materialwise Risk Assesment

Hear formula Risk = Severity x Probability is utilized. Materialwise **'hazard potential'** is classified and quantified as under.

1. Properties of the material.
2. Storage parameters.
3. Process parameters.
4. Manual exposures.
5. Visible or measured hazards.
6. Transportation hazards.
7. Pollution hazards.

These values give **'severity'** part of the risk.

Similarly values of **'Control Measures provided'** **can be classified and quantified** depending on the poor controls to the best controls. Classification of good, better and best control measures, is necessary. These values give **'probability'** part of the risk.

Then by using the formula, Risk = Severity x Probability, the existing risk level can be calculated and identified as low, high, higher or highest risk.

This method is useful to carry out 'material wise' risk assessment. This method is mostly useful for assessing risks to workers in the factory. Hazards are considered material wise and effect of control measures is multiplied. Therefore, this method gives residual risk assessment.

Method 2 : Matrix using Activitywise Risk Assesment

Here instead of materials, activities and sub activities are classified and quantified by assigning appropriate values (quantities) depending type of hazards. Each sub activity (probability part of the risk) and each status of control measure (severity part of the risk) are assigned sub value (quantity) and then they are multiplied to get R = P x S. Then using the matrix risk is assed as low, medium and high.

In both the above methods, efforts should be made to reduce the "residual risks" to further low level for the perpose of safety.

Method 3 : Method based on Computer Model

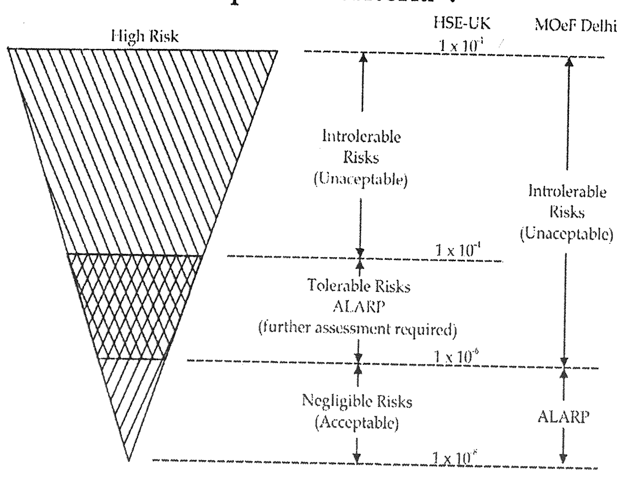
This method is mostly useful for accessing risks to public in vicinity. Gas dispersion models are used and toxic concentration or / and heat radiation effect or / and explosion over pressure effect at different distances (damage distances) are calculated.

Here it is assumed that if all or some control measures may fail, what would be the highest risk (mostly to public) in terms of toxic effect, fire, explosion or BLEVE effect and at what distances.

This calculation is very complex, needs 'source strength calculation', leak hole or release dimensions, mass released or release rate, wind speed, weather conditions and classification, path obstructions or sinking mechanism, dispersion calculation and use of computer models. Gaussian, Safety, Phast, Aloha, Cirrus, Archie, IIT-Kanpur, Whazan, Effect etc. are such computer models for assessment of this type of risks. Lastly foot prints and risk counters are to be interpreted. **Risk counters** plotted on geographical plot plan can give Arial view of the area likely to be affected and decision for **evacuation** or **stay-in** condition.

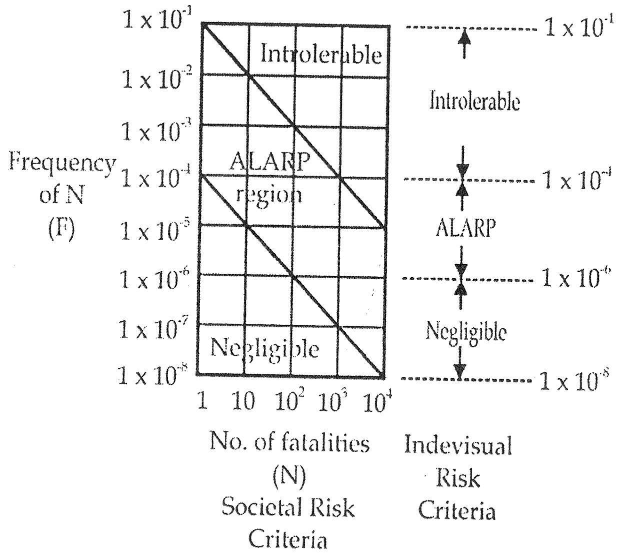
Main purpose of this type of risk assessment is to assess the risk to the **Public** and to make **Off-site Emergency Plan** based on those risks.

4.3.4. Risk Acceptable Criteria :



Frequency (probability)wise nebligible, tolerable and intolerable risks are shown in the figure. ALARP means 'as low as reasonably practicable' risk. Control measures are should be provided to achieve ALARP level of risk. If ALARP level is not achievable, further assessment is necessary to reduce the risk.

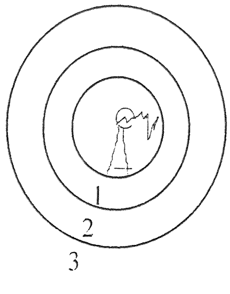
F-N curve for Societal Risk : HSE - UK :



Frequency (F) verses number of fatalities (N) are ploted in the figure to show societal risk criteria. Ranges of risks are shown as negligible, ALARP and intolerable.

4.3.5. Risk Counters (foot prints):

In case of toxic dispersion, normally three zones are considered. The inner most or zone-1 contains the highest concentrations of leaking gas wherein maximum fatality/injury can be predicted. No entry or no rescue operation may be possible there. Then in intermediate or zone-2, evacuation becomes most necessary and must be carried out at the earliest possible otherwise great fatalities or/ and injuries may result. This



is the target area of emergency planning and rescue activities. But in doing so, use of necessary personal protective equipment and vehicles is to be done very carefully. The outermost or zone-3 is a safe zone but it can be affected also if dispersion aggravates or lasts for a longer time. Therefore alert and warning action is required in this zone. People must be advised to go away by their own arrangement and should be helped if necessary.

Use of risks counters is useful in On-site and Off-site Emergency Plans for the judgement of area likely to be affected and emergency preparedness for evacuation and other emergency activities.

4.3.6 Types of Risk Control Measures or Elements of Risk Management :

They are as under:

(a) Mission Identification:

1. Establishing risk management policies and procedures.
2. Risk communications.
3. Management of contract portfolios.
4. Claims supervision.
5. Reviewing, monitoring and evaluating the risk management programme.

(b) Risk and Uncertainty Assessment:

1. Hazard identification.
2. Risk analysis.
3. Risk measurement.
4. Risk assessment.

(c) Risk Control:

1. Risk avoidance.
2. Risk or Loss prevention.
3. Risk or Loss reduction.
4. Information management.
5. Risk transfer. (Contract).

(d) Risk Financing:

1. Risk retention.
2. Risk transfer (Insurance).

(e) Programme Administration:

1. Day to day or short term planning.
2. Long term planning.

4.3.7. Risk Management Activities :

Basic steps of Risk Management are :

1. Identify the Hazards.
2. Analyse the Risk.
3. Select and Evaluate Remedies.
4. Implement any necessary Safeguards.
5. Audit & Review if necessary.

Risk control also includes methods to improve understanding or awareness within an organisation of activities affecting exposure to risk.

Risk reduction activities can be focused on-

1. Altering or modifying the hazard.
2. Altering or modifying the environment in which the hazard exists.
3. Intervening in the processes whereby hazard and environment interact. e.g. fire walls within a structure to separate fire-prone area from other area, shock absorbers to stop transfer of vibrations, silencers to stop transfer of noise, insulation to stop transfer of heat or electricity etc.

If however, risks cannot be controlled, the last resort is to **transfer** the risk by contract of job or property, or insurance to pay for losses. Risk transfer offers complete protection for the transferor. The burden of risk falls completely on the transferee. In case of accident causing injury, death or damage to property, money can compensate the financial losses but not the pain, suffering and loss to families. Thus risk transfer cannot eliminate all effects of risk. *Engineering risk control is the only best remedy.*

Risk Managers' duties *include* -

1. Assisting organisation in identifying risks.
2. Implementing risk control programmes.
3. Reviewing contracts and documents (e.g. safety audit, emergency plan, safety reports etc.) including insurance for risk management purposes.
4. Providing education and training on safety matters.
5. Implementing statutory provisions.
6. Arranging non-insurance financing schemes (e.g. self-insurance or captive insurance subsidiaries).
7. Claims and litigation management.
8. Designing and co-ordinating employee benefit programmes.

4.4 Preliminary Hazard Analysis (PHA) and Hazard Analysis :

This is an initial study to determine hazard causes, effects and controls. Facts of proposed product, process or operation are to be known to determine hazards. For example, for the product using electric power the hazards to be presumed are: electric shock, burns, fire, sparking, hot surface, inadvertent starts of equipment, failure of the equipment to operate at a critical time to cause accident, radiation effects, electrical explosions etc. Similarly adverse effects of foreseeable causes like chemical exposures, reactions, acceleration, mechanical effects, pressure etc. can be listed. Then appropriate remedies are selected and applied.

Since the PHA is fast, cost effective and not complicated like other methods of hazard assessment, it should be adopted as the first step. Its basic steps are as under :

1. Assume a type of accident or hazard possible (e.g. fire, explosion, toxic release, finger cutting etc.)
2. Find out which plant component, system or machine can cause this accident (e.g. storage vessel, reactor, pipeline, circular saw etc.).
3. Find out the event (result) initiating the hazard or accident (e.g. release of explosive or toxic gas, runaway reaction, leakage, running without guard etc.).

This will naturally suggest the corresponding safety devices (safety valve, rupture disc, alarms, gauges, guards, interlocks, trips etc.).

The component system or part in step-2 can then be further examined and analysed for details of failure and how to remove them.

This study indicates which system is more or less important from major hazard point of view and to limit the assessment to priority problems and screening less important ones.

Preliminary hazard identification is required at different stages of project as under :

1. R & D : Chemicals, reactions, impurities and pilot plant.
2. Pre Design : Hazard indices, hazard studies.
3. Design : Process design checks, HAZOP, Failure mode and effects.
4. Commissioning : Safety audits, mechanical commissioning tests, NDT, emergency planning.
5. Operation : Condition and corrosion monitoring.

PHA is generally used for early identification of hazards. It is based on –

Raw materials.	Operating environment.
Intermediates.	Operations.
Final products.	Other facilities.
Plant equipment.	Safety equipment etc.

Interface among system components.

For Hazard Analysis see Part 3.35 of Chapter 2. Based on this definition detailed analysis should be carried out.

4.5 Failure Mode and Effect Analysis (FMEA) :

This procedure considers each component of a plant in turn and all possible failure modes and rates and their consequences. The results are recorded in a standard format. HAZOP study is a well developed form of FMEA.

It is a process of hazard identification where all known failure modes of components or features of a system are considered in turn and undesired outcomes are noted.

It is a tabulation of system/plant equipment failure modes. Each failure mode assigns critical ranking. Human error/ operational error is not generally examined in FMEA.

This is the method derived from reliability engineering. A product or a piece of complex equipment is divided in its components and each component is studied to know how it can fail, at what rate and what could be the effect on it or on the other components. Failure rates of each item are determined and listed. The method is used to determine satisfactory operational life of an equipment, how failures might occur, modes and frequencies of failure and the necessity for proper and timely maintenance and replacements. This knowledge can be used to improve the life and quality of the product. Thus it is primarily more useful to a manufacturer than its user.

FMEA has its own limitations. Data of failure rates and calculations for failure frequency must be correct. The method cannot analyse the problems created by bad design, adverse environment and operators' errors.

FMEA consists of imaginatively constructing every conceivable situation that could arise with the component, including its designed failure point (life expectancy) and its effect on related components. Considerable imagination with much experience is needed to foresee how a component of the system can cause an unwanted occurrence.

Failure Effect Analysis can be tabulated as under :

Item No.	Assumed Failure	Possible Causes	Symptoms	Consequences
1	2	3	4	5

Compensating provisions	Effect on	Probability of occurrence	Failure classification	Remarks
6	7	8	9	10

In above table, compensating provision identifies what should be done to avoid the consequence of the assumed failure.

Probability of occurrence is the average elapsed operating time before a failure of the assumed type will occur.

Probability of occurrence can be expressed in terms of average time between failures as under :

Probable : 1 failure before 10000 hours of operation.

Reasonably Probable : 1 failure during 10001 to 100000 hours of operation.

Remote :	1 failure during 100001 to 10 million hours of operation
Extremely remote :	1 failure after 10 million hours of operation

Failure frequency data is difficult to obtain. It is obtained from two types of testing of component i.e. performance test or reliability test.

Failure classification distinguishes between the possible effects of the assumed failure. A four-part classification is safe, marginal, critical and catastrophic indicating increasing severity.

4.6 Hazard and Operability(HAZOP) Study :

See Part 3.40 of Chapter-2 for basic discussion.

HAZOP is defined as 'The application of a formal systematic critical examination to the process and engineering intentions of the facilities to assess the hazard potential of mal-operation or malfunction of individual items of equipment and the consequential effects on the facility as a whole'.

In HAZOP a multidisciplinary team searches deviations from design intent through fixed sets of guide words or checklists or knowledge.

HAZOP can be conducted to check the designs or operating procedures for a new project or an existing one. It can also be conducted to improve safety of existing facilities. It is also useful before implementing significant modifications or for other operational or legal reasons. After carrying out the Preliminary Hazard Analysis (PHA) as explained earlier, the plant component, system or machine/ equipment part which can cause 'major hazard' becomes known to us. Now to find out deviations or malfunctions leading to such event and its mode of operation, HAZOP helps us. Thus HAZOP is complimentary to PHA.

HAZOP study is carried out to determine deviations from normal operation and operational malfunctions which could lead to uncontrolled events.

Although the HAZOP study was developed to supplement experience-based practices when a new design or technology is involved, its use has expanded to almost all phases of a plant's life. It is based on the principle that several experts with different backgrounds can interact and identify more problems when working together then when working separately and combining their results.

Therefore HAZOP study is performed by a multidisciplinary expert group always including workers familiar with the installation.

The examination procedure takes a full description of the process, systematically questions every part of it to discover how *deviations* from the *intention* of design can occur and decides whether these deviations can give rise to *hazard*.

Each part of design is analysed with questions formulated around a number of guide words, which ensure that the question posed to test the integrity of each part of design will explore every conceivable way in which that design could deviate from design intention and then each deviation is considered for what the consequences it could lead to. The potential hazards are noted for remedial action. Trivial or meaningless consequences are dropped out.

Stages at which HAZOP can be carried out are:

1. At an *early* stage of development to decide the site and identify major hazards.
2. At *design freeze* stage i.e. when design is completed and construction is to be started.
3. At *pre-start-up* stage i.e. when construction is completed and the operation is to be started.
4. Studies on *existing plants.*
5. Studies *prior to plant modification.*
6. Studies *prior to taking a plant out of service.*
7. Studies on *research facilities.*

Procedure for HAZOP study follows the sequence- (1) Define objective and scope (2) Select the team (3) Prepare for the study (4) Carry out the examination (5) Follow up and (6) Record the results.

The objectives may be (1) to check a design (2) to decide whether and where to build (3) to decide whether to buy an equipment (4) to obtain a list of questions to put to a supplier (5) to check running instructions and (6) to improve the safety of existing facilities etc.

The team may be composed of Mechanical Engineer, Chemical Engineer, R & D Chemist, Production Manager, Project Manager, Instrument/ Electrical Engineers, Civil Engineer etc. The team should not be too large. The team is headed by an experienced specialist from works management or by a specially trained consultant.

After examining one part of the design and recording potential hazards if any, the study proceeds to examine the next part of the design and it is repeated until the whole plant has been studied.

The Preparative Work includes four stages (1) Obtain the data (2) Convert the data into a suitable form (3) Plan the sequence for the study and (4) Arrange the necessary meetings.

After discovery of a hazard, follow-up action becomes necessary. There may be a number of possible actions. Generally they are of four types :

1. Change in the process (material, recipe etc.).
2. Change in process conditions (pressure, temperature, flow etc.).
3. Alteration to the physical design including safety guarding.
4. Change of operating methods.

While choosing between such possible actions, two categories become relevant :

1. Those actions which remove the cause of hazard.
2. Those actions which reduce the consequences.

Obviously the first category is first preferable. But then the study should be carried out at *design stage* to execute it at the minimum cost and better integrity.

Suppose the hazard is 'sudden evolution of gas and pressure due to it'. For this, four actions are possible -

1. Change the material to eliminate the possibility of gas generation.
2. Change the process condition (e.g. cooling, catalyst, low temperature, temperature control and cut off etc.) to control the gas generation.
3. Provide safety valve/rupture disc and vent for safe discharge.
4. Provide personal protective equipment.

Action-1 is 100% effective and should be the first choice. Action-2 may be selected, if Action-1 is not possible and reliability of the control system is good. Action-3 may be selected, if Action-2 is not possible and effective only if the vent and dump-vessel can be designed to cope with the full discharge. Action-4 is the last resort if Action-1, 2, 3 are not possible or not effective.

Recording needs 'hazard file' containing -

1. Copy of the data as under :
   (1) Process description, process flow diagram, material and enthalpy balances.
   (2) Piping and instrumentation diagrams.
   (3) Process equipment layouts - plan, elevation and section.
   (4) Operating manual.
   (5) Safety manual.
   (6) Vendor information (P & I diagrams).
   (7) Equipment specification sheets.
   (8) Piping specifications.
   (9) Plot plan.
   (10) MSDS for materials.
   (11) Any reports on safety reviews.

   Copies of such documents should be marked by the team leader stating that they are examined.
2. Copy of all the working papers, questions, recommendations, redesigns etc. produced by the team and others as a result of the study.

The file should be retained on the plant and a report be prepared for the guidance of the managers.

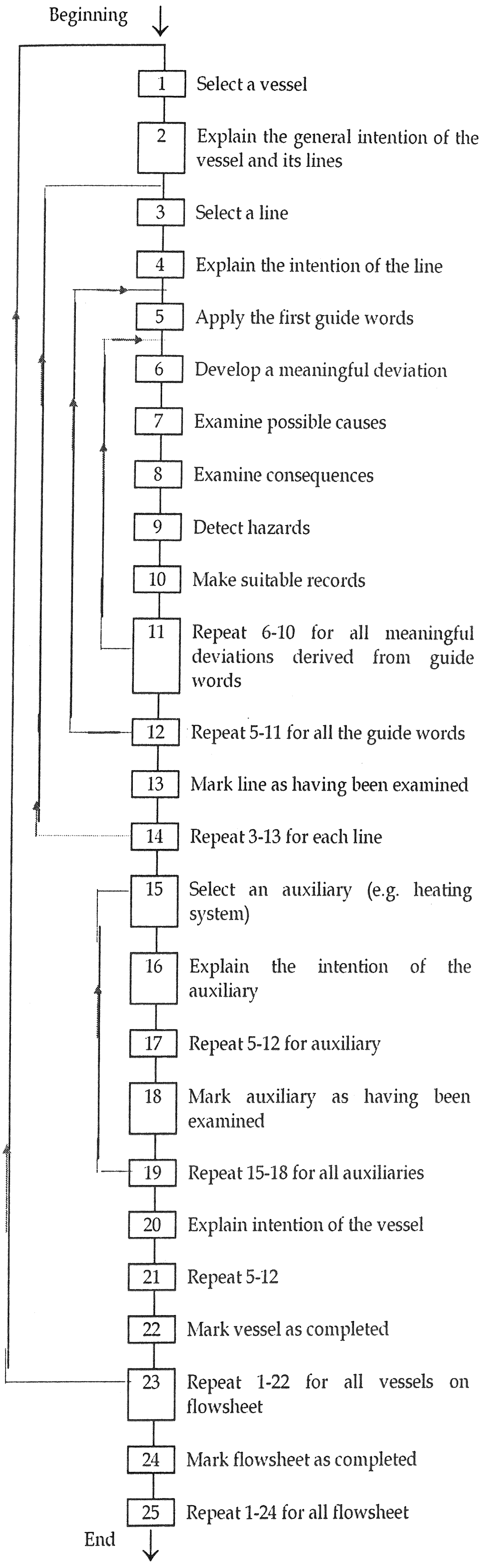
Guidewords used in HAZOP are given below.

A List of some Guide Words

Guide Words	Meanings	Comments
NO or NOT	The complete negation of these intentions	No part of the intentions is achieved but nothing else happens.
MORE LESS	Quantitative increases or decreases	These refer to quantities + properties such as flow rates and temperatures as well as activities like 'HEAT and 'REACT'
AS WELL AS	A qualitative increase	All the design and operating intentions are achieved together with some additional activity.
PART OF	A qualitative decrease	Only some of the intentions are achieved; some are not.
REVERSE	The logical opposite of the intention	This is mostly applicable to activities, for example reverse flow or chemical reaction. It can also be applied to substances, e.g. 'POISON' instead of 'ANTIDOTE' or 'D" instead of 'L' optical isomers.
OTHER THAN	Complete substitution	No part of the original intention is achieved. Something quite different happens.

A **Sequence of Study** proceeds as follows.

Sequence of HAZOP Examination



Various methods for HAZOP studies are described by DOW Safety Guide, HAZOP studies by ICI, by Chemical Industry Safety and Health Council (CISHC), by Kletz, Gibbsen, Lawley and other experts. The basis of studies may be a word model, a process flow sheet, a plant layout, fault free technique etc.

See Reference No. 29 for more details.

4.7 Hazard Ranking (DOW & MOND Index):

This is a method of identifying and ranking of hazards present in a process plant. It was developed by Dow Chemical, USA and is usually known as Dow Fire and Explosion Index. ICI improvement on this is known as Mond Index.

The index provides weightage for inventory, flammability, reactivity, toxicity and hazards due to reaction exotherm, operating condition, corrosivity, plant drainage, access, rotating equipment, leaky joints etc.

The ranking indicates damage radius, maximum probable property damage (MPPD) and maximum possible days outage (MPDO). The ranking is useful for decision making, for example, it shows why protection is more extensive in LPG storage sphere than LPG reflux drum.

DOW and MOND Index:

Various hazard indices have been developed to (1) *Quantify* the expected damage due to fire, explosion or toxicity (2) *Identify* the equipment that would create or escalate an accident and (3) *Communicate* such risk potential to management to take necessary remedial measures e.g. increasing separation distance, erecting a blast wall or fireproof construction and revision of fire fighting and gas control facilities.

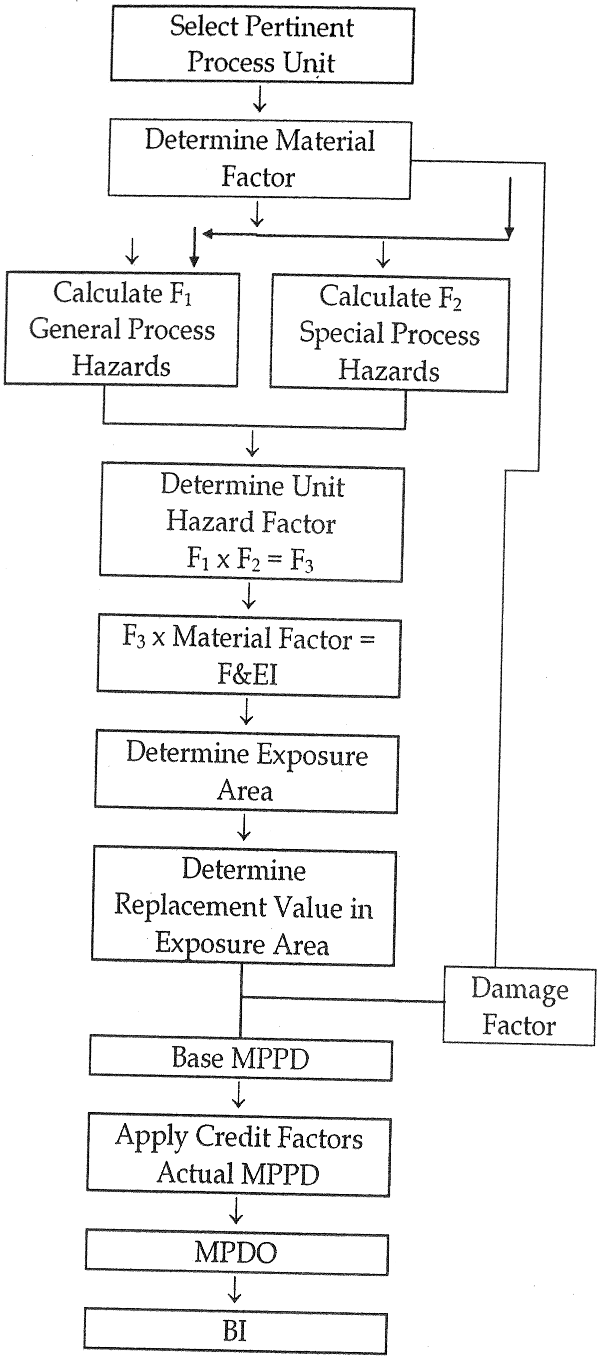
The most famous and widely used hazard index is the *Dow Index* developed by the Dow Chemical Company of USA since 1964. The *MOND Index* is an extended Dow Index based on the similar methodology with an useful extension e.g. to estimate fire load of an area and a unit toxicity index.

In the first three editions the methods of determining the Fire and Explosion Index (F & EI) were developed and in the fourth edition, the method of calculating Maximum Probable Property Damage (MPPD) from the F & EI was suggested and a Toxicity Index (TI) was introduced. For details the Company's *Guide* has to be referred.

To develop an F & EI and risk analysis summary, we need -

1. An accurate plot plan of the plant.
2. A process flow sheet.
3. An F & EI Hazard Classification Guide.
4. An F & EI Form.
5. An Unit Analysis Summary.
6. A Plant Risk Analysis Summary, and
7. A cost data for the installed process equipment under study.

A schematic diagram of procedure to calculate F & EI, MPPD, MPDO (Maximum Probable Days Outage) and BI (Business Interruption loss) is shown below.



As revealed from the figure, the procedure for assessment is summarised as under -

1. Identify on the plot plan any Process Units that are considered pertinent to the process and that would have the greatest impact on the magnitude of a fire or explosion.
2. Determine the Material Factors (MF) for each process unit. It can be calculated from flammability and reactivity, or from its ready table (some figures are given below).
3. Evaluate each of the contributing hazard factors listed on the F & EI Form, under 'General Process Hazards' and 'Special Process Hazards' and apply the appropriate penalties. This will give F_1 and F_2.
4. Unit hazard factor $F_3 = F_1 \times F_2$. This gives the degree of *hazard* exposure of the process unit. From the chart, using unit hazard factor with the MF to determine Damage Factor (DF) which represents the degree of *loss* exposure.
5. F & EI = MF x F_3. From the chart, by using F & EI, Area (radius) of Exposure surrounding the process unit can be determined.
6. Determine the Rupee value of all equipment within the Area of Exposure. This value is used to obtain the Base maximum Probable Property Damage (Base MPPD).
7. The Base MPPD can be reduced to an actual MPPD by applying various Credit Factors and/ or by relocating certain high value equipment outside the Area of Exposure.
8. Actual MPPD is used to obtain MPDO, from which Business Interruption (BI) can be calculated.

Material Factor (MF) is the basic starting value in the computation of the F & EI and other risk analysis values. It is a measure of the intrinsic rate of potential energy release from fire or explosion produced by combustion or chemical reaction.

The MF is obtained from N_f and N_r, the NFPA signals expressing flammability and reactivity (or instability) of a material at ambient temperatures. As fire and reaction hazards increase with temperature, 'Temperature Adjustment of MF' is also required. In case of mixture, normally the MF of the component with the highest MF value is considered.

The MF is a number in the range from 1 to 40 and higher number indicates higher hazard. MF and Heat of combustion H_c of some common chemicals are given in following table :

MF & H_C Values

Chemical	MF	Hc BTU/lb
Acetaldehyde	24	10500
Acetone	16	12300
Acetonitrile	24	12600
Acetylene	29	20700
Acrylonitrile	24	13700
Ammonia	4	8000
Benzene	16	17300
Bromine	1	0
Butane	21	19700
Carbon disulphide	16	6100
Carbon monoxide	21	4300
Chlorine	1	0
Ethyl alcohol	16	11500
Ethylene	24	20800
Ethylene oxide	29	11700
Formaldehyde	21	8000
Gasoline (petrol)	16	18800
Hydrogen	21	51600
Hydrogen sulphide	21	6500
Methyl alcohol	16	8600
Naphtha	16	18000
Nitrobenzene	10	10400
Nitro-glycerine	40	7800
Phenol	10	13400
Sulphur	4	4000
Sulphur dioxide	0	0
Toluene	16	17400
Vinyl chloride	21	8000
Xylene	16	17600

In the above table higher MF indicates high hazard potential and higher H_c indicates high heat generation while burning, which in turn, indicates more quantity of fire fighting material (e.g. water, foam, DCP etc.) and equipment. MF for dusts is determined by different methods.

The Toxicity Index is used to evaluate process exposure level for toxicity hazard and is defined as -

$$TI = \frac{Th}{100}\left(\frac{P+S}{100}\right)$$

where T_h is the factor for the most hazardous material present in appreciable quantity with the lowest TLV, P the total GPH (General Process Hazards) penalties used and S the total SPH (Special Process Hazards) penalties used.

T_h can be known from the NFPA health rating N_h as under -

N_h	T_h
0	0
1	50
2	125
3	250
4	325

Assessment from Index : The degree of hazard potential can be determined from the value of F & EI as under :

F & EI Range	Degree of Hazard
0 - 60	Light
61 - 96	Moderate
97 - 127	Intermediate
128 - 158	Heavy
159 & above	Severe

Example : Suppose General Process Hazard factor F_1 and Special Process Hazard factor F_2 have been calculated as 2.8 and 3.8 respectively. Then with a MF 24 for acrylonitrile (ACN), the F & EI value is F_3 x MF = F_1 x F_2 x MF = 2.8 x 2.8 x 24 = 255. As it is above 159, it indicates severe hazard.

Based on F & EI and toxicity index TI, following categories are available :

Category	F & EI	TI	Degree of Hazard
I	$F<65$	$T<6$	Low
II	$65\leq F<95$	$6\leq T<10$	Medium
III	$F\geq 95$	$T\geq 10$	High

Fire Potential can also be assessed if the Fire Load F (BTU/ft²) for particular area is known (calculated). Then a range of expected fire duration and hazard categories can be assessed from following table.

Fire load, Duration & Hazard Category

Fireload F in BTU/ft² of normal working area x 10³	Range of expected fire duration in hours	Hazard category	Example
0-50	0.25-0.5	Light	Buildings
50-100	0.5-1	Low	Dwellings
100-200	1-2	Moderate	
200-400	2-4	High	Factories
400-1000	4-10	Very high	Occupied
1000-2000	10-20	Intensive	buildings
2000-5000	20-50	Extreme	Rubber
5000-10000	50-100	Very extreme	Ware-houses

Explosion Potential can be known from the following table if Internal Plant Explosion Index 'E' or Aerial Explosion Index 'A' is known.

Category	E	A
Light	0 – 1	0 – 10
Low	1 – 2.5	10 – 30
Moderate	2.5 – 4	30 – 100
High	4 – 6	100 – 500
Very high	>6	>500

Thus by knowing the hazard potential categories, inter-unit separation distances and unit boundary distances can be determined from the following tables.

Inter Unit Separation Distances

Unit 'A' of Reduced Dow F & EI	Minimum distance in *Meters* to Unit 'B' having Reduced Dow F & EI of					
	Mild	*Light*	*Moderate*	*Moderately Heavy*	*Heavy*	*Extreme*
Mild	0	5	6	8	10	12
Light	5	6	8	10	12	15
Moderate	6	8	10	12	15	17
Moderately heavy	8	10	12	15	17	20
Heavy	10	12	15	17	20	25
Extreme	12	15	17	20	25	30

Within Unit Boundary Distances

Unit Reduced Dow F & EI	Minimum distance in *Meters* to		
	Works Boundary	*Plant Boundary*	*Offices, Amenities Control Rooms etc.*
Mild	20	15	10
Light	25	20	12
Moderate	30	25	15
Moderately heavy	40	30	20
Heavy	50	35	30
Extreme	75	50	45

It should be borne in mind that all such assessment and distances are approximation and suggest a minimum guideline. The complex computation method has its own limitations. DOW index cannot predict probability of hazard occurring. Corrosion and leakage have special effects. Reactions difficult to control, operation in or near flammable range and greater than average explosion hazard certainly contribute to high risk category.

Revised DOW index model of January 1993 is available. As stated its object is to know how to identify, assess and minimize potential hazards on chemical plant units for new and existing processes.

4.8 Fault Tree Analysis (FTA) :

It is a method to represent the logical combinations of various systems which lead to a particular outcome (top event).

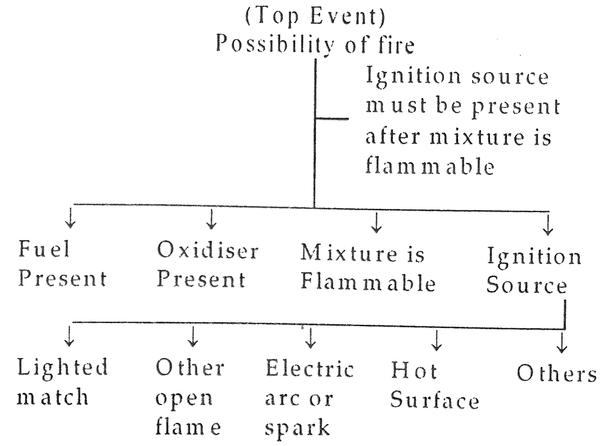
It is a graphic model that determines various combinations of equipment faults and failures that can result in an accident.

This is a sophisticated form of reliability assessment and it requires considerable time and skill. The procedure is to start from a selected undesirable top event such as 'gas coming out of a scrubber' and then trace it back to the combination of faults and conditions which could cause the events to occur. Apart from identification of hazards, it is widely used for quantitative risk analysis. It will be necessary to obtain meaningful failure data of each component to arrive at the frequency of occurrence of the 'top event'.

In fault tree analysis, abnormal operations are assumed in normal operations of a plant. The ultimate abnormal event (such as gas leakage) is shown in a rectangle at the top. Then all combinations of individual failures that can lead to that abnormal event are shown in the logical format of the Fault Tree. By estimating the individual failure probabilities and then using the appropriate arithmetical expressions, the probability of the top abnormal event can be calculated or predicted. This Fault Tree Analysis makes it easy to investigate the impact of alternative preventive measures. Fault tree is developed from top to bottom through a series of symbols which define the flow of logic from the base causes of an event itself. Detailed probability data are most desirable.

This method of Fault Tree Analysis was developed by Bell Laboratories (USA) in 1961 to predict potential catastrophic events which could occur with the Air Force. It is more useful to assess chemical hazards.

Without specific Fault Tree symbols (symbology), a schematic diagram of one top event (possibility of fire) is shown below.



Some sample top events for Fault Tree Analysis are -

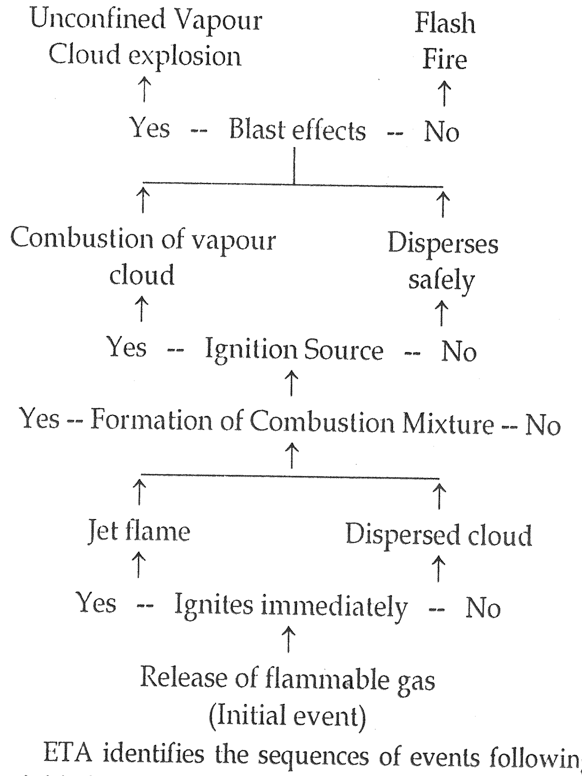
1. Injury to______
2. Damage to______from_______
3. Explosion of______
4. Loss of control of______
5. Rupture of______
6. Loss of pressure in______
7. Overpressurisation of______
8. Unscheduled release of______
9. Collapse of ______
10. Overheating of______
11. Uncontrolled venting of______
12. Inadvertent start of______etc.

A computer is much useful to carry out mathematical Fault Tree calculations using Boolean algebra.

4.9 Event Tree Analysis (ETA) :

Event tree analysis is a method to illustrate the intermediate and final outcomes which may arise after the occurrence of a selected initial event.

This technique is complementary to Fault Tree, but in reversed direction. Whereas a fault tree starts from a final event and works from the top down, an Event Tree begins with an initial event such as a power failure and explores all possible outcomes by working from the bottom up. An illustration is shown below, for an initial event of release of flammable gas.



ETA identifies the sequences of events following an initiating event that results in accident. Event tree considers operator response or safety system response to the initiating event in determining the potential sequence.

Some sample initial (bottom) events for Event Tree Analysis are :

1. Failure of pump of____
2. Failure of stirring of_____

3. Failure of water/cooling media/heating media in ______
4. Stoppage of motor at______
5. Mistake of______

4.10 Accident or Cause Consequence Analysis :

Cause-Consequence Analysis identifies potential accident consequences and the basic causes of these accidents.

Any hazard or risk assessment is incomplete if the *consequences* of a possible accident are not known. Therefore the last step in hazard assessment is to analyse the consequences that a potential major (credible) accident may cause on the plant itself, on the workers, on the surrounding and on the environment. Therefore an accident consequence analysis should contain -

1. Cause of the accident (fire, explosion, rupture of a vessel, pipe, valve etc.).
2. Estimate of the mass released (flammable, explosive, toxic quantity).
3. Calculation of the dispersion of the material released and the damage distance. (liquid, vapour or gas).
4. Estimate of the effects (heat radiation, blast wave, toxic, degree of burn, severity etc.).

1 & 2 can be known by using the results of the hazard assessment while mathematical models have to be applied in finding 3 & 4. See Part 4.12 for effect of 2,3,4 above.

The results of ACA can be used to select necessary PPE, FFE, alarm or pressure relief device. It is also useful in deciding plant siting and layout and emergency planning in addition to risk assessment.

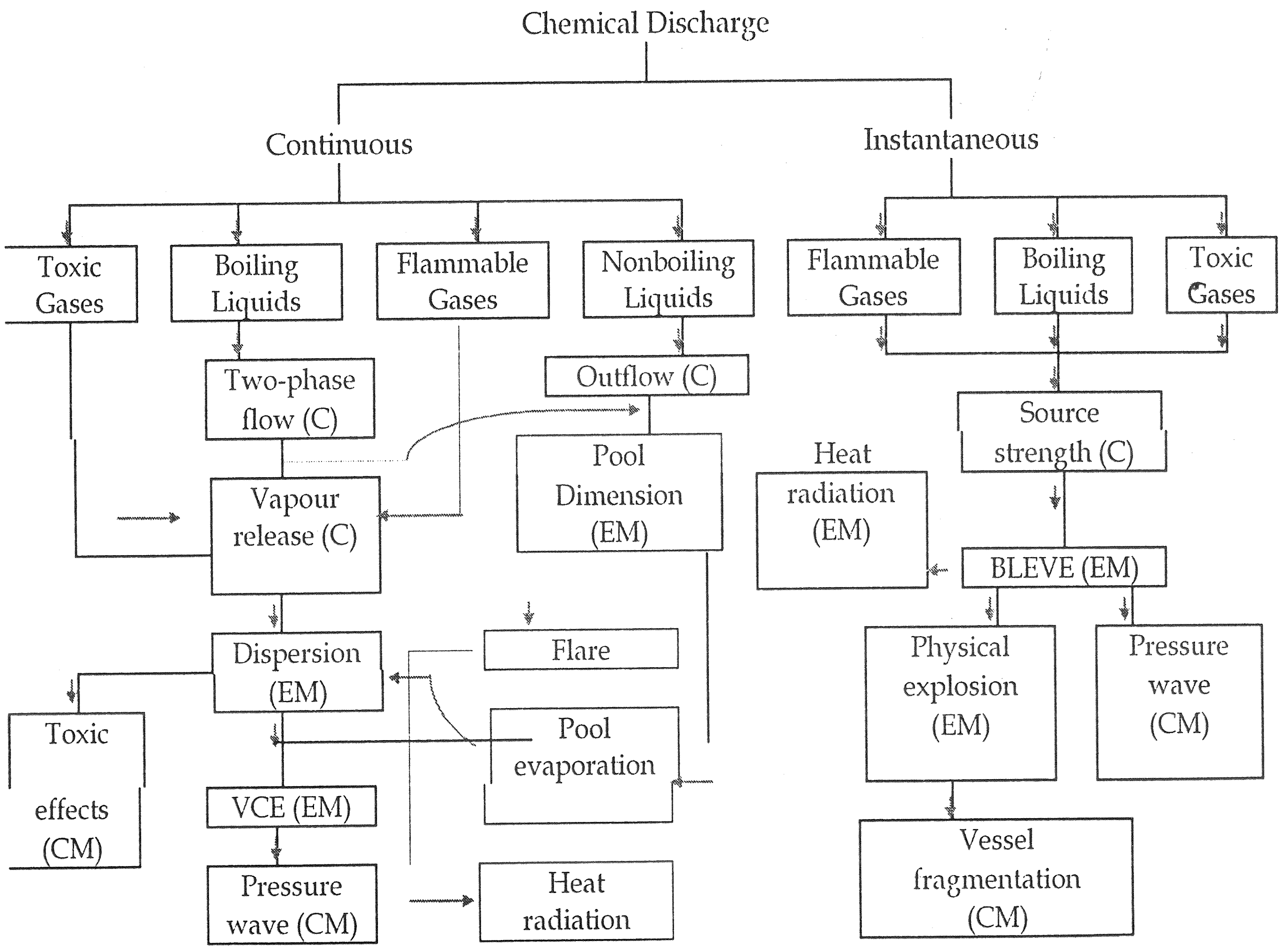
However higher estimates may lead to unnecessary additions to a plant and excessive capital cost. Therefore it is advisable that a company using such quantitative risk analysis should use its own experience and judgement to define targets for comparing the results.

The effects after accidental release of a chemical depend on many factors like type and quantity of the released chemical, meteorological conditions; topography, location or presence of ignition source. The accident scenarios can be divided into different categories such as -

1. Liquefied gas or boiling liquid release under pressure (e.g. LPG)
2. Flammable/explosive gas release (e.g. H_2)
3. Toxic gas release (e.g. Cl_2)
4. Non-boiling liquid release (e.g. benzene)

Following figure shows the typical chemical discharge modes and their linkup to show their effects (radiation, explosion, toxic release etc.) Consequence analysis considers physical effects and damage caused by them. A combination of different discharge effects should also be considered.

ifferent Discharge Modes to Consider Consequence Analysis



C = Calculation, CM = Consequence Model, EM = Effect Model

Extensive data are to be collected during preliminary MCAA. It includes physical, chemical, thermodynamic, transport and safety properties of hazardous chemicals, process units and overall layout of the chemical plant and meteorological and demographic conditions. Subsequently the integrity of the process and storage units, process activities and work culture at each site are to be assessed.

Overflow models calculate the source strength of the released material. Post-release phenomena (fire, explosion or toxic dispersion) can be quantified with the help of computer software packages based on mathematical models given below. Gaussian model is useful for neutral density (lighter) gases while other models (e.g. 3D) are also available for heavy gas dispersions.

Mathematical models for consequence analysis

Sl No	Phenomenon	Application models
1	*Outflow*	
	Liquid	Bernoulli flow equations;
	Two phase mixtures	phase equilibria; multiphase flow models;
	Gas/vapour	Orifice/nozzle flow equations; Gas laws; Critical flow criteria.
2	*Discharges*	
	Spreading liquid	Spreading rate equations for non penetrable surfaces based on cylindrical liquid pools.
	Vapour jets	Turbulent free jet model.
	Flashing liquids	Two zone flash vaporisation model.
	Evaporation of liquids on land and water	Spreading boiling and moving boundary heat transfer models; Film and metastable boiling phenomenon; Cooling of semi-infinite medium.
3	*Dispersions*	
	Heavy gas	(i) Buoyancy dominated, stably stratified and passive dispersion models (similarity). (ii) 3D models based on momentum, mass and energy conservation.
	Neutral gas	Gaussian dispersion models for neutrally byoyant plumes.
	Atmospheric stability	Boundary layer theory (turbulence); Gaussian distribution models.
4	*Heat radiation*	
	Liquid pool fires	Burning rate, heat radiation and incident heat correlations (semi-emperical); Flame propagation behaviour models.
	Jet fires	Jet dispersion models
	Fireballs	API fireball models relating surface heat flux of flame, geometric view factor and transmission coefficients.
5	*Explosions*	
	Boiling liquid expanding vapour cloud explosion	Fireball and physical over-pressure models, Deflagration and detonation models; ID gas dimensional computations.
6	*Vulnerability*	Probit functions; non-stochastic vulnerability models.

Criteria for heat radiation, explosion and toxic effects can be used to classify the accident scenarios for further investigations and to calculate effect and damage for primary events. Such damage criteria are as under :

Damage Criteria

Heat Radiation		Explosions		Toxic Gas Dispersions
Incident Flux kw/m²	**Damage**	**Peak over pressure, bar**	**Damage**	**Damage**
37.5	100% lethality; Heavy damage to equipment	0.3	Heavy (90%)	The extent of damage depends upon the concentration of the toxic compound in the atmosphere; The relation between percent of injuries and the toxic load is normally given in the form of Probit Functions.
		0.1	Repairable (10%)	
25	100% lethality; nonpiloted ignition	0.03	Damage of glass	
		0.01	Crack of windows	
12.5	100% lethality; piloted ignition			
4	Not lethal; 1st degree burns			
1.6	No discomfort even after long exposure			

Past accidents provide useful clues and supporting information for the effect and damage calculations. Data bank 'FACTS' of past accidents is available from TNO. The Netherlands has vital information of more than 15000 chemical accidents that occurred in various parts of the world. Such databank of accidents in our country can be developed by NSC or LPA.

4.11 Maximum Credible Accident Assessment (MCAA) :

See Part 3.100 of Chapter-2 for definition.

MCA means maximum credible accident i.e. an accident with a maximum reasonable damage distance possibility.

MCAA means maximum credible accident analysis or assessment. Here probability of accident occurrence is not calculated but the probability of maximum damaging effect (potential and distance) is calculated to assess injury to people or/and properties in the surrounding area.

Hazard potentiality is considered by (1) Type of material stored/processed (toxicity, flammability etc.) (2) Quantity of the material (it affects distance) (3) Process or storage conditions (temperature, pressure, flow etc.) (4) Location of the unit or activity with respect to adjacent population.

Based on above factors, units/activities are selected, accident scenarios established and effect (domino or cascade) and damage calculations are carried out.

Following steps are employed in MCAA :

1. Chemical Inventory Analysis.
2. Identification of hazardous processes in individual units.
3. Identification of chemical release and accident scenarios.
4. Data acquisition for MCAA.
5. Effect and damage calculations for the primary events.
6. Analysis of past accidents of similar nature.
7. Short listing of maximum credible accident scenarios.

These steps are explained below in brief.

The chemical inventory is to be identified by MSIHC Rules or Rule 68 J of the Gujarat Factories Rules (see Part 10.8 of Chapter-28), short listed and prioritised on the basis of hazard potential. The chemicals are generally classified as non-boiling and boiling liquids, gases/vapours and solids.

Hazardous processes are also identified by above statutory provisions. Runaway reactions need due consideration during preliminary MCAA.

4.12 Vulnerability Analysis :

Vulnerability is the susceptibility of life, property and the environment to injury or damage if a hazard manifests its potential.

The vulnerability analysis identifies what part of the community is susceptible to more damage if a hazardous substance releases. It provides information on :

1. Vulnerable zone (affected area) for a spill or release and the conditions that affect the zone (wind speed & direction, size of release).
2. Population, in terms of size (density) and types (residents, workers, sensitive population - hospitals, schools, nursing or care centres, old men's shelter, prisons, spectators in auditoriums or stadiums) lying within the vulnerable zone.
3. Private and public property (homes, offices, businesses) that may be damaged, including essential support system (water, milk, food, fuel, power, medical) and transport centres, and
4. Environments (land, air, water, crops, food, vegetable, animal habitats, livestock etc.) that may be adversely affected and impact on sensitive natural areas and endangered species.

To get information on 1 (i.e. vulnerable zone) mathematical and computer models or probit equation can be used. To get information on 2,3, & 4, following steps are useful -

1. Survey of the area (first hand information by driving through the area).
2. Interviews of fire, police, emergency and planning department personnel.
3. Review of planning department documents and statistics on land use, population, highway usage and the area's infrastructure.

By consequence analysis damage or physical effects resulting from the release of hazardous substances can be determined while by vulnerability analysis such effects (consequences) can be translated in terms of injuries and damage to exposed people, property and environment. All such exercises are useful for emergency planning (i.e. on-site and off-site emergency plans).

In estimating size of vulnerable zones following variables are considered :

1. Quantity and rate of release to air. This depends on (a) Total quantity released (b) Physical state (solid, liquid, gas) and (c) Conditions (pressure, temperature) of storage or handling.
2. Meteorological conditions.
3. Surrounding topography.
4. Level of Concern (LOC) i.e. the concentration of an extremely hazardous chemical (EHS) in air above which there may be serious irreversible health effects or death as a result of a single exposure for a relatively short period of time.

No precise measure of LOC is available. Different guidelines suggest different values. It is to be estimated from IDLH, LC/LD, TLV, STEL and other permissible values. Rough estimation is as under -

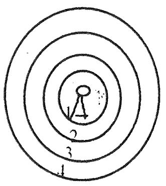
Estimated IDLH = LCL_0, or
= LC_{50} x 0.1, or
= LDL_0 x 0.1, or
= LD_{50} x 0.01

Then LOC = 0.1 x estimated IDLH or direct IDLH available.

$$\text{LOC (in gm/m}^3) = \frac{\text{LOC(in ppm)}}{1000} \times \frac{\text{MW}}{24.5}$$

Note : IDLH =immediately dangerous to life & health, LC=lethal concentration (gas), LD=lethal dose (solid or liquid), TLV=threshold limit value, STEL=short term exposure level and MW=molecular weight. See Part 6.9 of Chapter-24 for details.

5 Estimating vulnerable zones for initial screening and revaluation of the estimated zones as shown below.



It is important to mention that different assumptions or conditions give different radius of estimated vulnerable zones as shown in the figure.

The four circles differ as under -

1. Selection of higher LOC.
2. Use of higher wind speed and less atmospheric stability.
3. Small quantity and less rate of release.
4. Radius for initial screening zone.

Calculations should be based on credible worst case assumptions and considering wind speed, stability class and chemical toxicity. Instantaneous and continuous releases including spills, leaks, fires, explosions and BLEVE should be considered. Multiple point sources operating concurrently may be considered. Gaussian or other models may be used depending on prevailing conditions. Site effects of terrain are relevant. The results of the calculations should be represented in graphical format.

See Part 4.3.3 and 4.3.4 also.

Use of Probit Equation :

The probit function is given by

$$P_r = K_1 + K_2 \text{ Log } C$$

where P_r = Probit, a measure for the percentage of people exposed who incur a particular injury (for conversion table from probit to percentages see Part 6.2.3 or Reference No. 27), K_1 = a constant depending on the type of injury or type of load or causative factor C and K_2 = a constant depending on the type of load C.

For *toxic release* calculations, probit equation is given by -

$$P_r = K_1 + K_2 \text{ Log } (C^n t)$$

where C = concentration of the toxic substance in mg/m^3, t = the exposure time in minutes and K_1, K_2 and n are constants depending on the toxic substance.

For example, these values for three main gases are given as :

Chlorine, $P_r = -10.29 + 0.92 \text{ Log } (C^2 t)$

Ammonia, $P_r = -27.27 + 2.27 \text{ Log } (C^{1.36} t)$

SO_2, $P_r = -17.73 + 2.10 \text{ Log } (Ct)$

These equations estimate that in case of chlorine, death will occur in 50% of the persons exposed to a concentration of 1050 mg/m^3 at an exposure time of 15 minutes and in case of SO_2, 1% mortality will occur to a concentration of 550 mg/m^3 at 30 min exposure time.

Fire : For *heat radiation* calculations, probit equation is given by -

For lethality, $P_r = -36.38 + 2.56 \text{ Log } (C^{4/3} t)$

For first degree burn,

$$P_r = -39.83 + 3.0186 \text{ Log } (C^{4/3} t)$$

where ,

C = thermal load W/m^2 and t = exposure time in seconds. The values given are for unprotected body. If people are wearing clothes, injuries are assumed to be reduced by a factor of 7.

See Part 6.2.4 for further discussion.

Explosion : A pressure wave caused by BLEVE or gas cloud explosion will make probable damage as under:

Peak over pressure (bar)	Type of damage
0.01	Windows smashed.
0.03	Damage by flying fragments of glass.
0.1	10% of houses seriously damaged.
0.3	90% of houses seriously damaged.

A peak overpressure of 0.1 bar is taken as the limit for fatality and 0.03 bar as the limit for causing wounds. Within the zone of a peak overpressure of 0.3 bar, the risk of death in houses is 1 in 80 people.

See Part 6.2.3 also for effects of discharges.

Thus vulnerable analysis employs scientific assumptions and calculations to estimate damage zones and number of people likely to be affected. Emergency planning is not possible without such efforts.

4.13 What if Analysis :

The method involves possible deviations from the design, construction, modification, or operating plant. A question 'What if' is asked, e.g. What if wrong material is charged? What if pump stops functioning? This method identifies possible accident event sequences and thus identifies the hazards consequences and steps for risk reduction.

5 RELIABILITY ENGINEERING

Hazard control technology mostly involves the *probabilistic* methods to detect failure possibilities and accidents. Reliability engineering is a branch concerning this aspect.

An industrial product is designed to perform a certain function. The user buys a product with every expectation that it performs the assigned function well and gives trouble-free service for a stipulated period of time. Trouble free service given by any product may be termed as 'reliability'. The reliability of a machine or an assembly having a number of components depends upon the individual reliability factors of all the components. Most of the machines and systems in the modern day world, for example, power plants, chemical components on which reliable operation and smooth performance depend. To ensure the reliability of such machines and the plant as a whole, it is important that each individual component is reliable and performs its function satisfactory for an assigned period of time.

Reliability comes through improving the quality level of the components. The quality of products, components or parts depends upon many factors important among them are the design, raw material properties and fabrication techniques. Quality is related to the presence of those defects and imperfections in the finished product which impair the performance level. Many defects are also generated during service. The nature of these defects differs according to the design, processing and fabrication and service conditions under which the components have to work. An improvement in the product quality increases its reliability and in turn the safely of the machine and equipment, thus bringing economic returns to the user.

Various topics on reliability engineering include statistics, mathematics, set theory, failure rate and analysis, unreliability, availability, failure distributions including exponential, binomial and lognormal distributions etc., repair and maintenance, series, parallel and standby systems, Marco models, Monte Carlo simulation graphs, diagrams and flow sheets and computer programs.

Application of reliability engineering in process industry is very wide. It is applicable to mechanical, electrical and instrument systems, critical equipment and devices, nuclear systems, quality control, analysis of faults and abnormal occurrences, repair and maintenance etc.

5.1 Principles of Reliability Engineering:

IS:10139 on presentation of reliability, maintainability and availability predictions and IS:8161 (11 Parts) on guide for equipment reliability testing are most relevant. Reliability of electrical/electronic equipment and performance data is given in IS:7354 (6 Parts), 8607 (Part-8) and 1885 (Part 39) electro technical vocabulary - reliability of electronic and electrical items. IS:8161 guide for equipment reliability testing, Part-1 is for principles and procedures and out of total 11 parts, Parts 6 & 7 are on tests for validity of constant failure rate assumption and meantime between failures. They should be referred for details.

Reliability is defined as the probability that an item will perform a required function under stated conditions for a stated period of time.

Thus reliability depends on probability, time and failure. Failure may be due to failure in operation (e.g. equipment in continuous service) or failure to operate on demand or failure to operate before or after demand (e.g. equipment operating intermittently).

Probability P of a particular event is

$$P = \lim_{n \to \infty} \frac{\text{Number of occurrences of the event}}{\text{Total number of trials (n)}}$$

Thus if fire happens 5 times when trials (n) to cause it are made 10 times, the probability is 0.5, or

$$P = \lim_{n \to \infty} \frac{5}{10}$$

If an equipment fails 3 times when total operations (chances to fail) happened 1000 times, the probability or failure rate is said to be of 0.003.

If a person falls 2 times when he climbs a particular staircase 100 times, the probability of falling or the falling rate is said to be of 0.02.

Reliability - R(t) of an element or system can be defined as the probability that the element or system will operate to an agreed level of performance, for a specified period, subject to specified conditions.

In a measurement system 'agreed level of performance' could mean, for example, an accuracy of 1.5%. If the measurement system is giving error more than this, it is considered to have failed, even though it is otherwise working normally.

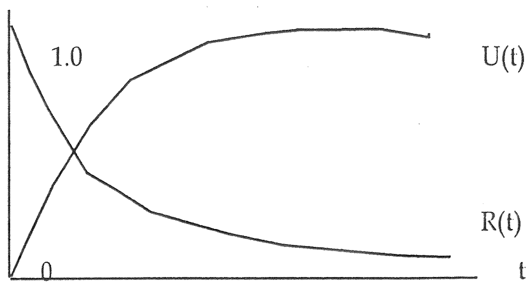
Reliability varies with time. A system just checked and calibrated should have a reliability of 1 when placed in service. After a year the reliability may be only 0.5 as the probability of failure increases.

Unreliability U(t) can be defined as the probability that the element or system will fail to operate to an agreed level of performance, for a specified period subject to specified conditions.

The sum of reliability and unreliability must be unity, i.e.

$R(t) + U(t) = 1$

See following figure for this relationship.



Variation of reliability and unreliability with time for constant failure rate and no repair.

Unreliability also depends on time. A system just checked and calibrated should have an unreliability zero, when first placed in service but it may increase to say 0.5 in few months.

Mean Time Between Failure (MTBF) is applicable to any type of equipment whose faulty component or unit can be replaced or repaired. Suppose N identical elements or systems are tested for a total period T years. Each fault is recorded, the equipment is repaired, put back into service and the total number of faults F_N during T found. Then

$$MTBF = \frac{NT}{F_N}$$

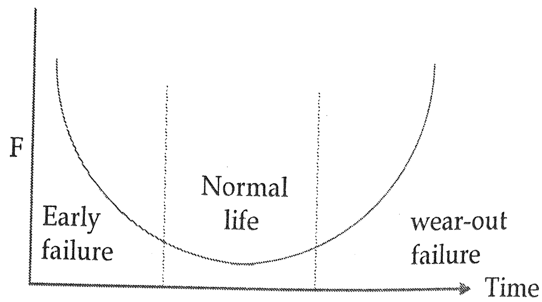
where the test interval T does not include the total repair time. Thus if 50 faults are recorded for 100 differential pressure transducers over 2 years, the

$$MTBF = \frac{100 \times 2}{50} = 4 \text{ years.}$$

Failure rate - F is the average number of faults per item of equipment, per unit time. It is mostly constant over much of their working life and therefore reciprocal of MTBF i.e.

$$F = \frac{1}{MTBF} = \frac{F_N}{NT}$$

The failure rate varies throughout the life of the equipment shown as under.



Variation in Failure rate (bathtub curve)

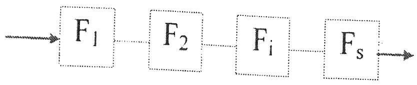
Three phases - early failure, mature failure (normal working life) and wear-out failure give bathtub curve as shown in the fugure. The early failure region, lasting normally for 6 months, is due to weak components and unfamiliarity in operating the system. The mature region, lasting possibly 10 years, is characterised by a low constant failure rate, all weak components have been removed from the system and the system is being operated correctly. The wear-out region is characterised by an increasing failure rate as components reach the end of their working life.

Relationship between R(t), U(t) and F is given by

$$R(t) = \frac{n_s}{n_o} = e^{-Ft} \quad \text{and} \quad U(t) = \frac{N_f}{n_o} = 1 - e^{-Ft}$$

where $n_s = n_o - n_f$ = number of items still serviceable, n_o = items of equipment set in operation at time t = 0, n_f = items survive after time t.

Reliability of a system in series is shown below. Here S elements of a system are in series with failure rates F_1, F_2, F_i, F_s. The system will only survive if each element survives.



Reliability of a system in series

If one element fails then the system fails. Assuming that the reliability of each element is independent of the other elements, then the system reliability is the product of the element reliabilities i.e.

$$R_{syst} = R_1 R_2 \ldots R_i \ldots R_s.$$

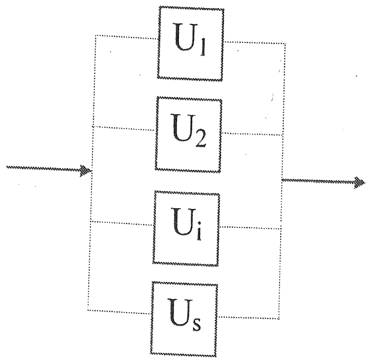
$$= e^{-F1t} \times e^{-F2t} \ \ldots \ e^{-Fit} \ldots \times e^{Fst}$$

$$= e^{-Fsyst} = e^{-(F1+F2+..Fi..+Fs)t}$$

$$\text{and } F_{sys}t = F_1 + F_2 + ..F_i.. + F_s$$

where $F_{sys}t$ is the overall system failure rate and F_1, F_2.. F_s are individual failure rates of S elements.

Reliability of a system in parallel is shown below. Here S systems are in parallel with their unreliabilities U_1, U_2 , Ui, Us.



Reliability of 'S' systems in parallel

The overall systems will only fail if every individual system fails. Assuming that the unreliability of each system is independent of unreliability of the other systems, the overall unreliability is the product of the individual system unreliabilities i.e.

$$U_{overall} = U_1 \times U_2 \times \ldots . U_i \times \ldots U_s$$

Common Mode Failure is that failure due to fault which causes more than one element in a system to fail. For example, loss of air supply to a pneumatic flow control loop causes failure of D/P transmitter, controller and valve.

Failure Rate Data of various components are needed for reliability calculations. Following Table gives some such data from international literature.

Average Failure Rates for some mechanical, hydraulic and pneumatic components

	Component	Failure Rate % per 1000 hrs	Type of Fault
1	Seals or Valves, Gaskets, Joints (pipes), Orifices, Diaphragms (metal), Bellows (metal)	0.05	Leakage/ blockage
2	Bourdon tubes	0.005 0.02	Leakage Creep
3	Joints (mechanical)	0.02	Breakage
4	Nuts, bolts, rods, shafts	0.002	Breakage or loose
5	Pressure vessels	0.3	Rupture or leakage
6	Pipelines	Failure rate per meter per year	
		Rupture	Leakage
	Dia upto 3"	10^{-6}	10^{-5}
	Dia 3" - 15"	10^{-7}	10^{-6}
	Dia > 15"	-	10^{-8}
7		Failure rate per year	
		Rupture	Leakage
	Pressure vessel	10×5^{-6}	10×5^{-5}
	Atmosph. vessel	10^{-4}	10^{-3}
8	Human error		Probability of error/task
	Walk through inspection		50^{-1}
	Checklist inspection		10^{-2}
	Non-routine operational error (start-up/ maintenance)		10^{-1}
	Non-critical routine task (misread temp/press data)		3×10^{-3}
	Critical routine task (tank isolation)		10^{-3}

Availability characteristics in a process plant are (1) Probability of obtaining nominal output and downtime (2) Probability of obtaining other outputs and downtimes and (3) Probability of infrequent but very long downtimes.

The objective of system availability analysis is to assess system availability and to identify critical aspects and then to effect required improvements.

Data on availability of whole subsystems are useful, otherwise it is necessary to calculate system availability from failure rate and repair time data. Availability of raw materials and services and availability of other plants which receive outputs like by-product, electricity, steam etc. are to be considered.

Availability A(t) is a function of time and may be expressed in terms of uptime u(t) and downtime d(t) as

$$A(t) = \frac{u(t)}{u(t)+d(t)}$$

The unavailability v(t) is

$$V(t) = 1 - A(t) = \frac{d(t)}{u(t)+d(t)}$$

In addition to methods like density function, Markov models, logic flow diagrams and throughput capability method, computer flow sheeting methods can also be used to determine plant availability. Plant availability is affected by storage (main and intermediate), which introduces additional flexibility and may allow units upstream or downstream of a failed unit to continue to operate for a time.

For other principles and mathematical details see Reference No. 27 at the end.

5.2 Application of Reliability Engineering :

Reliability engineering was developed during the second world war to solve the problems of reliability of the missile and vacuum tubes used in electronic equipment by the US Army.

Main fields of application of reliability engineering are electronic equipment [see IS:7354 (6 Parts) and IS:8607 (8 Parts)] and nuclear energy. Methods are developed to assess the hazards of nuclear reactors and to design instrument trip system to shut down safely. Its application to process industries was developed at a later stage.

Reliability of mechanical equipment pose less problem. Reliability application is also concerned with availability, maintenance, failure data, repairs and repair time etc. With the growth of instrumentation and control branch of engineering, applicability of the reliability engineering in process plants has become wide and more important. Complex distributed circuit systems (DCS), trips and alarms, auto control and auto corrections, locks and interlocks and a variety of process control equipment for inputs, outputs, flow, temperature/pressure measurement, recording etc. are increasing, day-by-day, the need of application of reliability engineering.

Work on reliability involves assessment and improvement of the system. The assessment work may show that the system is fully reliable or less reliable and the ways and means to improve the reliability. It is the duty of the **reliability engineer** to identify the areas where improvement is necessary. Existing level of reliability should be studied for further improvement. Failure rates, effects on people exposed if failure occurs and weather conditions are factors to be considered.

Quality control improves reliability. Deficiencies in specification, design or application are causes of unreliability. A good quality equipment, if badly designed, will remain unreliable.

5.3 Concepts of Critical Equipment and Devices :

Reliability analysis of critical equipment and devices like safety valve, auto control valve or device, trip device, flow, temperature or pressure control, trip device, alarm, measurement or recording device, actuators for safe venting, discharge or transfer, pumps, thermocouples, converter and many electronic subsystems, is of more significance and needs careful consideration of accurate data of failure rates, availability, repair time etc. Some concepts of reliability considerations for such critical equipment are mentioned below in brief :

1. Initially three steps are required (1) Assessment of system reliability itself (2) Identification of critical features interrupting reliability and (3) Methods to improve reliability and selection of a cost effective or safe methods from different alternatives.
2. For above purpose, first those subsystems (components) should be identified that affect the overall system reliability. No much effort is necessary to go into details of a subsystem which does not affect the overall reliability of the system.
3. Sometimes engineering estimates of data may be sufficient but sometimes field data are also necessary. The matching of the data to the application is more important.
4. For example, connections of three pumps with a storage tank, all in parallel or two in parallel and one as common standby give selective reliability. Similarly a temperature measurement system consisting of three identical thermocouple systems in parallel is reliable but expensive. Since the thermocouple failure rate is 11 times greater than converter and recorder failure rates, a more cost effective redundant system would have three thermocouples in parallel and only one converter and recorder. Alternative way is to place a middle value selector.
5. Use of logic flow diagram (Fault Tree Analysis) is a widely used method. Failure diagram for hazardous occurrences and success diagram for trip system operation or plant availability are utilised.
6. In event space method, a list of all possible events is made and failure and success events are sorted out.
7. In path tracing method the paths in a system are traced which constitute success. These paths are known as tie sets and the system reliability is obtained from the minimum tie sets.
8. The reversed method is to fit cut sets which break all the paths and thus ensure failure. System unreliability is obtained from the minimum cut sets.
9. Bayes' theorem is used to select a key component which makes it possible to decompose the system.
10. Markov models are used to determine repair rates and mean life for complex systems.
11. Monte Carlo simulation methods are also useful to determine reliability and/or availability of complex systems including critical equipment.
12. The concepts of consequence analysis i.e. effects on exposed and vulnerable people, property and environment, if any critical equipment or device fails, are to be considered and depending on their gravity, the reliability of the equipment should be selected.

6 MAJOR ACCIDENT HAZARD (MAH) CONTROL

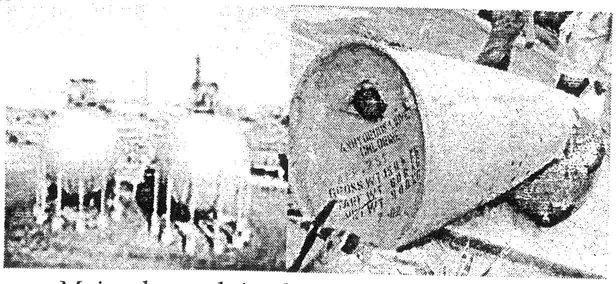
With the growth of chemical industry and use of hazardous chemicals, the world had seen many major accidents during last 50 years but the concept of major accident hazard (MAH) control came in our country after Bhopal accident in 1984 only. Thereafter there is a constant rise in bulk storage, hazardous processes and heavy transportation of dangerous chemicals. This needs to realise and take appropriate safety measures to identify and prevent the major accident causes and to mitigate their consequences.

6.1 Concept of MAH:

Some definitions are as under:

For definitions of 'major accident' and 'major accident hazard' (MAH) see definitions in rule 2 (j) and 2 (ja) of the Manufacture, Storage and Import of Hazardous Chemicals Rules 1989. See part 10.8 of Chapter 28 for further detail.

Major hazard means that hazard which arises because of (1) the hazardous nature of the substance and (2) its storage quantity equals or exceeds the threshold quantity prescribed in MSIHC Rules 1989.



Major hazard is due to isolated storage or industrial activity that has the potential to cause extensive damage to men, materials or environment within or outside the site boundary.

The Statutes - Manufacture, Storage and Import of Hazardous Chemicals Rules 1989, Rule 68J of the Gujarat Factories (Amendment) Rules 1995 and the Chemical Accidents (EPPR) Rules 1996 have defined the term 'major accident'. See Chapter-28 for these laws.

Some reported major industrial accidents are mentioned below:

Examples of Major Accidents

Year	Place	Deaths	Injuries	Chemical involved
1943	Germany	57	439	Butadiene & Butylene (butene), explosion
1944	US	136	77	Methane, fire
1948	Germany	207	3818	Dimethylether, explosion
1954	Germany	32	16	Kerosene, explosion
1966	Feyzin, France	18	81	LPG, fire, BLEVE
1973	US	40	-	LNG, fire
1974	Flixborough, England	28	36	Cyclohexane, explosion
1976	Seveso, Itali	250 Evacuated		TCDD toxic emission
1977	Columbia	30	25	Ammonia, toxic release
1978	Mexico	52	-	Methane, fire
1980	Spain	51	60	Propane, explosion
1984	Pemex, Maxico	542	4000	LPG
1984	Bhopal, India	2500	25000	Methyl isocynate, toxic release
1985	Mexico	650	2500	LPG, fire, BLEVE
1986	Chernobyl, Russia	31	203	Atomic radiation
1993	Thailand	211	-	Toy factory
1993	China	84	-	Plastic toy factory
2011	Fukushima, Japan	300 exposed to radiation		Atomic radiation

The Bhopal disaster has remained at the top and opened eyes throughout the world regarding major chemical hazards, their consequences and controls.

All such accidents, differing in the mode of happening and the chemical involved, have some common features as under :

1. They were uncontrolled events caused by fire, explosion or/and toxic release.
2. They resulted in death or/and injury of a large number of people, inside or/and outside the plant, or/and
3. They caused evacuation of people of the surrounding area, or/and
4. They caused heavy damage to plant, property and environment.

The storage, process, use and handling of such flammable, explosive or toxic chemicals pose high potential to cause disasters and are normally referred as *major hazards*. Their potential is due to their inherent nature (property) of the chemicals, their quantity, type of process, way of handling or sudden failure of some part of the plant including vessel, equipment, fitting, pipe and vehicle.

The main objectives of major hazard control system are :

1. To distinguish between minor and major accident potential and to set priority for identification and inspection of major hazard works first or more frequently.
2. To define hazardous chemical by defining its fire, explosion and toxicity criteria and to define their threshold quantities for storage and use to classify the work as MAH installation.
3. To define and list the hazardous processes to identify the unit as MAH installation.
4. To make, enact and implement the law for MAH chemical works or isolated storage by providing statutory provisions and requirements.
5. To identify the major hazards, developing and utilising the special techniques like hazard and risk assessment, HAZOP, FTA, ETA, consequence analysis, vulnerability analysis, environmental impact assessment etc. as mentioned earlier and carrying out plant safety inspection by various methods mentioned in Part 2 & 4 of this Chapter.
6. To take all possible preventive measures based on identified major hazards to prevent the causes of such hazardous events. Training and education may be incorporated.
7. To foresee the consequences on the workers, public and environment in case if any possible major accident may occur, and to work out an emergency action plan to control and mitigate the effects.

Components of a major hazard control system are :

1. Definition and identification of MAH installation based on types of hazards.
2. Information about the installation e.g. safety report, safety manual etc. Information should be given to workers, public and authorities.
3. Assessment of major hazards, by works management and competent authorities. Cause, effects, consequences and safety measures must be assessed.
4. Control of the causes of major industrial accidents by detecting causes and following sound engineering and management practices e.g. good design, fabrication, installation, operation, maintenance, inspection and use of good safety equipment and instrumentation.
5. Safe operation of major hazard installations by training to workers, following SOPs and investigating accidents and near misses.
6. Emergency planning i.e. on-site and off-site emergency plans and their regular rehearsals.
7. Siting and land-use planning by ensuring safe separation distances.
8. Inspection of MAH units by the plant management and also by the Govt. authorities at top priority and more frequently.

Causes of major accidents to be studied include component failure, deviations from normal operating conditions, human and organisational errors, outside accidental interference, natural forces, mischief and sabotage.

Safe operation of MAH installation should pay attention on -

(1) Design, manufacture and assembly of components,

(2) Process control,

(3) Safety systems (sensors, controllers, pressure-relief, emergency shutdown, bunds, water-spray, fire detector etc.),

(4) Monitoring of safety-related components and systems,

(5) Inspection, maintenance and repair,

(6) Effects of change,

(7) Training of workers,

(8) Supervision and

(9) Control of contract work.

6.2 Types and Consequences of MAH including Discharges and Disperson Effects :

Generally fire, explosion and toxic release are the main types of major hazards and death, injury, evacuation of people, property loss and environmental damage are the main types of their consequences.

6.2.1 Fire, Explosion and Toxic Release:

Fire can cause thermal radiation and skin burns. The severity (degree and percentage) of burns depends on heat intensity, exposure time and type of clothing.

$$\text{Heat radiation effect } \alpha = \frac{1}{\text{distance}^2}$$

Generally skin withstands a heat energy of 10 kW/m^2 for 5 seconds and 30 kW/m^2 for only 0.4 seconds before pain is felt.

Frequency of fires in industry is more than explosions and toxic releases but its lethal effects are comparatively less. However if the ignition of escaping flammable vapour is delayed, an unconfined vapour cloud may form and it may explode if ignited.

Types of fire may be a jet fire, pool fire, flash fire and BLEVE i.e. boiling liquid expanding vapour explosion. A jet fire occurs from an ignited gas pipe leak, a pool fire from drained material in a dyke, flash fire occurs if the gas reaches a source of ignition and rapidly burns back to the source of release and BLEVE occurs when flammable vapour leaking from any vessel or pipe expands and disperses in air as a cloud and when this cloud is ignited. Then a fire ball occurs causing enormous heat radiation. A BLEVE from a 50 tonne propane tank can cause third-degree burns at @200 mts and blisters at @400 mts.

Explosion is a shockwave that can damage where it hurts. Primary or direct effect is due to the shock-wave of the explosion itself. Those in the direct vicinity may die due to effects of over-pressure. People can also be thrown away, blown over or knocked down and buried under collapsed materials. Secondary or indirect effect is the effect of shock-wave generated by the primary effect. The history of explosions show that the indirect effects of collapsing buildings, flying or broken glasses and debris cause far more deaths and injuries.

The effects of shock-wave depend on the type of material, its quantity and the degree of confinement of the vapour cloud. A pressure of 5 to 10 kPa can cause direct injury. Death may occur at a higher pressure but demolition of building or breaking of windows occur at 3 to 10 kPa. The pressure decreases rapidly with distance. As an example, the explosion of a 50 tonnes propane tank can cause a pressure of 14 kPa at 250 mt and 5 kPa at 500 mt.

Types of explosion are deflagration, detonation, confined and unconfined vapour cloud explosion which could be for both, gas and dust.

When burning velocity or flame speed is slow (e.g. 1 to 10 m/sec), deflagration takes place in a confined space. It generates low pressure (e.g. 70-80 kPa).

When flame speed is very high (e.g. 2000-3000 m/sec), it causes detonation and generates high pressure like 200 kPa. Some degree of vapour confinement is necessary.

Explosion in a confined place like vessel, pipe-work, drain or building is called confined explosion and that occurring in the open air is called unconfined explosion. Confined explosion causes higher pressure and may reach upto hundreds of kPa.

Explosion of a vapour cloud after heavy leakage of a flammable gas can cause unconfined vapour cloud explosion (UVCE), boiling liquid expanding vapour explosion (BLEVE) or fire ball.

Explosion of a solid material in the form of dust, powder or small particles mixed with air is called dust explosion. Grain, milk powder, flour and coal dust are flammable dusts. Effect of dust explosion is mostly confined to the workplace.

See Chapter-13 for more details and control measures for Fire and Explosion.

Toxic releases are caused due to leakage and dispersion of toxic chemicals (gas or vapour) in air. As the workers are working nearby, they can be affected first. Therefore, workplace monitoring, air/gas sampling, environmental monitoring etc. as mentioned in Part 1.6 and 1.7 of Chapter-24 are all important.

Consequences of toxic release are influenced by wind speed, weather condition, leak rate or mass released, toxicity and concentration (ppm) at a particular place, and also by age, sex, genetic background, ethnic grouping, nutrition, vulnerability (old or tender age, sickness, disease etc.), exposure to other substances with synergistic effects, pattern of work, time of exposure and protected or unprocted.

Chlorine, ammonia and other chemicals like methyl isocynate have caused disasters. Study of toxicity and consequence analysis of such chemicals and advance emergency planning are most essential. For example, instantaneous release of 10 tonnes chlorine may produce 140 ppm at a 2 km downwind distance and 15 ppm at a 5 km distance in D5 weather. Chlorine can be lethal at 1000 ppm or at 100-150 ppm for 5-10 minutes. Its effect is dangerous even at 10-20 ppm for 30 minutes. Such data should be kept ready by all major hazard works in respect of their highly toxic chemicals with effect (distance and ppm) counters plotted on surrounding area.

6.2.2 Types of Discharges:

Phase wise there are three types of discharges -

(1) Liquid discharges (acid, alkali, solvent, oil, water etc)

(2) Liquid-Gas two phase discharges (Cl_2, NH_3) and

(3) Gas or Vapor discharges

(1) Liquid Discharges :

Material which is normally a liquid at atmospheric pressure and temperature, causes a pool to form. viz., benzene, acrylonitrile and other common solvents.

Rate of evaporation or vaporization from the pool depends on:

1. Vapour pressure of the liquid.
2. Temperature of the liquid.
3. Area of the pool.
4. Air temperature.
5. Ground temperature.
6. Heat transfer of convection & radiation etc.
7. Molecular weight of the material.
8. Mass transfer coefficient.
9. The ideal gas constant.

For liquids boiling from a pool, the boiling rate is limited by the heat transfer from the surrounding to the liquid in the pool. Heat is transferred (1) from the ground by the conduction, (2) from the air by conduction and convention, and, (3) by radiation from the sun and/or adjacent sources such as a fire.

The viscosity of the liquid determines the rate of growth of the pool, i.e. its area.

Generally the initial rate of emission will be greater per unit area than the equilibrium rate. The pool is cooled because of evaporation.

Following types of flow are possible:

1. Flow of liquid through a hole in a process unit :

Here energy of the liquid due to its pressure in the vessel is converted to kinetic energy with some frictional flow losses in the hole. Due to friction between moving liquid and the wall of the leak, some kinetic energy of the liquid is converted into heat (thermal) energy resulting in a reduced velocity. The total mass of liquid spilled depends on the total time the leak remains active.

2. Flow of liquid through a hole in a storage tank:

Here energy due to the pressure of the fluid height above the leak is converted to kinetic energy as the liquid exits through the hole. Some energy is lost due to frictional fluid flow. As the tank empties, the liquid height decreases and the velocity and mass flow rate decrease.

3. Flow of liquids through pipes:

Here a pressure gradient across the pipe is the driving force for the movement of liquid. Friction between the liquid and the wall of the pipe converts kinetic energy into heat energy. This results in a decrease in the liquid velocity and a decrease in the liquid pressure.

(2) Liquid - Gas Discharges :

Material stored in pressurized and/or refrigerated containers. viz. Cl_2, NH_3, LPG.

1. Two Phase release:

If the release rate is *slow enough* the material will enter the atmosphere as a *gas*. But in a *sudden release* such as a *tank rupture*, the dispersion process can be described in *4 phases*.

1. Turbulence called 'flash off' caused by rapid escape of the liquid or gas. For a 20-ton NH_3 tank rupture, tests suggest @20% vapour & 80% liquid aerosol coming out as a *cloud*.

2. The cloud (liquid cylinder or column) starts to slump like a water column starts to spread out. During slumping, air is entrained slowly. This second stage lasts 30 to 40 seconds for a 20-T NH_3 spill.

3. The gas cloud now enters the ground hugging phase. Most of the air entrainment takes place through the top surface. Depending on ambient temp., gases in the cloud will reach ambient air density in 3 to 5 minutes after slumping starts from a 20-T NH_3 spill.

4. The natural process of atmospheric turbulence takes over, and the cloud diffuses while travelling along with the wind, like any other material in the atmosphere.

2. Flashing Liquids:

Liquid stored under pressure above their normal boiling point temperature, may cause problems due to flashing. If the containment (vessel, tank, pipe etc.) develops a leak, the liquid will partially flash into vapor and if the liquid is flammable, fire or/and explosion may also take place. Flashing occurs very rapidly as an adiabatic process. The excess energy contained in the superheated liquid, vaporizes the liquid and lowers the temperature to the new boiling point. Flashing liquid escaping through holes and pipes require special consideration since two-phase flow conditions may be present.

(3) Gas Discharges :

Such discharges result in the formation of air-gas mixture at a temperature some what below ambient temperature.

Gas or vapor discharges may be of the following types-

1. Flow of Gas through a hole :

Energy contained in gas or vapor as a result of its pressure, converts into kinetic energy as the gas or vapor escapes and expands through the hole. The density, pressure and temperature change as the gas or vapor exits through the hole.

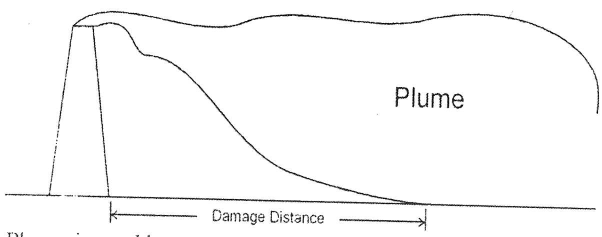
Gas and vapor discharges are classified into throttling and free expansion releases. For a throttling release, gas leak through a small hole or crack suffers large frictional losses and a small amount of energy due to gas pressure, is converted to kinetic energy. For a free expansion release, most of the pressure energy is converted to kinetic energy, indicating isentropic behavior. The gas properties and velocity change during the expansion. Knowing of maximum flow rate of gas through the hole is useful for safety studies.

2. Flow of Gas through a Pipe:

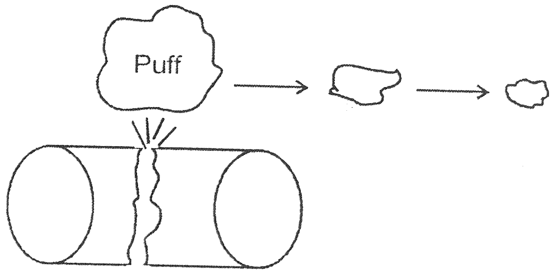
Gas or vapor flow through a pipe is of two types - adiabatic or isothermal behavior. The first case corresponds to rapid flow through an insulated pipe while the second case corresponds to flow through an un-insulated pipe maintained at a constant temperature (e.g. Underwater pipe). Real gas flow behaves somewhere between the adiabatic and isothermal cases. In adiabatic, non-choked flow of gas through a pipe, the gas temperature might increase or decrease, depending on the magnitude of the frictional losses. In isothermal flow of gas through pipe, the gas temperature remains constant across the entire pipe length and the pressure at the end of the pipe is equal to the pressure of the surroundings.

3. Dispersion Models:

Gas dispersion models describe transport of airborne toxic materials away from the release site and into the plant and community. After a release, the airborne material is carried away by the wind in a plume or puff form as shown in the figure.



Plume formed by a continuous release of gas



Puff formed by instantaneous release of gas

The maximum concentration of the leaked material occurs at the release point. Downwind concentration is less because of turbulent mixing and dispersion with air. Main factors affecting such atmospheric dispersion are -

1. Wind velocity or speed.
2. Height of release above ground level.
3. Momentum and buoyancy of the initial material released.
4. Atmospheric stability.
5. Ground conditions, buildings, water, trees and other obstructions.

As the wind speed increases, the plume becomes longer and narrower. The material is carried downwind faster but is diluted faster by more entrainment of air.

As the release height increases, ground level concentration decreases since the plume has to disperse a greater distance vertically as shown in above figure.

With the increase in release height, the damage distance (e.g. distance of fall point) also increases resulting into more dispersion and less concentration at ground level.

Momentum and buoyancy of the released material changes the "effective height of release". After the initial momentum and buoyancy is dissipated, ambient turbulent mixing becomes dominant and material comes to the air density.

Atmospheric stability relates to vertical mixing of air. During the day time, air temperature decreases rapidly with height, encouraging vertical motion of the leaked material. At the night, temperature decrease is less, resulting in less vertical motion. Sometimes inversion may occur. During such inversion, temperature increases with height, resulting in minimal vertical motion. Mostly this occurs at night as the ground cools rapidly due to thermal radiation.

Ground conditions affect the mechanical mixing at the surface and the wind profile with height. Tress, buildings or other obstructions increase mixing while lakes and open areas decrease it.

Mostly two types of gas dispersion models are used - the plume and puff models. The plume model describes the steady-state concentration of material released from a *continuous source* e.g. smoke release from a stack (chimney). The puff model describes instantaneous or *temporary single release* of a fixed amount of material e.g. release from a pipe failure or rupture of a storage vessel or flanged joint. Generally following types of dispersion models are considered–

1. Steady-state, continuous point release with no wind.
2. Steady-state, continuous point release with wind.
3. Non steady-state, continuous point release with no wind.
4. Steady-state plume with source on ground.
5. Continuous steady-state source having height above the ground.
6. Puff with no wind.
7. Puff with wind.
8. Puff with no wind with source on ground.

Calculations of concentrations of released material at different distances in above types of gas dispersion conditions (models) require very complex mathematical exercise but the computer software presently available has made this exercise easy and speedy.

6.2.3 Effects of Discharges:

Dispersion and diffusion due to discharges in air means spreading and dilution of gas in air. When smokes come out from a chimney, vaporisation takes place from boiling or evaporating liquid, any material leaks or spills due to leakage or handling and discharges gas or vapour in atmosphere, safety valve or vent opens and liberates gases, any accidental failure of any vessel or equipment occurs giving sudden rise of vapours or gases or due to any fire or explosion when gas comes out, dispersion phenomenon takes place.

Because of discharge pressure, lighter vapour density, buoyancy, kinetic energy, temperature etc. the escaping material travels in air and because of turbulence in air and wind velocity the mixing (air-entrainment), diffusion, dilution or dispersion and spreading in wind direction takes place. Weather conditions and topographical factors also affect. Dispersion may be of a flammable gas-air mixture or non-flammable (inert, toxic or corrosive) gas-air mixture. It may be a continuous emission (plume release) or instantaneous puff release.

Dispersion can be studied in four types of areas (1) Leaks and spillage (2) Dispersion from vents and jets (3) Dispersion of heavy gases and (4) Dispersion by fluid curtain. Simultaneous study of meteorological and topographical conditions becomes a part of the subject of dispersion and modelling.

The dispersion is of more concern when it is of very toxic gas or highly flammable vapour, because it can give direct rise to toxic effect, fire or explosion.

Toxic release in bulk quantity and for a long duration (e.g. Bhopal incident) affects public at large. To assess the consequence, fatalities, injuries and property damage and for the purpose of evacuation to save life, scientific calculations become necessary which include probit equation and analysis and a variety of gas dispersion modelling. The computer models can give quick results.

A flammable gas in explosive range with air can cause fire or explosion and may be consumed by combustion. But a large vapour cloud is capable of producing an unconfined vapour cloud explosion. Boiling liquid expanding vapour explosion (BLEVE) and/or fireball are also possible.

A dispersing gas gets diluted in air during dispersion, diffusion and travelling and its density becomes close to air density. Therefore the majority of dispersions are known as 'air-density or neutral density dispersion'. Only some dense gas dispersion needs special calculations and treatment.

A gas released from any point may be ignited if flammable and may cause, BLEVE, flare or pool fire and cause heat radiation damage. Fire may generate toxic products and adds toxic effects too. If immediate ignition is not possible, the gas may vaporise, disperse and may cause delayed ignition which by pressure wave may cause flash fire or explosion and ultimate damage. If the released gas is not flammable but toxic, it causes toxic effects and if it is inert like nitrogen, causes oxygen deficiency in a confined space. If the gas is in no way injurious, no adverse effect is possible.

Types of releasing gas may be of the following nature :

1. Liquefied pressurised gas (e.g. LPG).
2. Flammable gas (e.g. fuel gas, H_2).
3. Toxic gas (e.g. Cl_2, NH_3, CO).
4. Low boiling liquid (e.g. petrol, benzene).
5. Liquid with toxic combustion products.

Their **hazardous effects** may be of the following types.

1. Heat radiation from a jet, pool fire, a flash fire or BLEVE.
2. Explosion overpressure.
3. Toxic effects from toxic materials or toxic combustion products.

The following effects consequential to the accidental release of hazardous materials are of much interest :

1. Atmospheric dispersion as a function of source strength, gas density, weather conditions and topographical situation of the surrounding area.

2. Intensity of heat radiation (in kW/m^2) due to a fire or a BLEVE as a function of the distance of the source.

3. Energy of vapour cloud explosions (in N/m^2) as a function of the distance of the exploding cloud.

4. Concentration of the evaporated material which may be explosive or toxic.

5. Concentration of the toxic products of combustion produced by a fire and

6. Duration that these respective effects may prevail.

Some damaging effects due to heat radiation, blast overpressure and toxic concentration are summarised below :

(A) Radiation Effects of Heat Exposure :

Table A-1 : Heat flux and Risk severity criteria.

Heat Flux	Damage and Fatality
37.5 kW/m²	Capable of causing third degree burn. Heavy damage to plant equipment. 99% fatality.
30 kW/m²	Limit for class 1 building materials.
25 kW/m²	Capable of causing second degree burn. Non-piloted ignition. Wood ignites on prolonged exposure without a pilot flame. 50% fatality after 30 seconds of exposure.
16 kW/m²	Severe burns after 5 seconds of exposure.
12.7 kW/m²	Piloted ignition. 1 % fatality after 20 seconds of exposure.
12.5 kW/m²	Capable of causing first degree burn. Piloted ignition. 1% fatality after 30 seconds of exposure. Minimum energy required for melting plastic.
10 kW/m²	Second degree burn after 25 seconds.
8 kW/m²	First degree burns after 8 seconds of exposure.
6.4 kW/m²	Pain threshold reaches after 8 seconds. Second degree burns after 20 seconds of exposure.
5 kW/m²	Second degree burns after 40 seconds of exposure.
4.7 kW/m²	Accepted value to represent injury.
4 kW/m²	First degree burns after 20 seconds of exposure.
1.6 kW/m²	No discomfort. Pain threshold reached after more than 60 seconds of exposure.

Source - Environment Monitoring Training and Research Centre, New Delhi and Industrial Safety Chronicle, Vol. XXXIV, Jul-Sept., 2003, National Safety Council, Mumbai.

Table A-2 : Radiation effect with /without protection in kW/m^2.

Exposure time →	T = 10 seconds		T = 30 seconds	
	With protection	Without protection	With protection	Without protection
1st Degree Burns	8.5	6.9	3.7	3.0
1 % lethal injury	21.2	16.5	9.3	7.3

10 secs - It is assumed that exposed persons will find protection from heat radiation within 10 seconds.

30 secs - It is assumed that people do not run away immediately or no protection is available.

(B) Explosion Effects due to Overpressures :

Table B-1 Damage Criteria due to explosion overpressure.

Peak Overpressure(bar)	Injury or Damage
1.7	Bursting of lung
0.3	Heavy plant and building damage (90%)
0.2	Minor damage to steel frames
0.1	Repairable damage to building and equipment (10%)
0.07	Shattering of glass
0.03	Major glass damage
0.01	10% glass damage, crack in glass

Source : Environment Monitoring Training and Research Centre, New Delhi and Industrial Safety Chronicle, Vol. XXXIV, Jul-Sept., 2003, National Safety Council, Mumbai.

Table B-2 : Blast wave effects due to explosion overpressure.

Type of damage	Peak overpressure
Total destruction	0.830 E + 5 Pa = 0.830×10^5 Pa
Heavy damage	0.350 E + 5 Pa = 0.350×10^5 Pa
Moderate damage	0.170 E + 5 Pa = 0.170×10^5 Pa
Minor damage	0.035 E + 5 Pa = 0.035×10^5 Pa

Example : 0.830 E + 5 Pa = 0.830×10^5 Pa = 0.830×10^2 kPa
= 83 kPa = 0.82 bar

Approximately 0.1 bar peak over pressure may cause 1% fatality or serious damage to 10% of the housing/structures.

(C) Toxic Effects of Chemical Discharges :

Table C-1 : Fatal Effects due to Toxic Exposure.

Chemical	LC in mg/m³ (Lethal Concentration at 30 min exposure)	
	1% Fatality	50% Fatality
Cl_2	364	1005
HCl	391	3950
EO	432	4443
CO	787	7949
NH_3	1871	5999

Table C-2 : Lethal Toxicity Levels of some Gases for Humans.

Gas	LC_{50} at 30 minutes, ppm		
	Base case	Standard case	Exponent 'n'*
Methyl isocyanate	34	17	1
Phosgene	53	26	1
Hydrogen cyanide	131	65	½
Chlorine	500	250	½
Hydrogen sulphide	640	320	½
Bromine	750	375	½
Hydrogen fluoride	1200	600	½
Sulphur dioxide	2300	1150	½
Ammonia	11500	5800	½

Source : Withers, R.M.J., *Foundations for simple computer models.* Loughborough University of Technology MHC/86/2, pp 4-8, 1986.

In above table -

LC_{50} at 30 minutes means lethal concentration of the released gas which can kill 50% of the exposed persons (similar) if they continue to expose for 30 minutes in that concentration.

'Base case' relates to healthy humans at rest.

'Standard case' relates to enhanced breathing after physical activity.

* Concentration C x Exposure time T^n = Constant

Table C-3 : Toxicity Criteria under MSIHC Rules 1989.

Sr. No.	Degree of toxicity	Inhalation toxicity LC_{50} (mg/l)	Oral toxicity LD_{50} (mg/kg)	Dermal (skir toxicity LD_{50} (mg/kg
1	Extremely toxic	< 0.5	< 5	< 40
2	Highly toxic	> 0.5 - 2.0	> 5 - 50	> 40 - 200
3	Toxic	> 2 - 10	> 50 - 200	> 200 - 1000

6.2.4 Probit Analysis

Probit Analysis is a method (calculation) to assess *probability* of injury or damage due to serious or lethal dispersion. It is a mathematical expression in the form of a probit function as under :

$$V = K_1 + K_2 \text{ In } C \qquad (I_n = \log_e)$$

where V is a measure of the vulnerable resource (human or property) which gets injury or damage, and variable C is a measure of the intensity of the causative factor which harms the resource.

The logarithmic term (I_nC) i.e. $\log_e C$ in above equation arises because in any population, some people can tolerate high intensity of harmful causative factor than others. The distribution is slanting (oblique).

The constants K_1 and K_2 can be calculated from the relationship between the intensity of causative factor and the degree of harmful response. In case of fire, K_1 and K_2 depend upon effective time duration(s), radiation intensity (W/m^2), duration of pool burning(s) and radiation intensity from pool burning (W/m^2). In case of *explosion,* they depend on peak over-pressure (N/m^2) and impulse (Ns/m^2) and in case of *toxic release,* they depend on concentration (ppm) and time interval (min).

In case of fire, burn deaths may take place due to flash fire or pool burning. In case of explosion, deaths or injuries may take place due to impact, eardrum rupture, flying fragments, structured damage, glass breakage and lung haemorrhage. In case of toxic release, deaths or injuries may take place due to toxicity and concentration of the gas.

In case of fire, deaths or injuries may happen due to thermal radiation. This effect is time-dependent and is given by following probit equation :

$$P_r = K_1 + K_2 \text{ In } C^n t = K_1 + K_2 \log_e C^n t$$

where P is the probit i.e. a measure of probability of people that may be affected, K_1 and K_2 constants, C a causative factor (here radiation intensity in kW/m^2), n = constant and t = time in seconds.

The values for K_1 and K_2 are mostly derived from experiments with animals. However, human toxicity factors have been derived from past accidents. Inhalation experiments with rats seem to be best applicable to predict damage to people from acute intoxication.

In above probit equation following probit constants are relevant for the following chemicals :

Chemical	Probit Constants		
	K_1	K_2	n
NH_3	- 15.8	1	2.0
CO	- 7.4	1	1.0
Cl_2	- 14.3	1	2.3
EO	- 6.8	1	1.0
HCl	- 6.7	1	1.0

Examples :

(1) Let us consider C = 21.2 kW/m^2 radiation energy for 1 % lethality with exposure time 10 seconds, then for Ethylene oxide (EO),

P_r = $K_1 + K_2$ In $C^n t$

= - 6.8 + 1 In (21.2^1 x 10)

= - 6.8 + 1 In (21.2 x 10)

= - 6.8 + In 212

= - 6.8 + 5.35

= - 1.45

(2) Let us consider C = 1871 mg/m^3 concentration for ammonia at its LC_{30}, then for 20 seconds exposure,

P_r = $K_1 + K_2$ In $C^n t$

= - 15.8 + 1 In (1871^2 x 20)

= - 15.8 + In (3500641 x 20)

= - 15.8 + In 70012820

= - 15.8 + 18.06

= + 2.26

(3) Let us consider C = 25 mg/m^3 concentration for chlorine, then for 5 minutes (5 x 60 = 300 seconds) exposure,

P_r = $K_1 + K_2$ In $C^n t$

= - 14.3 + 1 In ($25^{2.3}$ x 300)

= - 14.3 + In (1641.57 x 300)

= - 14.3 + In 492473.96

= - 14.3 + 13.10

= - 1.2

The probit P_r is a random variable with a mean 5 and variance 1. The probability (range 0 - 10) is generally replaced in probit work by a percentage (range 0 - 100) from the following table :

Probit	% (approx)
2.5	0
2.67	1
3	3
3.5	8
4	15
4.5	30
5	50
5.5	70
6	85
7	98
7.5	100

Thus probit P_r = 2.67 represents 1% of the exposed population, P_r = 5 represents 50% of the exposed population, P_r = 5.5 represents 70%, P_r = 7 represents 98% and P_r = 7.5 represents 100% of the exposed population or percentage damage or degree of injury that can result from the exposure.

In previous example (2) of ammonia release, P_r = 2.26 indicates that approximately 0.9% of the population may be affected.

A common rough estimate for the hazard range for large pool fires is about 2 pool diameters, and for large drifting vapour clouds 1.5 cloud diameters.

Thus a probit equation generally gives the relation between the causative factor and the probability of death.

However it should be borne in mind that probit equations are just approximation in an impact model of hazard assessment and there may be a vast difference in actual result.

See also Part 4.12 for use of Probit Equation.

6.3 Criteria (Identification) for the Plant to become MAH unit :

Schedules 1, 2 and 3 of the Manufacture, Storage and Import of Hazardous Chemicals Rules 1989 (and also u/r 68J of the Gujarat Factories Rules) prescribe criteria for toxic, flammable and explosive chemicals, list out the hazardous chemicals and give their **threshold quantity** for application of certain rules. These storage quantities and processes listed in Schedule-4 are, now, **legal criteria** to identify the plant to be under MAH category. For details the Schedules should be referred.

Thus the plants keeping quantities *equal to or more than* the threshold quantities mentioned in the Schedule-3 (table below is a part thereof) or the isolated

Chemical	Quantity (t)	Chemical	Quantity (t)
Cobalt (Powder)	1	SO_3	15
Hydrogen	2	SO_2	20
Formaldehyde	5	Acrylonitrile	20
HCN, HF, H_2S	5	CS_2	20
EO	5	HCl gas	25
Acetylene	5	Bromine	40
Nitroglycerine	10	Nitrogen oxide	50
Chlorine	10	Ammonia	50

storage (other than a factory) storing quantities equal to or more than the threshold quantity mentioned in the Schedule-2 (e.g. Ammonia 60t, Flammable gases 50t, Highly flammable liquids 10000t, Bromine 50t) are to be identified as major hazard installations (factories or isolated storage).

As the Oleum is not named in Sch. 2 or 3, the quantity of SO_3 (15t) is to be considered for oleum.

For the purpose of determining the threshold quantity of a hazardous chemical in a factory or isolated storage, the aggregate of all installations within a distance of 500 mt of each other and belonging to the same factory/isolated storage (or the same occupier) shall be considered as mentioned in Sch. 2 & 3.

Based on above discussion, the MAH units are mostly those associated with -

1. Storage/processes of Cl_2, NH_3 & LPG.
2. Other chemical/petrochemical plants and refineries.
3. Pesticide factories.
4. Explosive factories and
5. Large fertiliser plants.

6.4 Role of the Management

Under the Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989 the general responsibilities of management of any MAH unit are to -

1. Provide information to the authorities, of criteria, quantities and processes of hazardous substances to identify the unit as an MAH unit. See Rule 4 & 7, and Sch. 7 & 9 for notification of site and MSDS.
2. Carry out Safety Audit and Risk Assessment and collection, development and dissemination of information as mentioned in Rule 17 and Sch. 8 to 12. Submit Safety Report and Safety Audit Report.
3. Report to the authorities the results of the hazard/risk assessment in the prescribed formats e.g. Safety Report in Sch. 8, MSDS in Sch. 9, Information of imported chemicals in Sch. 10, On-site Emergency Plan in Sch. 11 and information required by the authority to prepare Off-site Emergency Plan in Sch. 12. This plan is to be rehearsed once in a year.
4. Set up an emergency plan i.e. on-site and off-site emergency plan based on the guidelines from Factory Inspectorate. See Sch. 11 & 12.

Eyes and Face - Guide for selection of eye, face and ear protection 8520, 8521, maintenance and care 8940, for welding 1179, methods of test 7524 (Part 1 & 2), eye protectors, filters 5983, safety glass 2553, eye and face showers 10592

Ears - Guide for selection 8520, ear protectors 9167, earmuffs, method for measurement 6229

Hands - Guide for selection 8807, Gauntlets and mittens, leather 2573, gloves - safety 6994, rubber - electrical 4770, surgical 4148, post-mortem 4149

Feet & Legs - Footwear, selection 6519, 10667, Ankle boots for general purposes 583, boots and shoes safety, leather 1989, leather for firemen 4128, rubber - canvas for miners 3976, 10665, gaiters, protective 2472, knee boots, rubber 3736, 3738, leather for leg guard 3946, toe caps, steel for footwear 5852, boots for oilfield workmen 9885 (Part 1 & 2), footwear for steel plants 10348, for mines and heavy metal industry 13295, safety shoes for women workers in mines and steel plants 11225, footwear with direct moulding sole 11226, rubber footwear 11264, PVC boots 12254, chemical resistant 13292, 13695, PVC boots, oils and fats resistant 13038, code of practice for manufacture 13295, lined antistatic rubber footwear 13575, wooden, heavy duty 5520, rubber lined boots 5557, conducting 13996

Body - Guide for selection of body protection 8519, aprons - rubberised acid and alkali resistant 4501, rubber for hospital use 6407, lead-rubber, X-ray protective 7352, Clothing - fire resistant 4355, fire (flame) resistant suit 7612, leather 6153, sheath rubber 3701, fabrics, PVC coated for foul weather 3322, belt and strap, leather, lineman's safety 3521, material (nylon webbing) for aircraft safety belts 8947, maintenance and care of safety clothing 8990, evaluation of whole body vibration 13276 (Part 1 to 3), mechanical vibration and shock affecting man 13281

Lungs - Glossary of terms relating to respiratory protective devices 8347, selection, use and maintenance of respiratory, protective devices 9623, color identification of air purifying canisters and cartridges 8318, mouth-piece assemblies 14170, full face mask 14166, threads for face pieces 14138. Respirators - chemical cartridge 8522, canister type (gas mask) 8523, filter type for particulate matter 9473, CO filter 9563, bag type, positive pressure, manually operated 6194.

Breathing apparatus 10245 -

Part 1 : Closed circuit (O_2 cylinder).

Part 2 : Open circuit.

Part 3 : Fresh air line.

Part 4 : Escape type, short duration, self contained.

For breathing apparatus for fire brigade self contained IS 1910, For resuscitators for use with human's IS 13366 and for life jackets IS 6685.

IS 14489 - Code of Practice on OSH Audit:

Annex. C Item 139 to 146.

ITC EHS Guidelines - provide extensive coverage on assessment of need, care, maintenance, storage, inspection, issue procedure, body parts to be protected and conformity to standards of PPE.

Internationals Standards:

1. Occupational Safety and Health Act 1970, USA and Regulations made there under. Here content of training to be given to the users of PPE is also given.
2. Health & Safety at work Act 1974, UK
   Chemical Works Regulations 1992 (Reg.6) and Chromium Plating Regulations 1931 (Reg.3)

ILO

1. OSH and Working Environment Covn. No. 155 (1981) Article 16(3) and
2. OSH and Working Environment Recomm. No. 164 Para 10(e)

They require the employers to provide PPE, free of cost, to prevent risk of accidents or adverse effects on Health.

4 SELECTION AND CLASSIFICATION

Once it is decided that PPE is needed,

1. Select proper type of equipment (IS mentioned in Part 3 should be referred) and then
2. Make it sure that the supervisor sees to it that the worker uses and maintains it correctly. Proper selection, training and use of PPE are essential.

Factors of selection or requisite characteristics of PPE are :

1. It should give adequate protection against the nature, severity and type of hazard.
2. It should be of minimum weight, should give minimum discomfort with protective efficiency.
3. Attachment to the body should be flexible yet effective.
4. The wearer should not be restricted in movement or perceptions required for the job.
5. It should be durable and attractive.
6. It should not cause any hazard through its material, design, defect, use or failure.
7. It should conform Indian Standards and tests required
8. It should be easy to clean, repair and maintain. The parts, piece and service should be easily available.

If all above criteria are not available effort should be made to get maximum of them.

Classification of PPE for selection and understanding is given below and also in Table 25.1:

- PPE
  - Respiratory (Breathing)
    - Air purifying
      - Chemical Filters
        - Chemical gas mask, Chemical cartridge, Self rescue filters
      - Mechanical Filters
        - Dust or Nuisance filters, Micro filters
      - Combination of Chemical and Mechanical Filters
    - Supplied air
      - Air-lined
        - Airline respirator, Suction hosemask, Pressure hosemask or hood, Air Supplied Suits
      - Self-contained
        - Damage type (open-circuit)
          - Compressed air, Compressed oxygen
        - Re-circulating type (closed-circuit)
          - Compressed oxygen, Regenerated oxygen
  - Non-respiratory
    - For Protection of Head, Eyes, Ears, Face, Hands, Arms, Feet, Legs and Body. Special work clothing- e.g. asbestos, aluminised, leather and wool garments, lead clothing, disposal clothing etc.

Table 25.1 Selection and Classification of PPE according to the body part and hazards :

body-Part	Hazard	PPE necessary
Head	Falling objects, shock, chemical spurting	Safety helmet, hard hats, safety caps, headgear
Eye	Chemical splash, dust, flying particles, gas, welding, radiation.	Spectacles, lenses and goggles for chemical, welding, grinding, furnace, dust etc.
Ear	High level noise (>90 dB)	Earmuffs, plugs, inserts
Nose	Dust, toxic gases	Dust mask, cloth mask, rubber mask, fume mask, respirators for dust, gas and vapour, rescuer plus pressure suit, breathing apparatus (O_2 or Air), Canister gas masks, air line respirators, chemical/mechanical filters.
Face	Chemical splash, flying objects, hot substance.	Face shield, welding screen, furnace mask, face guard.
Hand	Hot substance, acid, alkali, pigments, chemicals, handling, cut, sharp edge.	Hand gloves of rubber, PVC, hosiery cotton, leather, asbestos, canvas, fibre glass, electrical rubber gloves, surgical gloves, arm sleeves.
Body	Chemicals, splashes, hot substance, fire, handling.	Aprons, coats and pants, pressure suit, suits of rubber, PVC etc.
Foot/ Leg	Striking against objects, chemicals, falling bodies	Leather or rubber sole shoes, steel toe-boots, antiskid sole shoes, ammunition boots, gumboots, leg sleeves.
Overall	Falling from heights, hurt by falling bodies, chemicals.	Safety belts, pole strap belt, nylon safety harness, all purpose safety harness belt, vertical lift safety harness, Boatswain's chair, rope ladders, nets, safety hooks.

Selection and classification of Respiratory equipment based on type of hazard :

- Hazard/Danger
- Hazardous substance (Toxic Contaminant)
  - Gas or Vapour
    - Eminent danger to life
      1. Self contained Breathing Apparatus
      2. Hose Mask and Blower
      3. Gas Mask
    - No eminent danger
      1. Airline respirator
      2. Hose Mask without Blower
      3. Chemical cartridge Respirator
      4. Gas Mask
  - Flying particles (Particulate matter)
    1. Dust, Mist or Fume Respirator
    2. Airline Respirator
    3. Abrasive Blasting Respirator
    4. Powered Respirator
  - Gas and Flying particles
    - Eminent danger to life
      1. Self contained Breathing Apparatus
      2. Hose Mask and Blower
      3. Gas Mask with Special Filter
    - No eminent danger
      1. Airline Respirator
      2. Hose Mask without Blower
      3. Chemical cartridge Respirator with Special Filter
      4. Gas mask
- Oxygen deficiency
  1. Self contained Breathing Apparatus
  2. Hose Mask and Blower with escape provision

Selection of Material of Construction of PPE is given in Table 25.2 :

Table 25.2 : Selection of Material of Construction for PPE

No.	**Material**	**For the protection from**
1	Metal	Flying particles, falling body, sharp edge, abrasion
2	Fibre metal	Sparks, falling body, flying particles, sharp edge, abrasion, machinery
3	Metal screen	Sharp edge & abrasion
4	Plastic, PVC	Hot liquid, moisture, water, petroleum product, acid, alkali, spark, falling body, flying particles, electric shock, sharp edge, abrasion, skin protection
5	Rubber	Hot liquid, moisture, water, acid, alkali, electric shock, machinery, skin protection
6	Conductive rubber	Explosive substance
7	Chrome leather	Hot substance, flying particles, sharp edge, abrasion, sparks
8	Canvas	Flying particles, sharp edge, abrasion, machinery
9	Asbestos	Heat, hot substance, sparks
10	Acidproof fabric	Acid & alkali
11	Reflective fabric	Hot liquid
12	Flameproof duck	Heat, hot substance, sparks, chemicals, flying particles, machinery
13	Cotton wool	Heat, sparks, machinery, skin protection
14	Cotton canvas	Sharp edge & abrasion
15	Steel toe boot	Falling body, striking
16	Non-skid shoes	Moisture, slippery surface
17	Wooden sole boot or sandal	Heat, hot substance, moisture, water, acid, alkali, slippery surface, sharp edge, abrasion
18	Soft silicon rubber or plastic	Moulded type ear plug

19	Plastic goggles with hydrophilic coating	To prevent fogging
20	Wirescreen lenses (face shield)	Heavy fog or dampness
21	Laser safety goggles (Antilaser eyeshield)	Laser beams
22	Aluminised welding helmet	Infrared rays and to reduce heat effects
23	Polarising lenses (filtershade lenses)	To prevent glare
24	Steel, reinforced plastic & hard rubber	Safety toe boot for foot protection
25	Boot with non-ferrous coating and conductive sole	Static charge, friction sparks, and to reduce fire and explosion possibility
26	Congress or gaiter type shoes	Work with hot metal in foundry, quick removable shoes without lash
27	Non-conductive or insulating (non-metallic shoes)	Electric work
28	Flexible metal reinforced sole or inner sole	Construction work and cold metal work with possibility of foot injury
29	Plastic shoe cover or cap	Pharmaceutical factory needing higher product safety.
30	Specially made asbestos clothing	To work with hot metal upto 1650 ^{0}C
31	Aluminised asbestos or glass fibre and wool lining	To work near a furnace at temperature upto 540^{0}C or for fire fighting. Such proximity clothing should not be utilised to enter into the fire. They are for working from a distance
32	Flameproof or flame resistant cloths - THPC, Nomex or Modaphrilic fabrics	Fireproof cloths to work in the fire flames
33	Cushion pads or padded duck	To carry heavy or sharp edged load on shoulder or back.
34	Apron of padded leather, fabric, plastic, hard fibre or metal	For protection of abdomen or middle body parts
35	Thermal net cotton or quilted material (decron or nylon)	To work in cold weather (unsuitable to work in hot or fire).
36	High visibility and night hazard clothing	For construction and maintenance, Police and Fire brigade and Traffic hazards
37	Disposable clothing (plastic or reinforced paper)	In less radioactive work or drug or electronic industry
38	Leaded clothing (leadglass fibre, leaded rubber, leaded plastic)	Laboratory work, protection against X and Gamma rays
39	Electromagnetic radiation suit	Radar field
40	Conductive clothing	For linemen to work at extra high voltage. Such clothing keeps the linemen at the proper potential.

5 NON RESPIRATORY EQUIPMENT

See Fig. 25.1(A) and (B) for Non respiratory PPE.

5.1 Head and Hair Protection :

Head protectors are hard hats, caps and helmets made of aluminium, PVC fibre glass, laminated plastic or vulcanised fibre. They may be fitted with brackets for fixing welding masks, protective face screen or a lamp. The hats and caps are provided with replaceable harness which provides sufficient clearance between the top of the head and shell. Selection is as follows:

	Material	Protects against
1	Asbestos	Sparks, hot materials, heat
2	Plastic rubber	Hot liquids, moisture, acids, alkalis, electric shocks, dermatitis
3	Cotton wool	Sparks and heat, dermatitis, machinery
4	Metal	Falling objects, flying particles, cuts, abrasions.
5	Plastic	Sparks, falling objects, flying particles, electric shock, cuts, abrasions.

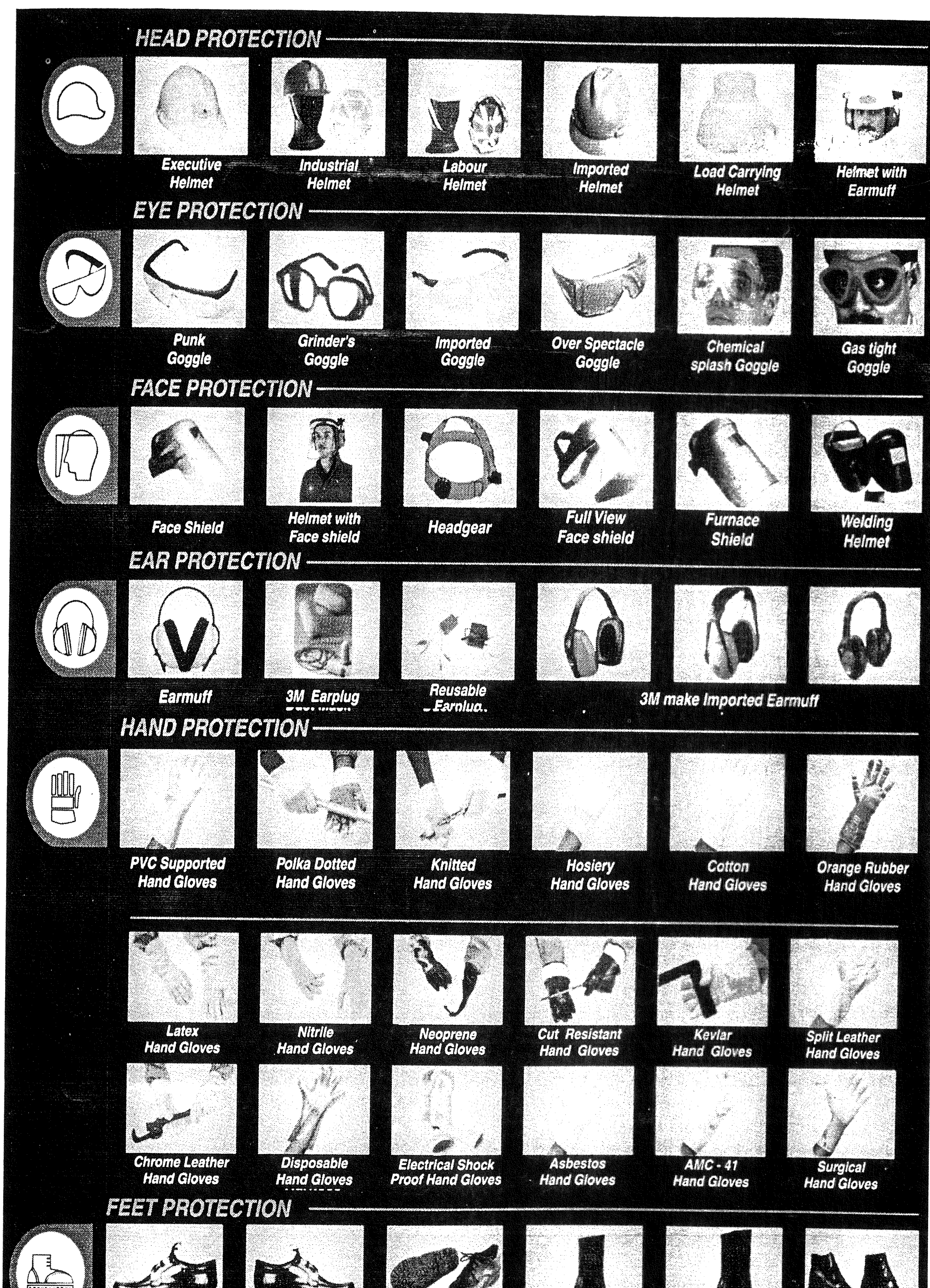


Fig. 25.1(A) Non Respiretory PPE

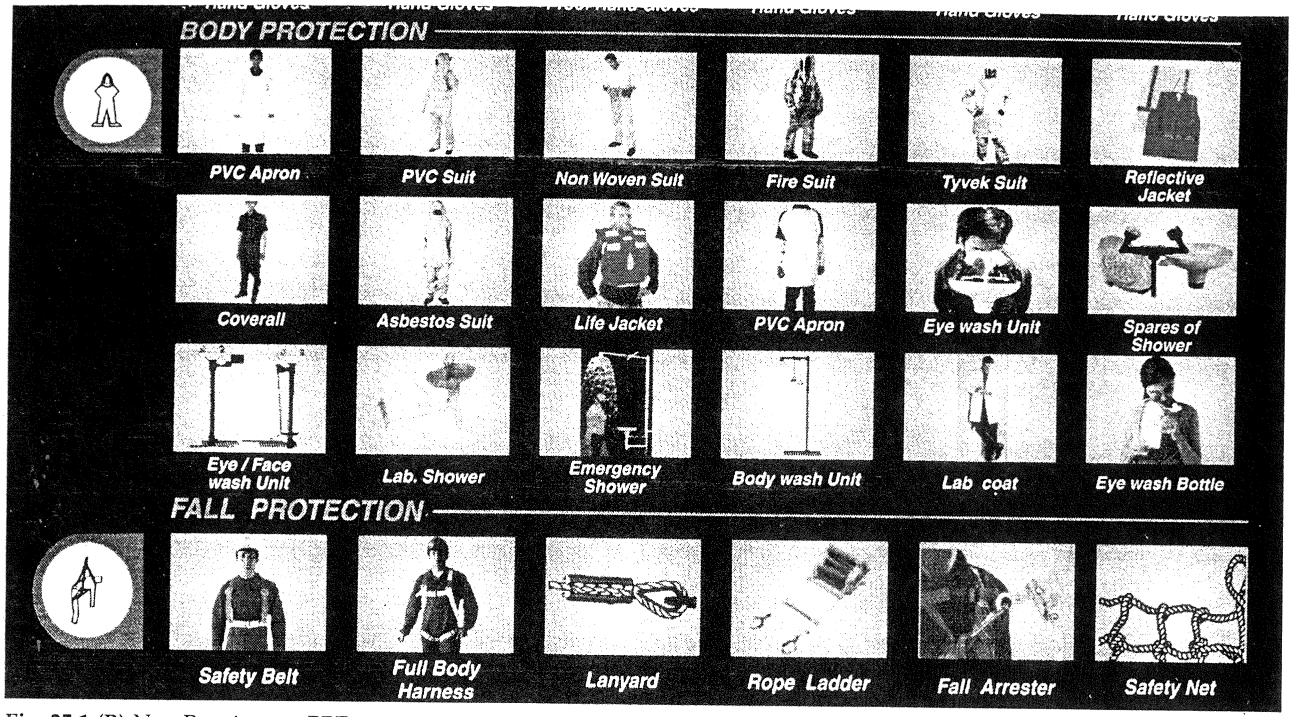
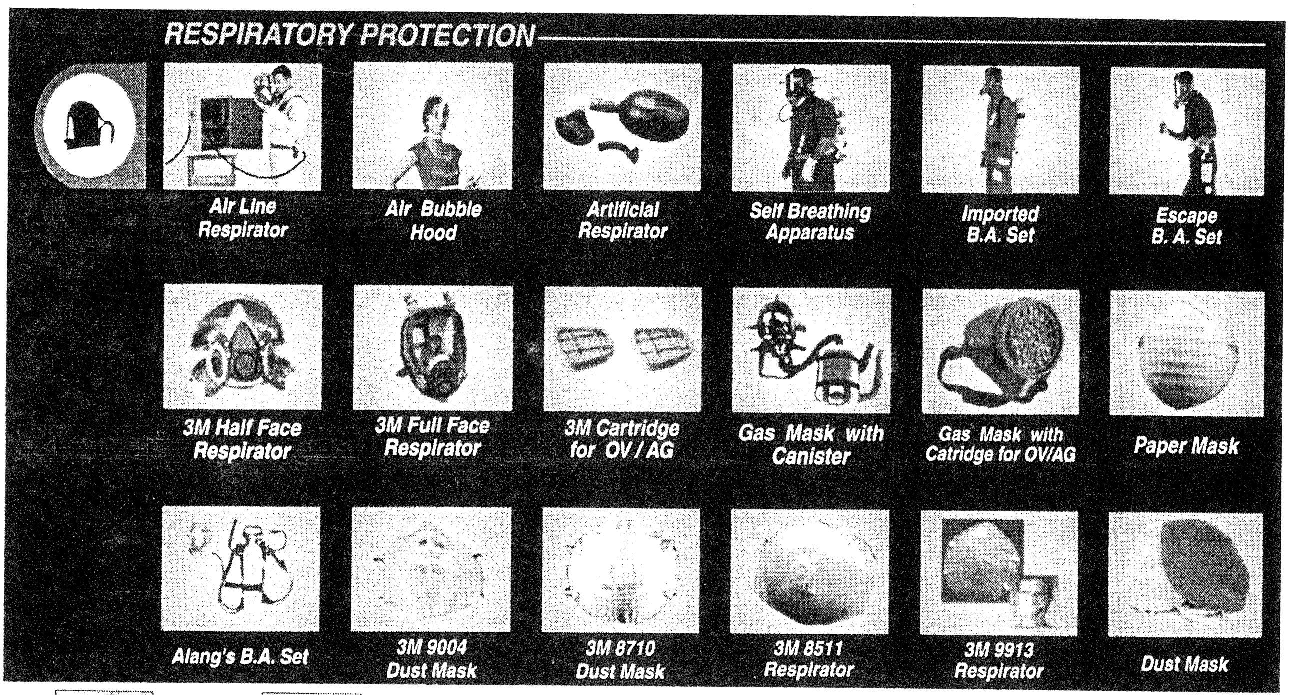
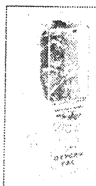


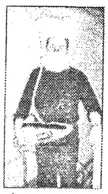
Fig. 25.1 (B) Non Respiretory PPE



Self contained open circuit breathing apparatus with seamless steel cylinder. CAP.:6L/300 bar& 9L/200 bar.

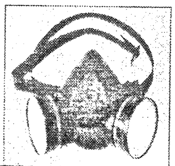


Life Oxygen pack : Provides supplementary oxygen with inhalator for breathing victim & through a resuscitator for non breathing victim. Cap. : 6LPM CF & 0 to 25 LPM.

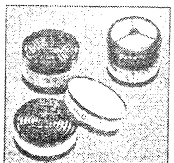


Short duration emergency escape breathing app. Half mask attachment & alarm whistle. 2 Ltr steel cylinder

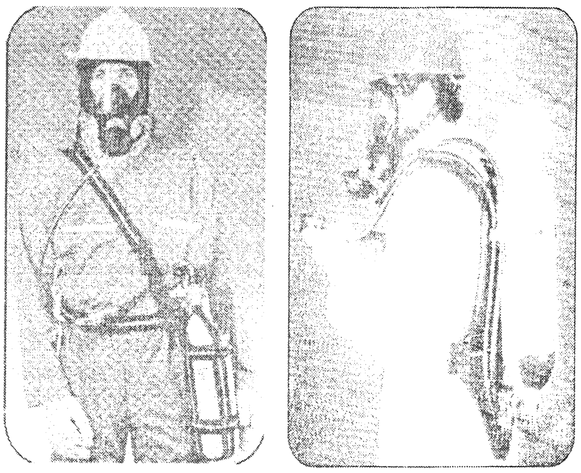
Full face mask with wide vision. Available in Polychloroprene & silicon rubber for use with gas filters.



Half mask with gas filters.



Gas filter cartridges in synthetic resin containers.



Self contained breathing apparatus (SCBA)

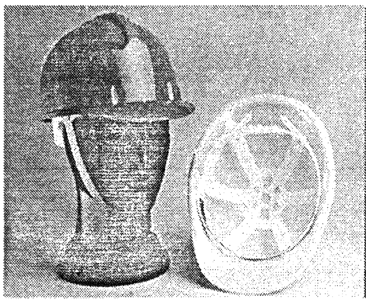
Fig. 25.2 Respiretory PPE

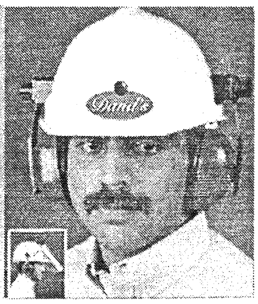
Utility and characteristics of head protectors are shown in Table 25.3

Table 25. 3 : Head Protectors

Type	Protects Against	Characteristics
Safety Helmet (Hard hat)	Falling objects, hitting against obstructions such as low ceilings, beams, scaffold members, etc.	Generally made of aluminium alloy, PVC, fibre-glass, or vulcanised fibre. Saddle (geodetic strap suspension) inside to dissipate impact pressure over wide area of head and to provide clearance between the head and the shell of helmet. Chin strap or other device to prevent displacement. Peak and full brim to protect face, neck, ears. Ventilation holes for comfort.
Electrical Safety Helmet	Electric shock when working near live electrical lines.	Made of synthetic electrically non-conductive materials (PVC etc.)
Welders' Cap	Falling welding spatters from above.	Made of leather with cloth lining inside
Crash Helmet	Skull injuries in road accidents.	Usually fibre/plastic material, with saddle inside, without peak or rim and with chin strap. Covers forehead, temples and lower portion of head (above neck)

Soft caps and hoods are also used for protection against heat, spark and other dangerous materials and are made of appropriate materials. Some time hoods are made with rig frame which is held away from the head.





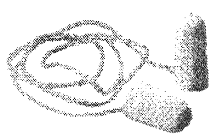
Long hair or beards may be caught in moving machine parts (e.g. belts, chain, in-running nips etc.) while seeing or leaning down or by heavy static charges. Protective caps covering the hairs are useful. Hair net is not a full protection. The hair cap should be of flame- retardant material for protection against sparks or hot metal. It should be cool, lightweight, adjustable and with visor in front.

Types of equipment available :

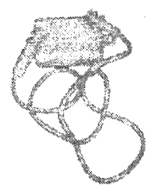
Adjustable head gear and chinstrap.
Sand/shot blasting helmet.
Glass fibre safety helmet.
Safety helmet attached to ear muff.
Darvic plastic helmet.
Safety helmet made of aluminium.
Black fibre or moulded fibre glass.
Hard hats and safety caps.
V-Guard protective caps & hats.
Topguard protective caps & hats.
Thermalguard caps & hats.
Skullguard protective headwear.
Shockguard caps & hats.
T-aluminium caps & hats.
Vanguard helmets for lateral protection.
Winter liners.
Foldback faceshield frames for caps & hats.
Welding shields.
Auto change welding helmet.
Universal cap & hat adapters.
Sparkguards.
Goggle retainer (on helmet).
Chin straps.
Defender fire helmets.

5.2 Ear(Hearing) Protection :

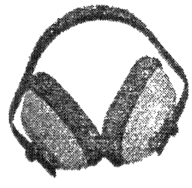
See Chapter-12 for permissible noise levels and control measures in detail. Hearing loss is an occupational disease under Sch.3 of the Factories Act, 1948. Hearing lkoss caused by exposure to loud noise is irreversible.



Foam ear plug with cord



Ear seal with cord



Ear muff

Noise level above 90 dBA is hazardous for an exposure more than 8 hrs/day or 48 hrs/week. It may cause deafness, fatigue, loss of efficiency, irritation and also loss of hearing. Noise level can be measured by a noise average meter or a noise dose meter. Ear plugs or Ear muffs reduce to @ 25 to 40 dBA. Ear plug is made of plastic, rubber or polyurethane foam. Ear muffs covers external ear and provides better attenuation than ear plug.

See Part 6.7 of Chapter-12 for ear protectors.

Types available :

Ear muffs, or cups (circumaural).
Plugs or inserts.
Dielectric ear muff.
Formable (disposable) aural inserts.
Full enclosure (e.g. astronaut).
Superaural or canal cap.

Hearing protecting devises are labeled with a noise-reduction rating (NRR) according to EPA requirements. These are determined in ideal laboratory settings and so the real world sound reduction protection that they provide may actually be much less.

5.3 Face and Eye Protection :

Eye injuries can be caused by mechanical, chemical, thermal and radiation hazards such as dusts, flying particles, splashes and harmful radiation. Eye protectors are safety spectacles, mono goggles, impact goggles, welding goggles, foundry goggles, chemical goggles, gas tight goggles, face shields, welding helmets etc. Possible hazards are :

1	Large flying particles from	Chipping, fettling, riveting, sledding, chalking.
2	Dust and small flying particles from	Scaling, grinding, stone dressing, wood working.
3	Splashing of metals from	Pouring of liquid metal from ladle, crucible etc., casting of metals, galvanising and dipping in molten metals.
4	Splashing of liquids, gases and fumes from	Handling of acids and other chemicals.
5	Reflected light, glare and radiant energy from	Foundry work, glass furnaces, gas welding and cutting, arc welding.

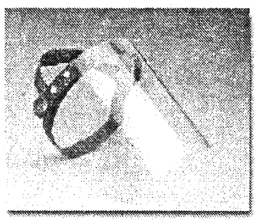
Utility and characteristics of eye protectors are shown in Table 25.4.

Table 25.4 : Eye Protectors

Type	Protects Against	Characteristics
Spectacle-type Goggles	Flying bodies (dust, metal chips, etc.)	Plain, shatter-proof, toughened glass or plastic lenses. With or without side shields. Metal or heat-resistant frame.
Panorama Goggles	Oil and paint splashes, dust and chip exposure	Light in weight, Non-fogging cellulose clear visor. Ventilation holes on either side. Soft pliable plastic frame wide enough to wear over prescription glasses.
Leather-mask Goggles	Smoke, dust, foreign bodies	Sweat lining along edges, ventilation holes with baffles for light and dust. Shatter-proof lenses.
Chemical Goggles	Chemicals and toxic dusts	Acid/alkali-resistant rubber frame with clear lenses and shielded ventilating ports.
Gas-tight Goggles	Irritating fumes, vapour or gases	Airtight-fitting without ventilating ports.
Welding Goggles	Gas Welding/ Cutting, flames & sparks	Similar to panorama goggles with filter glass of suitable grade and indirect ventilation ports.
Welding Shields	Arc Welding/ Cutting flames and sparks	Fibre or fibreglass shield, hand-held or suspended from helmet, with window for filter glass.

Eye and face protection standards are provided for - Rigid and non rigid welding helmets, Welding hand shields, Attachments like lift fronts, chin rests, aprons, magnifiers, snoods etc., Face-shields, Flammability, Goggles for welder, cutter, chipper (eye cups) and dust & splashes and Spectacles of metal, plastic or combination.

Face Protection :



Face Shield

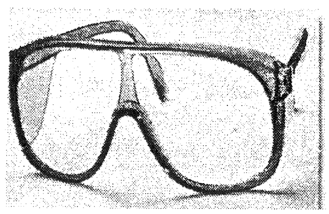
Plastic face shield with acrylic visor, and Darvic guard with fibre/PVC head band, with adjustable head gear helmet attached to face shield.

Welding screen shield.

Furnace masks.

Eye Protection :

Large vision red vinyl goggles with perspex lens and sponge lining.



Dust Goggle

Chemical Splash Goggle

Panorama type.
Full view perspex goggle.
Plastic spectacle with ventilated side shields.
Welding goggle.
Fibre goggle for grinding, chipping etc.
Gas tight goggle.
Rubber frame goggle.
Leather mask goggle.
Bakelite general purpose goggle.
Metal frame spectacle.
Stoker's goggle.
Dust goggle.
Furnace goggle.

Laser eyewear should be marked with optical density values and wavelengths for which they are to be used. Laser glasses or goggles designed for specific wavelengths should not be used for different wavelengths of laser radiation.

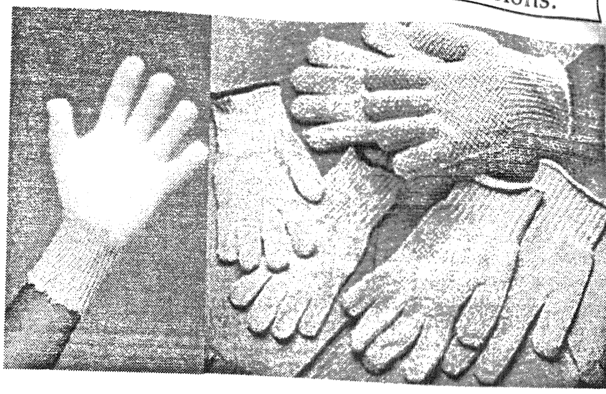
Always ensure that your eye protection fits properly and does not interfere with other equipment like respirator. Safety goggles should fit tight to your face. Never use eye protection that is badly scratched or damaged. Clean your equipment after chemical exposure.

5.4 Hand and Arm Protection :

Protection of hands and arms are required when workers have to handle materials having sharp end, sharp edges, hot and molten metals, chemicals and corrosive substances. The protective equipment may be gauntlet gloves, wrist gloves, mittens, hand pads, thumb and finger guards and sleeves. Gloves, hand leathers, arm protectors, finger stalls, mittens etc. should not be used near moving machinery or machine parts. Selection guideline is given in Table 25.5.

Table 25.5 Selection of Gloves :

	Material	Protects against
1	Asbestos	Sparks, hot materials, heat.
2	Chrome leather	Sparks, hot materials, hot liquids, flying particles, cuts, abrasions.
3	Flame proofed Duck	Sparks, hot materials, heat, flying particles, machinery.
4	Plastic	Hot liquids, moisture, acids and alkalis, dermatitis.
5	Rubber	Hot liquids, moisture, acids and alkalis, electric shock, dermatitis.
6	Chemical resistant material	Acids and alkalis.
7	Reflective fabric	`Hot liquids.
8	Plastic rubber coated fabric	Hot liquids, moisture, acids and alkalis.
9	Metal Mesh	Cuts and abrasions.
10	Cotton Canvas	Cuts and abrasions.



Glove material selection should be as under:

1. **Natural rubber** *gloves are stretchable and highly resistant to punctures. They perform well in mild caustics and ketone-based solutions and in temperatures ranging from 0°F to 300 °F. These gloves work well for job which require handling rough materials or sharp-edged objects such as plate glass and lumber.*

2. **Neoprene** is a premium-grade, synthetic rubber. Gloves coated with neoprene are resistant to strong acids, oils, grease, solvents and caustics. They perform well in temperatures from 0°F to 300 °F.

3. **Nitrile** is a super synthetic compound available in either a smooth or rough finish. They perform well in temperatures from 25°F to 300 °F. Nitrile-coated gloves offer superior abrasion, snag and puncture resistance for tasks such as handling coarse building materials and rough castings.

4. **Viton** gloves are especially useful for resisting chemical permeation from chlorinated and aromatic solvents as well as many other liquids and vapours.

5. **Polyvinylchloride (PVC)** plastic gloves resist a broad range of chemicals and abrasives. They provide ample flexibility and durability in temperatures ranging from 25°F to 150 °F. PVC-coated gloves are ideal for jobs which involve handling rough machine parts, castings or petrochemicals.

6. **Butyl rubber** gloves offer high permeation resistance to many gases and vapours.

7. **Latex** gloves are not appropriate for primary chemical resistance but offer good protection from standard grit/grime.

Utility and characteristics of hand protectors are shown in Table 25.6.

Table 25.6 : Hand Protectors

Type	Protects against	Characteristics
Leather gloves	Cuts, bruises, abrasions, lacerations during handling of metal sheets and other sharp-edged objects and sparks	Plain, cut-resistant leather with or without metal mesh at palm.
Aluminised fabric gloves	Flames, intense heat radiation, burn injuries	Heat-resistant aluminised fabric or other special material
Asbestos gloves	-do-	Padding inside for comfort and to withstand high temperatures
Acid/ Alkali-proof rubber/ synthetic gloves	Corrosive chemicals (organic acids or petroleum products)	Rubber, neoprene or vinyl material
Lead-lined gloves	Ionising radiation (X-rays, gamma rays, etc.)	Rubber, leather or plastic with lead lining
Canvas gloves	Grease, oil, dust and dirt which may cause slipping of hands	Fabric or coated fabric
Electric gloves	Low voltage electric shocks (up to 4000V) High voltage electric shocks (tested 11 KV)	Made of insulated rubber having required dielectric strength and electrical resistance. Generally red in colour
Barrier Cream	Contact dermatitis from solvents, lubricants and other oils.	

Types available:-

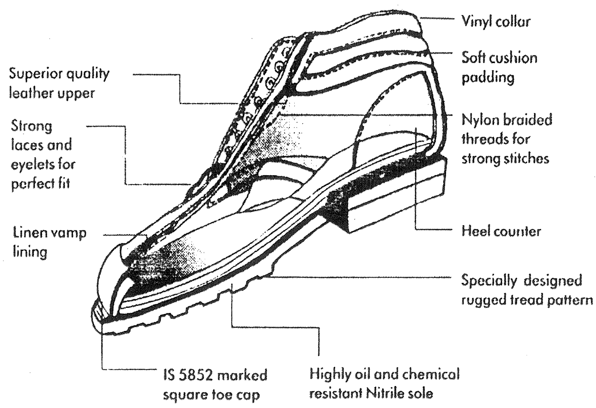
Chrome or plain leather gloves.
Mittens, Gauntlets.
Corrugated rubber gloves.
Cotton gloves.
Asbestos gloves or mittens.
Sleeves made of leather, asbestos, rubber, or PVC.
Iron hand gloves.
Chemical resistant gloves.

Always protect your hands while working with chemicals. Never touch chemicals or solvents with bare hands. Never use a solvent to wash since it may speed skin adsorption. Always read MSDS and Glove selection guide. Ensure that gloves are not cut or damaged in any way and stop using them immediately if they become punctured or damaged. Wash your hands and get a new pair. Never reuse disposable gloves. Decontaminate useable gloves after use. Wash your hands after removing gloves in case any material was absorbed thorough the gloves.

5.5 Foot and Leg Protection :

Some typical risks are handling of heavy materials, caustic and corrosive liquids, wet conditions, molten metals, etc. Common foot and leg protective equipment are safety shoes or boots, leggings and foot-guards. Leg guards (e.g. Cricketer type) are used to protect - shins against impact. Knee pads are worn by mould loftsmen and others who do continual kneeling. Selection is as follows:

Safety shoes/boots may be conductive, non conductive or spark resistant. Rubber boots are useful to work in wet conditions, steel toe boots against impact and puncture resistant soles to walk on surfaces having nails, sharp objects etc.



Conductive shoes allow draining of static charges and non-ferrous shoes reduce possibility of friction sparks and much useful in fire/explosion prone area. Conductive footwear resistance should not exceed 450 kilo ohms.

Conductive shoes are used where floors are non-conductive and grounded such as in manufacture of certain explosive compounds or while cleaning tanks that have contained solvent or volatile hydrocarbons. These shoes have conductive soles and non-ferrous metal parts.

Foundry workers should wear gaiter or congress type safety shoes which have no fasteners or lashes and rapidly removable. The tops of the shoes should be covered by full pant leg, spats or leggings to keep out molten metal.

Electricians need insulated shoes with non-metal parts. Leather shoes are useful to work in wet condition. Wooden soles to walk on hot surfaces and rubber shoes for working with acids and alkalis but not with solvents which dissolve the rubber.

Belts, harnesses, lifelines, lanyards, buckles, joints, D-ring etc. should be checked for weak points, washed regularly and kept dried at room temperature.

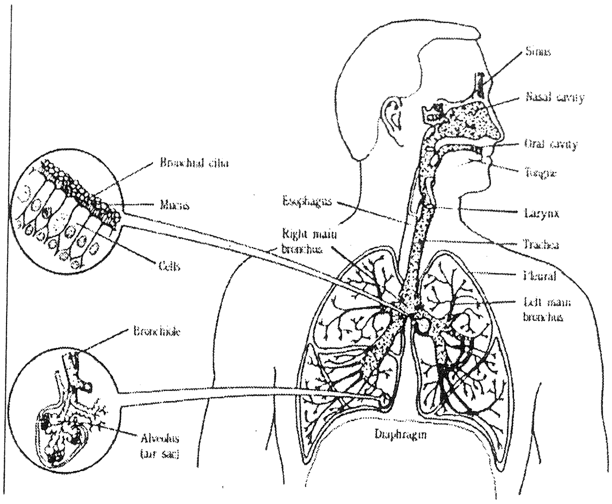
See Chapter-16 for other details.

6 RESPIRATORY EQUIPMENT

See fig. 25.2 for respiratory equipment.

The Respiratory System

Respiration is the act of inhaling fresh air into the lungs and exhaling stale air from them. When we breathe in and out, our chest cavity housing the lungs, expands and contracts. The entire rib cage, curving round the chest, is flexible and expands readily by special muscles.



The nose, mouth, upper throat, larynx, trachea, bronchi (all air passages) and the lungs where oxygen is passed into the blood and carbon dioxide expelled, are the respiratory organs that form the respiratory system. The diaphragm and chest muscles perform the movements of inspiration and expiration. The system is an intricate one with built-in safeguards against normal,. everyday hazards. The nostrils (hairs) filter dust particles from inhaled air; the specially structured nasal passage monitors the air temperature; the mucous secreted by the membrane in the nasal passage continuously drips into the throat, heating and moistening the inspirited air and trapping bacteria and dust. There are many other such barriers but they are obviously no match against sustained onslaughts of unusual and ruinous hazards posed by contaminated or higher concentration of toxic chemicals, dusts, mists, gases and sprays.

Broadly speaking, oxygen-deficient air and harmful toxic contaminants in the atmosphere are the major respiratory hazards.

Atmospheric contaminants include harmless substances to toxic dust, fumes, smokes, mists, vapour and gases. Processes which present hazards of exposure to harmful substances should be closed or ventilated to eliminate or minimise the hazard. If enclosure, ventilation or other engineering controls are not possible, respiratory equipment should be provided to the workers exposed to such hazard. Even though engineering controls are applied satisfactorily, supply of appropriate protective equipment should be readily available for use, as plant breakdown, maintenance or repairs may have to be carried out in contaminated environments.

Respiratory protective equipment should be considered a last resort, or additional stand-by protection and never a substitute for effective engineering control.

Workers should be aware of other routes of entry also (e.g. skin contact and oral) and looking to such nature or possibility of chemicals, they should adopt other protections also.

Selection of respiratory protection depends on-

1. Identification and classification of hazards.
2. Evaluation of the hazard i.e. measurement of concentration and to decide which worker(s), which process, place or environment need respiratory protection, and
3. Selection and application (use) of the appropriate type of the equipment.

Protection Factor (ratio of measured or suspected concentration / TLV) is important in selection of a respiratory PPE. It should be higher if the toxicity of the gas is higher. If varies from 4 to 10. It is like a factor of safety.

6.1 Classification of Respiratory Hazards:

Type of hazards to which a worker is exposed is the basis of selection of the right type of respiratory protective equipment.

Respiratory Hazards :

Before initiating a respiratory protection program, it is important to first understand the types of respiratory hazards inherent to your industry.

Of the three normally recognised ways toxic materials can enter the body - (1) through the gastrointestinal tract. (2) skin and (3) lungs - the respiratory system presents the quickest and most direct avenue of entry. This is because of the respiratory system's direct relationship with the circulatory system and the constant need to oxygenate tissue cells to sustain life.

There are three basic classifications of respiratory hazards: oxygen-deficient air; particulate contaminants; and gas and vapour contaminants.

6.1.1 Oxygen Deficiency :

Normal ambient air contains an oxygen concentration of 20.8 percent by volume. When the oxygen level dips below 19.5 percent, the air is considered oxygen-deficient. Oxygen concentration below 16 percent is considered unsafe for human exposure because of harmful effects on bodily function, mental processes and co-ordination.

It is important to note that life-supporting oxygen can be further displaced by other gases, such as carbon dioxide or nitrogen. When this occurs, the result is often an atmosphere that can be dangerous or fatal when inhaled. Oxygen deficiency can also be caused by rust, corrosion, fermentation or other forms of oxidation which consume oxygen. The impact or oxygen-deficiency can be gradual or sudden.

Atmospheres in confined spaces such as vats, tanks, hold of the ships, etc. may contain air with oxygen content much lower than normal (21% by volume). This may be due to dilution or displacement of the air by other gases or vapours or because of loss of oxygen due to decay of organic matter, chemical reaction and natural oxidation over a long period of time. A person breathing air with oxygen content of 15% or less may exhibit symptoms ranging from increased rate of breathing, acceleration of pulse rate to unconsciousness and death,. Such oxygen deficiency condition can easily be detected as the flame of a safety lamp will be extinguished in such atmosphere. Oxygen deficient atmosphere is immediately dangerous to life. The respiratory protective equipment in such conditions should either supply normal air or oxygen to the wear. Self contained or combination breathing apparatus is suitable.

6.1.2 Gaseous Contaminants :

Gas and vapour contaminants can be classified according to their chemical characteristics. True gaseous contaminants are similar to air in that they possess the same ability to diffuse freely within an area or container. Nitrogen, chlorine, carbon monoxide, carbon dioxide and sulphur dioxide are examples.

Vapours are the gaseous state of substances that are liquids or solids at room temperature. They are formed when the solid or liquid evaporates. Gasoline, solvents and paint thinners are examples of liquids that evaporate easily, producing vapours.

In terms of chemical characteristics, gaseous contaminants may be classified as follows :

Inert Gases - These include such true gases as nitrogen, helium, argon, neon, etc. Although they do not metabolise in the body, these gases represent a hazard because they can produce an oxygen deficiency by displacement of air.

Acidic Gases - Often highly toxic (corrosive), acidic gases exist as acids or produce acids by reaction with water. Sulphur dioxide, hydrogen sulphide and hydrogen chloride are examples.

Alkaline Gases - These gases exist as alkalis or produce alkalis by reaction with water. Ammonia and phosphine are such examples.

In terms of chemical characteristics, vaporous contaminants may be classified as follows :

Organic Compounds - Contaminants in this category can exist as true gases or vapours produced from organic liquids. Gasoline, solvents and paint thinners are examples.

Organometallic Compounds - These are generally comprised of metals attached to organic groups. Tetra-ethyl-lead and organic phosphates are examples.

These may be toxic or inert gases or vapours. The toxic gases may produce harmful effect even if they are present in relatively low concentrations. The inert gases produce undesirable effects primarily by displacement of oxygen. Vapours are from volatile, evaporating liquids. Gaseous contaminants can also be classified as-

1. **Gaseous Contaminants Immediately Dangerous to life:** These contaminants are gases present in concentrations that would endanger life of a worker breathing them even for a short period of time. In other words, a gas is immediately dangerous to life if it is present in certain concentration. Where it is not possible to determine the extent of concentration or the kind of gas, all gases should be considered as immediately dangerous to life and health. IDLH values of many gases and dusts are available. Positive pressure self-contained or combination breathing apparatus is suitable.
2. **Gaseous Contaminants not immediately Dangerous to life :** These contaminants are gases present in concentration that could be breathed by a worker for a short time without endangering his life but which may cause possible injury after a prolonged single exposure or repeated short exposures. But even after the concentrations of the contaminant is known, no exact formula can be applied to determine if the contaminant is immediately dangerous to life or not. Air - line respirator, hose mask with or without blower and chemical cartridge respirator are suitable.

6.1.3 Particulate Matter or Contaminants :

Particulate contaminants can be classified according to their physical and chemical characteristics and their physiological effect on the body. The particle diameter in microns (1 micron = 1/25400 inch) is of utmost importance. Particles below 10 microns in diameter have a greater chance to enter the respiratory system and particles below 5 microns in diameter are more apt to reach the deep lung or alveolar spaces.

In the healthy lungs, particles from 5 to 10 microns in diameter are generally removed by the respiratory system by a constant cleansing action that takes place in the upper respiratory tract. However, with excessive "dust" exposures or diseased respiratory system, the efficiency of the cleansing action can be significantly reduced.

The various types of airborne particulate contaminants can be classified as follows :

Fumes - An aerosol created when solid material is vaporised at high temperatures and then cooled. As it cools, it condenses into extremely small particles - generally less than 1 micron in diameter. Fumes can result from operations such as welding, cutting, smelting or casting molten metals.

Dusts - An aerosol consisting of mechanically produced solid particles derived from the breaking up of larger particles. Dusts generally have a larger particle size when compared to fumes. Operations such as sanding, grinding, crushing, drilling, machining or sand blasting are the worst dust producers. Dust particles are often found in the harmful size range of 0.5 to 10 microns.

Mists - An aerosol formed by liquids, which are atomised and/or condensed. Mists can be created by such operations as spraying, plating or boiling, and by mixing or cleaning jobs. Particles are usually found in the size range of 5 to 100 microns.

Majority of particulate contaminants are not immediately dangerous to life. They may be solid, liquid or a combination of solid and liquid and may be classified into three broad groups- dust, mist and fumes. Dust and fumes are solid flying particles, fumes being extremely small. Mists are tiny liquid droplets given off by spraying or very fast mixing or agitating.

Dust, mist or fume respirator, air-line respirator and abrasive blasting respirator are suitable.

Types of contaminants can also be classified as under:

1. **Toxic particulate contaminants :**

   These when inhaled may pass from the lungs into the blood stream and are then carried to the various parts of the body. The effect may be chemical irritation, systemic poisoning or allergic reactions. Common contaminants in this group are antimony, arsenic, cadmium, chromic acid and chromate, lead and manganese.

2. **Fibrosis-producing dusts :**

   These dusts do not pass into the blood stream but remain in the lungs and may cause pulmonary impairment. The common example under this group are asbestos, coal, iron, bauxite and free silica.

3. **Nuisance Dusts :**

   These may dissolve and pass directly into the blood stream or may remain in the lungs neither producing local nor systemic effects. Examples are saw dust, chalk, clay, starch, cement dust etc.

6.1.4 Combination of Gaseous and Particulate Contaminants :

Here gaseous and particulate contaminants occur together as in case of paint spraying where solvent vapour (gas) and paint mists are mixed. They may be entirely of different substances like carbon monoxide and oxides of nitrogen produced by blasting or volatile liquids.

For contaminants immediately dangerous to life, positive pressure self-contained or combination breathing apparatus or gas masks with special filter and for not immediately dangerous to life, air line respirator, hose masks with or without blower and chemical cartridge respirator with special filter are suitable.

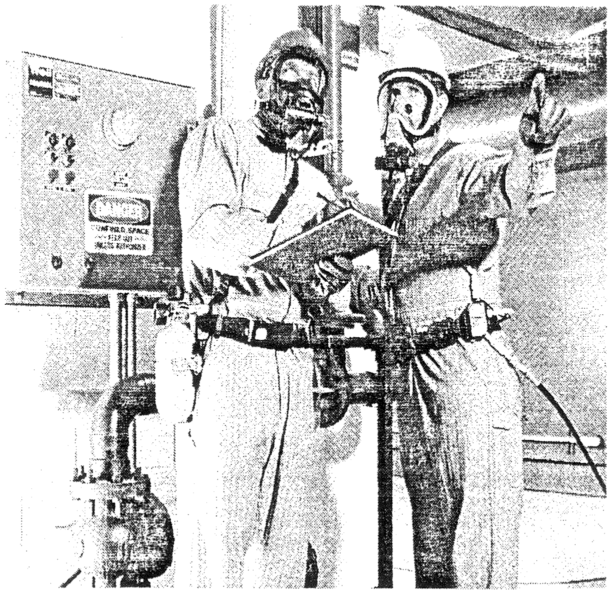
6.2 Classification of Respirators :

Respiratory protective equipment are already classified in foregoing Part-4 of this chapter. They are of two types : Air-supplying or Air-purifying. Air supplying respirators include air-line respirator, self-breathing (air or oxygen) apparatus, suction hose mask, pressure hose mask etc. Air-purifying respirators include canister, cartridge or filter respirators which need replacement of these parts. They are briefly described below :

6.2.1 Air Supplying Respirators :

(1) Airline Respirators :

Airline respirator consists of a face-piece (half or full mask or a loose fitting helmet or hood) to which



Air Line Respirator

air is supplied through a small diameter hose. It may be a continuous flow type or a demand type.

In a constant or continuous flow type, air is supplied continuously to the face piece helmet or hood. Exhaled air or the excess air entering the face-piece escapes to the atmosphere. Air supplied should be at least 110 litres of air per minute to enter the face-piece and at least 170 litres per minute to enter the helmet or hood.

Abrasive blasting (e.g. shot or sand blasting) respirator is a continuous flow type airline respirator with the addition of mechanical protection for head and neck from abrasive particles. It may cover shoulder and chest also.

In a pressure demand type respirator, air is supplied to a face-piece when the wearer inhales and the rate is governed by his volume rate of breathing. Air from an air compressor cylinder is supplied to the face-piece through a demand valve which is actuated by the slight negative pressure created when the wearer inhales. On exhalation the demand valve closes and exhaled air escapes to the surrounding atmosphere through exhalation valve. Helmets or hoods are not used with demand type respirator.

Airline respirators provide protection so long as the air supply is maintained but the wearer's travel is restricted by the length of the air supply hose. They are not used in IDLH atmosphere. Air temperature and pressure should be comfortable and the air should be supplied through an air-cleaner. Care should be taken to ensure that the air supply is respirable and is not contaminated and is free from objectionable odours, oil or water mist and rust particles from the supply line. The air line connection should be tight (non-detachable) and should be checked before use. One worker died due to detachment of air supply line when he was working in oxygen deficient atmosphere (95% Nitrogen) to fill a pyrophoric catalyst in a reactor.

(2) Suction Hose Mask :

It consists of a full face piece connected to a large diameter flexible hose. The worker draws in air by his own breathing effort, the hose is attached to the wearer's body by a suitable safety harness with safety line and the air inlet end of the hose is provided with a filter to arrest particulate matter. Air can be drawn in by respiratory effort of the wearer upto 30 ft length of the hose.

(3) Pressure Hose Mask (Air supplied hoods):

This hose mask or hood is similar to suction hose mask except that the air is forced through a large diameter hose by a hand or motor-operated blower or compressor. The blower is to be operated continuously while the mask is in use. Respirable air of comfortable pressure and temperature should be supplied at least 6 ft^3/min.

(4) Air-Supplied Suits :

Air line respirators are used where normally nose and face are exposed to hazards and not the other body parts. But where all body parts including nose, need protection, for example, to do any repair or emergency work in extremely corrosive atmosphere affecting skin and mucous membranes or acutely toxic and immediately dangerous to life, a full body suit of impervious clothing with respirable air supply, is a must.

The air line is connected to the suit itself and also to helmet and distributing air evenly throughout on the body, because without such ventilation and cooling effect, it is very difficult and fatiguing to wear such suit for a longer time. Particularly, in our country where majority of the days are hot, workers are reluctant to wear such full suit. They should be properly explained its need and utility. They should be rotated in case of more inconvenience.

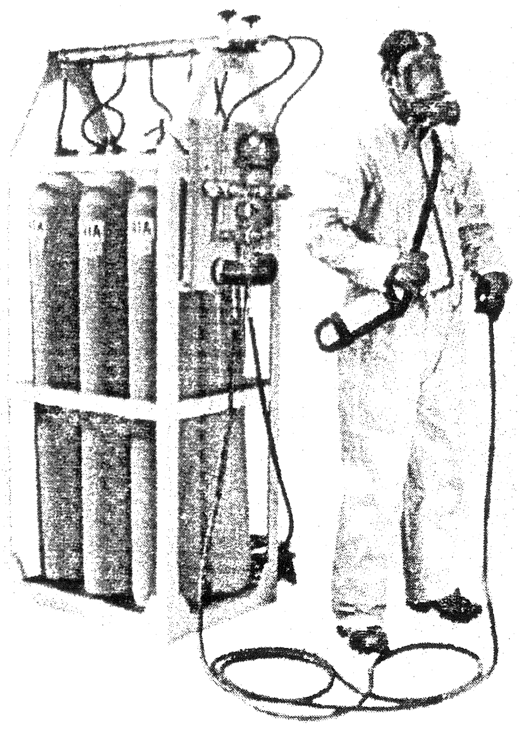
6.2.2 Self-Contained Breathing Apparatus :

They are of two types.

(1) Self-Contained Compressed Air or Oxygen Breathing Apparatus :

This is a device by means of which the wearer obtains respirable air or oxygen from compressed air or oxygen cylinder which is an integral part of the apparatus.

In a demand type Self-Contained breathing apparatus, air or oxygen is admitted to the face piece through a two stage pressure reducing mechanism, only when the wearer inhales and the quantity of air or oxygen admitted is governed by his breathing. The wearer's exhaled breath escapes to the surrounding atmosphere.



In compressed oxygen cylinder recirculating type breathing apparatus, high pressure oxygen from the cylinder passes through a pressure reducing and regulating valve into a breathing bag. The wearer inhales this oxygen through a one-way breathing valve and his exhaled breath passes into a canister containing chemicals to absorb exhaled carbon dioxide and moisture and then through a cooler into the same breathing bag. Oxygen enters the breathing bag from the supply cylinder only when the volume of gas in the bag has decreased sufficiently to allow the supply valve to open.

From respiratory point of view, self-contained breathing apparatus has no limitation as to the concentration of the gas or deficiency of oxygen in the surrounding atmosphere but other factors may limit the time that the wearer can remain in a contaminated atmosphere. Many gases are very irritating to the skin and many can be absorbed in dangerous amounts through the unbroken skin.

(2) Oxygen-Regenerating Recirculating type Self-Contained Breathing Apparatus :

In this type of apparatus moisture content from the wearer's exhaled breath reacts with granular chemical in a canister to liberate oxygen. Also the exhaled carbon-dioxide is absorbed by the chemicals in the canister. The oxygen enters the breathing bag from which the wearer inhales through a corrugated breathing tube connecting the bag to the face-piece.

6.2.3 Air Purifying Respirators :

Air purifying respirators purify the air of gases, vapour and particulate, but do not supply clean or fresh air. Therefore they must *never be used in oxygen deficient atmosphere*. Purification of breathing air is done by mechanical filtration, adsorption, chemical reaction or catalysis.

The life of such respirators depends on concentration of the contaminant, scrubbing capacity of the medium (cartridge) and breathing demand of the wearer. The respirator has a face piece and a connected canister (box) or cartridge to purify the air passing through it.

The canister or cartridge *should not be used* -

1. After its date of expiry or after 100 hours after its first use.
2. When air coming to nose, gives irritation, smell or indication of saturation or non-effect of the scrubbing medium.
3. When oxygen is less than 18% in air.
4. When the gas or vapour has no smell or odour.
5. When the gas or vapour is highly toxic.
6. When the gas or vapour is highly irritating to eyes without necessary eye protection, and
7. Above the limit of concentration marked on it.

Main types of air-purifying respirators are explained below :

(1) Canister Gas Mask :

This consists of a canister, containing appropriate chemical, a full face-piece and body harness to hold the canister. Air is drawn through the canister by the wearer and during its passage through the chemical in the canister the contaminant present in the incoming air is absorbed and reacted with the neutraliser. The canisters are designed for specific gases and it is very important that the appropriate type is used.

The canister gas mask can only be used in atmosphere not deficient in oxygen and not containing more than 20% by volume of most toxic gases. Also, the life of the canister will depend upon the type of canister, the concentration of gas and the activity of the wearer.

(2) Chemical Cartridge Respirator :

This consists of a half-mask attached to one or two cartridges., Like canisters, the cartridges are filled

with appropriate chemicals to absorb gases or vapours drawn through them. This respirator is a non-emergency gas respirator and it should not be used in an atmosphere deficient in oxygen. Like canister gas mask, chemical cartridge respirator provides respiratory protection for a period that depends on vapour concentration and the wearer's activity. It is recommended for low concentration gases and vapours, 0.1% or 1000 ppm of organic vapour, acid gases upto 500 ppm, ammonia upto 700 ppm and mercury vapour.

(3) Self-rescue type Respirators :

This is designed to provide the greatest possible respiratory protection consistent with the practicability of carrying the device at all times so that it is always available for use during escape. It consists a filter element, a mouth piece, a nose clip and means of carrying conveniently on the body. The filter elements apparatus, pressure hose apparatus, face mask with canister, face mask with screw filter canister, small gas filter, oxygen breather, compressed air breathing apparatus, protective suits for fire fighting and rescue operation, automatic resuscitator, plastic foil respirator, cloth mask, dust guard, full vision face mask, lung protector, fibre glass hood respirator, pressure fresh air hose apparatus etc.

6.2.4 Selection, Instruction and Training in the use of Respirators :

Respiratory protection programme should include - Policy and administration, identification, measurement, evaluation and control of respiratory hazards, Selection and use of proper respiratory PPE, Training, inspection, maintenance and repair of equipment, Medical surveillance and review of the programme.

The following factors should be considered for **selection** of the respirators:

1. Nature of the hazard.
2. Severity of the hazard.
3. Type of contaminant.
4. Concentration of the contaminant.
5. **Protection factor** which should be

   $\geq$ Hazard Ratio = Contaminant concentration / TLV

   Assigned protection factors to respirators are as under :

   Air purifying respirators- Half mask 10
   - Full facepiece 50

   Powered air purifying respirators
   - Loose fitting facepiece 25
   - Half mask 50
   - Full facepiece 1000

   Supplied Air respirators (Airline)
   - Continuous flow- Loose fitting facepiece 25
   - Half mask 50
   - Full facepiece 1000
   - Pressure demand with full facepiece 1000

   SCBA 1000
6. Period for which respiratory protection must be provided.
7. Location of the contaminated areas with respect to a source of respirable air.
8. Expected activity of the wearer, and
9. Operating characteristic and limitations of the available respirator.

Instructions for care should include the following aspects :

1. Why and how it is to be used.
2. Protecting the equipment from dust, heat, moisture, extreme cold and damaging chemicals. Storing in a dry cool place.
3. Checking that it is in good operating condition. Valves should be maintained in efficient working condition.
4. Fitting of respirator on the wearer and
5. Proper use and maintenance of the respirator.
6. Cleaning and keeping it in a sealed plastic bag with name tag of the user.

Training for respiratory equipment should include following points :

1. Reasons of need of respiratory protection and limitation or inability of other controls or methods.
2. Identification and understanding of the hazard for which the equipment is to be used and selection procedure.
3. Limitation, capability, function and operation of the respirator.
4. Proper fitting, wearing, adjusting face piece & valves and removing of the respirator.
5. Maintenance and storage procedure.
6. Practice to wear first in a safe atmosphere to become familiar with its characteristics.
7. Practice to wear in a test atmosphere under close supervision of the trainer, and to do similar activities and to detect respirator leakage or malfunction.
8. How to ascertain and handle emergency situation.
9. Statutory provisions regarding use of respirators.
10. When and how to replace filters, cartridges, canisters and cylinders.
11. Instructions for special use if any.

The trainer should be qualified safety officer, industrial hygienist, safety professional or manufacturer's representative

6.2.5 OSHA Standard for Respiratory Protection :

Program Requirements :

The OSHA Respiratory Protection Standard (29 CFR 1910.134) lists seven key elements that every respiratory protection program should contain. These include :

1. A written plan detailing how the program will be administered.
2. A complete assessment and knowledge of respiratory hazards that will be encountered in the workplace.
3. Procedures and equipment to control respiratory hazards, including the use of engineering controls and work practices designed to limit or reduce employee exposures to such hazards.
4. Guidelines for the proper selection of appropriate respiratory protective equipment.
5. An employee training program covering hazard recognition, the dangers associated with respiratory hazards, proper care and use of respiratory protective equipment.

6. Inspection, maintenance and repair of respiratory protective equipment, and
7. Medical surveillance of employees.

Administration :

The responsibility for administration of these procedures should be assigned to one individual who may, and probably will, have assistance. The necessity for a central authority is to ensure consistent co-ordination and direction. The actual respiratory protection program will vary widely depending upon many factors and may require input from specialists such as safety personnel, industrial hygienists, health physicists and physicians. But program responsibility should reside with a single individual if the program is to achieve optimum results.

The first step in a respiratory protection program is to establish written standard operating procedures governing the selection and use of respirators.

Finally, there should also be regular inspection and evaluation of the program itself to ensure its continued effectiveness.

For types of respiratory hazards see Part 6.1

Hazard Assessment :

Proper assessment of the hazard is the first important step to protection. This requires a thorough knowledge of processes, equipment, raw materials, end-products and by-products that can create an exposure hazard.

To determine an atmosphere's oxygen content or concentration levels of particulate and/or gaseous contaminants, air samples must be taken with proper sampling instruments during all conditions of operation. The sampling device, the type and frequency of sampling (spot testing or continuous monitoring) will be dictated by the exposure and operating conditions. Breathing zone samples are recommended and sampling frequency should be sufficient to assess the average exposure under the variable operating and exposure conditions.

If contaminant concentrations exceed exposure limits recommended by the American Conference of Governmental Industrial Hygienists (ACGIH), OSHA or NIOSH, hazard control procedures must be implemented promptly.

Exposure monitoring plays a critical role in the respirator selection process. The results from such tests will help you determine whether respiratory protection is needed and, if it is, the type of respirator required. Generally respirator selection is based on three factors:

1. The results of your atmospheric monitoring or sampling programme,
2. The accepted ACGIH, OSHA or NIOSH exposure limits for the substance(s) present and
3. The maximum concentration (of a substance) for which a respirator can be used.

Exposure limits include ACGIH Threshold Limit Values (TLVs), OSHA Permissible Exposure Limits (PELs), NIOSH Recommended Exposure Levels (RELs) and AIHA Workplace Environmental Exposure Levels (WEELs). These values are guides for exposure concentrations that healthy individuals can normally tolerate for eight hours a day, five days a week without harmful effects. Unless otherwise noted, exposure limits are eight-hour, time-weighted-average (TWA) concentrations.

In general, gas and vapour exposure limits are expressed in ppm by volume (parts of contaminant per million parts of air), while particulate matters (concentrations) are expressed as mg/m^3 (milligrams of concentrations per cubic meter of air). For substances that can exist in more than one form (particulate or gaseous), concentrations are expressed in both values.

It is important to note that exposure limits and other exposure standards are constantly changing as more data is gathered about specific chemicals and substances. As such, you must be certain that you are using the most recent data when determining allowable exposure levels for employees.

Hazard Control :

Hazard control should start at the process, equipment and plant design levels where contaminants can be effectively controlled at the outset. With operating processes, the problem becomes more difficult. In all cases, however, consideration should be given to the use of effective engineering controls to eliminate and/or reduce exposures to respiratory hazards. This includes consideration of process encapsulation or isolation, use of less toxic materials in the process and suitable exhaust ventilation, filters and scrubbers to control the effluents.

Because it is sometimes not practical to maintain engineering controls that eliminate all airborne concentrations of contaminants, proper respiratory protective devices should be used whenever such protection is required.

Respirator Selection :

Respiratory protective devices vary in design, application and protective capability. Thus, the user must assess the inhalation hazard and understand the specific use limitations of available equipment to assure proper selection.

The respirators fall under two classifications : air-purifying and air-supplied. Air-purifying respirators are used against particulate, gases and vapours. These include negative-pressure respirators that use chemical cartridges and/or filters; gas masks; and positive-pressure units such as powered air-purifying respirators (PAPRs), Air-supplied devices rely on a primary air source to deliver a steady flow of respirable air to the user's facepiece. These include SCBA and air-line devices.

For training, maintenance and care of PPE, See Part 7.

Medical Surveillance :

Workers should never be assigned to any operations requiring respiratory protection until a physician has determined that they are capable physically and psychologically to perform the work using the respiratory protective equipment.

Although instituting a sound respiratory protection program will take effort and financial investment, the objective of such a program is sound - ensuring that every worker is protected against potentially fatal diseases.

6.2.6 Cleaning Procedures for Respirators:

1. Remove filters, cartridges, or canisters. Disassemble facepieces by removing speaking diaphragms, demand or pressure-demand valve assemblies, hoses, or any components recommended by the manufacturer. Discard or repair any defective parts.
2. Wash components in warm (43°C/110°F maximum) water with a mild detergent or with a cleaner recommended by the manufacturer. A stiff bristle (not wire) brush may be used to facilitate the removal of dirt.
3. Rinse components thoroughly in clean, warm, preferably running water. Drain the components.
4. When the cleaner used does not contain a disinfecting agent, respirator components should be immersed for two minutes in-

   Hypochlorite solution (50 ppm of chlorine made by adding approximately one milliliter of laundry bleach to one liter of water at 43°C/110°F), or

   Aqueous solution of iodine (50 ppm iodine) made by adding approximately 0.8 milliliters of tincture of iodine (6-8 grams ammonium and/or potassium iodine/100 cc of 45% alcohol) to one liter of water at 43°C/110°F
5. The importance of thorough rinsing is most important. Detergents or disinfectants that dry on facepieces may result in dermatitis. In addition, some disinfectants may cause deterioration of rubber or corrosion of metal parts if not completely removed.
6. Components should be hand-dried with a clean, lint-free cloth, or air-dried.
7. Reassemble facepiece, replacing filters, cartridges, and canisters where necessary.
8. Test the respirator to ensure that all components work properly.

7 TRAINING, MAINTENANCE, PRECAUTION AND CARE OF PPE

Training :

For proper use of any respiratory protection device, it is essential that the user be properly instructed in its selection, use and maintenance. Both supervisors and workers must be so instructed by competent persons.

Minimum training must include the following:

1. Methods of recognising respiratory hazards.
2. Instruction in the hazards and an honest appraisal of what could happen if the proper respiratory protection device is not used.
3. Explanation of why more positive control is not immediately feasible. This must include recognition that every reasonable effort is being made to reduce or eliminate the need for respiratory protection.
4. A discussion of why various types of respiratory protection devices are suitable for particular purposes.
5. A discussion of capabilities of the device and limitations.
6. Instruction and training in actual use of respiratory protection equipment and close and frequent supervision to assure that it continues to be properly used.
7. Classroom and field training to recognise and cope with emergency situations.

Training should provide personnel with an opportunity to handle the device, have it fitted properly, test its face-to-face piece seal, wear it in normal air for long familiarity period and, finally, to wear it in a test atmosphere.

Training is very important for supervisors who have to supervise the use of any type of personal protective equipment as well as for the users. Generally no one should wear personal protective equipment until he has been thoroughly trained to use it correctly. He should know -

1. The hazards for which protection is required, control measures provided or not possible.
2. Reasons of selection of particular type of PPE.
3. The limitations of the equipment.
4. How to wear, use and remove each equipment. Removal is particularly important where the equipment may be contaminated with a highly toxic material.
5. Demonstration how to fit, adjust and use the PPE and practice by the worker for that.
6. How to clean, repair and maintain in good condition the PPE.
7. How to inspect for damaged equipment to ensure adequate protection.
8. How to deal with emergencies, and
9. Location of the equipment before and after use.

Training should be given by a qualified safety professional or manufacturer's representative and may include lectures, demonstrations, drills and on the job guidance. Training should include new and most suitable PPE available in the market.

Maintenance :

It is a co-operative activity between the employee who takes care of his equipment and the safety professional who teaches him how to use it and provides proper instructions. After inspections, cleaning and necessary repair, personal protective equipment shall be stored to protect against dust, sunlight, heat, extreme cold, excessive moistures or damaging chemicals to retain its original effectiveness. When in doubt about the maintenance of any type of personal protective equipment, it is a good practice to contact the manufacturer. All PPE should be cleaned and examined after each use. Respirators should be cleaned daily. Face-piece should be washed in warm water with soap or a detergent. Filter and chemical cartridge should be replaced when needed.

General Precautions to use PPE :

Following precautions are useful for training and practice -

1. Hazards at workplace must be thoroughly studied, gas, oxygen, contamination, noise etc. should be measured and their level should be minimised by engineering controls first and then only the need of necessary personal protective equipment (PPE) should be ascertained.
2. PPE should be kept ready and in sufficient number. Gloves, shoes, goggles, aprons, earplugs etc. should be given individually and kept clean by the worker in his locker.
3. PPE should be of approved (IS) quality and tested before use. Manufacturer's instructions, limitations, time limit if any, procedure or method of use, symptoms of malfunctioning, emergency action if it does not work and instructions for maintenance and care should be well understood before using any PPE.
4. Written instructions should be prepared and displayed or given to the workers for the safe use of the equipment. After medical examination of the worker, need and type of the equipment shall be reconsidered. Change if any, should be incorporated.
5. Laziness in using PPE is not good. A cloth in place of effective respirator is insufficient. Avoiding PPE because the use is for a few seconds or minutes, is unsafe.
6. Loose PPE should be kept away from the moving machine parts.
7. While entering in a tank or working at height, safety belt must be worn, in addition to good sitting and supporting arrangement (safe platform or fencing). Gas and oxygen level should be measured and kept safe as far as possible. PPE shall be selected based on its level.
8. Cotton clothing in hot days, woollen clothing in cold days and tight fitting clothing while working near machinery are basic requirement. Synthetic cloths are unsuitable to health. PPE on cotton clothing gives more comfort.
9. A man working on electricity should wear non-conductive helmet. Conductive shoes or clothing are required to discharge static electricity induced in a human body.
10. Canister gas mask and dust mask are useful for low concentration (100 to 200 ppm) and for the gas and duration mentioned on the mask only. Filter is to be changed or cleaned soon after choking. Canister gas mask is not useful if oxygen is insufficient (less than 18%) in air. Different types of gas masks are recommended for different level of concentration.

    Canister mask is not safe while working in a tank. When gas is less than 5% of LEL, canister mask may be worn just to clean the tank. If this level is from 5 to 20% of LEL, airline respirator may be used. If concentration is more than this it should be diluted.

    Six months old canister mask should not be used. Every six months its chemical is to be freshly filled. It should not be used after 100 hours after breaking its seal. If facepiece is used by another person, it may be reused only after sterilisation. User of a gas mask should get his heart and lungs checked by a doctor.

    Canister mask of a gas which has no smell (e.g. CO, PH_3), should be used new every time. Gas mask should be kept away from moisture and heat and should be regularly checked.
11. Chemical cartridge and dust respirators can be used where flammable gas, fume or dust concentration is so low that canister mask is not necessary. When the gas is poisonous or in high concentration, eye burning, or without smell or where oxygen is insufficient, chemical cartridge or dust respirators cannot be used. The cartridges should be kept dry. If they are moist or giving smell, they should be changed. Valves for inhale and exhale should be checked and kept efficient.
12. Where oxygen is less, gas, dust or smoke are more, toxic gases like Cl_2, CO, H_2S, PH_3, phosgene exist, proper canister gas mask is not available or where one has to work in a tank for a long time, an airline respirator is useful, because fresh air is available through blower or air compressor and polluted air is being driven

away near the nose. But because of the limited length (80 mt maximum), where one has to move at a longer distance or upstairs and downstairs at different floors, only SCBA is useful.

Connections (joints, clamps, clips etc.) of air line should always be checked before use, otherwise accidental detachment of air supply will cause harm to the wearer. Air drawing point should not be kept in polluted air. Air filter (cleaner), air control valve, safety valve and alarm are all necessary. Air flow should not be less than 6 ft^3/min and its temperature should be comfortable. If hydrocarbon gas content is more than 20% of LEL, it is unsafe to enter into a tank with air hose mask. Air inlet valve should not be completely closed (it should remain partially open).

Cooling effect and circulating air type suits are also available which are useful in working near high temperature.

13. Earplugs should be washed with soap and water, dried and put into its box after every use. Earplugs used by others should be sterilised before use. Earplugs should be supplied individually to the workers. Ear muffs should also be cleaned before and after use.

14. Fire rescue (proximity) suit should be worn by two persons at a time so that one may act as a standby. Air cylinder and lifeline should also be kept ready.

15. Safety belt should be kept clean, dry and in sound condition. Its connections and wear and tear should be checked before every use. Its free end should be tied with a fixed (immovable) structure while working at height or given in another person's hands while entering in a tank.

    Strength members of a safety belt should be of very sound material other than leather. Buckles should withstand 1815 kg tensile test and be quickly openable.

    Lifeline should not be of pieces tied together. Nylon rope of ½ inch diameter is safe. Wire rope should be made oily before and after using it in acidic atmosphere. Metallic life line shall not be used near electric work.

16. Nothing should be kept in helmets. It should be checked for crack and proper fitting.

17. Contact lenses are to be protected against gas, vapour, fumes, excessive heat, molten metal and chemical splashes. Therefore safety goggles over the lens or numbered glass are always necessary. Safety goggles are also necessary with the faceshield. When goggles or faceshield are splashed with chemicals, they should be washed by a water shower before taking out from the face. Plastic lenses are more useful than glasses. Side shields are useful.

18. Mechanical filter respirators are useful for dust and smoke. Filters are to be changed or cleaned when choked. Mechanical filter respirators are not suitable for solvent vapour, toxic gas or oxygen deficiency. In fire fighting work, only SBA is useful and not the gas mask.

19. A respirator should be carefully selected while working in IDLH (immediately dangerous to life and health) environment. An operator is necessary with blower hose mask. One can run away till the air is available from the hose even when the blower is closed. While working with SBA, one should come out after hearing the low pressure alarm.

20. No other gas mask than SBA or air line is useful where oxygen is less than 18%. Level of oxygen should be measured with oxygen meter.

21. When gas concentration is more than its safe limit or within explosive range (between LEL and UEL) or oxygen is less than 18% in a tank (or confined space), it should be ventilated by air (not by oxygen), the levels should be again measured and when they are safe, permit to enter should be signed.

22. Air supplying hoods are useful in hot or dusty atmosphere to work for a longer time.

23. Where atmospheric pressure is more than 2 bar, oxygen SBA should not be used because of the possibility of oxygen poisoning. Quick start canister used in closed circuit oxygen self generating (recirculating) SBA, may prove dangerous in atmosphere of gas having less than 315 ^{0}C auto ignition temperature. Venting device to release excess oxygen is required in that case. Used canister should be disposed safely. SBA should be used by a healthy and trained worker only.

24. In empty air cylinder, oxygen should not be filled. It may cause fire due to contact with oil or grease.

25. Safety toe shoes should withstand 300 ft pound impact load. Resistance of conductive shoe should not exceed 450 kilo ohms.

    Electrician's boots should not have any metal parts, and steel toe if any, should be insulated.

Sole with flexible metal sheet inside, give protection against nails and sharp edges.

26. Where full hand gloves are not required,. stalls for fingers, mittens or pads for palms, and other PPE for thumb, wrist, palm and elbow are also available.

    Leather gloves are useful to work with glass or metal sheet or sharp edges but not useful to work above 65 ^{0}C temperature.

    Natural rubber is not suitable to work with oil, grease or organic solvent.

    Hand gloves with any metal part are not suitable for electric work. High voltage tested rubber gloves are suitable for such work.

27. After the use is over, PPE should not be left anywhere. They should be returned to the proper person or put in a cupboard meant for it.

28. Arrangement for keeping, cleaning, testing and disposal of PPE should be provided and every such person should be properly trained in addition to the user.

Respirator Care and Maintenance :

Proper inspection, maintenance and repair of respiratory protective equipment is mandatory to ensure success of any respiratory protection program. The goal is to maintain the equipment in a condition that provides the same effectiveness it has when first manufactured.

Inspection

All equipment must be inspected periodically before and after each use. A record shall be kept of all inspections by date with the results tabulated. Follow precisely the recommendations of the manufacturer.

Maintenance

All respiratory protective equipment shall be cleaned and decontaminated after each use.

Repair

Replacement of other than disposable parts must be done only by personnel with adequate training to ensure the equipment is functioning properly after the work is accomplished. Only parts supplied by the manufacturer for the product being repaired shall be used.

8 DETECTION EQUIPMENT

8.1 Classification of Equipment :

Many times with or without the personal protective equipment, various types of detection equipment are to be used as under :

Detecting Equipment (Environmental Surveillance)

- Combination Instruments
  - Passport personal alarm (multigas detector) with sampling probes, Gasport gas tester (detection of CH_4, CO, H_2S & O_2), Portable alarms (pocket instruments to detect combustible gas and O_2), Portable indicator & alarm, Remote alarms
- Combustible Gas Indicators
  - Explosimeter, Combustible gas indicators, Portable combustible gas alarm, Calibration check kits
- Toxic Gas and Oxygen Indicators
  - Organic vapour monitor, Detector tube pump, Gas tester pump, Detector tubes, Oxygen indicators, Mini series gas indicators, HazMat response kit, CO/CO_2 response kit
- Personal Sampling Pumps
  - Pump for personal & area sampling, Micro air sampler, Quick-flow area sampler, Ventilation smoke tube kit, Pump calibration check devices

Use of such detection equipment is necessary to ascertain the working environment for selection of a right type of PPE.

8.2 Detection Methods(Environmental Surveillance) :

Battery-powered, direct-reading detection instruments are classified by two groups – single-gas instruments or multiple-gas instruments – typically monitoring one or a combination of the following atmospheric conditions :

1. Oxygen deficiency or enrichment;
2. The presence of combustible gas; and
3. The presence of certain toxic gases.

Depending on the capabilities of the instrument, monitoring can be conducted simultaneously for oxygen and combustible gas or for oxygen, combustible gas and toxic gases. These devices are commonly referred to as 2-in-1, 3-in-1, 4-in-1 or 5-in-1 alarms.

No matter which type of instrument is used to check environmental gas concentrations, regular monitoring should be performed because a contaminant's level of combustibility or toxicity might increase even if it initially appears to be low or non-existent. In addition, oxygen deficiency can occur unexpectedly.

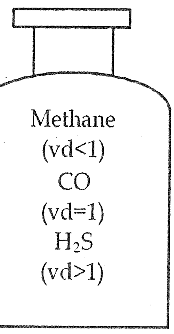
8.2.1 Atmospheric Composition :

To determine the composition of an atmosphere, reliable instruments should be used to draw air samples. If possible, do not open the entry portal to the confined space before this step has been completed. Sudden changes in atmospheric composition within the confined space could cause violent reactions or dilute the contaminants in the confined space, giving a false low initial gas concentration.

When testing permit spaces for acceptable entry conditions, always test in the following order:

1. Oxygen content,
2. Flammable gases and vapours, and
3. Potential toxic air contaminants.

Comprehensive testing should be conducted in various locations within the work area. Some gases are heavier than air and tend to settle at the bottom of a confined space. Others are lighter and are usually in higher concentrations near the top of the confined space. Still others have the same molecular weight as air, so they can be found in varying concentrations throughout the space. This is why test samples should be drawn at the top, middle and bottom of the space to pinpoint varying concentrations of gases or vapours as shown below.



Gas position according to vapour density.

The results of the atmospheric testing will have a direct impact on the selection of protective equipment necessary for the tasks in the area. It may also dictate the duration of worker exposure to the environment of the space or whether an entry will be made at all. Substance-specific detectors should be used whenever actual contaminants have been identified.

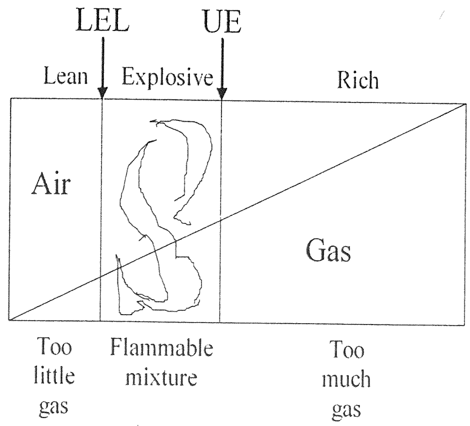
Combustible Gases :

In order for combustion to occur, there must be three elements:

1. Fuel.
2. Oxygen to support combustion and
3. Heat or a source of ignition.

This is known as the fire triangle, but if you remove any one of the legs, combustion will not occur.

The percentage of combustible gas in the air is important. For example, a manhole filled with fresh air is gradually filled by a leak of combustible gas such as methane or natural gas, mixing with the fresh air. As the ratio of gas to air changes, the sample passes through three ranges: lean, explosive and rich.



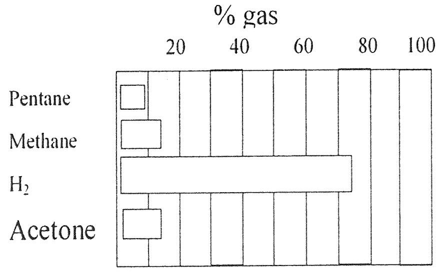
In the lean range there isn't enough gas in the air to burn. On the other hand, the rich range has too much gas and not enough air. However, the explosive range has just the right combination of gas and air to form an explosive mixture. Care must be taken, however, when a mixture is too rich, because dilution with fresh air could bring the mixture into the flammable or explosive range. An analogy is the automobile that won't start on a cold morning (a lean atmosphere because the liquid gasoline has not vaporised sufficiently), but can be flooded with too much gasoline (a rich atmosphere with too much vaporisation). Eventually, when the right mixture of gas and air finally exists (explosive), the car starts.

8.2.2 Working of Combustible Gas Monitors:

To understand how portable combustible gas detection instruments work, it is first important to understand what is meant by Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL). When certain proportions of combustible vapours are mixed with air and a source of ignition is present, an explosion can occur. The range of concentrations over which this reaction can occur is called the explosive range. This range includes all concentrations in which a flash will occur or a flame will travel if the mixture is ignited. The Lowest percentage at which this can happen is the LEL; the highest percentage is the UEL.

Most combustible instruments display gas concentrations as a percentage of the LEL. Some models have gas readouts as a percentage by volume and others display both percent of LEL and percent combustible gas by volume. What's the difference? For example, the LEL of methane (the major component in natural gas) is 5 percent by volume, and the UEL is 15 percent by volume. If we slowly fill the room with methane, when the concentration reaches 2.5 percent by volume, it is 50 percent of the LEL; at 5 percent by volume it is 100 percent of the LEL. Between 5 and 15 percent by volume, a spark could set off an explosion.

Different gases need different percent by volume concentrations to reach 100 percent of the LEL. Pentane, for example has an LEL of 1.5 percent. Instruments that measures in percent of the LEL are easy to use because, regardless of the gas, you are most concerned with how close the concentration is to the LEL.



Explosive range

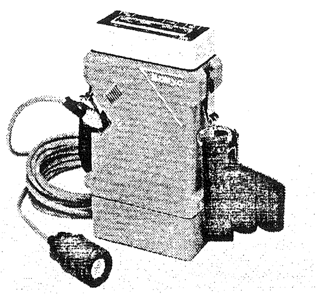
8.2.3 Working of different Gas Monitors :

They are explained below -

(1) Single Gas Monitors for Oxygen Deficiency

Oxygen indicators measures atmospheric concentrations of oxygen. Concentrations are generally measured over a range of 0 to 25 percent oxygen in air, with readings being displayed on either digital readout or an analog meter.

Oxygen indicators are calibrated with uncontaminated fresh air containing a minimum of 20.8 percent oxygen. With some models, an alarm is activated when oxygen levels drop below 19.5 percent.

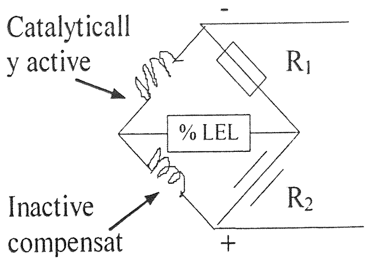


Hand held oxygen indicator with wlarm

(2) Single Gas Monitors for Combustible Gases

Single-gas instruments for monitoring combustible gases and vapours are generally calibrated on pentane and are designed for general purpose monitoring of hydrocarbon vapours. Such instruments operate by the catalytic action of a heated platinum filament in contact with combustible gases. The filament is heated to operating temperature by an electric current. When the gas sample contacts the heated filament, combustion on its surface raises the temperature in proportion to the quantity of combustibles in a sample.

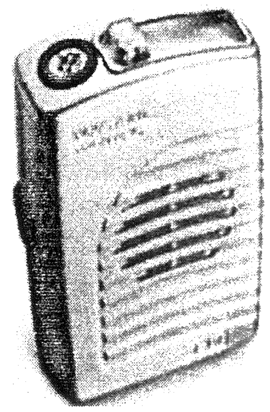
A Wheatstone bridge circuit, incorporating the filament as one arm, measures the change in electrical resistance due to the temperature increases. This change indicates the percentage of combustible gas present in the sample.



Wheatstone Bridge

(3) Single Gas Monitors for Toxic Gases

Compact, battery-powered devices can be used to measures levels of such gases as carbon monoxide (CO) or hydrogen sulphide (H_2S), depending on the model selected. Toxic gas monitors use electrochemical cells. If the gas of interest enter the cell, the reaction produces a current output proportional to the amount of gas in the sample. With these instruments, audible and visible alarms sound if the gas concentration exceeds a present level. These devises are well suited for use in confined spaces containing motors or engines, which can generate large quantities of CO, as well as in sewers, waste treatment plants and "sour crude" processing stations which tend to have hazardous volumes of H_2S.

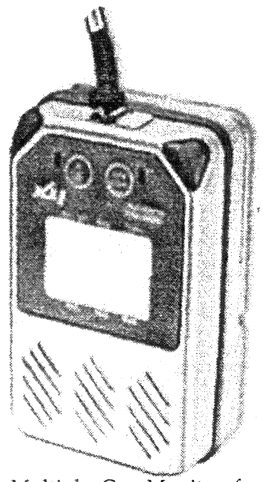


(4) Multiple Gas Monitors for Oxygen and Combustible Gas

In applications where it is necessary to determine oxygen and combustible gas levels simultaneously, 2-in-1 diffusion-type devices can be used. Sensors measure 0 to 100 percent of LEL and oxygen from 0 to 25 percent. Remote sampling requires either a pump module or an aspirator bulb adapter.

(5) Multiple Gas Monitors for Oxygen, Combustible and Toxic Gases

Toxic gases and vapours, which can be inhaled or absorbed through the skin, are frequently found in confined spaces. Sometimes, these atmospheric hazards can also displace oxygen and may incapacitate the body's ability to maintain respiration. Some toxic gases and vapours can also cause long-term physical damage to the body in cases of repeated exposure.



Multiple Gas Monitor for six gases and LEL/CH_4 over range protection

A number of instruments are available to assist in detecting toxic gases. Whereas the pocket size monitors operate by diffusion or an aspirator bulb, larger (but still handheld) 2-in-1 and 3-in-1 instruments have been developed with built-in pumps to draw samples from the immediate area or from outside the confined space work area when used with sampling lines. For 2-in-1 devices, side-by-side analog displays show percentage for both oxygen and the LEL. With 3-in-1, 4-in-1, and 5-in-1 devices, the user selects either a sensor readout on a digital display or automatic sequential scanning of sensors contained in the instruments. Regardless of the number of sensors selected or the reading being displayed, all sensors should be designed to monitor continuously.

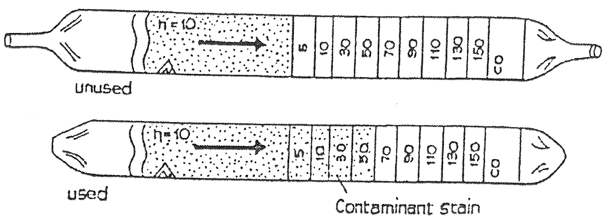
Diffusion-type instruments are available for simultaneously measuring the LEL of combustible gases, oxygen levels and toxic levels (in parts per million) of H_2S, CO and other toxic gases. Alarms also alert the user to low and high oxygen levels. Remote sampling pump adopters are available to convert these diffusion type instruments into pump-style instruments.

(6) Photoionization Devises for Toxic Gases and Vapours

A photoionization detector, featuring micro-processor technology, uses ultraviolet light to ionise molecules of chemical substances in a gaseous or vaporous state. A real-time digital readout allows the user to make an immediate determinations of gas and vapours are measured over a 0.1 to 200 ppm scale. Some instruments automatically compensate for signal loss due to humidity, which is inherent in all PID detectors.

(7) Detector Tube Sampling Systems

Detector tube-type devices are recommended for conducting quick evaluations of potential hazards *that cannot otherwise be measured*. With detector tubes, a known volume of air is drawn through the tube using a manually operated sampling pump. If gas or vapour is present in the air, chemically treated granules in the tube are stained a different colour. By measuring the length of the colour stain within the tube, users can determine concentration levels.



Most tubes available today are made of glass, have break-off tips, and are filled with treated chemical granules. They generally have a shelf life of 12 to 24 months.

One type of pump frequently used with a detector tube is a compact, bellows-type device. Accurate and repeatable sample flows can be assured by a shaft that guides the bellows during compression. Some models feature an end-of-stroke indicator that lets the user know when a full air sample has been drawn. Models with an integral stroke counter eliminate the tedious recording of multiple pump strokes.

(8) Personal and Area Sampling

Two kinds of sampling- personal and area- are used to determine the concentration of airborne contaminants. Personal sampling pumps are designed to measure individual worker's exposure, so they typically are lightweight, belt-mounted, battery-powered devices. Area sampling pumps collect fibres in ambient air, so they usually are stationery. AC-powered devices draw air in high volume.

No matter whether personal or area sampling is done, the process of sampling is essentially the same. It entails drawing a predetermined volume of air through a filter designed to trap contaminants. The filter is contained in a plastic cassette, which is attached by plastic tubing to a personal or area sampling pump calibrated to draw a specific, known volume of air into the filter. After air samples are drawn, the filters are sent to a laboratory where they are examined to determine the level of exposure.

Personal sampling determines the concentrations found in the "breathing zone" or the area near the worker's face, which is usually measured at or near the collar or lapel.

Calibration

To ensure the accuracy of all monitoring and detection equipment, calibration should be performed regularly. If the instrument reading differs significantly from the values of the known standard, the instrument should not be used until it has been adjusted or, if necessary, repaired.

See Part 1.6.5 of Chapter-24 also.

9 PPE TESTING PROCEDURES AND STANDARDS

Fit Testing

Respirators should fit properly to provide protection. To obtain adequate respiratory protection, there must be a proper match between respirator and wearer. Respirators not properly fitting cause illusion of protection. To accommodate the variability of face size characteristics among individuals, a number of manufacturers offer face pieces in several sizes and models.

Purpose :

The primary purpose of fit testing is to identify the (1) specific make (2) model, style and size of respirator best suited for each employee.

In addition, fit testing also provides an opportunity to check any problem with respirator wear, methods of donning and wearing the respirator.

Requirement :

1. Fit testing is required for all negative or positive pressure tight-fitting facepiece respirators.
2. The OSHA respiratory protection standard requires that fit testing be performed before an employee first starts wearing a respirator in the work environment, whenever a different respirator facepiece is used, and at least annually thereafter.

Method :

Prior to the actual fit test, the employee must be shown how to put on a respirator

Position it on the face, set strap tension, and determine an acceptable fit. Next, the employee must

3.6 *Machine Controls and Displays:*
- 3.6.1. *Location & Sequence of Operation.*
- 3.6.2. *Natural Expectation of Control Movement.*
- 3.6.3. *Preventing Accidental Activation.*
- 3.6.4. *Foot controls.*
- 3.6.5 *Displays & Light Signals.*

4. OCCUPATIONAL HEALTH :
- 4.1 *Meaning.*
- 4.2 *Occupational Diseases:*
  - 4.2.1. *Common Occupational Diseases.*
  - 4.2.2. *Notifable Diseases under the Factories Act 1948.*
  - 4.2.3. *Occupational Diseases under the WC Act & the ESI Act.*
  - 4.2.4. *ILO List of Occupational Diseases.*
- 4.3 *Occupations involving Risk of Occupational Diseases & their Diagnostic Methods.*
- 4.4 *Evaluation of injuries.*
- 4.5 *Occupational Health Services & Medical Examinations.*
  - 4.5.1 *Meaning & Function of Occupational Health Services.*

5. STATUTORY PROVISIONS :
- 5.1 *Provisons regarding Industrial Hygiene*
- 5.2 *Provisons regarding Occupational Health*

6. INDIAN STANDARDS :

7. WORKED EXAMPLES :

1 INDUSTRIAL HYGIENE :

1.1 Meaning of Industrial Hygiene(IH):

Industrial (Environmental) hygiene is defined by the American Industrial Hygiene Association (AIHA) as that science and art devoted to the anticipation, recognition, evaluation and control of those environmental factors of stresses, arising in or from the workplace, which may cause sickness, impaired health and well-being or significant discomfort and inefficiency among workers or among the citizens of the community.

Thus **Industrial Hygiene** deals with (1) anticipation ie. identification (2) recognation ie. acceptance (3) evaluation ie. measurment and assessment and (4) control of workplace hazards or environmental stressess (heat, cold, humidity etc) imparing health of the workers or public.

Anticipation includs prior knowledge of possible hazards and their effects on health. It includs all methods of identification of hazards.

Recognation means acceptance of ill-effects of the identified hazards and accepting that environmental stressess endanger life and health accelerate ageing process or causes discomfort. (qualitative assessment)

Evaluation means measuring or calculating the degree of hazard (quantitative) by instruments, air sampling and analysis, comparision with standards and taking judgement whether measured or calculated hazard is more than or less than the permissibl standard. (quantitative assessment)

Control includes enginearing and administrative controls, safe disposal of wastes, medical examination, use of PPE, education, training and supervision.

The scientific approach adopted in applying *Industrial Hygiene* includes, identifying the extent of toxicity (harmful effects) of chemical, physical and biological agents; identifying the extent of employee exposure through inhalation, skin absorption or ingestion; recommending and implementing process controls that reduce exposure to harmful substances and following safe work practices including use of personal protective equipment to guard against the exposures.

The Health effects are unlikely to occur unless exposure occurs. The science of qualitative and quantitative exposure assessment is applied in determining the extent of exposure. These data then are used in determining the need for implementing prevention and control measures.

For Statutory and other standards see Part 5.1

1.2 Difference between Industrial Hygiene & Occupational Health:

Industrial hygiene deals with **Control Techniques** to reduce or eliminate ill-effects of environmental hazards like chemical, physical, biological and ergonomic hazards on human health. The control techniques are mostly **Engineering Control Measures** which try to measure, quantify, monitor, control and eliminate (i) Chemical hazards like dust, gas, fumes, acids, solvents etc. and (ii) Physical hazards like temperature, pressure, noise vibration, radiation etc. (iii) Biological hazards like bacteria, virus, fungus, insects, moulds, parasite, algae, protodones, mematotes, mycoplama, cells lines and other micro-organisms or genetically engineered organisms or cells that can cause a disease and aspects of drinking water, cleanliness, waste and sewage disposal, food contamination etc., and (iv) Ergonomic hazards like pain, illness or accidents due to wrong design, awkward position, improper lifting, man-machine (or job) non-alignment etc. Application of engineering and biomechanical principles can eliminate such hazards.

Thus branch of industrial hygiene needs primarily engineering and biomechanical knowledge and expertise. Therefore, it is called "Hygiene Engineering" also.

Occupational health studies the mode, effects and consequence of environmental hazards or stress - chemical, physical, biological and ergonomic - on **human health**. The techniques are mostly **medical** and study (i) Ill-effects or diseases on health, bodily disorder or maladjustment (ii) M*edical remedies* to remove occupational illness or disease and improve health (iii) Preventive measures to avoid disease and to maintain good health and (iv) Improvement of nutrition and general physical and mental health of the workers.

Industrial hygiene attempts to eliminate or minimise the exposure of environmental or work hazards on human or public health by engineering controls and good housekeeping and keeps the workplace environment clean, pollution free and hygienic while **occupational health** deals with the effects of exposure that penetrates human health, gives medicines to improve it and by pre-employment and periodical medical examinations, it strives to anticipate (early detection of) occupational disease and tries for continuous health care of the workers.

Occupational Health, also known as **Occupational Medicine,** aimes at identifying occupational diseases in the early stage. **Industrial Hygiene** is aimed at identifying and rectifying causes leading to occupational diseases. By the time an occupational disease is identified, it may be too late. Therefore prevention and control of factors leading to occupational illnesses and disease is the best option. Ultimately it increases the life span.

Even if no occupational disease has occurred, the hazards at workplaces reduce the life of exposed people from a few days to few years. Therefore **industrial hygiene practice** is always useful and most desired to assess and make the workplace safe and to stop decreasing the precious life span.

Distinction with public health: Occupational health deals with man in relation to his work and working environment inside the workplace, both physically and mentally, whereas public health deals with man in relation to his environment in society, outside the workplace and where hazards such as air and water pollution, noise, nutrition and infections may affect his health.

1.3 Work co-ordination between Industrial Hygienist, Safety Officer and Factory Medical Officer for the purpose of safety.

The work of Industrial Hygienist, Safety Officer or professional and Occupational Health Specialist or Factory Medical Officer is reciprocal and useful to each other.

Industrial Hygienist can measure and report the hazard level (noise in dBA, gas vapour in ppm, or percentage, light in lux, oxygen level, air velocity, heat stress etc.). He can carry out personal monitoring and report individual exposures. He can assess the need of biological monitoring and report to the Director.

Safety Officer can study this report and suggest appropriate engineering and other controls.

If industrial hygiene practices are implemented first, there will be less work for the occupational health specialist or doctor and less ill-effects on workers, public and environment.

The work of industrial hygienist is useful to health physician (doctor) in drawing some conclusion and conversely the diagnostic doubt of the physician can be scientifically replied by the hygienist.

Health specialist or Doctor can examine the worker for effect of exposure, can carry out biological monitoring if necessary and suggest necessary medical measures.

Thus work of all the three officers should be coordinated for the purpose of safety.

1.4 Occupational Health Hazards :

1.4.1 Introduction & Classification of Occupational Health Hazards.

In the past, mostly the workers' health was considered in relation to their work and working conditions in industrial places like factories, mines, workshops etc., hence the terms *industrial safety and health* and *industrial hygiene* were developed and used. But gradually the concept of *health and safety at work* was developed and workers' health at any work-place or occupation, not limited to industry, was considered in USA (Occupational Safety and Health Act, 1970) and UK (Health & Safety at Work Act, 1974) and now, therefore, the modern concept is to use the term *Occupational Health and Safety* covering industrial and non-industrial occupation health hazards, their effects, controls and preventive measures.

The range of occupational health was also originally limited to occupational diseases or injuries concerned with the work, working condition or the working environment. But with the research in bacteriology at the end of 19th century it was accepted that a disease may arise due to combination of many factors and the definition of occupational health was widened in 1950 at the joint ILO/WHO Committee meeting, to consider promotion, maintenance and protection of health from all factors adverse to health.

Normally workers' health is influenced by non-occupational and occupational factors which can be sub classified as under :

Workers' Health or Work Environment (adversely affected by)

- **Nonoccupational Hazards**
  air, water, food, clothing, housing, personal habits, climate
- **Occupational Hazards**
  - Environmental
    - Chemical
      - **Inflammable**
        Solvent, Hydrocarbons, Phosphorous, CS_2, Flammable substance
      - **Explosive**
        Dust Solvent, Vapour, Powder, Solid, Substance
      - **Toxic**
        Dust, Fumes, Gas, Vapours, Mist, Poisons, Carcinogens
      - **Corrosive**
        Acid, Alkali, Irritant
      - **Radioactive**
        Atomic energy
    - **Physical**
      Noise, Vibration, Heat, Cold, Pressure, Ventilation airchanges, air velocity, Humidity, Light & Colour, Excessive weight, Overtime work, Physical workload, Radiation
      - **Ionising**
        Alpha, Beta, Gamma, X-rays, Neutrons
      - **Nonionising**
        UV, IR, Microwaves, Laser beams
    - **Instrumental**
      No proper instrument, No control instrument, Faulty instrument, No interlock, No alarm, No trip, No autocontrol, No process correction
    - **Mechanical**
      Unguarded machinery, No fencing, No safety device, No control device, Unsafe machine, equipment, instrument etc.
    - **Electrical**
      No earthing, Short circuit, Faulty design, Current leakage, Open wire, No fuse or cut off device, Static electricity, Nonflameproof fitting or equipment
    - **Biological**
      Bacteria, Virus, Fungi, Parasitic, Plant pest, Micro-organism, Infection, Diseases
    - **Ergonomic**
      Wrong design or layout of machinery, Poor housekeeping, No man-job alignment, Improper design, height or position of controls, Wrong tools, Awkward position
    - **Unclassified**
      Not known but causing health effect
  - Non-environmental
    - **Physiological**
      Tender age, Old age, Sex, Illhealth, Sickness, No physical fitness, Nervous strain, Fatigue
    - **Psychological**
      - **Employee's side**
        Wrong attitudes or aptitudes, No motivation or demotivation, Job habit, Smoking, Alcoholism, Emotional upsets, Unskilled, Poor discipline, Absenteeism, Accident proneness, No job security, No job satisfaction, Leadership etc.
      - **Employer's side**
        No education, information or training system for workers

Details and controls of above hazards are explained in respective chapters.

The occupational health is studied by various specialised branches considering different health hazards as under -

Faculty or Approach	Factors or Hazards
Occupational Physiology	Heavy work, heat stress, fatigue etc.
Occupational Psychology	Mental factors like job satisfaction, motivation, attitude, interest etc.
Ergonomics	To make the work suitable to man considering his anatomy, physiology and psychology.
Occupational Pathology or Medicine	Diseases due to exposure to skin, nose and mouth and due to physical factors like noise, vibration, radiation, heat, light etc.
Occupational Hygiene (engineering)	Measurement and assessment of physical and chemical factors like noise, vibration, light, ventilation, temperature, gas, dust, fume etc., and suggesting engineering and medical controls.
Occupational Safety	Accident prevention considering mechanical, chemical, physical and human factors.
Occupational Psychiatry	Mental deviation or nervous disease due to physical or mental work environment or human relations at work.
Occupational Sociology	Attitudes or behaviour at work, working conditions, management etc.

1.4.2 Adverse Health Effects and Controls:

A short synopsis of above hazards, their adverse effects and control measures are given below.

(1) Heat & Cold

Heat causes burns, exhaustion, stroke, cramps, fatigue, decreased efficiency, pain, discomfort, heat collapse, systemic disorders, skin disorders, psychoneurotic disorders and tendency to cause accident. Acclimatisation to high temperature requires reduction in heart rate and internal body temperature at the expense of increased sweating. Radiant heat (e.g. ovens, furnaces), stagnant heat (e.g. textile mills), and high temperature (e.g. mines, glass furnaces) create stress and impair health.

The amendment (1995) in Gujarat Factories Rules has prescribed certain limits - Room temperature < 30 °C (80 °F), Air movement ≥ 30 mt/min, Ventilation openings > 15% of the floor area and in summer when temperature exceeds 35 °C and humidity 50%, air cooling is required. For humidity control dry and wet bulb temperatures are also prescribed u/r 18A.

One UK Standard suggests the following criteria -

Environmental Factor	Standard
Air temperature	21 °C
Mean radiant temperature	≥ 21 °C
Relative humidity	30-70 %
Air movement	30-60 mt/min
Temperature gradient (foot to head)	≤ 2.5 °C

The cold causes chilblains, shivering, frostbite, trench foot, vasoconstriction, hypothermia and erythrocyanosis.

The control measures include (1) sufficient intake of water and salt (2) cotton and protective clothing (3) break in exposure time and more rest intervals (4) engineering controls (5) medical control and (6) acclimatisation of the workers.

For details see Part 8 of Chapter-10.

(2) Air Pressure :

Abnormal air pressure can cause decompression sickness known as 'Bends' (dull throbbing pain in joints or deep in muscles and bones) and 'chokes' (subternal distress and difficulty in deep inspiration with coughing).

(3) Light & Colour :

Improper and insufficient illumination causes eye strain, eye fatigue, headache, lachrymation, congestion around cornea and miner's nystagmus (chronic effect). Glare or excessive brightness causes visual discomfort and fatigue, tiredness and irritability. There should be sufficient and suitable lighting - natural or artificial in all work areas. For details see Chapter 9.

(4) Noise & Vibration :

Noise - too low or too high cause ear strain or pain. Auditory effects are temporary or permanent hearing loss. Non-auditory effects cause nervousness, fatigue, difficulty in conversation, decreased efficiency, annoyance and psychological and systemic effects. The degree of injury depends on intensity and frequency of noise, exposure time (duration) and individual susceptibility.

Vibration of 10 to 500 Hz frequency range as normally found with pneumatic drills, hammers and grinders affects the hands and arms. After exposure of months or years, fingers become sensitive to spasm known as *white fingers*. Vibrations also produce injuries to joints, elbows and shoulders.

For details see Chapter-12.

Sick or Tight Building Syndrome is a health effect on workers, mostly IT personnel due to heat or cold stress, poor ventilation, poor lighting, or monotonous work in fixed type of environment for a longer period. Sickness is resulted in health effects like indigestion, psychosis (mental fatigue), visual problem, mental feeling of impotency, headache, backache, uneasiness, obesity, acidity etc. Remedial measures include-change in working environment, new and attractive atmosphere, good lighting and ventilation, good house keeping, rotation of persons, recreation facility and staggered working hours instead of continuous eight or more working hours.

(5) Ionising & Non-ionising Radiation :

Electromagnetic radiation consists of varying electric and magnetic fields, operating at right angles to each other. It has both particulate and wavelike aspects. Following table shows the wavelength and frequency for various electromagnetic radiation. Long-waves have low energy, short-waves have high. The higher energy wavelengths (short-waves) are more penetrating i.e. more damaging. X-rays, Gamma rays and cosmic rays have short wavelengths, 10^{-6} cm and less, and high frequency, 10^{16} c/s and above and cause **ionising radiation**.

Others i.e. electric waves, radio waves, micro waves, visible light, IR, UV and lasers have longer wavelength and less frequency and cause **non-ionising radiation**. Lasers are involved in visible light, IR and UV regions of the spectrum given below :

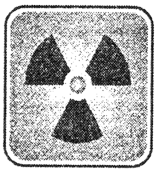
The Electromagnetic Spectrum		
Energy Form	*Frequency, c/s*	*Wavelength, cms*
Non-ionising radiation :		
Electric waves	10^2 to 10^4	10^{12} to 10^6
Radio waves	10^4 to 10^{11}	10^6 to 10^{-1}
Infrared (IR)	10^{11} to 10^{14}	10^{-1} to 10^{-4}
Visible light	10^{15}	$7x10^{-5}$ to $4x10^{-5}$
Ultraviolet (UV)	10^{15} to 10^{16}	10^{-5} to 10^{-6}
Ionising radiation :		
X-rays	10^{16} to 10^{18}	10^{-6} to 10^{-9}
Gamma rays	10^{18} to 10^{21}	10^{-10}
Cosmic rays	10^{21} on	10^{-11} on

Types and Limits of Radiation :

(A) Ionising Radiation:

The Ionising radiation in the electromagnetic spectrum consists of Alpha, Beta, X-rays (Hard & soft) & Gama radiation and neutrons of various energy intensities. These are having a variety of application such as Research, Military, Industrial and Medical. Radiation safety is ensured by adjusting time, distance & shielding.

Ionising radiation means electromagnetic or corpuscular radiation capable of producing ions directly or indirectly in its passage through matter. It is not visible by normal eyes. X-rays, Alpha, Beta, Gamma, fast neutrons, thermal neutrons and radionuclides are ionising radiation. Radioactive



substance (chemical) must be firmly sealed within metal container to prevent dispersion to active material into surrounding. *Radiation hazard* means the danger to health arising from exposure to ionising radiation which may be external or internal.

Animal and human studies have shown that exposure to ionizing radiation can cause carcinogenic, teratogenic or mutagenic effects, as well as other sequelae. The NCRP has formulated exposure limits. Some such limits are given below :

Exposure limits given in *rems per year* are as under :

Whole body exposure Long term accumulation	5 (Age in year-18) x 5
Testicles, Ovaries and Red bone marrow	5
Skin, Thyroid, Bone	15 to 30
Hands, Feet and Ankles	75
Forearms	30
All other organs	15
Pregnant woman, total during pregnancy.	1 0.5 in gestation period
Population 1 Individual 2 Average	0.5 wholebody 5 gonads

International Commission on Radiological Protection (ICRP) has prescribed a dose-equivalent limit of 0.5 SV (50 rem) to prevent non-stochastic effects.

Radiation dosimetry in health physics tries to know whether individual radiation exposures are within permissible dose. Various fixed and portable monitors (detectors and survey instruments) are used for radiation exposure measurement. Some fixed monitors are as under:

heat required to raise temperature of 1 litre water from 15 °C to 16 °C is called *Kilocalorie (Kcal)* or a *Calorie (Cal)*. 1 Cal = 4.184 Joule.

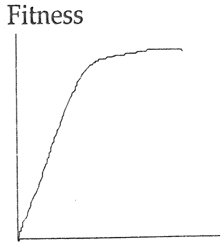
Mainly there are six categories of nutrients - Proteins, Carbohydrates, Fats and Oils, Minerals, Vitamins and Water. Proteins are made of amino acids (some 23 types) and useful in body building and repair. Growing children and nursing mothers need extra protein. Cereals, nuts, peas, beans are plant sources and meat, fish, milk, cheese and eggs are animal sources of protein. Plants provide carbohydrates and also proteins, vitamins and minerals. 1 gm of carbohydrate produces @ 4 cal energy. Fats and oils are obtained from plant or animal and provide @ 9 cal/gm, and aid some vitamins. Minerals are needed in small quantity. Calcium in milk and milk products (except butter) is essential for teeth and bones, clotting of blood after a wound and for normal contraction of muscles. Iron is necessary for red blood cells. Iodine is a part of thyroid hormone which helps to regulate growth, mental development and rate of body functions. Vitamins (20 identified) are equally useful for growth, development and body function. Their quantity required is small. Vitamin A prevents night blindness, B protects nerves, C prevents scurvy and D ensures strong and straight bones. 60 to 70% of the human body is made up of water and it is most essential for life. Water controls the body temperature, digestion, absorption and distribution of foods to body tissues, removal of waste and functioning of the kidneys. During heavy work and in hot environment, extra water is required to compensate sweating and to keep the body temperature within limits.

Energy is always expended in work and food (nutrients) is the basic need to supply this energy. Even a simple meal provided at workplace can remarkably improve production rate and earnings.

A diet which provides enough food of different types and tastes to meet nutritional values is called a *balanced diet*. It varies from person to person,, states to states and countries to countries because of the varieties of factors.

Food should be fresh, warm and non-contaminated. It should be eaten after washing hands, mouth and teeth.

Nutrition and Physical Fitness Relationship :



Above discussion makes it clear that nutrition has direct relationship with physical fitness. The fitness increases with nutrition to its maximum level beyond which nutrition cannot help and may result in waste.

Depending on quantum of physical (muscular) work, type of weather, digesting power, hunger, thirst etc., one should maintain his nutrition standard to maintain good health. More nutrition is necessary by growing children, pregnant women, nursing mothers, hard workers, athletes and people living in cold countries. To regain health after illness or injury, good and gradual nutrition is most essential. We all have to remember this relationship till our life.

3 ERGONOMICS

After studying 'Physiology' it is in chronology to study 'Ergonomics' as it includes physiological movements, measurements, limitations etc.

3.1 Introduction to Ergonomics and its Constituents :

3.1.1 Introduction to Ergonomics :

Refer Part 6.1 of Chapter-14 for meaning of *Ergonomics*. It is explained there for the purpose of machine guarding.

The term 'ergonomics' is derived from the Greek word 'ergo' meaning work and strength and 'nomos' meaning rule or law. It simply means "fitting the job to the worker (and not the worker to the job)". The object of ergonomics is "to achieve the best mutual adjustment of man and his work to improve his convenience, efficiency and well being". Ergonomic approach includes designing of machines, tools, controls, equipment, process, layout, housekeeping etc. to increase efficiency of both - man and the machine. Application of ergonomics reduces accidents and improves health and efficiency.

The term 'human engineering' is used in USA while the term 'ergonomics' is used in the rest of the world. Both are synonym.

Ergonomics is also defined as 'the study of human characteristics for the appropriate design of the living and work environment'. It is human - centred, transdisciplinary and application oriented. It can be applied to jobs, equipment, working place, tools, utensils or any complicated working system (e.g. multiperson sociotechnical system).

Successful application is measured by improved efficiency, safety, productivity and acceptance of the ergonomic design.

The disciplines that can be utilised in ergonomics are : physiology, anthropology, biomechanics, engineering and psychology. They include both technological and human components.

Ergonomists draw data from full spectrum of human and biological sciences, technology and acquire additional data through experiment, survey and research. Data on body dimensions, physiological reactions to environmental hazards, sensory capacities, decision making abilities, psychomotor performance, ability to make precise, rapid and correct control movements, ability to modify behaviour through training, biological aspects of eating, drinking and waste disposal and psychological factors due to fatigue, emotion, danger etc. also become the subject-matter of ergonomics.

The ergonomic design should begin with an understanding of *the user's role and should consider human variability as a design parameter. The ultimate design incorporates both human capabilities and built-in safeguards to reduce or avoid the impact of human error.*

In short, the aim of ergonomics is to achieve safety, ease and efficiency at work (by considering physiological and environmental factors).

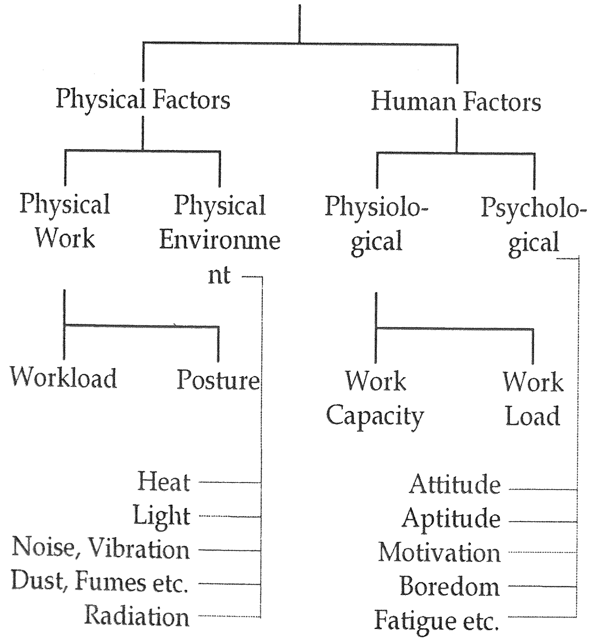
Website in pharma industry:

http://www.hse.gov.uk/pharmaceuticals/index.htmr

3.1.2 Constituents of Ergonomics :

Human factors (HF) was the old discipline concerned with how humans react with their worktasks and environment aiming to make the relationship safer, healthier and more efficient. The new name of this discipline is Ergonomics. Previously known 'Human Engineer' or "Engineering Psychologist" is now known as "Ergonomist or Ergonomicist (in great Britain). The term Ergonomics is *biotechnological* and covers the same scope and complexity of interests that human factors embraces. Therefore, *human factors* are the main constituents of ergonomics. For main division of factors affecting work including human factors see Part-5 of Chapter-3. In a schematic diagram they are shown below :

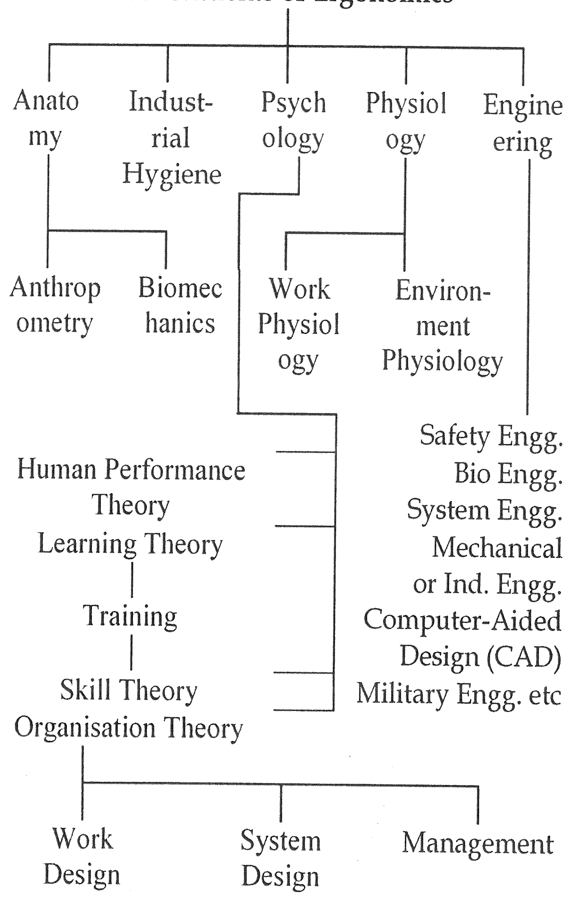
Work Performance or Man at Work



Ergonomics studies the *'human factors'* and designs the system or suggests application or modification of the existing system to make the work more suitable or convenient to the man at work. Thus in this context, for its procedural aspect, all human factors - physiological and psychological contribute in constituting the science.

But from *discipline point of view,* main constituents of ergonomics are anatomy, physiology, psychology and engineering. Schematic diagram of disciplines (work areas) constituting the ergonomics is also shown below :

Constituents of Ergonomics



3.2 Application of Ergonomics for Safety and Health :

Application of ergonomics can solve the problems of stress and strain due to work load, high or low temperature, more or low illumination or glare, noise, vibration, radiation, awkward work positions and orthopaedic problems due to them. The field of application is very wide which includes following as some of the areas :-

1. Hand tools.
2. Design of Controls.
3. Design of work.
4. Design of information displays.
5. Man/machine information exchange.
6. Limitations of the sense organs.
7. Age, fatigue, vigilance and accidents.
8. Problems of body size and posture.
9. Effects of climate.
10. Human energy, optimising its efficient use.
11. Work tolerance.
12. Anatomy of function.
13. Physiologic measurements.

14. Application of skeletal-muscular forces (e.g. manual handling and lifting.)

Ergonomics is also utilised at design stage where it is called. *"System Ergonomics"* in contrast to *"Classical Ergonomics"* which is applied to solve the ergonomic problems as and when they occur once a design has been put in use. System ergonomics is a higher level of practice involving a knowledge of (1) Different tasks the machines can perform.(2) The relative cost. (3) A variety of tasks and satisfactory work for personnel.

In designing work, ergonomics can be applied for the design of systems, work places, environments, interfaces and work situations. Some examples are as under :

Sr. No.	Type of Design	Examples.
1.	Systems	Man-machine relationship, procedure.
2.	Workplace	Posture, seat and control design, bench position, displays.
3.	Environ-mental	Required lighting, heating, ventilation, noise, vibration etc.
4.	Interface	Exchange of information between man and machine/environment, scales, pointers, letters, numbers, their size, shapes, position, forces etc.
5.	Work situation	Hours of work, rest pauses, shift work, interpersonal and organisational aspects of work.

Following are some of the examples of application of ergonomics (human engineering) to matters of health and safety :

1. Stresses of excessive heat, light, humidity, noise, vibration etc., their safe limits, type of worker e.g. age, sex, fitness etc., and task to be performed - all should be considered and suitable environmental conditions should be designed to fit appropriately to the worker and his task.
2. Surrounding space, seat design, bench design and positioning of displays, controls, materials, tools, equipment, instruments etc. should fit the human body so that he can work without excessive effort within the range of healthy posture.
3. Interface display and control design should consider effective information between the man and the machine or environment in type and size of numbers, letters, pointers, shapes and discrimination, identification etc.
4. Working hours, rest pauses, shift work, interpersonal and management problems should be studied and resolved to maintain health and safety of work people.
5. It should be aimed to do work with a minimal use of energy and materials and without waste resulting from mistakes. Human errors should be minimised for safety and health.
6. Design and production of automotive vehicles, communication equipment, farm machinery, military service, aerospace systems, computers and electronic equipment can be made safe and most suitable to the operators.
7. Highway signs, typewriters, data processing systems, machine tools, kitchen stoves, street and highway design, rapid-transit facilities, health facilities, housing , pollution control, education, law enforcement, postal service, airports etc. are newer areas where ergonomic design can give good results and reduce accidents.
8. Deciding allocation of functions between men and machines. Functions of perceiving, responding to emergency situations, some typical judgements etc. are better done by men than by machines. Functions of heavy lifting, computing, auto regulation, handling large amount of information etc. are better performed by machines than by men. These are to be considered at an early stage of design.
9. Task analysis to decide selection standards, workloads, training requirement, manpower requirement, equipment design can be carried out.
10. Factors of control design, e.g. control display ratio, safeguards against accidental activation, control coding etc. are part of ergonomic design.
11. Workplace dimensions, location of controls and displays, seat and penal design, the design of doors and access for easy entry and exit and protective devices for emergency situations need to be well designed.
12. For good maintenance easy and simple maintenance manuals, tools and test equipment, better location of units for easy access, fault-finding techniques etc. are to be designed properly.
13. Allowance for local weather conditions, ventilation in cramped premises, providing stool to put container to avoid frequent bending, elementary checklists are ergonomic aspects.
14. Manual material handling has a large scope of ergonomic considerations. Process flow, job design, layout, selection of equipment, machine, tools, space requirement, control design, visibility, colour and signs, allowing push and pull instead of lift and lower, avoiding severe bending, lifting and lowering between knuckle (hip) height and shoulder height, avoiding excessive weight, avoiding sharp edges, corners, pinch points, training for safe lifting practice and lifting rules (dos and don'ts), personnel selection etc. must be well considered.

15. Wrong design of hand tools can create bending of wrist, pressure points between the hand and the handle, sustained exertions, vibrations etc. Therefore handtools should be designed in such a way that they eliminate or minimise these hazards. Oblique angle of the handle, proper shape, diameter and length of the handle, rounding off all edges and sharp corners, minimising noise and vibration etc. are useful criteria.

16. Office, other work places and workstation design call for specific criteria. Ideal, practical and detail planning, work process, equipment, workplace layout, final enclosure, mock-up, trial and redesign, clearance for the operator's body, sufficient head room, visual field, auditory information, standing or sitting position (both have advantages and disadvantages), work space dimensions, body position to operate computer, healthy work postures, eye height, elbow height, knee height, seat design to reduce physiological and biomechanical stresses by providing wide range of adjustments and postures to suit the individual (seat height adjustable between 15 to 20 inch, deep 15 to 17 inch, wide 18 inch or more and backrest to support back and neck and opportunity to change body posture frequently) etc. are some important criteria.

17. Controls - continuous or détent - should be designed by considering consistency of movement, control actuation force, multidimensional operation, operator-control orientation, control-effect relationship, time lag, arrangement and grouping, coding and prevention of accidental activation etc.

18. Light signals provide useful safety and functional indications as mentioned below : See also Part 7.3 of Chapter-9.

19. Displays provide necessary information to the operator. They may be visual (lights, scales, counters), auditory (bells, horns), tactile (shaped knobs, Braille writing) or audio-visual (buzzer with light, TV display). Selection depends on type of information to be provided and to whom provided.

20. Labelling permits rapid and accurate performance of controls, displays and other items that should be identified, read, manipulated or located. Label characteristics are: accuracy, time of response or recognition, distance, illumination, nature of function and consistency. Their visibility, legibility, location, orientation, abbreviation, brevity and standardisation are necessary. Legal notices must be displayed.

From above varieties of examples it is evident that ergonomics has wide applicability to many functions in addition to health and safety.

3.3 Load Carrying :

3.3.1. Safe Use of Muscle System & Lever System in Load Carrying.

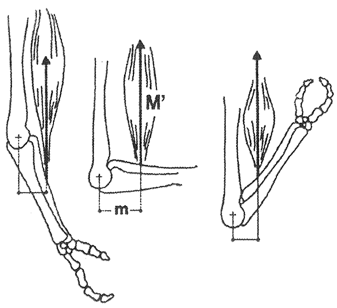
Muscle system consists of about 200 skeletal muscles in the body. They are in the form of bundles of muscles and wrapped on each other. They are connected with tissue carrying nerves and blood vessels inside. The tissues combine to form tendons which connect the ends of the muscle to bones. The sheaths of the connective tissues provide mechanical properties to the muscle.

A muscle has only action to contract. Elongation is by external force. Filaments of muscle sliding along each other provide automatic contraction after elongation. Signal to contract comes from brain by the neuromuscular system. Signals coming to motor units of the muscle can be observed by electromyogram (EMG).

Lever system is consisted of links (bones) joined in their articulations and powered by muscles bridging the joints. As elbow angle changes, lever arm (LA) also changes with the muscle force (MF).

Safe use of these muscle and lever system of human body is most desirable to prevent injury, damage or pain to the body. Excessive load causes excessive stress in muscle which may result in strain, stretch or pain. Therefore excessive weight limits are legally prescribed. Some safety measures are as under:

1. While handling material, force exerted by hands should be transmitted through the whole body parts including feet to the floor. In this chain of forces, weak link is spinal column, particularly at the low back. This limits the capability of a person to work. Therefore task should not be too heavy.



2. Tasks, equipment and system should be designed to provide ease and efficiency of manual handling.
3. Layout of material transfer and facilities should be convenient and comfortable to the people.
4. Job design should be safe, efficient and agreeable for the worker.
5. Selection of tools, machines, equipment should be proper. Sufficient space for movement, visibility, lighting, colour coding and control design are important.
6. Select persons capable of performing the job. The job should be designed to fit the worker.
7. Give training for safe lifting practices.

3.3.2 Physiological Problems with Load Carrying (Injuries, Fatigue etc.) & their Solutions.

Problems with load carrying activity are as under :

1. **Limits of human capability** of movement in body joints and in spinal column, body size, sex, age, energy capacity (heart rate). etc. Therefore load carrying capacity varies with age, sex and overall strength of a person..
2. **Physical Fatigue** due to overexertion that causes temporary decrease in physical performance. Reasons of fatigue are workload i.e. static and dynamic work, lack of rest or sleep, illness, pain, poor food intake etc.
3. **Mental fatigue** due to psychological factors like monotony, conflict, worry, de-motivation etc.
4. **Work and rest cycle** depending on intensity of work. Heavy work requires more rest periods at short intervals.
5. **Faulty layout** of material transfer requiring more time and more effort.
6. **Wrong design** of job. Where machine is required, job is given for manual working or carrying. Excessive weight, odd size, sharp edges, hot material, oily or slippery surface, invisibility etc are some of such factors.
7. **Non-provision of** sufficient space for movement, necessary hand tools, proper controls, signs (e.g. arrow) for lifting or placing etc.

Solution to above problems require -

1. Decision whether man is required or machine is required for a particular job.
2. Weight should be within limit i.e. not excessive for a person to be employed.
3. Proper design of job itself and of facilities, tools and equipment etc.
4. Sufficient space for movement, illumination, necessary rest intervals, proper clothing, drinking and food arrangement etc.
5. Proper selection of persons based on their size, sex, age, strength etc so that work matches with the people.
6. Break down whole material movement process from receiving to distribution into different functions or segments and in each such division plan the actives of material handling in detail and separate out jobs for machines and men. Then allocate accordingly.
7. Plan movement of material in horizontal plane. Arrange push or pull instead of lift or lower. Avoid severe bending movement.
8. Delivery of material at workplace should be at hip height instead on ground floor.
9. Lifting and lowering height should be between hip and shoulder height. This will cause less injury.
10. Handling should occur close to and in front of the body.
11. Material should be light, compact and easy to grasp. It should not have sharp edges, corners or pinch points.
12. Containers or bins should be of sufficient size. Material can be put or removed easily.

See also part 2 of chapter 15 for manual material handling.

3.4 Hand Tools and their Use :

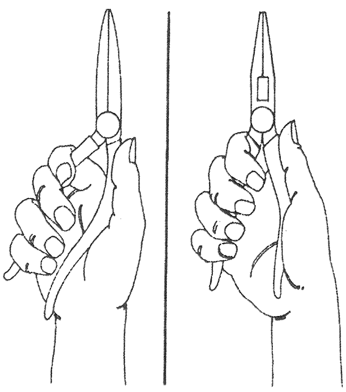
See Chapter 17 for figures and other details of safe use of hand tools and power tools.

3.4.1. Design of Tools in relation to Body Postures.

Ergonomic design of hand tools is necessary so that tools and their handles properly fit to the hand grip, avoid unnecessary bend, movement or pressure of fingers and wrist, provides smooth surface and shape for safe handling, insulation for electrical tools and requires less force while working. Some such design criteria are as under -

1. Tools should have bend and should be best fitting to the shape, size and functions of the hand.

2. There are different interactions between the hand and the handle, control or support viz. finger touch, palm touch, hook grip, tip grip, pliers grip, side grip, writing grip, disc grip, finger palm enclosure, power grasp etc. Handle, control, knob, lever or support should be properly designed for such couplings between hand and handle, control etc.



3. Cross section and longitudinal shape of the handle must be proper. Circular cross section is mostly preferred.

4. Handle size should accommodate the palm for sufficient grip.

5. Pressure points and rough surface of handle should be avoided.
6. Round off sharp edges or corners on the handles for safe holding.

7. Avoid cooling or heating the hand by appropriate covering (insulation) on handle.
8. Hand tools should have minimum vibration.
9. Gloves should be used if useful.

3.4.2 Safety while using Hand tools.

See part 3.2 of Chapter - 17

3.4.3 Safety while using Power tools.

See Part 4.1 of Chapter - 17

3.4.4 Tool boxes, Kits & Tool maintenance.

See Part 3.4 and 4.2 of Chapter - 17

3.5 Work Station Design:

3.5.1. Introduction to Anthropometry.

Anthropometry and biomechanics are branches of ergonomics dealing with physical dimensions and properties of the human body.

Anthropometry means measuring the human body. Height, breadth, depth and various distances of the body parts are measured. Curvatures and circumferences are also measured. Measurements are taken in stand-erect or seated position.

Body dimensions are measured by anthropometers, calipers, taps and a scale. Such dimensions are useful in designing work spaces, tools, equipment, seating arrangement, vehicles and workstations so that they can best fit to the users.

3.5.2. Concept of Percentiles.

Percentile indicates which percentage of a known population is fitted by a design range. Suppose work seat height is to be designed most convenient to majority of men and women, its range should fit to the women in 5th percentile to the man in is 95th percentile. This means much deviation will not be required in this range of seat height (say lowest 35.5 cm to its highest setting at 48.8 cm). Then addition of 2 cm for heal height may be required. 50th percentile corresponds to a single fixed seat height of 41 cm for a mixed male-female population, but, this will be too high for about 50 % of the people and too low for the rest. Thus designing for the average fits nobody.

5th, 50th and 95th percentiles measurements for human height, depth, breadth, head, hand and foot dimensions are available for ergonomic design purpose.

3.5.3. Health problems related to wrong postures, back pain etc.

Sitting or standing in the same posture for a long time exert muscle tension and spinal compression. Therefore this should be avoided by providing rest periods, physical activities or exercises.

Computer operators keep the head in a fixed position for a long time and therefore suffer pain and tension in the neck area. Intensity, frequency and long hours of muscle contractions cause severe discomfort, pain and other musculoskeletal disorders that last for long periods.

Lumber spine suffers more force while sitting on a stool without backrest than in standing at ease. Leaning back over the backrest and arms hanging down reduces compression force. Straight upright backrests do not support the body and high disk forces may occur. When it is declined back and upper body weight is rested on backrest, internal forces are also declined. Relaxed leaning on a declined backrest is the least stressful sitting posture.

See Part 7 of Chapter 7 Part 2.4.1 of Chapter 15 also. See Part 13.4.4 of Chapter-5 for musculoskeletal and trauma disorders to computer operators.

3.5.4. Ergonomic Office Furniture and Utility Tools

Workstation consists of furniture, equipment, work material and overall environment. Persons do job there. Work posture includes movement of body parts and work activities include visual, auditory, vocal and motor types. Their combined effect is performance output and persons' well being.

Work space design, good lighting and ventilation, attractive and comfortable work situation are basic requirement. Office furniture and utility tools like controls, displays, switches, trays, bins, office equipments and instruments also play an important role.

General system components include computers, keyboards, tables, chairs and cupboards. But operator is the most important component in this system, because work output depends on him and he utilizes other components of the system. He should be most comfortable. His body dimensions are useful in designing workstation dimensions as under -

1. Dimensions should be slightly adjustable according to individual's requirement.
2. Visual tasks - monitor, key board, papers, books etc. - should be at eye height.
3. Keyboard, mouse, notepad, pen and hand controls should be convenient to elbow height and forearm length.
4. Leg room height depends on knee height, and thigh thickness and its depth depend on foot length.
5. Thigh width and lower leg length (Poplitcal height) decide the width and height of the seat pan.

6. Functional reach decides height of shelves and other furniture.
7. Furniture should provide user freedom to extend legs or hands, to lean foreword or backward, to rotate left or right and to take any posture.
8. Ergonomic chairs with large backrest are most comfortable as they provide support to back and neck. Seat height must be fully adjustable. (height 35 to 50 cm, depth 35 to 45 cm and width 45 cm). Seat surface should not generate any pressure to the seated person.
9. Armrests are useful in reducing compression load on the spinal column.
10. Visual targets should not be spaced apart in direction or distance from the eye. They should be easily viewable in the front.
11. All components of workstation should fit each other and each should fit the operators. Flexibility for individual requirement is also necessary.

3.5.5. Ergonomic aspects of Computer Workstations

Work on computer has been increased too much. The use of Visual display terminals (VDTs) in workplace is widespread. Long usage of VDTs may cause Cumulative Trauma Disorders (CTDs), vision problems, back pains, eyestrain, eye fatigue etc.

Risk factors involved in working on computers are stresses due to repetitive work without adequate alternative activity, awkward postures, glare - direct or indirect, constant position of hands, back, neck and other body parts.

Ergonomic design of computer workstation requires many aspects such as screen orientation, forced air exhaust, proper illumination, equipment and document location, window luminance, colour usage, viewing distance and angle, keyboard position, seat height and width, seat pan angle, angle between seat back and set pan, backrest, chair castors etc. Some details are as under:

1. Neutral posture at the keyboard and mouse - arms comfortably at the sides, elbows bent at approximately 90 degrees, forearms parallel to the floor, knees slightly below hips, and wrists straight.
2. The work surface should be large enough to support the keyboard, mouse, monitor and documents. Not having enough space for the mouse to be adjacent to the keyboard is, unfortunately, one of the most commonly observed ergonomic hazard especially.
3. The top line of the screen should be just below eye level to keep the neck straight. (Adjustable arms, tables or platforms can help bring the screen to the proper height.) Screens that tilt vertically and swivel horizontally help the worker adjust the best viewing angle.
4. Monitors should be placed 18-30 inches away from worker for viewing. The distance depends on the size of the monitor, the use of corrective lenses and visual acuity among other factors.
5. Keyboards and monitors should be detachable so the angle and position can be adjusted.
6. Keyboard and work-surface edges should be rounded to prevent contact stress.
7. Documents should be at the same height and distance as the screen.
8. The sereen and document should be easily viewed so that the worker's head does not have to turn to the side or tilt up or down regularly.
9. To prevent glare, the monitor and keyboard should be perpendicular to windows and between (not directly under) overhead lights. If this is not possible, then adjustable window coverings should be installed to reduce backlighting and/or glare.
10. Screen contrast and brightness should be easily adjustable.
11. screen characters should be clearly displayed, neither warey nor flickering. The refresh rate on the monitor should be set above 72 Hz or higher if possible.
12. Wrist/palm rests may be used to protect wrists and palms from hard or sharp edges and to help keep the wrists in a neutral position. Howerver, continually resting wrists on a wrist/palm rest during keying can put pressure on nerves or in other words be a source of contact stress. Wrist/palm rests should be made of soft but supporting material and be the same height as the front edge of the keyboard.

To prevent pain and discomfort, in addition to proper design aspects as above, exercises by computer operator at regular intervals are also necessary. This includes exercises of neck, shoulders, elbow/arm, lower back/hip, knee/lower leg etc.

3.6 Machine Controls and Displays:

3.6.1. Location & Sequence of Operation.

Controls are mostly hand or foot operated. They transmit inputs to machine, vehicle or equipment. They are selected on basis of their functional utility and located in easy reach so that operator's body parts are not overstressed.

Controls are of 'continuous' type (e.g. crank, knob wheel etc) or 'detent' type (e.g. key lock or switch, bar knob, thumbwheel & different switches) where step wise operation is required.

Controls having sequential relations should be arranged in functional groups with their associated displays and in operational sequence.

If sequential operation follows fixed pattern like car gear handle, they should be arranged to facilitate operation i.e. top to bottom or left to right. Sufficient spacing s required for movement.

Controls should be located as per operator's requirement i.e. easy operation. Time lag between control input and system response should be minimum and consistent with safe and efficient operation.

Knobs are provided where little force is required and when fine adjustment is necessary.

Hand wheels are used for two hand control. Then knurling (corrugation) should be provided for good grasping.

When levers are used for fine or frequent adjustment (e.g. car gear lever) limb support are useful. e.g. elbow support for large hand movement, forearm support for small movement and wrist support for finger movement.

When several levers are located side by side, the lever handles should be coded. Levers should be labeled for their direction of motion and function. For joystick controls (three dimensional steering), elastic resistance is added for smooth displacement.

3.6.2. Natural Expectation of Control Movement.

Control movement should match with natural expectation e.g. foreword motion for front driving, backward motion for reversed driving, clockwise motion for right direction and anticlockwise for left direction, forward motion for boom descend and vice-versa. In electrical switches, downward indicates 'on' and upward indicates 'off' position. This is natural expectation.

In key lock switches (e.g. car ignition switch), key's vertical position indicates 'off' position, turning clockwise indicates 'start' position and key should not come out without turning the switch i.e. without stopping the vehicle or machine. The 'on' and 'off' positions should be labeled.

3.6.3. Preventing Accidental Activation.

Controls should be so designed and located that they will not move or change their position accidentally. They should not come out accidentally or by slight touch from 'off' to 'on' position and start the vehicle or machine [Section 24(3) of the factories Act]. Such inadvertent operation can cause accident to person, machine or system. To prevent such accidental activation, following measures are useful -

1. Cover or guard the control.
2. Provide interlock so that extra movement is required to change the position.
3. Provide resistance by spring action or viscous friction so that extra effort is required for actuation.
4. Provide rotary action for operation.
5. Provide recess, slot, shield etc to contain controls within it and finger is required to insert inside. e.g. push button or switch in recess or guard on foot pedal of a power press.
6. Provide 'on' and 'off' button separately and with different colour.
7. Provide' Dead man control' which will keep the system working till the control is pressed and will stop the system when the control is released, e.g. petrol nozzle trigger (knob) or drill machine push button.

3.6.4. Foot controls.

Foot controls have specific use and where powerful braking force is required or when leg is only convenient limb, viz. brake pedal or acceleration control lever in car or brake pedal for power press, press brake, metal shear and other machines.

3.6.5. Displays and Light Signals.

These are useful to provide necessary information to operator. They may be dial gauges, pointers, digital, audio, visual, analog etc. Bell, horn and warning notices are also displays which give information. Colored signals have some meaning as under -

1. Red - Stop position
2. Flashing Red - Emergency condition.
3. Green - 'On' position or 'yes' indication to proceed.
4. Yellow - Wait, delay or be in readiness position. It also indicates caution or rechecking.
5. White - No right or no wrong, transitory condition.

Displays should have clear meaning. They should be easy to understand and visible, properly illuminated, also visible when power fails, coded and labeled according to function.

Numerical display indicates time, temperature, pressure, flow, humidity, pH, speed etc. Moving pointer on a fixed scale have many shapes - circular, curved, horizontal straight or vertical straight. Numbers or figures should not be obstructed by pointer.

Displays should be located in viewing area and perpendicular to the line of sight.

Labels should be provided where extra information is necessary.

4 OCCUPATIONAL HEALTH

4.1 Meaning :

Occupational Health is eventually a branch of preventive medicine which examines the relationship between work and health and effects of work on the health of the worker.

Occupational Health includes all factors relating to work and working conditions, methods and environment, that may cause diseases, injuries or deviation from health including maladjustment to work. It implies not only health protection but also health promotion for improving the health and working capacity of the worker, viz. preventive measures against diseases, improvement of nutrition and general mental health.

Occupational Health was defined by ILO/ WHO committee in 1950 as "Occupational health should aim at : the promotion and maintenance of the highest degree of physical, mental and social well-being of workers in all occupations, the prevention among workers of departures from health caused by their working conditions, the protection of workers in their employment from risks resulting from factors adverse to health, the placing and maintenance of the worker in an occupational environment adapted to his physiological and psychological ability and to summarise : the adoption of work to man and of each man to his job."

It includes medical examinations of workers, their health records, placement according to health condition and adjusting work to man and man to his work. It is a team work of chemists, safety professionals, industrial hygienists and doctors.

4.2 Occupational Diseases :

4.2.1 Common Occupational Diseases :

(1) Occupational Lung Diseases :

Normally dusts cause lung diseases and therefore the types of dusts and their effects are discussed below.

(A) Types of Dusts and their Effects :

Dust is a disperse system (aerosol) of solid small particles in air or gas whose size distribution is like a colloid. It originates from mechanical communication of coarser material. Mining, breaking, crushing, grinding, mixing, polishing and handling are the main dust generating processes.

Small particles of 0.1 to 5 μm size (respirable dust) can remain in the alveolar passages of which smaller particles (<0.1 μm) behave as colloids or smoke, deposit in lungs or other part and cause health effect. Particles of larger size (>5 μm) are driven back by the clearance mechanism. Asbestos fibre of 3 μm or less in diameter and upto 100 μm length can reach the alveoli, while the smallest fibres can reach upto pleura and pleural space.

2nd Schedule of the Factories Act prescribes TLV (permissible time-weighted average i.e. TWA concentration per 8 hours) of cotton, asbestos, coal, cement and silica dusts.

Types of dusts can be classified as under :

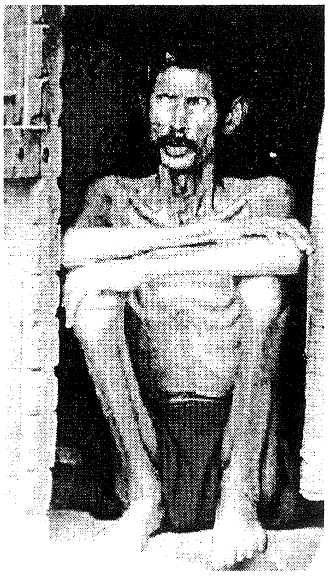
1. Quartz and mixtures containing quarts : Coal dust, mineral ores, sand, rock, fluorspar, quartzite etc. They are found in mining, ceramic industries, refractories, pastering, mixing and insulating materials. They cause nodular fibrosis and silicosis.
2. Asbestos and mixtures containing asbestos : Raw asbestos, chrysotile, amphibole, asbestos cement talk etc. It is used in some 3000 products of textile, insulation, packing, jointing and building material. It can cause diffuse fibrosis, carcinoma, asbestosis and telcosis.
3. Metals and metal compounds : Metals like iron, nickel, lead, manganese, aluminium, beryllium, chromium, cadmium, vanadium and their oxides are extensively used in metallurgy, metal working, welding, electroplating, furnaces, sintering etc. They can cause irritation, diffuse fibrosis and different types of lung diseases known as siderosis, bronchial carcinoma or asthma, tracheobronchitis, aluminium lung etc.
4. Plant and Animal (organic) dust : Wood, animal hides, skins, hair, feathers, scales, cotton flax, hemp, sisal, jute, mouldy hay, straw, cereals, bagasse, crushed grain and bran, enzymes etc. They are found at wood working, agriculture, poultry, textile, grain or sugar mill etc. and cause irritation, immune reaction, carcinoma, allergic rhinitis, bronchial asthma, farmer's lung, bagassosis, byssionosis etc.
5. Other dusts : These are chemical dust like carbon dust, soot, graphite, phthalic and maleic anhydride and arsenic dust etc. and found in mining, metallurgy, rubber, plastic and chemical industry. They can cause irritation, carcinoma, systemic effect, ulceration, conjunctivitis, graphite pneumoconiosis etc. Inert dusts are also hazardous.

Following table shows some dusts and lung diseases that may be caused by them.

Dust	Lung Disease
Quartz (Silica)	Silicosis.
Asbestos	Asbestosis
Talc	Talcosis, mesothelioma, bronchial carcinoma, carcinoma of upper respiratory tract.
Aluminium and its oxides	Aluminium lung, bauxite smelter's lung, CNSLD
Beryllium & its oxides	Tracheobronchitis, pneumonitis, beryllosis.
Cadmium and its oxides	Tracheobronchitis, bronchopneumonia, emphysema of the lung.
Chromium, Chromate, Chromoxide	Ulceration and perforation of nasal sputum, bronchial asthma, carcinoma of nasal cavity, CNSLD.
Hard metals	"Fibrosis, immune reaction.
Iron, Iron oxide	Siderosis.
Manganese, Manganese oxide	Manganic pneumonia, CNSLD.

Nickel, Nickel oxide, Nickel salts,	Bronchial carcinoma, carcinoma of nasal cavity,
Platinum compounds (Salts)	Allergic rhinitis, bronchial asthma.
Vanadium pentoxide	Tracheobronchitis, bronchial asthma, CNSLD.
Milled or crushed grain and bran	Allergic rhinitis, chronic rhinitis, bronchial asthma CNSLD.
Wood (exotic types)	Allergic rhinitis, bronchial asthma, carcinoma of the nose and nasal cavity, CNSLD.
Animal hides, skin, hair, leather and scales .	Allergic rhinitis, bronchial asthma.
Mould hay, straw, cereal,. and bagasse	Farmer's lung, bagassosis.
Enzymes	Allergic rhinitis, bronchial asthma
Cotton, flax, hemp sisal, jute.	Byssionosis, CNSLD.
Arsenic, arsenic trioxide, arsenic salts.	Ulceration and perforation of nasal septum, tracheobronchitis, carcinoma of nasal cavity.

(CNSLD : Chronic non-specific lung disease)



Effect of Silica Dust

Biological effects have been well established and have recognised specific illness due to specific dust, e.g. silicosis due to silica, siderosis due to iron, byssionosis due to cotton dust etc. Where there is no specific clinical picture, the case is referred as CNSLD i.e. chronic non-specific lung disease. The types of effects are fibrogenic, carcinogenic, systemic, toxic, allergic, irritant and skin effects.

For silicosis, Siderosis and Anthracosis see Part 9 of Chapter 20 and for Byssionosis see Part 10.1 of Chapter 21.

A new occupational lung disease due to inhalation of nano-particles in the manufacture of poly-acrylate and other polymers is detected, said by Dr. Aruna Dewan of NIOH, Ahmedabad. It is much faster than silicosis.

(B) Dust Control Methods :

To prevent lung diseases, some control measures are as under -

1. Know the **exposure limits** of dusts. Dust below 5 microns size is invisible. Depending on toxicity, exposure limits vary from 0.1 to 10 mg/m^3. See also 2nd Schedule under the Factories Act (Table 15 of Chapter-32). Employ effective measures based on this safe limit and nature of the dust.

2. **Elimination** of dusty process e.g. improved casting technique to eliminate dusty fettling process.

3. **Substitution** by a less toxic or non-toxic dust, e.g. shot-blasting in place of sand blasting, metal moulds in place of sand moulds and glass fibre or slag wool in place of asbestos insulation.

4. **Segregation and enclosure** of the process if dust generation cannot be prevented. Dusty process should be enclosed in a room and be connected with effective exhaust and dust collector. Complete enclosure is the best segregation. e.g. blasting cabinet, fuming cupboard.

5. **Wet methods** prevent particles becoming airborne. Powdered material is suspended or dissolved in a liquid. The correct degree of wetting should be maintained and it should not be allowed to dry out.

6. **Local exhaust ventilation** should be applied to collect the dust from the nearest possible distance. The smaller enclosure gap requires smaller exhaust rate. Suction flow should be away from the worker's breathing zone. Dust collection, filtration and disposal are the subsequent steps. Various kinds of air cleaning devices are also available.

(2) Occupational Dermatitis :

An inflammation of the skin produces dermatitis which is the most common skin disease. The part of body most exposed is affected first, so it starts on hands. With some dusts and fumes, the first signs may appear around the eyes, neck and face also. The disease can be caused by many chemicals and apparently harmless substances including all forms of mineral oils (including diesel, lubricating and fuel oil); chemicals (alkalis, chromate, dichromate and synthetic resin), solvents (thinners and degreasers such as white spirit, paraffin, trichloroethylene, turpentine, and petroleum product); tar pitch and other coal products including chemicals in the phenol and cresol family; soot; radiation including X-rays and radiant heat; friction particularly when dust or grit gets between clothing and skin.

Contect dermatitis

Chromate and dichromate used in chromium plating, dyeing and tanning produces chrome ulcers or holes as well as dermatitis. In one chemical factory at Vadodara (Gujarat), 43 workers with holes in nasal diaphragm, 3 workers with chrome ulcer and 23 workers with dermatitis were detected. They were working with sodium and potassium dichromate. The liquid or dust from the process gets into cracks or cuts in skin and forms deep holes. Chromic acid, concentrated potassium dichromate, arsenic trioxide, calcium oxide, calcium nitrate and calcium carbide are well known ulcerogenic chemicals. Chemical or thermal burns, blunt injury or infections resulting from bacteria and fungi may result in ulcerous excavations on the part affected.

Occupationally induced changes in skin colour can be caused by dyes, heavy metals, explosives, certain chlorinated hydrocarbons, tars and sunlight. The change in skin colour may be simply a chemical fixation within keratin.

Primary Skin Irritants in industry are organic and inorganic acids and alkalis, some metal salts, nickel, phenol, trichloroethylene, solvents and acne producers.

Primary Skin Sensitizers are dyes and dye intermediates, photographic developers, rubber accelerators and anti-oxidants, insecticides, oils, natural and synthetic resins, coal-tar and its derivatives, explosives, plasticizers and others.

Skin cancer is caused by long periods of contact with a variety of substances including mineral oils, paraffin, tars, arsenic and several kinds of radiation including X-rays and ultra violet light. The cancer will usually develop in direct contact with the above substances. Other parts can be affected if the substance penetrates the clothing.

Dermatitis is a skin disease caused by **primary irritants** like acids and alkalis, organic solvents, soaps, detergents, lime, cement, turpentine, synthetic coolants, abrasives, nitropaints, hardeners, dyes, peroxides, pesticides, weedicides, gum, inks, chlorinated diphenyls, disinfectants etc. and by *sensitizers* like formaldehyde, fungicides, azo dyes, chromium, nickel, mercury and cobalt salts.

Dermatitis can also be caused by physical agents (e.g. heat, cold, moisture, radiation, friction, pressure etc.) or biological agents (e.g. bacteria, fungus, virus etc.)

Occupations involved are leather, metal, paint, printing, plastic, rubber, textile, electroplating, engineering, construction, cleaners, chemical, bakers etc.

Signs and symptoms are eczematous lesions.

For diagnosis it is useful to know the occupational history and to observe many workers, in identical situations, who develop cutaneous changes. Patch tests are indicative.

Occupational dermatitis is preventable if timely diagnosed and controlled. Preventive measures are :

1. Engineering measures to control the harmful agents by various methods.
2. Pre-employment or pre-placement medical examination and sorting out the workers having suspected dermatitis or pre-disposition to skin diseases and keeping them away from the jobs having skin hazards.
3. Use of necessary PPE and barrier creams.
4. Personal hygiene. Adequate washing and bathing facility with warm water, soap, nail cutter and clean towels.
5. Periodical medical examinations of workers and transferring the job of the affected workers.

(3) Occupational Cancer :

Occupational cancer is a form of delayed toxicity, serious in clinical course and outcome, due to exposure to chemical or physical agents (carcinogens) in the workplace.

Following figures of ESIC indicate incidence of cancer in our workers :

Year	Total insured workers (lakh)	Workers having cancer	Cancer workers per 10000 workers
1983-84	63.00	1890	3
1984-85	61.61	1848	3
1985-86	61.52	1235	2
1987-88	61.09	2414	4
1988-89	59.97	599	1
1992-93	66.91	14720	22
1993-94	66.24	6630	10

In Gujarat, in 1993-94, new 36 workers were detected for this disease. Most of these cancers may be occupational.

Carcinogenic substance means a substance or preparation which by inhalation, ingestion or cutaneous penetration can induce cancer or increase its frequency. It causes an increased incidence of benign and/or malignant neoplasm, or a substantial decrease in the latency period between exposure and onset of neoplasm in human or in experimental species as a result of any exposure which induce tumours at a site other than the site of administration.

It is unknown that how many chemicals are actually carcinogenic to humans and how many human cancers could be prevented by improving working conditions. There may be mixed reasons - occupational and non- occupational also.

The ACGIH has classified carcinogens in five categories :

A1 - Confirmed Human Carcinogen

A2 - Suspected Human Carcinogen

A3 - Animal Carcinogen

A4 - Not classified as a Human Carcinogen

A5 - Not suspected as a Human Carcinogen

Some such carcinogens are listed below with their TLVs (TWA) and above category.

Carcinogens, TLVs and Category

Substance	TLV (TWA)		Category
	PPM	mg/m^3	
Acrylamide	-	0.03	A3 skin
Acrylonitrile	2		skin
Allyl chloride	1		A3
Aniline	2		A3 skin
Antimony trioxide	-	-	A2
Arsenic as As	-	0.01	A1
Asbestos, all forms fibre/cc	0.1	-	A1
Benz(a) anthracene	-	-	A2
Benzene	0.5	-	A1 skin
Benzidine	-	-	A1 skin
Benzo(a) pyrene	-	-	A2
Beryllium as Be	-	0.002	A1
1.3 Butadiene	2	-	A2
Cadmium	-	0.01	A2
Carbon tetrachloride	5	-	A2 skin
Chloroform	10	-	A3
Bis Chloromethyl ether	0.001	0.0047	A1
Chloromethyl methyl ether	-	-	A2
Coal tar as benzene soluble	-	0.2	A1
DDT	-	1	A3
Diazomethane	0.2	-	A2
Ethyl acrylate	5	-	A4
Lead chromate			
- as Pb	-	0.05	A2
- as Cr	-	0.012	A2
β-Nephthylamine	-	-	A1
Nickel-soluble inorganic compounds	-	0.1	A4
o or p- Toluidine	2	-	A3 skin
1,2,3 - Trichloropropane	10	-	A3 skin
Uranium compounds as U	-	0.2	A1
Vinyl bromide	0.5	-	A2
Vinyl chloride	1	-	A1
Zinc Chromates as Cr	-	0.01	A1

Courtesy : 2007 TLVs and BEIs, ACGIH.

Some tables are also given below to understand occupation or substance and body part (site) being affected by cancer.

Occupation, Substance and Site of Cancer:

Occupation	Substance (carcinogen)	Site (body part)
Asbestos & products	Asbestos	Lung, pleura
Metal and Mining	Arsenic, Chromium, Uranium, Benzo(a)pyrene (BAP), Nickel	Lung, skin Lung, Lung Lung Lung, nasal sinuses
Chemical industry	Vinyl chloride BCME, CMME Dyes-benzidine, 2-naphthylamine, 4-aminodiphenyl Auramine, other aromatic amines Isopropyl alcohol	Liver Lung Bladder Bladder Paranasal sinuses
Petroleum industry	Polycyclic hydrocarbons	Scrotum
Insecticide, pesticide	Arsenic	Lung
Gas industry	benzo(a)pyrene (BAP) Coal carbonisation products, β-naphthylamine	Lung Lung, Bladder Scrotum

Gas industry	benzo(a)pyrene (BAP) Coal carbonisation products, β-naphthylamine	Lung Lung, Bladder Scrotum
Rubber industry	Benzene Aromatic amines	Lymphatic and Leukaemia Bladder
Leather industry	Leather dust, benzene	Nose, bone marrow
Wood pulp and paper industry	Wood dust	Nose (adenocarcinoma)
Roofing, asphalt work, steel prod.	BAP	Lung
Others - Diethylstil	Diethylstilboestrol Melphalan Mustard gas Soots, tars and mineral oils Conjugated oestrogen Cyclophosphamide	Female genital tract, breast Haematolymphopoietic system Lung, pharynx Skin, lung, bladder, GIT Uterus Bladder

Body part and Substance having risk of Cancer :

Body part	Substance (carcinogen)
Bone	Beryllium (benzene-bonemarrow)
Brain	Vinyl chloride
Gastrointestinal tract (GIT)	Asbestos
Haematolymphopoietic tissue (leukaemia)	Benzene, styrene, butadiene and other synthetic rubber, alkilating agent, cyclophosmamide, melphaln, busulphan, vinyl chloride
Kidney	Lead, coke oven gas, finasetin
Liver	Alcohol, vinyl chloride, stiroids, eflatoxin, DDT, PCB, trichlor ethylene, chloroform, aldrin, dieldrin heptachlor, chlordecon, mirex, CCl_4
Liver	Alcohol, vinyl chloride, stiroids, eflatoxin, DDT, PCB, trichlor ethylene, chloroform, aldrin, dieldrin heptachlor, chlordecon, mirex, CCl_4
Larynx	Tobacco smoking, alcohol, asbestos, chromium, mustard gas
Lung	Tobacco smoking, arsenic, asbestos, iron, chromium, nickel, vinyl chloride, cadmium, uranium, bis-chloromethyl ether (BCME), chloromethyl methyl ether (CMME), benzo(a)pyrene (BAP), coke oven gas, mustard gas, tar, polyclinic hydrocarbons (PCH)
Lymphatic tissue	Arsentic, benzene
Mouth	Alcohol, *pan*, lime, tobacco, *gutkha*, textile fibre
Nose	Chromium, nickel, wood dust, leather dust, tanning, formaldehyde, IPA, benzene
Pancreas	Benzidine, PBC
Peritoneum	Asbestos
Pharynx	Tobacco smoking, alcohol, mustard gas, textile fibres
Plural cavity	Asbestos
Prostate	Cadmium
Scrotum	Soots, tar, β-naphthylamine, chloroprin, polyclinic hydrocarbons (PCH)
Skin	Arsenic, cutting oil, mineral oil, soots, tar, cock oven gas, PCH
Bladder	Tobacco smoking, α or β-naphthylamine, benzene, benzidine, 4-aminodiphenyl, alkilating agent, chlorophosmamide, auramine, 4-nitrodiphenyl, aromatic amines
Vagina	Oestrogen
Female genital tract, breast	Diethylstilboestrol
Central nervous system (CNS)	Vinyl chloride
Uterus	Conjugated oestrogen
Buccal cavity	Oil mist, solvents, dyes, cadmium, lead
Multiple myeloma	Solvents

Diagnostic methods for assessing cancer should consider detailed occupational history to know whether in past the worker was exposed to any carcinogen. If worker does not know it, factory records should be gone through or interrogated with his supervisors. A questionnaire may be useful in collecting such past information. Screening may be useful to some extent.

Preventive measures are -

1. Not to use carcinogenic substances or processes.
2. Research to find safe substitutes should be developed.
3. To eliminate contact of workers from carcinogenic substances by
   (1) Employing closed system of work (i.e. no manual handling or direct exposure).
   (2) Work environment monitoring, biological monitoring and keeping the exposure far below the permissible limits.
   (3) Using personal protective equipment.
   (4) Following safe waste disposal methods.
4. Avoiding personally susceptible workers at the time of recruitment.
5. Rotating workers exposed to risks and thus reducing their exposure time.
6. Advising to stop smoking and to improve personal hygiene.
7. Referring serious cases to a cancer hospital or onco-surgeon.

4.2.2 Notifiable Diseases under the Factories Act 1948 :

Following four sections of the Factories Act are relevant :

Section	Provision
89	Notice of certain diseases.
90	Power to direct inquiry into cases of accident or disease.
91	Power to take samples.
91A	Safety and Occupational health surveys.

Under Sections 89 and 90 above, the Third Schedule gives a list of Notifiable (occupational) Diseases as under :

1. Lead poisoning including poisoning by any preparation or compound of lead or their sequelae.
2. Lead tetra-ethyl poisoning.
3. Phosphorus poisoning or its sequelae.
4. Mercury poisoning or its sequelae.
5. Manganese poisoning or its sequelae.
6. Arsenic poisoning or its sequelae.
7. Poisoning by nitrous fumes.
8. Carbon disulphide poisoning.
9. Benzene poisoning, including poisoning by any of its homologues, their nitro or amino derivatives or its sequelae.
10. Chrome ulceration or its sequelae.
11. Anthrax.
12. Silicosis.
13. Poisoning by halogens or halogen derivatives of the hydrocarbons of the aliphatic series.
14. Pathological manifestation due to -
    (a) Radium or other radio-active substances and
    (b) X-rays.
15. Primary epitheliomatus cancer of the skin.
16. Toxic anaemia.
17. Toxic jaundice due to poisonous substances.
18. Oil acne or dermatitis due to mineral oils and compounds containing mineral oil base.
19. Byssionosis.
20. Asbestosis.
21. Occupational or contact dermatitis caused by direct contact with chemicals and paints. These are of two types, that is, primary irritants and allergic sensitizers.
22. Noise induced hearing loss (exposure to high noise levels)
23. Beryllium poisoning.
24. Carbon monoxide (poisoning).
25. Coal miners pneumoconiosis.
26. Phosgene poisoning.
27. Occupational cancer.
28. Isocyanates poisoning.
29. Toxic nephritis.

Rule 104 of the GFR, Rule 116 of the MFR and Rule 97 of the TNFR require that notice of poisoning or disease should be sent forthwith to the Chief Inspector, Certifying Surgeon, Medical Inspector of Factories and Administrative Medical Officer of ESIC. It should be in Form No. 22 (GFR).

4.2.3 Occupational Diseases under the W.C. Act and the ESI Act :

Sch. III u/s 3 of the Workman Compensation Act and u/s 52A of the Employees State Insurance Act gives a list of occupational diseases for which legal compensation is available. For detail this Schedule should be referred.

4.2.4 ILO List of Occupational Diseases:

ILO recommendation No. 194 of 2002 gives a list of occupational diseases as under:

(1) Diseases caused by chemical agents or their toxic compounds: - beryllium, cadmium, phosphorus, chromium, manganese, arsenic, mercury, lead, fluorine, carbon disulphide, halogen derivatives of aliphatic or aromatic hydrocarbons, benzene, nitro and amino derivatives of benzene, nitroglycerine, alcohols, glycols or ketones, asphyxiants, acrylonitrile, oxides of nitrogen, vanadium, antimony, hexane, mineral acids, pharmaceutical agents, thallium, osmium, selenium, copper, tin, zinc, ozone, phosgene, irritants like benzoquinone.

(2) Diseases caused by physical agents:- Noise, vibration, compressed air, ionizing radiations, heat radiations, ultra violet radiation, extreme temperatures (sunstroke, frostbite).

(3) Diseases caused by biological agents:-

(4) Diseases caused by target organ systems:- Respiratory diseases, Pneumoconioses, bronchopulmonary dieseases, occupational asthma, Extrinsic allergic alveolitis, siderosis, chronic obstructive pulmonary diseases, lung diseases by aluminium, skin diseases, occupational vitiligo, musculo-skeletal disorders,

(5) Occupational Cancer caused by: Asbestos, Benzidine and its salts, Bis chloromomethyl ether, Chromium and its compound, coal tars, beta napththylamine, vinyl chloride, Benzene or its homologues and its nitro & amino derrivatives, ionizing radiation, tar, pitch, bitumen, mineral oil, anthrancene, etc. coke oven emissions, nickel compounds, wood dust.

(6) Miners' nystagmus.

4.3 Occupations involving Risk of Occupational Diseases and their Diagnostic Methods:

Following table gives a short synopsis of some occupational diseases, occupations involved and signs, symptoms and diagnosis.

Occupational Diseases, Symptoms and Diagnosis				
	Disease caused by	Occupations involved	Signs & Symptoms	Diagnosis/Indicator (see BEI if available)
	Metals :			
1	Lead	Alloys, ammunition, lead batteries, lead lining, rubber, inks, lead burning, paints, ceramics, insecticides	Weakness, insomnia, motor weakness, muscle tenderness, impaired fertility, abdominal pain, lead line on gingival tissues	History, Pb in - urine >65 μg/l blood >30 μg/100 ml. Zinc protoporphyrin level > 3 μg/gm Hb
2	Phosphorous	Insecticides, fireworks, matchworks, explosives, detergents, chemicals	Irritation of respiratory tract, toothache, swelling of jaw, facial disorder	History, teeth X-ray, pulmonary oedema in case of PCl_5
3	Mercury	Acetaldehyde, acetylene, acetic acid, chlorine, thermometers, mercury vapour tubes, lamps (CFL), x-ray tubes, antifouling paint	Gingivitis, bitter taste in mouth, bluish line on gums, gastritis, bronchitis, nervous system effect	History, test for presence of tremors at rest or with movement In urine > 50 μg/*l* In blood > 3 μg/*l*
4	Manganese	Anti-knock agent in petrol, ceramics, electrode coating, glass, ink, mining, paints, pesticides, steel, alloy, tanning of leather	Chills, fever, headache, weakness, voice sinks, speech irregular, inability to run, cannot walk backwards	History, Mn in urine > 21 μg/*l* Faeces > 60 μg/Kg Hair > 4 μg/Kg
5	Arsenic	Insecticides, fungicides, glass, metallurgy, pigment, rodent poison	Conjunctivitis, visual and nasal disturbances, cancer of skin, lung, larynx, gangrene of fingers	As in Urine > 1 mg/*l* Hair & nails may be useful
6	Chromium	Chromium plating, salts, leather tanning, photochemical processing, refractory bricks	Ulcers of nasal septum and fingers, irritation and conjunction pharynx and larynx, headache, jaundice, impaired liver function, lung cancer	Increased Cr in urine. Electrocardiogram, sputumgram stain and culture, white blood cell count and arterial blood gas analysis
7	Beryllium	Alloys (as hardening agent) Nuclear reactors (as moderator), ceramics, fluorescent powders, lamps and tubes	Swollen mucous membranes, bleeding points, fissures and ulceration, weakness, weight loss, joint pain, breath shortness, skin injuries	History, clinical tests, Be in lung tissue > 0.05 μg/100 gm is a strong indicator
8	Cadmium	Alloys, cadmium-nickel batteries, electroplating, engraving, soldering, paints for ceramics, glass, leather, plastics, rubber, inks, enamel	Chest tightness, nose irritation, cough, difficulty in breathing, vomiting, lung & kidney damage, dermatitis, anaemia, yellow teeth, metal fume fever, cancer and death	History Cd in blood > 5 μg/*l* indicates exposure
	Dusts :	Diseases of respiratory tract, caused by mineral dusts (silica, coal dust and asbestos) are called *pneumoconiosis*. They are silicosis and asbestosis. Fibres of sugar-cane cause *bagassosis* and those of cotton and textile cause *Byssionosis*.		
9	Silicosis	Sandblasting, cutting of quartzite, agate, gneiss, granite and slate. Manufacture of glass, porcelain, pottery, mines, quarries, foundry and furnaces	Dyspnoea on exertion, cough, wheezing, chest illness, pulmonary TB or infection, respiratory difficulty and death	Periodic radiological examination, egg-shell type calcification of lymph glands in 2-4% cases. Good chest X-ray with history. Should not be wrongly diagnosed as TB

10	Asbestosis	Asbestos mining and lining, insulation, safety garments, cement, fire blankets	Chest pain, breathlessness, pleurisy, fever, leucocyfosis, cyanosis, finger	History, chest radiograph, reduction in lung volume and forced vital capacity (FVC)
11	Bagassosis	Plywood, cardboard, pressboards, paper, poultry feed, fertiliser, fuel, refractory bricks. Moist bagasse in sugar industry is not harmful. Dry bagasse is harmful	Breathing problem, cough, fever, chest pain, weakness, weight loss, sputum with cough or blood	History, gradual recovery after separating patient from contact of bagasse
12	Byssionosis	Cotton ginning, pressing, blowroom, carding, flax and soft hemp, linen	Chest tightness, respiratory irritation, breath shortness, sever intolerance	History, fall in ventilatory capacity, measurement of FEV_{10} or airway resistance
13	Extrinsic allergic alveolitis	Organic dust in animal and vegetable matter processing	Dry cough, breathlessness, fever, muscular pain, sound in chest, asthma	History, sensitisation by antibodies, disturbances in lung function or positive inhalation provocation test
	Gases, fumes, vapours etc. :			
14	Nitrous fumes	Nitration, use of nitric acid, neutralisation, bleaching of rayon	Lung irritation, pulmonary oedema, vomiting, drowsiness, dizziness	History, chest X-ray for basal scars, blood test for methaemoglobin, lung function affected
15	Phosgene	Dyestuff, coal tar, urea isocyanates, acid chlorides, metallurgy, pharmaceuticals	Eye irritation, throat dryness or burning, vomiting, chest pain, cyanosis, skin or eye burns by splashes	History, electrocardiogram, sputumgram stain and culture
16	Carbon monoxide	Mines, tunnel work, boilers, blast furnaces, garages, industrial gases, metallurgy (as reducing agent), organic synthesis, metal carbonyls	Headache, tachypnoea, nausea, weakness, dizziness, cyanosis, syncope, hallucinations, mental damage. 50 ppm for 90 min cause aggravation of angina pectoris	History, cherry pink colour of blood, depression of ST segment of electrocardiogram, level of carboxyhaemoglobin > 40% collapse >25% headache, nausea
17	Iodine	Photographic film, iodine spray in salt	Irritation to eyes, nose and skin, lacrimation, blepharitis, rhinitis, stomatitis, chronic pharyngitis, headache and chest tightness	Electrocardiogram, sputumgram stain and culture, differential WBC count, arterial blood gas analysis
18	Fluorine	Electroplating, metal pickling, etching of glassware, artificial cryolite, insecticides, uranium compounds, aircraft piston engines, use as HF acid	Laryngeal spasm, bronco spasm, pulmonary oedema, mild dyspepsia, exposure to mice showed liver and kidney damage	Fever, myalgias, lymphocytosis, radiographs of tibia and fibula show bony spicules, fluoride in urine and mother's milk
19	Chlorine	Chlor-alkali plant, use of Cl_2 gas, chlorination, bleaching process, metal fluxing, water cleaning, synthesis	Irritation of eyes , nose and skin, cough, substernal pain, nausea, vomiting with blood, headache, cellular damage, fall of BP, cardiac arrest	Electrocardiogram, sputumgram stain and culture, differential WBC count and arterial blood gas analysis

20	Bromine	Manufacture or use of bromine, anti-knock compound for gasoline, bleaching agent, dyestuff, gold extraction, fuel additives, military gas	Irritation of eyes, nose, lungs and skin, inflammation of eye-lids, cough, vertigo, headache, nausea, diarrhoea, stomach pain, tongue & palate inflamed, chemical burns of lungs	Electrocardiogram, sputumgram stain and culture, differential WBC count and arterial blood gas analysis
21	Benzene	Chemical synthesis, use as solvent, reagent, fuel, detergents, pesticides, paint remover, shoe-making, producing other organic chemicals	Narcotic action, CNC depression, irritation to skin and nose, euphoria, nausea, vertigo, damage to bonemarrow, blood-forming tissues, leukaemia	Phenol in urine (50 mg/g creatinine). For CNS symptoms, neurologic examination. Complete blood count necessary
22	Hydrogen sulphide	Disinfectant, thiophene, inorganic sulphides, sulphuric acid, present in sewers, oil wells and petroleum products, natural decay of organic matter	Exposure of 500 ppm causes inflammation of nose, pharynx, bronchi & lungs, eye injury. 10 ppm for many days cause headache, weight loss, CNS disorders	History Periodical medical examination
23	Acrylonitrile	Acrylic fibres, pesticide fumigant, organic synthesis	Eye irritation, sneezing, headache, vomiting, weakness, skin contact can cause blister and dermatitis, inhalation may cause death	History Measurement of blood pH, plasma bicarbonate and blood lactic acid
	Chemical Compounds :			
24	Organo phosphorous compounds	Pesticides - parathion, malathion etc.	Fast absorption through inhalation, ingestion and skin contact, convulsions, vomiting, blurred vision, coma, BP increases and drops before death, oedema of lungs, loss of appetite, cyclical movement of eye-ball (nystagmus)	History 60% or more decrease in blood cholinesterase activity. Serum cholinesterase depressed in serious cases. Changes in blood picture (leukocyte count & formula) with a shift to the left. Increased secretion of saliva, tears and mucus
25	Carbon disulphide	Solvent used for alkalis, cellulose, fats, oils, resins and waxes. Viscose rayon, pesticides, oil extraction	Neurotoxic poison. Nausea, vomiting, headache, excitation of nervous system, vision and sensory changes, chronic fatigue. Sexual, menstrual disorder & abortions in women	TTCA in urine 5 mg/g creatinine (at the end of shift), blood and urine test, iodineazide test of urine, medical examinations
26	Halogen derivatives of aliphatic hydrocarbons viz. chloroform, chloromethane, vinyl chloride, CCl_4 etc.	Solvents, refrigerants, anaesthetics, fumigants, plastic intermediates, gauge fluids	Lung irritants, eye and skin injury, vinyl chloride is carcinogen, effects on nervous system, headache, nausea, convulsions, paralysis, affected speech, effect on kidneys and liver	History, for CNS depression blood glucose, rectal temperature to be noted and neurological examination. Liver function test if liver is suspected
27	Isocyanates	Polyurethane, PUF, paints, pesticides, varnishes	Irritation of skin, eye and mucous membranes, respiratory system, asthmatic effect, rhinitis	History, workers with respiratory antecedents are more affected

28	Nitro/Amido toxic derivatives of benzene or its homologues	Antioxidants, dyes, explosives, insecticides, pigments, plastics, resins, rubber, solvents, textiles, pharmaceuticals, fuel additives, elastomers	Cyanosis, anaemia, fatigue, nausea, chest pain, numbness, difficulty in breathing. Dermatitis due to DNCB. Liver damage due to 2-4 dinitro toluene. Some are carcinogens	Urine & blood analysis. Haemoglobin should not be below 13 g/100 ml. Methamoglobin above 10% indicates high exposure
29	Dinitro phenol, its homologue or salts	Dyes, explosives, wood preservative and chemical production	Dermatitis. If ingested results in cataracts. Inhalation may damage liver, kidneys and induce fever. Skin contact makes the skin yellowish	History, skin pigmentation, presence of dinitro or aminonitro phenol in urine (Derrien's Test)
30	Hydrofluoric acid	Fluorides, fluorocarbons, metal refining, pottery, etching glass	Irritation of eye, throat and nose. Skin burns. Oedema of lungs after 12 to 24 hours	History. Differential WBC count, electrocardiogram, sputumgram stain and culture
31	Fluoro-acetic acid, Sodium fluoroacetate & compounds	Chemical weapons, insecticides, pesticides, rat poison	Nausea, vomiting, stomach pain, low BP, convulsions after 6 hrs, effect on CNS and CVS	History, organically bound fluorine in body and increase of citrate in kidneys
32	Nitro-glycerine or nitroacid esters (e.g. nitro-cellulose)	Cardiovascular drugs, explosives	Headache, dullness, reduced BP, nausea, vomiting, weight loss, cyanosis, CNS disorders, hallucinations, heart problems, skin effect, ulcer under nails	History, Electrocardiogram if chest pain is reported
33	Methanol	Antifreeze mixtures, dewaxing preparations, dyes, formaldehyde, inks, paints, plastics, textile soaps, unshutterable glass, water proofing, as solvent	Enter through skin (may cause death), mouth and nose. If swallowed, can cause blindness, headache, vomiting, diled pupils, constant movement of eyeball (nystagmus), skin injury	History Disturbance in vision In urine - methanol > 10 μg/ml formic acid - present
34	Acetone	Use as solvent. Production of acetic anhydride, chloroform, iodoform, vitamin C. Used in celluloid, dying, explosives, leather, lubrication, rubber, silk, varnish	Irritation to skin and mucous membrane. Difficulty in breathing. Damage to kidney and liver. Headache, blood changes, skin dryness & redness	History, albumin, RBC & WBC in urine indicate damage to kidneys. High levels of urobilin and bilirubin indicate damage to liver
35	Ketones	Use as solvent. Production of artificial silk, cosmetics, perfumes, plastics, explosives and pharmaceuticals	Narcotic if inhaled. Irritation to eyes, skin and respiratory system, CNS affected	Medical examination of nerve, conduction velocity, CNS, eyes, kidneys, liver and respiratory system
	Radiation :			
36	Radioactive substances and ionising radiation (X, A, B, G rays)	Radiography, gas chromatography, nuclear reactors, uranium mining, aerosol fire detectors, radioactive tracers, radium dial painting, X-ray clinics	Exposure above 1 Gray results in nausea, vomiting, diarrhoea, intestinal symptoms, ulceration in mouth and throat, hair loss. Late effects leukaemia and cancer	Drop in lymphocyte count followed by slower and biphasic fall in granulocyte and platelet counts. Possible fall in RBC count. In intestine, ulceration of mucous membrane possible
37	Cataract by IR radiation	Arc processes, hot furnaces, lasers, molten glass, molten metal	Eye lens or capsule become opaque	History. Regular eye examination

	Noise & Vibration :			
38	Hearing loss	High noise levels in loom shed, POY spinning dept, compressor room, pneumatic chipping or machining	Ringing in ear, difficulty in hearing (e.g. ticking clock), sound perceived in abnormal manner	Audiometric examination and noise level measurement in work place
39	Decompression sickness	Work in compressed air or with vibrating tools or equipment, deep sea diving	Dizziness, nausea, blood formation in ear drum, limb pain, skin effects, headache, coronary dysfunction, bone or joint pain	Regular medical examination for respiratory and cardiovascular problems. Radiographs of shoulder, hip and knee joints
	Bio-hazards :			
40	Diseases caused by biological agents (see Part 7.2.2 also)	Contact with domestic, laboratory and other animals, laboratories, hospitals, dairy, forestry, meat or bone processing, poultry, tanneries	Anthrax (see Part 9.4 also), dermatitis, inflammation, infection, jaundice, fever, upset stomach, muscular pain, headache, skin effect etc.	Redness or discoloration of skin, glandular tumour. In fungal infections swelling of fingers. Herpes virus may cause meningitis

Mode of causation may be many but the routes of entry in the body are inhalation, ingestion, skin contact and injection as explained in Part 6.6

Diagnostic Methods or tests are necessary to detect the disease. They are general as well as specific. Before selecting such test it is always useful to know the occupation of the worker, chemicals and other physical, biological agents involved in the occupation, work environment, work methods, protective wears used or not used, personal habits, family history and other possible combined causes which may be contributory to the cause of the disease, illness or poisoning. Some general or common diagnostic methods are given below and others in the table following.

Medical history and records.
Clinical examination.
Eye examination.
Biological examination of blood, urine, faeces (stools), breath, plasma, hair, nails, sweat, tissue, body organ etc.
Haematological indicators.
Spectrophotometric analysis.
Measurement of FEV 10.
Pathological tests.

Audiometry and measurement of noise level.
X-ray and radiographs.
Lung function and FVC test.
Lever function test.
Step test.
Medical Examinations:
- Pre-employment
- Pre placement
- Periodic
- Special
- Post sickness
- On request
- Retired workers

Cardiogram.
Sonography.

4.4 Evaluation of Injuries :

Evaluation of industrial injuries is required for the purpose of assessing the workmen compensation.

Injuries may be scheduled (Sch I & III, WC Act) or non-scheduled and it may result in (a) Death, (b) Permanent total disablement (c) Permanent partial disablement and (d) Temporary disablement, total or partial, as per section 4 of the WC Act.

For the Scheduled injuries, Sch. I gives percentage of loss of earning capacity for the injury type (b) and (c) mentioned above.

For non-scheduled injury, loss of earning capacity is to be assessed by a doctor as per section 4 (1) (c) (ii) of the WC Act, and while such assessment, the doctor has to give due regard to the percentages of loss of earning capacity in relation to different injuries specified in Sch. I.

Loss of earning capacity depends on loss of function which varies from part to part and its components are motion, strength and co-ordination.

In upper extremity, loss of each factor in the sholder has following estimation :

Motion	- 50%
Strength	- 30%
Co-ordination	- 40%
Disability of arm radical	- 50%
Disability of hand radical	- 30%
Disability of entire extremity	- 50%

In lower extremity, main function is weight bearing. The components of the function are motion, strength and weight bearing.

For fracture of the central body part, the assessment is as under :

1	Lumber region	- 50 to 100 %
2	Dorsal region	- 25 to 50 %
3	Cervical region	- 20 to 30 %
4	Spinous or traverse process	- 5 to 10 %
5	1 rib	- No disability
6	3 to 4 ribs	- 5 to 10 % when there are after effects
7	Sterrum	- 5 to 10 %

Another assessments are as under :

EYE :

1	Loss of vision of both eyes	- 100 %
2	Loss of vision of one eye	- 30 %
3	30% loss of vision	- 9 %
4	40% loss of vision	- 12 %
5	50% loss of vision	- 15 %

EAR :

1	Total loss of hearing	- 100 %
2	Loss of hearing of one ear	- 15 %
3	Loss of voice	- 25 to 50 %

HEAD :

1	Headaches and giddiness	- 10 to 20 %

See Part 7 for worked examples.

See Part 9 of Chapter 26 also.

4.5 Occupational Health Services & Medical Examinations:

Functions of Occupational Health Services and statutory requirements are discussed below.

4.5.1 Meaning and Functions of Occupational Health Services :

Occupational health service, is operated to achieve the statutory declared aims of occupational health by medical and technical measures. Its role is mainly preventive and to give first aid and emergency treatment. It is certainly useful in early detection of any occupational or non-occupational disease or any mal-adjustment of the man-job relationship.

Occupational health services include -

1. Medical examinations : pre-employment, periodic and others.
2. Supervision of the working environment-industrial hygiene, safety, job analysis and adaptation of the job to the worker in good working conditions.
3. Advice to management and workers.
4. Health education and training.
5. Health statistics.
6. Medical treatment-first aid, emergency and ambulatory treatment.
7. Health counselling-individual.
8. Nutrition.
9. Family planning.
10. Research in occupational health.
11. Co-operation with other services in the undertaking.
12. Collaboration with external services.

Other purposes of industrial medical services are : (1) Identifying the hazards (2) Preventing or minimising the hazards (3) Curative treatment in case of exposure and (4) Determining the compensation for damages.

The services can be broadly divided into four phases : (1) Constructive medicine (2) Preventive medicine (3) Curative medicine (4) Educative medicine.

Constructive medicine includes - (1) Pre-placement examinations (2) Periodic health examinations (3) Premature medical retirement.

Purpose of Periodic Health Examination are : (1) To anticipate and prevent diseases (2) To detect potential illness and troubles in time and (3) To assist workers in maintaining normal health curve.

Periodic Health Check-up includes:

1. Complete clinical check-up.
2. X-ray of chest.
3. Vision testing.
4. Blood routine, sugar and cholesterol.
5. Urine routine.
6. ECG for workers above 40 years.
7. Indirect laryngoscopy for workers above 40 years.
8. Spirometry for workers employed in dusty, and smoky environment.
9. Audiometry for those, working in noisy environment.

See also Form XXII u/r 37 of the Insecticides Rules, 1971 in Part 4.2 of Chapter-28.

Industrial Medical Services in broad sense should be as follows:-

Sr. No.	Facility	For No. of Workers.	Staff.
1.	First-aid box (post)	Less that 150.	Trained first aid attendant in each workshop.
2.	First aid room of @ 35 m^2	Between 150 to 500	As above plus part time or full time nurse.
3.	Medical Examination Room (Ambulance Room)	Between 500 to 1000 Trained first aid.	Trained first aid attendant for each shift plus nurse and Health Officer.

CHAPTER - 13

Fire and Explosion

THEME

1. ***Fire Phenomena***
   1.1 *Nature of Fire*
   1.2 *Need of Fire Safety*
   1.3 *Chemistry & Pyramid of Fire*
   1.4 *Stages of Fire*
   1.5 *Spread of Fire*
   1.6 *Definitions*
   1.7 *Factors Contributing to Fire*
   1.8 *Common Causes of Industrial Fire*
2. ***Classification of Fire and Extinguishers***
3. ***Statutory and other Standards***
   3.1 *Statutory Provisions*
   3.2 *Indian Standards*
   3.3 *Guidelines of Regional Tariff Advisory Committee (TAC)*
   3.4 *NFPA Code (NFC)*
4. ***Design for Fire Safety***
   4.1 *Fire Resistance of Building Materials*
   4.2 *Fire Safety of Building, Plant, Exit, Equipment etc.*
5. ***Fire Prevention and Protection Systems:***
   5.1 *General Control Measures*
   5.2 *Fire Detection and Alarm Systems*
   5.3 *Fire Load Determination*
   5.4 *Fire Suppression or Extinguishing Systems:*
      5.4.1 *Portable Fire Extinguishers*
      5.4.2 *Fixed Fire Installations: Hydrants, Sprinklers, Water spray, Foam, Carbon dioxide, DCP and other systems*
      5.4.3 *Automatic Fire Detection & Extinguishing System*
   5.5 *Control of Fire and Explosion in Flammable Substances*
   5.6 *Fighting Fires of Pesticides*
   5.7 *Electrical Fires*
   5.8 *Effects of Combustion Products*
   5.9 *Fire Emergency Action Plan & Drill*
6. ***Explosion Phenomena***
   6.1 *Explosion*
   6.2 *Types of Explosion*
      6.2.1 *Dust Explosion*
      6.2.2 *Deflagration*
      6.2.3 *Detonation*
      6.2.4 *Confined and Unconfined Vapour Cloud Explosion (VCE)*
      6.2.5 *BLEVE*
7. ***Inspection, Maintenance and Training for Fire Protection***
8. ***Worked Examples :***

1. FIRE PHENOMENA :

Fire is the oldest phenomena. People have seen fire since their existance. Controlled fire is a friend of mankind and is useful in many ways. It is an **uncontrolled fire** for which fire safety is required.

1.1 Nature of Fire :

Fire is an igneous element whose potentiality is well recognised in our Indian culture. Like प्रकाश (light), वायु (wind) and जल (water), अग्नि (fire) is our देव and we worship them to protect us. They are the supreme elements and without them the human life is not possible. वसुनां पावकश्चामि and अहमग्नि is said by Lord Krushna in *Gita* meaning thereby that he is अग्नि amongst eight *Vasus.* यज्ञ is the divine form of अग्नि and through यज्ञ we achieve everything.

The destructive nature of fire and need of protection is also explained as follows:

ऋणशेषश्चाग्निशेषः शत्रुशेषस्तथैव च।

पुनः पुनः प्रवर्धन्ते तस्मात् शेषं न शेषयेत् ।।

Remainder of debt, fire and enemy grows again and again, therefore, they should be ended, not leaving any remainder. It is explained earlier that न कूपखननं युक्तं प्रदीप्ते वह्निना गृहे i.e. it is of no use (too late) to dig well when it is already fired in the home. *Thus prevention is better than cure and it is truer in case of fire prevention.*

1.2 Need of Fire Safety :

Main object of fire safety is to protect life first and property next from the ravages of fire. Objectives of fire safety design are safety of life, protection of property and continuity of operations. Fire safety planning is required for sites as well as buildings. In industry, it is required for workers and public.

Potentiality of fire is tremendous as it holds the largest range of damaging capacity from a small burn to the disastrous damage of plants, persons and properties. Some glorying examples of fire and explosion are given in Table 13.1.

Table 13.1 Examples of Major Fire & Explosion.

Year	Plant & Place	Death	Serious Injuries
1942	Coal dust explosion, China	1572	–
1944	Ship explosion, Bombay	231	476

1947	Ship fire/explosion, Texas, USA	576	2000
1956	Truck explosion, Columbia	1100	–
1975	Mine explosion, Chasnala, India	431	–
1984	Petrol line fire, Brazil	500	–
1984	LPG fire, Mexico	500	7000
1993	Fire in a toy factory, Thailand	211	–
1994	Huge fire in oil refinery, Cairo, Egypt	132	
"	Fire in a dance hall, Beijing, China	233	16
1995	Fire in a moving train, Moscow, Russia	375	–
"	Fire due to short circuit, Sirsa, Hariyana	368	–
"	A leaking gas pipeline exploded, Taegu, South Korea	109	160
1997	Gas fire in pilgrims' tents, Mecca, Saudi Arabia	343	–
"	Fire following explosion in a refinery, Vishakhapatnam, AP	60	-
"	Fire while mopping up petrol spillage from a burst pipeline in Southern Nigeria, Egypt	500	-
1999	Gas explosion in a coal mine, Beijing, China	35	8
2000	Fire at Christmas party (discotheque) in lqoyang city in China on 26-12-2000.	309	

Courtesy : LP News.

See also Table 13.9 for Explosion events.

Similarly some examples of estimated fire loss inferred from the fire insurance claims are given in Table 13.2.

Table 13.2 Examples of fire loss

Date	Place	Loss in Crore of Rs.
5-6-82	Calico Mills, Baroda	15.01
3-6-94	Parasrampuria Synthetics	13.32
5-12-94	Tata Chemicals	10.00
18-11-95	Madras Refineries	51.60
14-12-95	Vikram Ispat	62.00
18-11-96	Fire on goods train in Tunnel, France	366 USD
14-9-97	Fire at HPCL refinery, Vizag, AP	50

Courtesy : LP News.

These roaring figures of heavy losses of men and money strengthen the permanent need of fire safety. In industry, we store and use many materials which are capable of giving or catching fire. Many processes, equipment and situations create fire hazards. All these need proper detection and measures of fire prevention and control. This is in the interest of all.

1.3 Chemistry and Pyramid of Fire :

1.3.1 Triangle of fire.

According to old concept, three elements are necessary to start fire. They are (1) Fuel (2) Oxygen and (3) Heat or Source of ignition. Fire is not possible if any one of these elements is not available. This is shown in figure 13.1.

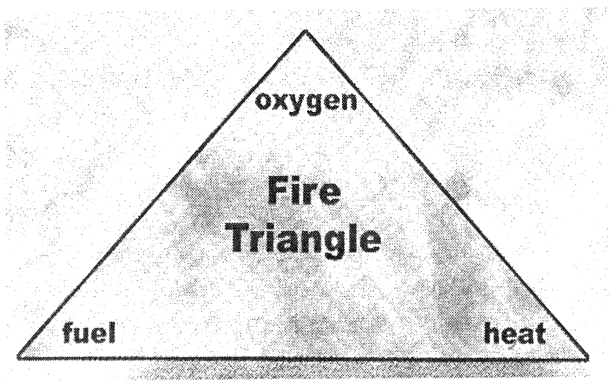


Fig 13.1 : Triangle of Fire.

1.3.2 Pyramid of Fire.

According to this concept, four elements are necessary to start fire. They are as under -

1. Fuel (combustible material and reducing agent).
2. Oxygen or oxidant or oxidiser (from the atmosphere).

3. **Heat** or source of ignition (necessary to start the fire initially, but maintained by the fire itself once it has started and
4. **Chain reaction** through free radicals to maintain the fire.

This is shown in fig. 13.2

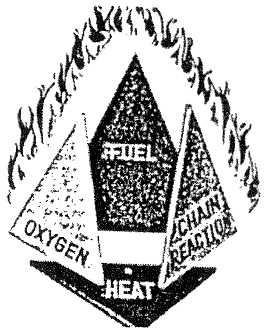


Fig. 13.2 : Pyramid of fire.

If any one of above four elements is removed, the fire goes out. Therefore **methods of fire extinguishment are dependent on:**

1. Removing or shutting off the source of fuel.
2. Excluding oxygen or decreasing it below 14 to 18% by adding inert gases.
3. Removing heat from the fire faster than its liberation and
4. Removing free radicals to discontinue chain reaction and flame propagation. Dry powder chemicals and halogenated hydrocarbons capture free radicals and put out fire in this way.

Thus fire is a rapid chemical oxidation reduction reaction. Oxygen in air acts as an oxidiser and fuel acts as a reducing agent and burning meterial. It is an oxidation of a substance (which burns ie fuel) accompanied by heat, light and flame. Due to incomplete combustion it evolves smoke and carbon monoxide which creates invisibility and toxic atmosphere for fire fighters.

An excess of air can cool the combustion gases to quench the fire, if the combustible material is small, otherwise it cannot, as in case of forest fire where the combustible material is too much to cool.

The chemical reaction is exothermic as it evolves heat and the heat released is used for the reaction to continue.

Fire is a burning or combustion phenomena and the combustion may be kinetic or diffusive depending upon homogenous or inhomogeneous air-fuel mixtures. The combustion may be complete or incomplete. The complete combustion gives product like CO_2, SO_2, water vapour etc., which cannot burn any more. The incomplete combustion (due to insufficient or blocked air) gives CO, alcohol, aldehydes etc., which can burn further more.

The amount of air required to burn 1 kg. of combustible material (or 1 m^3 of gas) is roughly given by $V = 1.12\ Q/1000$, where Q is the heat of combustion kJ/Kg. or kJ/m^3. Rate of burning also depends on the status of fuel i.e. solid, liquid or gas.

1.4 Stages of Fire :

Mostly fire develops in **four stages** as under -

1. **Incipient stage** - No visible smoke, flame or more heat developed. Invisible combustion particles are generated over a period of minutes, hours or days. Ionisation detectors respond to these particles.
2. **Smouldering stage** - Visible smoke generation. Photoelectric detectors can detect this smoke.
3. **Flame stage** - Flame starts after point of ignition. Smoke decreases and heat increases. Infrared detectors can detect this stage.
4. **Heat stage** - Heat, flame, smoke and gases are produced in large amount. Thermal detectors respond to this stage.

See Part 5.2 for such types of detectors and alarms.

1.5 Spread of Fire :

It depends on the following factors :

1. The area of the substance exposed;
2. The amount of heat generated or given off by the burning substance;
3. The ability of the substance to conduct the heat away from the zone of combustion;
4. The atmospheric humidity and the wind velocity.

Thus fire will spread more if more combustible area is available, if more heat is given by the burning material, if more heat conduction is possible and if atmospheric humidity is less and wind speed is high.

It is important to prevent or reduce the spread of fire. Following factors are useful in this regard.

1.6 Definitions :

To understand fire and explosion phenomena and their related subjects, following definitions are useful.

1. **Auto-ignition (spontaneous ignition) temperature** is the temperature at which a material will self-ignite and sustain combustion in the absence of a spark or flame.
2. **Automatic Fire Alarm System** is a fire alarm system comprising components and sub system required for detecting a fire, initiating an automatic alarm for fire and initiating other action as required.

3. **Combustibility (Flammability or Ignitability)** is the capacity of a substance to ignite and continue to burn in the presence of a heat source.

4. **Combustion or fire** is a chemical change (reaction) accompanied by the evolution of heat and light.

5. **Control Centre** is a permanently manned room preferably on ground floor within the premises at risk for the receipt of emergency calls and equipped with communications needed for transmission of calls for assistance to services, such as fire and police.

6. **Detonation** is propagation of flames following shock wave through pipes, vessels, etc., at a very high speed (supersonic) and high localised pressure.

7. **Explosion** is an extremely rapid chemical (explosive) transformation of fuel accompanied by release of energy and compression of gases capable of producing mechanical work.

8. **Extinguishing media** are agents which can put out fires. Common extinguishing agents are water, carbon dioxide, dry chemical, alcohol foam, halogenated gases (Halons) and water jel compound.

9. **Fire or combustion** is a rapid oxidation-reduction reaction which results in the production of heat and generally visible light. A substance combines with an oxidant and releases energy. Part of the energy released is used to sustain the reaction.

10. **Fire Alarm System** is a combination of components for giving an audible and visible and/or other perceptible alarm of fire. The system may also initiate other ancillary action. It includes manual call points for initiating alarm.

11. **Fire Point** is the lowest temperature at which a mixture of vapour and air continues to burn when ignited.

12. **Fire Resistance** is the ability of an element of building construction, component for structure to fulfil, for a stated period of time, the required stability, fire integrity and/or thermal insulation and/or other expected duty in a standard fire resistance test (see IS 3809).

13. **Fire Resisting Wall** is a wall capable of specifying the criteria of fire resistance with respect to collapse, penetration and excessive temperature rise.

14. **Flammability limits (Explosive range)** i.e. the values (upper and lower) expressed in percent by volume of fuel vapour in air, is the range of concentration within which a particular vapour or gas mixture with air will burn (or explode) when ignited. Below the LEL the mixture is too lean to burn and above the UEL it is too rich to burn.

15. **Flameproof Enclosure** is an enclosure for electrical machinery or apparatus that will withstand, when the covers or other access doors are properly secured, an internal explosion of the flammable gas or vapour which may enter or which may originate inside the enclosure, without suffering damage and without communicating the internal flammation (or explosion) to the external flammable gas or vapour in which it is designed to be used, through any joints or other structural openings in the enclosure. (The term 'explosion proof' is synonymous).

16. **Flash back** occurs when a trail of flammable gas, vapour or aerosol is ignited by a distant spark, flame or other source of ignition. The flame then travels back along the trail of fuel to its source resulting into fire or explosion.

17. **Flash fire** is vary rapid combustion.

18. **Flash Point** is the lowest temperature at which a liquid will give off enough flammable vapour at or near its surface, such that its mixture with air can be ignited by a spark or flame. It is of more interest in safety than the fire point.

19. **Fuel** is a substance that acts as a reducing agent, giving up electrons to an oxidiser (e.g. Oxygen in air) in a chemical combustion. It may be an element like carbon, hydrogen, magnesium etc., a single compound like CO, methane CH_4, a complex compound like wood or rubber or mixture like LPG.

20. **Ignition** of a flammable mixture takes place when it comes in contact with a source of ignition with sufficient energy or the gas reaches an auto ignition temperature and self (auto) ignites.

21. **Ignition Temperature** is the lowest temperature at which ignition occurs in a mixture of explosive gas and air when the method specified in IS 7820 is followed. (Flash point is a higher temperature at which the most explosive mixture will ignite spontaneously on account of the environmental temperature).

22. **Material Factor** of a substance is a measure of its energy potential and is a function of flammability and reactivity of the substance. The flammability depends upon the flash point or heat of combustion while the reactivity depends upon the instability of water. Higher is the Material Factor, higher is the fire and explosion

hazard potential of a particular substance. For details see NFPA-704-M-1969.

23. **Smoke Vents** are openings, fitted with manual shutters for removal of smoke from a fire.

24. **Spontaneous Ignition or Combustion** occurs as the result of the gradual development of heat generation by chemical changes. For example, baggas (grass) cubes heaped to be used as fuel, generate sometimes, spontaneous combustion without spark and resulting into fire. Similarly oil soaked rags can sometimes ignite without spark due to combining with oxygen (oxidation), evolving heat and if the heat given off reaches the apparent ignition temperature of the rags it may burst into flame and result in fire. Water spraying can avoid such phenomenon.

25. **Venting Fire** is the process of inducting heat and smoke to leave a building as quickly as possible by such paths that lateral spread of fire and heat is checked, fire fighting operations are facilitated and minimum fire damage is caused.

1.7 Factors Contributing to Fire :

They are many. Some are easily detectable while some are hidden. Easily detectable factors contributing to fire are as under :

1. Easy availability of combustible material like rubbish, solvent, paper, wood etc.
2. Easy availability of air, oxygen or any oxidizing material.
3. Sources of ignition like spark, static discharge, contact of hot surfaces, friction etc.
4. Continuous running machinery without proper lubrication and maintenance.
5. Non flame proof electrical fitting in flammable areas.
6. Habit of smoking in flammable areas.
7. No provision of fire detectors in fire prone areas.
8. No provision of fire extinguishers in fire prone areas.
9. Open handling of flammable substances.
10. No compliance of fire safety rules.

Some hidden factors contributing to fires are as under:

1. Chemical reaction going out of control.
2. Sudden stoppage of cooling media protecting flammable reaction or distillation of solvent.
3. Trapping of metal parts, nails etc. in rollers or moving machinery giving sudden spark.
4. Non availability of inert material on reaction of flammable substances.
5. Sudden lightning from the sky.

1.8 Common Causes of Industrial Fire:

One study of more than 19000 fires in industrial plants revealed the following causes of fire:

Causes of Fire	%
Electrical	19
Friction	14
Foreign substance	12
Open flames	9
Smoking & matches	8
Spontaneous ignition	8
Hot surfaces	7
Not determinable	7
Combustion sparks	6
Miscellaneous	5
Overhead materials	3
Static electricity	2
Total	100%

Another study of more than 25000 fires reported to the Factory Mutual Engineering Corporation from 1968 to 1977 gives following causes:

Causes of fire	% Share
Electrical	22
Incendiaries (deliberate fire)	10
Smoking	9
Hot surfaces	9
Friction	7
Overheated materials	7
Cutting & Welding	7
Burner flames	6
Spontaneous ignition	5
Exposure	4
Combustion sparks	3
Miscellaneous	3
Mechanical sparks	2
Molten substances	2
Static sparks	2
Chemical action	1
Lightening	1
Total	100

Above percentage indicates the frequency of fire causes. It is not indicative of their relative importance at particular plant, place or property. These are old figures and old causes. Change in causes is always possible.

These causes can be subdivided in many sub causes as under:

Sparks may be mechanical, electrical, static, due to cutting and welding etc.

Hot surfaces may be due to bearings and shafting, stoves, heaters and small appliances, petrol, kerosene, LPG, acetylene or alcohol torches, potable furnaces, blow torches, smoke pipes, chimneys, flues and stacks, stationary heating devices, gas fired appliances viz. stoves, heaters, boilers, salamanders etc.

Spontaneous ignition is due to oxidation of fuel where air is sufficient but ventilation is insufficient to carry away the heat as fast as it is generated. Exposure to high temperature and presence of moisture increases the tendency toward spontaneous ignition. Wet unslaked lime and sodium chlorate, rags or waste saturated with linseed oil or paint, sawdust, hay, grains etc., and finally divided metals promote spontaneous ignition.

Hazardous chemicals and metals like phosphorous, sodium, potassium, oxidising materials, nitro-cellulose film and pyroxylin plastics, fuels, solvents, lubricants, wood, paper, cloth and rubber products, sprays and mists, LPG and other flammable or explosive gases are known for fire hazards.

Hyperboles, pyrophoric substances, adiabatic compression, radiation, catalytic action, natural sources, lightening, cooking equipment, electrical distribution and installation, static electricity, arson, rubbish, playing with fire, hand tools, pallet material storage and explosive dust, gas, vapour or air mixture are all causes contributing to fire.

Common causes of industrial fire and remedial measures are given in Table 13.3.

Table 13.3 : Causes of Fire & Remedial Measures

	Cause	Remedial Measure
1	Electricity	Standard and safe wiring, over load protection, double insulation and earthing on portable equipment, ELCB and waterproof cord in wet environment, use of proper flameproof equipment in hazardous area and periodical inspection
2	Bad house keeping	Storing rubbish, waste , oil, grease etc. in a waste-bin with closed cover, regular cleaning and inspection, bund (dyke) to storage tanks of flammable liquids, dust collectors, safe disposal, incineration.
3	Bidi-Cigarretts	No-smoking notices, separate smoking booths, checking of match box, lighter etc. at security gates.
4	Hot surfaces	Good insulation, fencing, ducting for smokes and flue.
5	Friction	Good lubrication, proper belt tension, alignment, dust removal, inspection and maintenance.
6	Excessive Heat	Cooling, temperature controls, trained operators and supervisors.
7	Welding cutting	Special place or partition, heat resistant floor, spark control, keeping flammable substance away, hot work permit, flammability test in tank before hot work, use of proper equipment.
8	Flame and combustion	Proper design, operation and maintenance, sufficient ventilation and ignition safety, heater insulation, hood, chimney, keeping flame away, trips and interlocks.
9	Self ignition	Keeping environment cool and dry, necessary ventilation and protection, keeping ducts and passages of waste and smoke clean, separate store of highly flammable materials, not to put oil soaked rags on hot surfaces, lagging and cladding, small vessels, good house keeping.
10	Exposure	Barrier wall, sprinklers on fire path, wire glass in windows.
11	Ignition sparks	Proper equipment, closed combustion chamber, spark arrester on flammable vent and vehicle exhaust, flare, trip.
12	Mechanical sparks	Machine guarding to avoid entry of foreign particle, fencing, magnetic separator, non-sparking tools.
13	Molten hot substance	Proper equipment with handles, better operation and maintenance, non-mixing of water.
14	Static electricity (Due to belt drive, paper/plastic reeling,	Grounding, bounding, ionisation and humidification, vehicle earthing while transfer through pipeline, earthing of vessel, equipment and

	human body, fluidised bed, pneumatic conveying, dust handling, liquid mixing, flow in vessel or pipe agitation etc.	piping, flow rate reduction, avoiding flammable atmosphere, splashing and settling, using earthed probe, antistatic device, conductive shoes and flooring, copper earthing with earth resistance less than 10 ohm, additive to change liquid resistance, keeping filters away from storage tanks, extending inlet pipe up to bottom to avoid free fall of liquid, non-conductive parts and earthing of level gauges, avoiding oil drops in water, small size of non-conducting plastic containers, using N_2 instead of CO_2 as inert gas, electrostatic eliminators on paper/plastic reeling machines, use of radioactive ionisation etc.

2 CLASSIFICATION OF FIRE AND EXTINGUISHERS

Table 13.4 and 13.5 give the classes of fire (A to E) and portable fire extinguishers necessary for them.

Table 13.4 : Classes of Fire and Extinguishers

Class of fire	Description	Extinguishing Medium	IS No.
A	Fires involving ordinary combustible materials like wood, paper, textiles, fibres and vegetables etc. where the **cooling effect of water** is essential for the extinction of fires	Water type (Soda acid)	934
		Water type (gas pressure),	940
		Water type (constant air pressure),	6234
		Anti-freeze types and	
		Water buckets	
B	Fire in flammable liquids like oils, grease, solvents, petroleum products, varnishes, paints etc. where a **blanketing effect** is essential	Chem. Foam	933
		Carbon dioxide	5507 10474 2878 8149
		Dry Powder	2171 4308
		Dry Powder Mechanical foam	10658 10204
		Halon 1211	11108
		Sand buckets	
C	Fires involving gaseous substances under pressure where it is necessary to **dilute the burning gas** at a very fast rate with an inert gas or powder	Carbon dioxide	2878 8149
		Dry Powder Dry Powder	2171 4308
		Halon 1211	11108
D	Fire involving metals like magnesium, aluminium, zinc, potassium etc., where the burning metal is reactive to water and which requires **special extinguishing media or technique**	Dry powder	2171
		Special dry powder for metal fire	4861 11833
		Sand buckets	
E *	Fires involving electrical equipment where the **electrical non-conductivity** of the extinguishing media is of first importance	Carbon dioxide	2878
		Dry chemical powder	2171 4308
		Halon 1211	11108
		When electrical equipment is de-energised, same as for Classes A & B Sand buckets	

* Class E is ommitted in some literature (eg. IS:2190) Class K is suggested for fire involving cooking oils.

Note : For other IS see Part 3.2 of this Chapter.

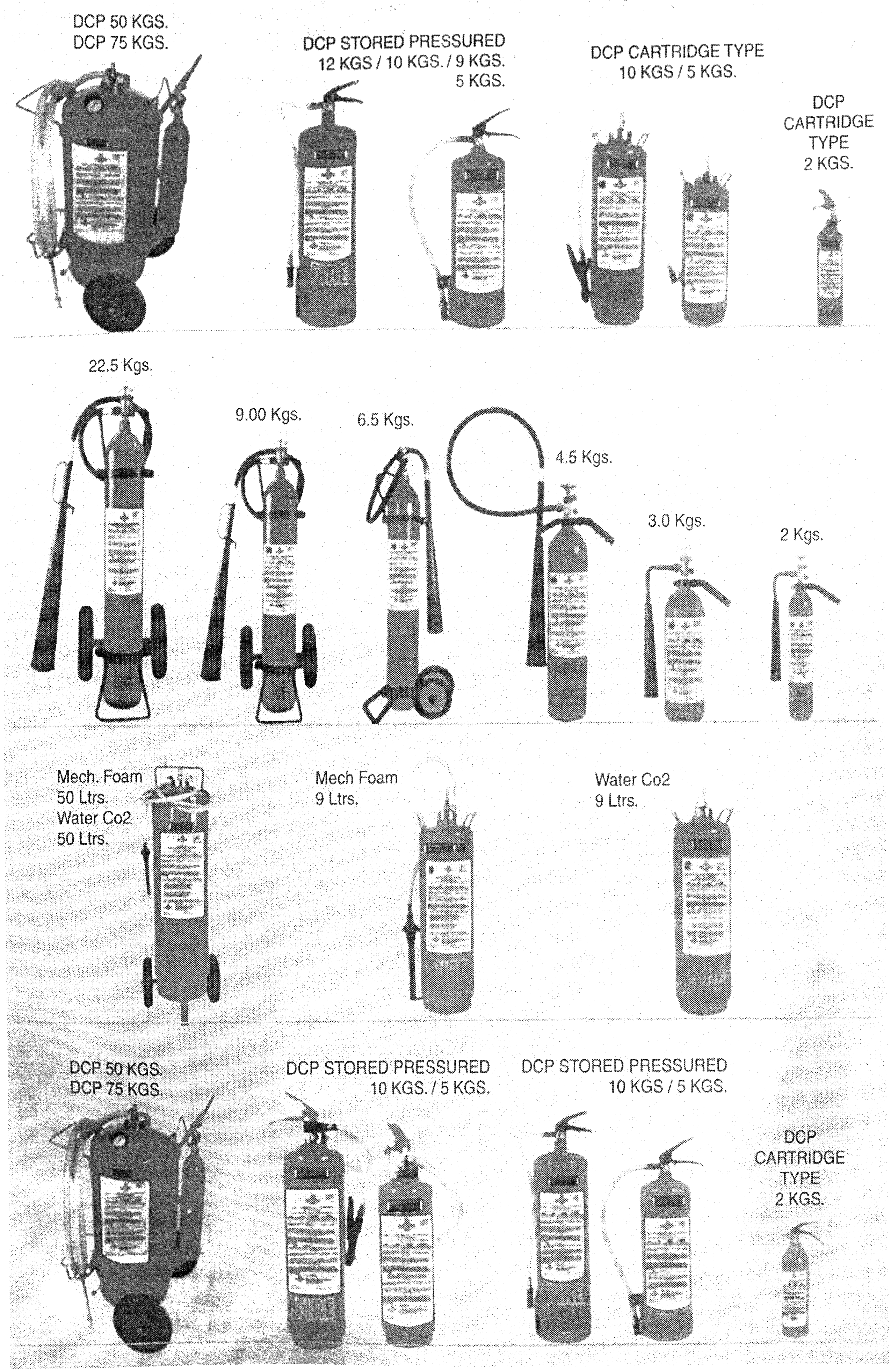


Fig. 13.3 Types of portable fire extinguishers.

Plant layout : Segregation of hazardous processes and storage, drainage and compliance of statutory standards.

Design and Construction : Relief valves, by-passes, rupture discs, explosion vents, safety interlocks, flame arresters, flameproof fittings, selection of material, fire resistant construction, underground storage.

Plant Operation : Limited storage of flammable materials, good housekeeping, good ventilation, work permit system, emergency action plan and training of employees.

Plant Maintenance : Reliability and monitoring procedures, inspection, testing and preventive maintenance, spares availability and maintenance of fail-safe safety devices.

IS:1642, 3594, 6329, 1646 and IS:2190 must always be followed for material and details of construction of buildings, storage and use of portable fire extinguishers.

See Part 3.1 for statutory detail.

5 FIRE PREVENTION AND PROTECTION SYSTEMS

A broad classification of fire safety system is explained below :

- **Fire Safety**
  (Existence of fire hazard and awakening of fire consciousness of the management)
- Fire Prevention
  - Detection by Detectors (alarms)
  - Elimination of hazard or source of ignition
  - Control over combustibles in storage, handling and process
- Fire Protection
  - Fire resistant design of buildings, equipment, means of escape and fixed installations
  - Suppression, Extinguishment or control by various extinguishers
- Fire Fighting
  - Equipment and hardware
  - Staff, training and readiness

Above steps are explained below :

Fire prevention : This is an activity directed towards elimination of possible and potential sources of fires. It mainly indicates measures to avoid inception of fires. Where the source cannot be eliminated or avoided, exercise sufficient control to ensure its safe usage. The activity also involves control over handling, storage and process of combustibles.

Fire Protection : This is an activity directed towards limiting the spread of fire to its place of origin by resorting to design , compartmentation, utilisation of fire resistive materials, provisions of safe means of escape, control by portable and fixed automatic extinguishing systems.

Fire protection being wider term includes fire prevention stated above and fire fighting mentioned below. Fire detection, prevention, extinguishment or control, all aim to *protect* plant, people and property.

Fire protection engineering is a highly developed specialised branch of engineering and a degree of B.E. (Fire) is awarded in college at Nagpur. Such qualified fire engineer and if he is not available, qualified safety officer should look after fire protection activities.

Fire Fighting : This is an activity directed towards provisions of proper fire fighting equipment, proper maintenance, personnel with proper organisation, training programme and readiness to fight fire.

Salvage : This is an activity to minimise the damage due to fire, smoke and water to the uninvolved property.

Return to normalcy : This is contingency plan where the various steps are laid down to bring back the industry to productive stage from the crippling damage due to the fire.

Some systems are as follows :

5.1 General Control Measures :

Main steps in controlling fire are :

1. To detect the fire at the earliest possible.
2. To confine the fire, and
3. To extinguish the fire at the earliest possible.

Six fundamental principles of fire prevention and reduction are :

1. Fire prevention engineering.
2. Regular periodic inspection.
3. Prevent the start of fire.
4. Early detection and extinguishment.
5. Limiting the spread and damage due to fire and fire control.
6. Prevention of personal injuries from fire or panic, including prompt and orderly evacuation of personnel.

Based on fire chemistry explained in Part 1.3, **four fundamental methods** of fire control are :

1. Eliminate the oxygen of the air.
2. Remove or shut of the fuel supply.
3. Reduce the temperature below the kindling point and
4. Break the chain reaction continuing the fire.

To achieve the most efficient fire protection system, involvement of the building designer(architect) and contractor, local authority (urban planer), interior designer, structural engineer, electrical engineer, fire detection system, manufacturer/supplier, building safety engineer and local fire marshal is necessary.

An automatic sprinkler system becomes most useful as it starts initially. Early detection of fire, speedy response, trained staff, emergency planning and preparedness and fixed extinguishing system based appropriately on fire load are the essential key points in any fire fighting arrangement.

To stop the fire occurrence, following **fire prevention activities** are desired:

1. **Fire Inspections** : Fire prone area, equipment and conditions should be inspected. Periodicity may be daily, weekly, monthly etc depending on requirement. A check list should be designed best fitting to the premises and activities. It should include checking of poor housekeeping, accumulation of dust or flammable material, readiness of fire hydrants, hoses, sprinklers, alarms, detectors, water storage, pumps/engines, charged portable fire extinguishers, foam, carbon dioxide, DCP and other protection systems, fire doors, aisles, exits, control room, electrical equipment, hot processes and machinery, and placement of fire fighting and personal protective equipment, tools etc.
2. **Hot-work permits** : Many fires have taken place while doing hot-work in flammable areas. A hot-work permit form and tag should be designed and used to check all points in advance and to take necessary precautions. Following steps are useful:
   1. Check the area where work is to be done.
   2. List steps, equipment and procedure necessary and prepare the permit.
   3. While at work, constant watch (supervision) is necessary if hazard exists.
   4. Standby workers should be ready on the spot with fire extinguishers.
   5. Isolate flammable materials (stop its flow if possible) from sources of ignition.
   6. Isolate sources of ignition by all possible ways.
   7. Stop unauthorised use of spark producing equipment nearby.
3. **Fire brigade and Drills** : A plant fire brigade of qualified and trained personnel is necessary to fight fire till outside public fire brigade arrives and helps.

   Regular scheduled training of all members of the unit should be carried out. On-site emergency plan involving other employees should be prepared and rehearsed.
4. **Fire-retardant treatments** : Such coatings can be applied on wood, plastics, paper etc. to withstand flame. Fire rating of such substances should be studied for comparison to the non-treated material. Chemical treatment to fabrics reduces their flammability. Flame retardant canvas can be used up to 250 ^{0}C. For higher temperatures, asbestos or chrome leather is preferred. Water gel compound can be used to soak a cloth-piece to make it fire-retardant. It should be noted that all such treatments are temporary and not foolproof.
5. **Communication** : After noticing a fire, fast communication is necessary, to call for fire fighting team and to alert occupants to the emergency. Well arranged bells, fire call buttons or a coded computerised fire alarm system are essential. Equally important is the training of persons to react after hearing the alarm.
6. **Protecting nearby buildings** : After noticing a fire, it is also necessary to protect the adjacent plant and building by closing windows, positioning personnel at each window nearest the fire, with fire extinguishers or fire hoses and stationing fire fighters on the roof of the exposed building with hose lines to keep the roof wetted and to put off any local fire.
7. **Assessment of Fire Risks** : For effective fire protection, it is necessary to analyse and evaluate the fire risk. Such process aims at -
   1. Recognition of hazards and potential hazards.
   2. Evaluation of hazards and expected losses.
   3. Evaluation of the proposed counter measures.

A fire risk survey should be carried out to list fire hazards. Site, building construction, plant contents, management factors, people factors, fire protection system and post fire activities are the areas to be covered. Highly flammable material and processes, smoke and toxic gas generation, people likely to be affected, fire load calculation and specific nature of industry are relevant points.

5.2 Fire Detection and Alarm Systems:

Various types of detectors are available operating on principles of thermal expansion, thermoelectric sensitivity, thermo conductivity or photosensitivity to detect presence of smoke, increase in temperature, light intensity or total radiation. Their types are : Thermal expansion detectors, Radiant energy detectors, Light-interference detectors and Ionisation detectors. They should be properly located depending upon their range. They simply give alarm and cannot extinguish fire. They make us alert for fire fighting.

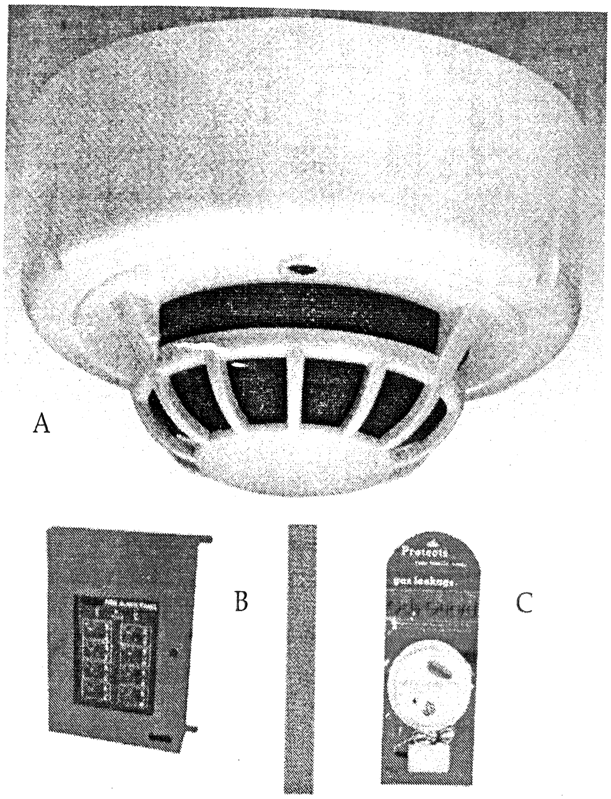


Fig. 13.4 Fire detectors (A & B) and LPG detector (C)

Though fire detection and alarm systems are separate systems but the latter has to operate just after the former operates. Therefore they are considered together. IS 2175 and 2189 also deal with them together.

Two main functions of any fire detection system are-

1. To give alarm to start up extinguishing procedure, and
2. To give early warning to area occupants to escape.

It is wrong to speak 'fire detectors'. Actually they detect sensible heat, smoke density or flame radiation to operate before actual fire follows. Their 'sensor' detects measurable quantity of these parameters. A decision making device coupled with the sensor, compares the measured quantity with a predetermined value, and when it is different, an alarm is sounded. A detector both detects and signals.

Human being is a good detector as he can act in a flexible way i.e. run away, put out the fire or call the fire department. No other detector can work in such selective manner.

Selection of the type of detector is important. For example, low risk areas need thermal detectors, a ware house may have infrared and ionisation detectors and a computer area requires ionisation or combination detectors.

Location and spacing should be determined to obtain the earliest possible warning.

Sensitivity, reliability, maintainability and stability are important factors for selection.

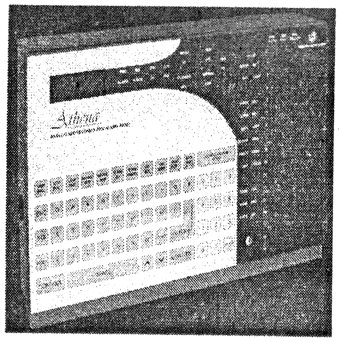
Fire process has four stages - incipient stage, smouldering stage, flame stage and heat stage. Many types of fire detectors are available for various situations and useful at different stages of a fire (see part 1.4).

Thermal detectors are of fixed temperature detectors, rate-compensated thermal detectors, rate of rise thermal detectors, line thermal detectors and the bulb detection system.

Smoke detectors are of photoelectric type and are of two classes - The beam photoelectric or reflected beam photoelectric detectors.

Flame detectors are of infrared (IR) or ultraviolet(UV) type.

Ionisation (combustion products) detectors are the single chamber or dual chamber ionisation detector and the low-voltage ionisation detector.



Fire alarm system

Fire Alarm system may be separate to run manually or connected with fire detectors and operable automatically. All workers must be made aware of the sound pattern and its meaning. Fire alarm sound should be distinguishable from other sound in that area. It should be clearly audible to all facility personnel. Sound for beginning of fire and end of fire should be kept different.

5.3 Fire Load Determination :

After fire detection and alarm system and before fire suppression or extinguishing system, it is necessary to know the **fire load** so that based on that, amount of fire extinguishing system can be designed and number of fixed and portable fire extinguishers can be calculated.

Fire load is the concentration or amount of combustible material in a building per sq. mt. of floor area. It is defined as the amount of heat released in kilo calories by the fuel per square meter area of the premises. Fire loads are useful to calculate the water requirement to quench the fire, as when water comes in contact with burning surface it absorbs heat. 1 cc of water absorbs 1 cal of heat when the temperature is raised by 1^0C. The fact should also be considered that all the fuel does not burn at a time and all the water does not absorb heat as it flows away.

Bombay Regional Committee (BRC) on fire has prescribed rules for fire load calculation. Fire loads are calculated to assess potentiality of fire hazard, need of amount of fire prevention and protection systems (e.g. water or other agent) and amount of premiums required for fire insurance. Fire load classification is as follows:

Low fire load - Less than 1 lakh B.Th.U.
Moderate fire load - Between 1 to 2 lakhs B.Th.U.
Higher fire load - More than 2 lakhs B.Th.U

See Rule 66A(11) of the Gujarat Factories Rules for area calculation by ABCD formula.

For fire load calculation see last Part 8.

5.4 Fire Suppression or Extinguishing Systems :

Mainly three methods are used in all such systems : **(1) Starvation or isolation** i.e. shutting off or preventing the flow of fuel and blanketing the fire surface with form to seal air-vapour mixture **(2) Cooling** by application of water, foam or dry chemical powder and **(3) Smothering** by applying inert gas (to reduce oxygen), steam, dry chemicals or vaporising liquids such as CO_2, freon FE 1301, methyl bromide etc.

Two types of extinguishers are used, portable and fixed.

5.4.1 Portable Fire Extinguishers :

In addition to the fixed fire installations stated in next part, portable (first-aid) fire extinguishers are always desirable for quick manual use on small fires and for the period till automatic equipment or outside fire fighters work. All such extinguishers should be (1) of reliable make, standard (IS) and properly identified (2) of right type depending upon the class of fire (3) sufficient in number (4) properly located where they are necessary and readily accessible (5) recharged periodically, inspected and maintained in good working condition and (6) known by the operators who are trained to use them.

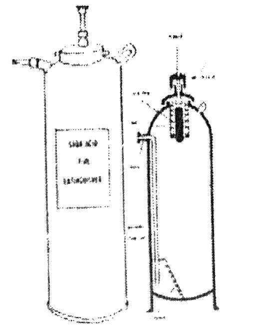
Their types are : (1) Water type (2) Soda acid type (3) Carbon dioxide type (4) Foam type (5) Dry chemical powder type and (6) Vaporising liquid type. IS:2190 is most useful for selection, installation and maintenance of portable first aid fire extinguishers. Details of these six types are also given in IS:940, 6234, 934, 2878, 933 and 2171. Tables of their suitability according to class of fire and scale i.e. their range or area coverage are also given therein. Based on them, number of extinguishers can be determined. Methods of their testing and test form are also prescribed. Refer them for further details.

See Table 13.4 and 13.5 for selection of portable extinguishers.

For small fires mostly portable fire extinguishers are used. They are explained below in brief:

(1) Soda Acid (Water Type) Extinguisher:

This extinguisher is useful for class A fire (wood, paper, fabrics, rubbish etc.). It should not be used on fires of electricity, oil, chemical or metal. It is available in both the shapes- cylindrical and conical.



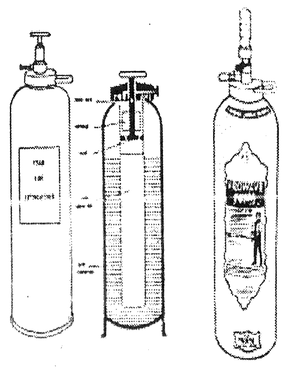
Soda Acid (Water type) extinguisher

Its normal capacity is 9 Ltr (weight 14 Kg) and to be used in a range of 6 to 8 mt. It consumes within 1 to 1.5 minute. It should be checked every 3 months.

It is held vertically up (not inverted). By standing 4 to 5 mt. away from the fire, after opening the plunger, it is struck on the hard surface. A small H_2SO_4 (Sulphuric acid) bottle breaks and due to its mixture with soda bicarbonate solution, CO_2 (Carbon dioxide) is generated. Pressure of CO_2 throws water at a distance. Its handle and bottom are held by two hands and water is sprayed on fire to extinguish it.

(2) Foam Extinguisher :

It is used on class B small fires. It should not be used on electrical or metal fire. It is available in 9 Ltr cylinder and used in 4 to 6 mt range. It consumes within 1.5 minute. It is available in wheel mounted trolley of 18 Ltr and 150 Ltr capacity for longer use. It should be checked every 3 months.

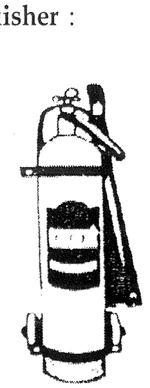


Form type extinguisher

By standing 3 to 4 mt away from the fire, the plunger is pulled up and turned right up to a slot. It is shaked by turning 180^0 twice. Then it is held inverted. By chemical reaction CO_2 is generated which throws foam outside. The foam is not thrown directly in fire but it is thrown on nearer hard surface so that because of striking further foam is generated and spread on burning surface. It stops oxygen availability for burning and controls the fire. Foam is effective up to 120 ^{0}C temperature only.

(3) CO_2 (Compressed gas) Extinguisher :

It is useful on class E i.e. electrical fire because CO_2 is non-conductive gas. It can be used on class B and C fire also, as it diminishes oxygen to control fire. It is not advisable to use it in a closed room as more CO_2 may be inhaled. Therefore open doors and windows before using it in a room. It should not be used on fires of metal, sodium, potassium and metal hydrides.

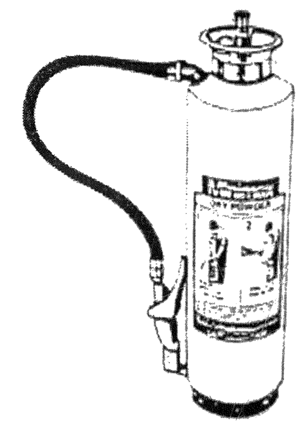


CO_2 Extinguisher

It is available in 2 kg , 4 kg, 6.8 kg and 22.5 kg capacities. Small cylinders have handles and big cylinders have wheels. Its range is 1 to 1.5 mt. CO_2 pressure is at 64 to 70 bar. It should be checked every three months.

(4) **Dry Chemical Powder (DCP) Extinguisher :**

This can be used on any class of fire. Therefore it is known as *'universal type extinguisher'*. It is generally used on fire of flammable liquid. It is not effective on fire of benzene, ether, EO and CS_2. For metal fire, special powder extinguishers are available. 1,2,5 and 10 kg extinguishers in cylinders and 68 kg in wheel models are available.



DCP extinguisher

A 10 kg cylinder is consumed within 12 to 15 seconds and its range is 3 to 6 mt. A 68 kg cylinder is consumed within 1 to 1.5 minute and its range is 6 to 8 mt. Both should be checked at 3 months interval.

By standing 6 to 8 mt near the fire, the cylinder is shacked twice by turning 180^0, a safety clip is removed and plunger is pressed or struck so that CO_2 bottle breaks and it throws dry chemicals out. The dry powder blankets the burning surface, stops O_2 contact and CO_2 coming out also diminishes O_2 proportion. Therefore fire is controlled by double action. Its long nozzle should be turned in wind direction like a broom.

(5) **Halon Gas Extinguisher (Halon Alternatives):**

Halon 1011, 1211 or 1301 a liquid gas is filled in extinguishers. It is used in place of CO_2 extinguishers but is lighter in comparison. 1.5 , 3 and 6 kg cylinders and bigger sizes are available in wheel mounted model. By pressing a knob in cap-assembly it can be started. Nose should be covered to avoid direct inhalation.

It is suitable for class B and C fires. See IS 11108 for Halon 1211.

Halon is a fast extinguishing agent. It is ideal for intense and rapid fires. It is non-conductive and leaves no traces when applied. Therefore it is also suitable for electrical fires, computer rooms etc.

Halon interrupts the chain reaction at the flame zone of fire. It is two times as effective as CO_2 on a weight basis and five times as effective as CO_2 on volume basis.

Halon is stored under pressure in a cylinder. A squeeze grip type nozzle is provided on top of the cylinder valve depending upon capacity. It is available in 2, 4, 5, 25 and 50 kg capacities. Mostly two types of Halons (halogenated agents) are used as they are less toxic - (1) Halon 1211-Bromochloro difluromethane i.e. CF_2BrCl and (2) Halon 1301 - Bromotrifluromethane CF_3Br.

5.4.2 Fixed Fire Installations :

Fixed automatic fire installations are desirable from the design stage, as they can be used for longer time and are more effective than the portable type.

(1) **Fire Hydrants :**

Fire hydrants are economical and should be installed freely around the plant. They should be kept accessible, unobstructed and protected for safety. Indicator posts are advisable.

Fire hydrants, hoses, nozzles and couplers are part of the system. Fixed nozzles are single or double headed. Monitor nozzles are on swivel joint and can be turned as desired and to clear any obstruction. Hose nozzles can be extended and laid (i.e. more flexible) wherever required. They are of fixed flow type, adjustable flow (variable discharge) type and a combination type.

The number of hydrants needed depends on the fire exposure and the hose-laying distance to the built-up areas. The discharge ports should be at least 18 inch (45 cm) above the ground level.

Fire Hose and Nozzles of standard size, double jacketed rubber-lined should be stored in hose boxes and should be subjected to a full pressure test once a year. Space around hose lines and control valves should be clear. Aisles and door ways should be wide enough and clear to allow rapid use of hose reel cart or mobile equipment.

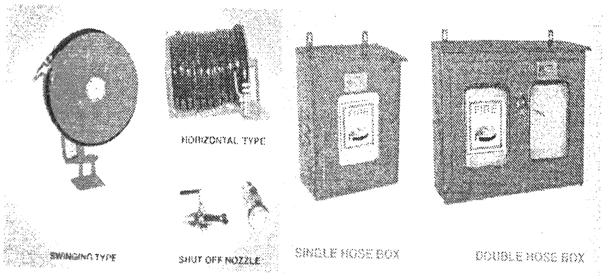


Fig. 13.5 Hoze reel, Hoze Box and Nozzle.

Monitor Nozzles are used in yards and large congested areas where it is difficult to lay hose line in an emergency. The nozzle is so positioned to direct a high pressure water stream over desired area and height.

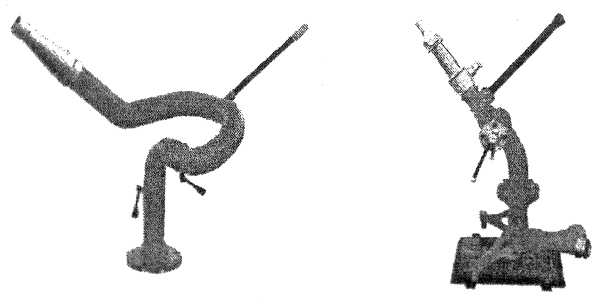


Fig. 13.6 Fixed monitor & Portable Ground Monitor

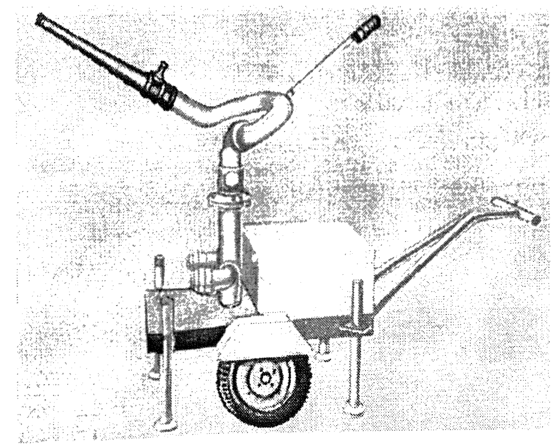


Fig. 13.7 Trolly mounted water monitor.

Water Reservoirs are necessary for the supply of fire water at good pressure and volume. They should not be used for other purposes such as process requirement. If the reservoir is common, suction pipe (its bottom end) for process water should be at a higher level than the suction pipe for fire water into the bottom of the reservoir to maintain the level of reserved water for fire protection.

Water Supply from reliable sources is essential. Reservoirs, overhead tanks, pressure tanks, pumps, pipes and connections must be maintained well. Flow discharge may vary from 10 to 40 litres per second and pressure from 7 to 10 kg./cm^2.

TAC guidelines(rules) for water supply for hydrants are as under :

Water for the hydrant service shall be stored in any easily accessible surface or underground lined reservoir or above ground tanks of steel, concrete or masonry. The effective capacity of the reservoir(above the level of the foot valve seat in case of negative suction and above the level of the top of the pump casing in case of positive suction) for the various classes of occupancies (as per rule 7.2) and size of hydrant installations shall be as indicated in Table 13.6 hereunder :

Note 1: Reservoirs of and over 2,25,000 litres capacity shall be in two interconnected compartments to facilitate cleaning and repairs.

Note 2: Large natural reservoirs having water capacity exceeding ten times the aggregate water requirements of all the fire pump drawing therefrom may be left unlined.

Table 13.6 : Capacity of water storage

Nature of Risk	Capacity of static storage exclusively reserved for hydrant service
1. Light Hazard	Not less than 1 hour's aggregate pumping capacity with a minimum of 1,35,000 litres.
2. Ordinary Hazard	Not less than 2 hour's aggregate pumping capacity.
3. High Hazard (A)	Not less than 3 hours' aggregate pumping capacity.
4. High Hazard (B)	Not less than 4 hours' aggregate pumping capacity.

Note 1 : The capacity of the reservoir for Ordinary and High Hazard Class Occupancies may, at the discretion of the Committee, be reduced by 2 hours' inflow from a reliable source (other than a town's main) but in no case shall the reservoir capacity be less than 60% of that mentioned above.

Note 2 : In case of Light Hazard Class Occupancies the minimum capacity of the reservoir shall be increased to 2,25,000 litres if the highest floor of the building is more than 15 mt. above the surroundings ground level.

The capacity for hydrant service shall be determined by the class of occupancy and size of installation as per Table 13.7.

Table 13.7: Pump, Capacity and Delivery Pressure :

Sr. No.	Nature of Risk	Number of Hydrants	Pump Capacity in Litres/Sec (m^3/hour)	Delivery pressure at rated capacity kg/cm^2
1.	Light hazard	i) Not exceeding 20	27(96)	5.6
		ii) Exceeding 20 but not exceeding 55	38(137)	7
		iii) Exceeding 55 but not exceeding 100	47(171)	7
		iv) Exceeding 100	47(171) plus 47(171) for every additional 125 hydrants or part thereof.	7/8.8
Note : The total pumping capacity need not be greater than 190(683) irrespective of the number of hydrant points				
2.	Ordinary Hazard	i) Not exceeding 20	38(137)	7
		ii) Exceeding 20 but not exceeding 55	47(171)	7
		iii) Exceeding 55 but not exceeding 100	76(273)	7
			76(273) plus	7/8.8

		iv) Exceeding 100	76(273) for every additional 125 hydrants or part thereof	
Note : The total pumping capacity need not be greater than 302(1092) irrespective of the number of hydrant points.				
3.	High Hazard (A)	i) Not exceeding 20	47(171)	7
		ii) Exceeding 20 but not exceeding 55	76(273)	7/8.8
		iii) Exceeding 55 but not exceeding 100	114(410)	7/8.8
		iv) Exceeding 100	114(410) plus 114(410) for every additional 150 hydrants or part thereof.	7/8.8/ 10.5
4.	High Hazard (B)	i) Not exceeding 20	Two of 47(171)	7
		ii) Exceeding 20 but not exceeding 55	Two of 76(273)	7/8.8
		iii) Exceeding 55 but not exceeding 100	Two of 114 (410)	7/8.8
		iv) Exceeding 100	Two of 114 (410) plus one of 114 (410) for every additional 200 hydrants or part thereof.	7/8.8/ 10.5

This provision will apply only in cases where the hydrant service has been hydraulically designed as per NB 3(b) u/r 7.5.10.

Note : In case of Light Hazard Occupancies, the pump delivery pressure will need to be 7 kg/ cm^2 if the highest floor of the risk is at a height exceeding 15 mt above the surrounding ground level.

Proper drainage facility shall be provided to drain the fire-fighting water out of the basement.

Storage of material in the open shall be protected as under :

Metals, Metallic goods, Machinery and other non-hazardous storage	One single hydrant for every 60 m. of the storage periphery located beyond 2 m., but within 15 m. of storage area.
Coal or Coke	One single hydrant for every 45 m. of the storage periphery located beyond 2 m., but within 15 m. of storage area.
Other Storage	One double hydrant for every 45 m. of the storage periphery located beyond 2 m., but within 22.5 m. of storage area.

Note 1 : In case of open storage areas of following materials, at least 50% of hydrants shall be replaced by fixed monitors having nozzle bore of 38 mm diameter if the individual stack height is more than 6 m. and total storage exceeds 5000 tonnes.

Bamboo Bagasse.

Grass/Hay. Timber.

Note 2 : Where hydrants/monitors located along one longer side of a storage area are more than 90 m. from those along the other longer side, such a storage area shall not be deemed to be protected.

Protection for combustible/flammable liquid Storage Tanks :

Tank less than 20 m. in diameter	One double headed preferably two single headed hydrants located beyond 15 m., but within 35m. of tank shell.
Tanks over 20 m. in diameter	Two double headed or four single headed hydrants located beyond 15 m. but within 35 m. of tank shell.

Note 1: In case tanks are located more than 22.5 m. from the dyke walls, one double hydrant or two single hydrants shall be replaced by a 38 mm monitor.

Note 2: Where the distance of tank from the monitor exceeds 45 m. in addition to provisions of Note 1, the tank shall be protected by Fixed Foam or Medium Velocity Water Spray System having prior approval of the Committee.

Note 3: Hydrants/Monitors shall not be installed within dyked enclosures nor can the hydrant main pass through it.

Note 4 : Fixed roof type storage tanks, floating roof type storage tanks exceeding 30 m. in diameter and Bullets/Spheres containing products having flashpoint below 32 ^{0}C shall be protected by Medium Velocity Water Spray System conforming to relevant regulations.

However, manually-operated systems shall also be acceptable.

"Water spray systems shall not be insisted for Insulated vessels/Spheres."

"Water spray protection for small size tanks up to 10 mtr diameters in ordinary and high hazard risks shall not be insisted upon."

(2) Automatic Water Sprinklers :

They are of six types. Wet pipe, dry pipe, pre-action, deluge, combined dry pipe and pre-action and sprinklers for limited water supply system. Automatic alarms operated by the flow of water should be a part of sprinkler installation. Such an alarm may be connected to a central fire station. The sprinklers should be regularly checked to avoid their failure to work.

Automatic sprinklers are most efficient and widely used. It reduces insurance premium considerably.

Its basic function is to spray water automatically to a fire, the system can also work as a fire alarm. This can be done by installing an electrical water flow alarm switch in each main riser pipe.

Sprinklers should be selected on the basis of temperature rating and occupancy. Their types are - Either heat-element or chemical melts or expands to open the sprinkler. Normal detector setting is 68 ^{0}C. Sprinklers heads normally cover 12 m^3 per head. Amount of water required depends on risk protected, flow range being 0.04 to 0.514 l/m^2.

In **deluge system**, water is admitted to sprinklers that are open at all times. Deluge valves (water supply valves) can be operated manually or automatically by an automatic detection system.

Maintenance and inspection of water supply valves, system piping for obstruction, nozzles and water supply tests etc. are necessary.

(3) Water Spray System :

Water spray system uses water in small droplets through special nozzles giving various pressures. The system is supplemented to and not a replacement for automatic sprinklers. *It should be checked that the water should not be reactive with the material burning.*

The system is similar to the deluge system except that the open sprinklers are replaced by spray nozzles. The system is generally applied to flammable liquid and gas tanks, piping and equipment, electrical equipment such as oil filled transformers, switches and motors. *To avoid short circuit, current should be cut off before applying the spray.*

The spray nozzle holes are smaller than those in ordinary sprinklers, therefore they can be choked. To avoid this, strainers (filter or screen) are required in water supply lines. The nozzles having the smallest holes, have their own internal strainer in addition to the supply line strainer.

TAC guidelines on Water Spray Systems give detailed rules. Some extract is given below:

Definitions and terminology relating to the components of the water spray systems are as follows:

(a) Water Spray System : A special fixed pipe system connected to a reliable source of fire protection water supply and equipped with water spray nozzles for specific water discharge and distribution over the surface or area to be protected. The piping system is connected to the water supply through an automatically actuated Deluge Valve which initiates flow of water. Automatic actuation is achieved by operation of automatic detecting equipment installed along with water spray nozzles. There are two types of systems namely High Velocity and Medium Velocity systems. The former is useful for liquids with flash point above 65 ^{0}C and the latter for flash point below 65 ^{0}C.

(b) Spray Nozzle and Valves : A normally open water discharging device which, when supplied with water under pressure will distribute the water in a special directional pattern peculiar to the particular device. Nozzles used for High Velocity Water Spray systems are called "Projectors" and nozzles used for Medium Velocity Water Spray systems are called "Sprayers". Both these nozzles are made in a range of orifice sizes with varying discharge angles so that discharge can be controlled for optimum protection.

Different types of valves are used with fire water piping system or water hydrants as shown in fig. 13.8.

(c) Deluge Valve : A quick opening valve which admits water automatically to a system of projectors or sprayers and is operated by a system of detectors and/or sprinklers installed in the same areas as nozzles.

(d) Control of Burning : Application of water spray to equipment or areas where a fire may occur to control the rate of burning and thereby limit the heat release from a fire until the fuel can be eliminated or extinguishment effected.

(e) Exposure Protection : Application of water spray to structures or equipment to limit absorption of heat to a level which will minimise damage and prevent failure whether source of heat is external or internal.

(f) Impingement: The striking of a protected surface by water droplets issuing directly from projectors and/or sprayers.

(g) Run Down : The downward travel of water along a surface caused by the momentum of the water or by gravity.

(h) Slippage : The horizontal component of the travel of water along the surface beyond the point of contact caused by the momentum of water.

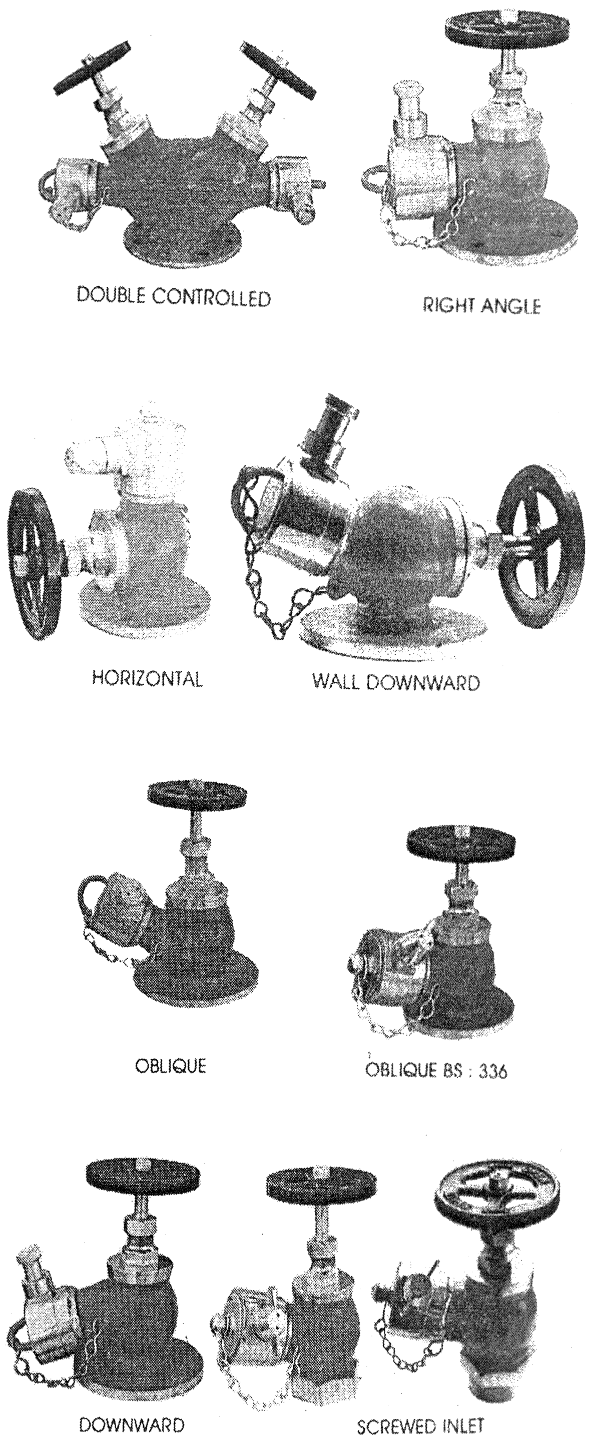


Fig. 13.8 Types of valves.

(i) **Insulated Equipment :** Equipment, structures, vessels provided with insulation which for the expected duration of exposure, will protect steel from exceeding a temperature of 454 °C (850 °F) for structural members and 343 °C (650 °F) for vessels.

(j) **Density :** The unit rate of water application to an area or surface expressed in litres/min/m^2.

(k) **Automatic Detection Equipment :** Equipment which will automatically detect one or more components directly related to combustion such as heat, smoke, flame and other phenomenon and automatic actuation of alarm and protection equipment.

(l) **Fire Barrier :** It is a continuous wall or floor that is designed and constructed to limit the spread of fire.

(m) **Range Pipes :** Pipes on which sprinklers are attached either directly or through short arm pipes which do not exceed 30 cm in length.

(n) **Distribution Pipes :** Pipes which directly feed the range pipes.

Testing and maintenance of water spray system is given in Table 13.8.

Table 13.8 Periodical Testing and Maintenance Chart

Sr	Subject	Activities	Duration
1	Reservoir	Level checking	weekly
		Clearing	once in 2 years
2	Pump	Running test	daily
		Test flow	5 minutes
		Lubrication	annually
		Gland	quarterly
		packing	weekly
		Overhaul	once in 2 years
3	Engine	Running	once in day (5 mins)
		Fuel tank check	daily
		Lubrication	quarterly
		Battery status	weekly
		Load test	annually
		Overhaul	once in 2 years
4	Motor	Lubrication	weekly
		Starter contact checking	weekly
		Insulation resistance check	half yearly
5	Main piping	Gauge pressure	check daily
		Flushing	once in 2 years
6	Sluice valves	Operation	Monthly
		Gland packing	monthly
		Lubrication	quarterly
7	Deluge valves	Operation	weekly
		Alarm check	weekly
		Cleaning	quarterly
		Overhaul	annually