

# 1

# Safety Assurance and Assessment

## Introduction to Safety, Health, and Environment Management

Health, Safety, and Environmental (HSE) management is an integral part of any business and is considered to be extremely essential when it comes to managing business in oil and gas sectors. HSE requirements are generally laid out considering the expectations of the divisional compliance with that of the standard policies. This is the most important part of HSE through legislation in the recent decades and thus forms the basis of HSE regulations in the present era. Apart from setting out the general duties and responsibilities of the employers and others, it also lays the foundation for subsequent legislation, regulations, and enforcement regimes. HSE standards are circumscribed around activities that are “reasonably practicable” to assure safety of the employees and assets as well. HSE regulations impose general duties on employers for facilitating the employees with minimum health and safety norms and members of the public; general duties on employees for their own health and safety and that of other employees, which are insisted as regulations.

## 1.1 Importance of Safety

There are risks associated with every kind of work and workplace in day-to-day life. Levels of risk involved in some industries may be higher or lower due to the consequences involved. These consequences affect the industry as well as the society, which may create a negative impact on the market depending upon the level of risk involved (Ale, 2002). It is therefore very important to prevent death or injury to workers, general public, prevent physical and financial loss to the plant, prevent damage to the third party, and to the environment. Hence, rules and regulations for assuring safety are framed and strictly enforced in offshore and petroleum industries, which is considered to be one of the most hazardous industries (Arshad Ayub, 2011). The prime goal is to protect the public, property, and environment in which they work and live. It is a commitment for all industries and other stakeholders toward the interests of customers, employees, and others. One of the major objectives of the oil and gas industries is to carry out the intended operations without injuries or damage to equipment or the environment. Industries need to form rules, which will include all applicable laws and relevant industry standards of practice. Industries need to continuously evaluate the HSE aspects of equipment and services. It is important for oil and gas industries to believe that effective HSE management will ensure a good business. Continuous improvement in HSE management practices will yield good return in the business apart from ensuring goodness of the employees (Bottelberghs, 2000). From the top management through the entry level, every employee should feel responsible and accountable for HSE. Industries need to be committed to the integration of HSE objectives into management systems at all levels. This will not only enhance the business, but also increase the success rate by reducing risk and adding value to the customer services.

## 1.2 Basic Terminologies in HSE

*ALARP*: To reduce a risk to a level 'as low as reasonably practical' (ALARP). It involves balancing reduction in risk against time, trouble, difficulty, and cost of achieving it. Cost of further reduction measures become unreasonably disproportionate to the additional risk reduction obtained.

*Audit*: A systematic, independent evaluation to determine whether or not the HSE-MS and its operations comply with planned arrangements. It also examines whether system is implemented effectively and is suitable to fulfill the company's HSE policies and objectives.

*Client:* A company that issues a contract to a contractor or subcontractor. In this document the client will generally be an oil and gas exploration company that will issue a contract to a contractor to carry out the work. The contractor may then take the role of a client by issuing contract(s) to subcontractor(s).

*Contract(s):* An agreement between two parties in which both are bound by law and which can therefore be enforced in a court or other equivalent forum.

*Contractor(s):* An individual or a company carrying out work under a written or verbally agreed contract for a client.

*Hazard:* An object, physical effect, or condition with the potential to harm people, the environment, or property.

*HSE:* Health, safety, and environment. This is a set of guidelines, in which security and social responsibilities are recognized as integral elements of HSE management system.

*HSE capability assessment:* A method of screening potential contractors to establish that they have the necessary experience and capability to undertake the assigned work in a responsible manner while knowing how to effectively deal with the associated risks.

*HSE Plan:* Is a definitive plan, including any interface topics, which sets out the complete system of HSE management for a particular contract.

*Incident:* An event or chain of events that has caused or could have caused injury or illness to people and/or damage (loss) to the environment, assets, or third parties. It includes near-miss events also.

*Inspection:* A system of checking that an operating system is in place and is working satisfactorily. Usually this is conducted by a manager and with the aid of a prepared checklists. It is important to note that this is not the same as an audit.

*Interface:* A documented identification of relevant gaps (including roles, responsibilities, and actions) in the different HSE-MS of the participating parties in a contract, which, when added to the HSE plan will combine to provide an operating system to manage all HSE aspects encountered in the contract with maximum efficiency and effectiveness.

*Leading indicator:* A measure that, if adopted, helps to improve performance.

*Subcontractor(s):* An individual or company performing some of the work within a contract, and under contract to either the original client or contractor.

*Third party:* Individuals, groups of people, or companies, other than the principal contracted parties, that may be affected by or involved with the contract.

*Toolbox meeting:* A meeting held by the workforce at the workplace to discuss HSE hazards that may be encountered during work and the procedures that are in place to successfully manage these hazards. Usually this is held at the start of the day's work; a process of continual awareness and improvement.

*Accident:* It refers to the occurrence of single or sequence of events that produce unintended loss. It refers to the occurrence of events only and not the magnitude of events.

*Safety or loss Prevention:* It is the prevention of hazard occurrence (accidents) through proper hazard identification, assessment, and elimination.

*Consequence:* It is the measure of expected effects on the results of an incident.

*Risk:* It is the measure of the magnitude of damage along with its probability of occurrence. In other words, it is the product of the chance that a specific undesired event will occur and the severity of the consequences of the event.

*Risk analysis:* It is the quantitative estimate of risk using engineering evaluation and mathematical techniques. It involves estimation of hazard, their probability of occurrence, and a combination of both.

*Hazard analysis:* It is the identification of undesired events that lead to materialization of a hazard. It includes analysis of the mechanisms by which these undesired events could occur and estimation of the extent, magnitude, and likelihood of any harmful effects.

*Safety program:* Good program identifies and eliminates existing safety hazards. Outstanding program prevents the existence of a hazard in the first place. Ingredients of a safety program are safety knowledge, safety experience, technical competence, safety management support, and commitment to safety.

*Initial response from HSE:* There are two sets of regimes namely: (i) goal-setting regimes; and (ii) rule-based regimes. *Goal-setting regimes* have a duty holder who assesses the risk. They should demonstrate its understanding and controls the management, technical, and systems issues. They should keep pace with new knowledge and should give an opportunity for workforce involvement. *Rule-based regimes* consist of a legislator who sets the rules. They emphasize compliance rather than outcomes. The disadvantage is that they are slow to respond. They give less emphasis on continuous improvement and less work force involvement.

### *1.2.1 What Is Safety?*

Safety is a healthy activity of prevention from being exposed to hazardous situation. By remaining safe, the disastrous consequences are avoided, thereby saving the life of human and plant in the industry.

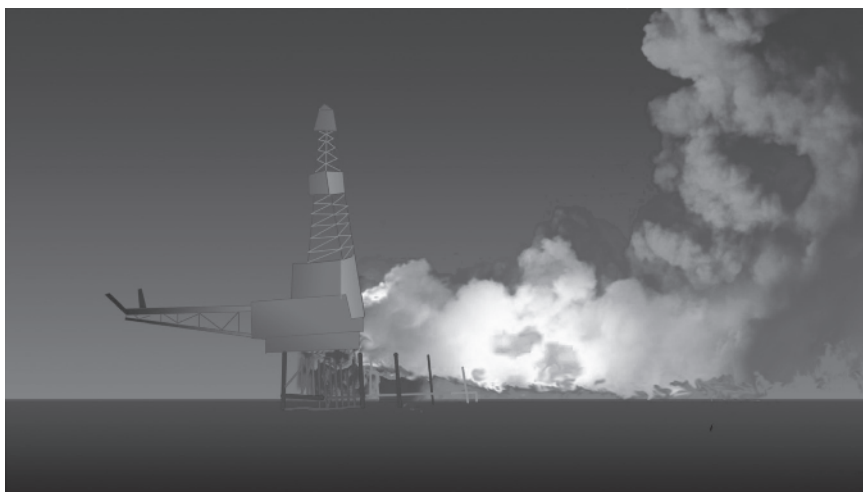
### *1.2.2 Why Is Safety Important?*

Any living creature around the world prefers to be safe rather than risk themselves to unfavorable conditions. The term safety is always associated with risk. When the chances of risks are higher then the situation is said to be highly unsafe. Therefore, risk has to be assessed and eliminated and safety has to be assured.

## **1.3 Importance of Safety in Offshore and Petroleum Industries**

Safety assurance is important in offshore and petroleum industries as they are highly prone to hazardous situations. Two good reasons for practicing safety are: (i) investment in an offshore industry is several times higher than that of any other process/production industry across the world and (ii) offshore platform designs are very complex and innovative and hence it is not easy to reconstruct the design if any damage occurs (Bhattacharyya et al., 2010a, b). Prior to analyzing the importance of safety in offshore industries, one should understand the key issues in petroleum processing and production. Safety can be ensured by identifying and assessing the hazards in each and every stages of operation. Identification and assessment of hazard at every stages of operation are vital for monitoring safety, both in quantitative and qualitative terms. Prime importance of safety is to ensure prevention of death or injury to workers in the plant and also to the public located around. Safety should also be checked in terms of financial damage to the plant as investment is huge in oil and petroleum industries than any other industry. Safety must be ensured in such a way that the surrounding atmosphere is not contaminated (Brazier and Greenwood, 1998).

Piper Alpha suffered an explosion on July 1988, which is still regarded as one of the worst offshore oil disasters in the history of the United Kingdom (Figure 1.1). About 165 persons lost their lives along with 220 crew members. The accident is attributed mainly due to a human error and is a major eye-opener for the offshore industry to revisit safety issues. Estimation of property damage is about \$1.4 billion. It is understood that the accident was



**Figure 1.1** Piper Alpha disaster

mainly caused by negligence. Maintenance work was simultaneously carried out in one of the high-pressure condensate pumps' safety valve, which led to the leak of condensates and that resulted in the accident. After the removal of one of the gas condensate pumps' pressure safety valve for maintenance, the condensate pipe remained temporarily sealed with a blind flange as the work was not completed during the day shift. The night crew, who were unaware of the maintenance work being carried out in the last shift on one of the pumps, turned on the alternate pump. Following this, the blind flange, including firewalls, failed to handle the pressure, leading to several explosions. Intensified fire exploded due to the failure in closing the flow of gas from the Tartan Platform. Automatic fire fighting system remained inactive since divers worked underwater before the incident. One could therefore infer that the source of this devastating incident was due to a human error and lack of training in shift-handovers. Post this incident, significant (and stringent) changes were brought in the offshore industry with regard to safety management, regulation, and training (Kiran, 2014).

On March 23, 1989, Exxon Valdez, which was on its way from Valdez, Alaska, with a cargo of 180 000 tons of crude oil collided with an iceberg and 11 cargo tanks, got punctured. Within a few hours 19 000 tons of crude oil was lost. By the time the tanker was refloated on April 5, 1989, about 37 000 tons was lost. In addition, about 6600 km<sup>2</sup> of the country's greatest fishing grounds and the surrounding shoreline were sheathed in oil. The size of the



**Figure 1.2** Exxon Valdez oil spill

spill and its remote location made it difficult for the government and industry to salvage the situation. This spill was about 20% of the 18000 tons of crude oil, which the vessel was carrying when it struck the reef (Figure 1.2).

Safety plays a very important role in the offshore industry. Safety can be achieved by adopting and implementing control methods such as regular monitoring of temperature and pressure inside the plant, by means of well-equipped coolant system, proper functioning of check valves and vent outs, effective casing or shielding of the system and check for oil spillages into the water bodies, by thoroughly ensuring proper control facilities one can avoid or minimize the hazardous environment in the offshore industry (Chandrasekaran, 2011a, b).

## **1.4 Objectives of HSE**

The overall objective is to describe a process by which clients can select suitable contractors and award contracts with a view to improving the client and contractor management on HSE performance in upstream activities. For brevity, security, and social responsibilities have not been included in the document title; however, they are recognized as integral elements of the

HSE-management systems. Active and ongoing participation by the client, contractor, and their subcontractors are essential to achieve the goal of effective HSE management. While each has a distinct role to play in ensuring the ongoing safety of all involved, there is an opportunity to further enhance the client–contractor relationship by clearly defining roles and responsibilities, establishing attainable objectives, and maintaining communication throughout the contract lifecycle. The aims of HSE practice are to improve performance by:

- Providing an effective management of HSE in a contract environment, so that both the client and the contractor can devote their resources to improve HSE performance.
- Facilitating the interface of the contractor’s activities with those of the client, other contractors, and subcontractors so that HSE becomes an integrated activity of all facets of process.

These guidelines are generally formulated and provided to assist clients, contractors, and subcontractors to clarify the process of managing HSE in contract operations (Chandrasekaran, 2014a, b). This generated document does not replace the necessary professional judgment needed to recommend the specific contracting strategy to be followed. Each reader should analyze his or her particular situation and then modify the information provided in this document to meet their specific needs to obtain appropriate technical support wherever required. Oil and Gas Production Secretariat is the custodian of these guidelines and will initiate updates and modifications based upon review and feedback from users through periodic meetings. In general, these guidelines are not intended to take precedence over a host country’s legal or other requirements (Chandrasekaran, 2011e).

## **1.5 Scope of HSE Guidelines**

HSE guidelines provide a framework for developing and managing contracts in offshore industry. While HSE aspects are important in the development of a contract strategy, these guidelines do not cover many vital aspects of the contract process. They prescribe various phases of the contracting process and associated responsibilities of the client, contractors, and subcontractors. It begins with planning and ends with evaluation of the contract process.

## 1.6 Need for Safety

Employers establish teams, such as quality assurance (or control) teams to get employees involved in the quality process. Employees are empowered to stop an entire production line if they become aware of any problem affecting production or quality. This is a common industrial practice as this ensures increased participation for improving quality standards and also to reduce the cost line. A similar trend is necessary in practicing safety norms as well. Unfortunately, it is observed that in many process industries, employees are not involved in the safety process except that they are members of the safety committee. But it is important to realize that if one desires to improve something for which employees are responsible, then one should establish it as an important component of their workday by making it an important element of their business. By involving the employees in the safety assurance program, they get a keen sensation of consciousness and ownership; results include better production and lower price. It is not recommended to punish a worker who broke a safety principle but turn a blind eye to the supervisor or manager who sanctioned the violation through his/her silence. The task of the supervisor or manager is to guarantee that the job is performed right and safe.

As Managers are part of the system that challenges safety, they should also be responsible to provide the answer to the perceived challenges. Long-lasting safety success cannot be assured unless the management team is a function of the safety effort. The goal of every organization should be to build a safety culture through employee engagement. By getting employees involved in performing inspections, investigations, and other procedures, needs of safety and health programs can be easily met. Employee safety can be maximized by making safety culture through increased consciousness. In particular, a skillful director of an oil company will make every effort to improve and regularize the outcome of the business in its entirety, although it is not unusual for a manager to excel in certain fields. In the workplace, there are several micro issues that must be successfully managed for the company to succeed in the business. One may establish quotas or reward individual achievements to recognize outstanding production effort of an individual employee or a group of employees. Alternatively, one should ensure that in this rigorous task, safety is not compromised even unknowingly. As for safety and health, if the company contrives to manage them for the maximum success, then there is also a need to execute the program in the same manner. Safety managers are the experts who coordinate efforts and keep top management informed on issues linked to safety and health.

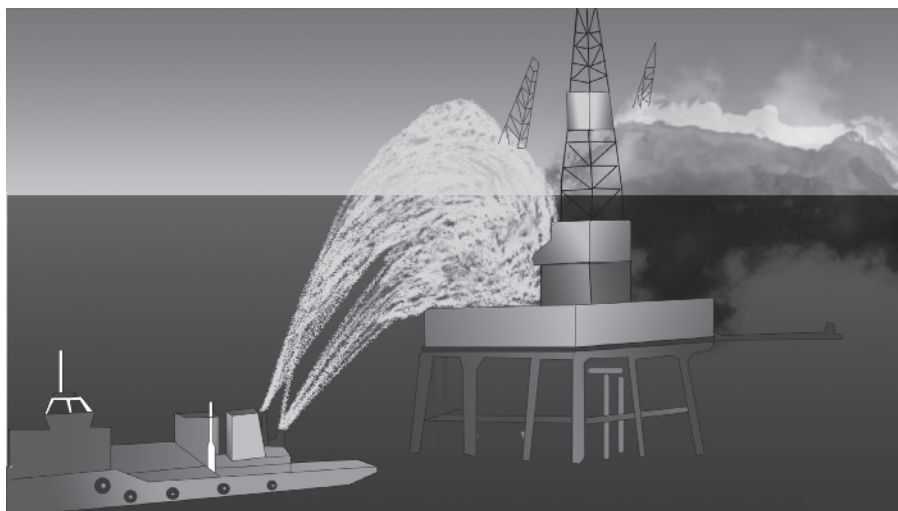
Policies and procedures, along with the signs and warnings, provide some measures of restraint. The point of control is only as effective as the level of enforcement of the indemnities. Where enforcement is weak, control and thus compliance are weak as well. The best-suited example is the signboard, which is utilized as a way of mastering the speed point of accumulation in highways. But only where the signs are strictly enforced can one see the drivers complying with the indicated speed limits. In most of the cases, they will drive as fast as they think law enforcement will take into account. Therefore, it is not the signal that controls speed on the highway; it is the degree of enforcement established by local law. Therefore, to prevent employee injury and sickness, one should maximize the management of safety and health at workplaces.

## 1.7 Organizing Safety

Major accidents reported in oil and gas industries in the past are important sources of information for understanding safety. Lessons learnt from these accidents, through detailed diagnosis, will be helpful in preventing the occurrence of similar accidents in the future. It is evident from the literature that in the last 15 years, major accidents in the offshore industry has declined (Khan and Abbasi, 1999). It is true that the important experiences gained from these events may be blanked out and the information may not be brought forward to the future generation if analyses of such accidents are not reported. The major risk groups in offshore and oil industry are blowouts, hydrocarbon leaks on installations, hydrocarbon leaks from pipelines/risers, and structural failures (Vinnem, 2007a). Some of the major accidents that took place in the past and the lessons learnt from these accidents are discussed in the next section.

### 1.7.1 Ekofisk B Blowout

On April 23, 1977, a blowout occurred in the steel jacket wellhead platform during a workover on a production well. The Blow Out Preventer (BOP) was not in place and could not be reassembled on demand. All the personnel on board were rescued, through the supply vessel, without injuries but the accident resulted in the oil spill of about 20000 m<sup>3</sup>. The well was then mechanically capped after 7 days after the event and production was shut down for half a dozen weeks to allow cleanup operations. Although the Ekofisk B blowout did not result in any human death or material damage and was

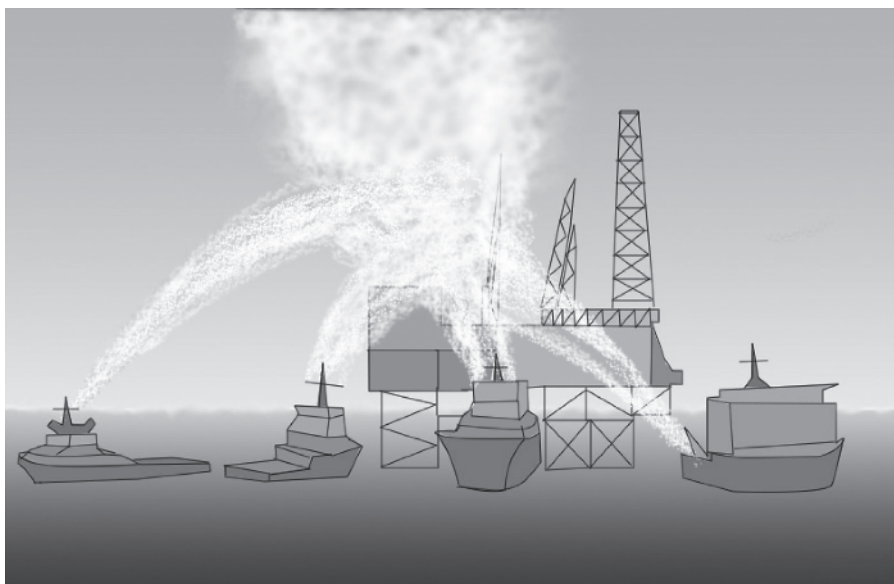


**Figure 1.3** Ekofisk blowout

exclusively limited to spills, an important lesson learnt is that capping of a blowout is possible, although it requires time. This may be vital information from a design point of view, which can be considered in modeling and analysis of BOPs (Kiran, 2012) (Figure 1.3).

### *1.7.2 Enchova Blowout*

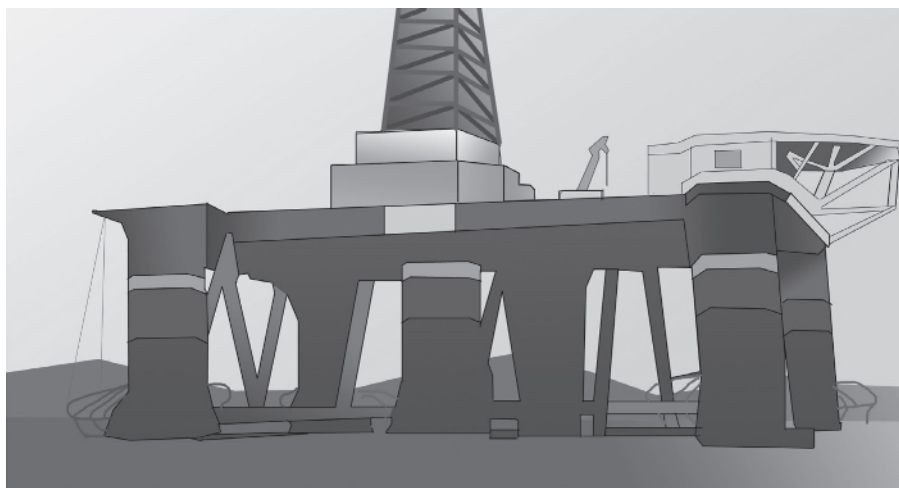
On August 16, 1984, a blowout occurred on the Brazilian fixed jacket platform Enchova-1. It was producing 40 000 barrels of oil and 1 500 000 m<sup>3</sup> of gas per day through 10 wells. The first fire was due to ignition of gas released during drilling, which was under constraint. But, the fire due to oil leakage led to a knock. The ensuing flame was blown out late the following day. The platform's drilling equipment was gutted but the remainder of the platform remained intact. Thirty-six people were killed while evacuating as the lifeboat malfunctioned, 207 survivors were rescued from the platform through helicopters and lifeboats. The most vital lesson learnt from the accident was the use of conventional lifeboats for evacuation purposes. Failure of hooks in the lifeboat gained attention and led to improvement in the design later on. Lack of competence to control the release mechanism led to stringent training of personnel on safety operations during rescue and emergency situations (Chandrasekaran, 2011d) (Figure 1.4).



**Figure 1.4** Enchova blowout

### *1.7.3 West Vanguard Gas Blowout*

The semisubmersible drilling unit, *West Vanguard*, experienced a gas blowout on October 6, 1985, while conducting exploration drilling in the Haltenbanken area, Norway. During drilling, the drill bit entered a thin gas layer, which was about 236 m below the sea bottom. This caused an influx of gas into the wellbore, which was followed by a second influx of gas after a day; third influx of gas had a gas blowout. It was noticed that the drilling operation was carried out without the use of BOP. When the drilling crew realized the gas blow out happened, inexperienced personnel started pumping heavy mud and also opened the valve to divert gas flow away from the drill stack. But, within minutes, erosion in the bends of the diverter caused the escape and the gas entered the cellar deck from the bottom. An attempt to release the coupling of the well head of the marine riser, located on the sea bed, was unsuccessful due to the ignition hazard in all areas of the platform. Ignition finally occurred from the engine room in 20 minutes after the initial start of the event, which led to a strong explosion and a fire. Two lifeboats were launched for the crew members immediately after the burst. One of the



**Figure 1.5** West Vanguard gas blowout

lessons learnt was the time management of launching lifeboats, which saved the lives of people onboard. However, inexperienced attempts made to divert the gas flow away from the drilling stack remained an important lesson to learn (Figure 1.5).

#### *1.7.4 Ekofisk A Riser Rupture*

The riser of steel jacket wellhead platform Ekofisk Alpha ruptured due to fatigue failure on November 1, 1975. The failure occurred due to insufficient protection in the splash zone and led to rapid corrosion. Leaks occurred at once at a lower part of the living quarters, causing an explosion and flame propagation. Intense flame remained for a short duration as the gas flow was immediately shut down; the blast was completely eliminated within 2 hours due to the efficient design of fire-fighting system. Only a modest damage to the platform was caused due to fire. The most important lesson learnt from the accident is about the location of riser below the living quarters (Chandrasekaran, 2010b). Best training and emergency evacuation procedures adopted and practiced by the crew resulted in minor injuries with no fatalities. The platform only suffered limited fire damage due to the short duration of intensive fire loads.

### 1.7.5 Piper A Explosion and Fire

On July 6, 1988, an ignition caused a gas leak from the blind flange in the gas compression area of Piper A. The explosion load was estimated to be about 0.3–0.4 bar over pressure. The first riser rupture occurred after 20 minutes, from which the fire increased dramatically; this resulted in further riser ruptures. The personnel escaped from the initial explosion gathered in the accommodation and were not given any further instruction about the escape and evacuation plans. Onboard communication became nonfunctional due to initial stages of the accident. Evacuation with the aid of helicopters was not possible due to blast and smoke around the platform. A total of 166 crew members died in the incident. Most of the fatalities were due to the smoke inhalation inside the accommodation, which subsequently collapsed into ocean. From a design perspective, location of the central room, radio room, and accommodation, which were very close to the gas compression area, the accident could have been avoided (Chandrasekaran, 2015). Further, not protecting them from blast and fire barriers was also a design fault. Location of accommodation on the upside of the installation led to quick accumulation of smoke within the quarters, which is also a major design fault. Lessons learnt from the operational aspects are as follows: fire water pump was not kept on automatic standby for a long time. This was a serious failure of the installation, which led to the unavailability of water for cooling oil fire.

#### 1.7.5.1 What Do These Events Teach Us?

From these accident cases it is well known that there is limitation of knowledge in forecasting the consequences of such incidents. Past experiences alone are not sufficient to calculate the sequence of outcomes (Kletz, 2003). This is due to the fact that such accidents are very uncommon and cannot be predicted. However, catastrophic consequences in most of the cases could have been avoided by taking proper care during the design stage and also by imparting emergency evacuation training to all personnel onboard.

## 1.8 Risk

Fatality and damages caused to the human and material property will result in a financial loss to the investor. Risk involves avoidance of loss and undesirable consequences. Risk involves probability and estimate of potential losses as well. According to ISO 2002, risk is defined as the *combination of probability of an event and its outcome*. ISO 13702 defines risk as *probability*



**Figure 1.6** Piper Alpha explosion

at which a specified hazardous event will occur and the harshness of the effects of the case. Mathematically risk ( $R$ ) can be expressed for each accident sequence  $i$  as below:

$$R = \sum_i (p_i C_i) \quad (1.1)$$

where,  $p$  is the probability of accidents and  $C$  is the consequence. The above expression gives a statistical look to the risk definition, which often means that the value in practice shall never be discovered. If the accident rates are rare, an average value will have to be assumed over a long period, with low annual values. If during 50 years, one has reported only about six major accidents with a sum of 10 fatalities, then this amounts to about 0.2 fatalities per year. Risk, therefore converts an experience into a mathematical term by attaching the consequences of the occurred events. Risk, is a post-evaluation of any event or incident, but risk can also be predicted with appropriate statistical tools (Chandrasekaran and Kiran, 2014a, b) (Figure 1.6).

## 1.9 Safety Assurance and Assessment

Safety and risk are contemporary. Safety is a subjective term, whereas risk is an abstract term. As safety cannot be quantified directly, it is always addressed indirectly using risk estimates. Risk can be classified into individual risk and

societal risk. Individual risk is defined as the frequency at which an individual may be expected to sustain a given level of harm from the realization of hazard. It usually accounts only for the risk of death and is expressed as risk per year or Fatality Accident Rate (FAR). It is given by:

$$\text{Average individual risk} = \frac{\text{number of fatalities}}{\text{number of people at risk}} \quad (1.2)$$

Societal risk is defined as the relationship between the frequency and number of people suffering a given level of harm from realization of any hazard. It is generally expressed as FN curves, which shows the relationship between the cumulative frequency ( $F$ ) and the number of fatalities ( $N$ ). It can also be expressed in annual fatality rate in which the frequency and fatality data are combined into a single convenient measure of group. As it becomes important to quantify risk, risk estimates are attractive only because of the consequences associated with the term. But for the consequences, risk remains as a mere statistical number. Now, one is interested to know methods to estimate loss. This is due to the fact that financial implications that arise from the consequences can be easily reflected in the company's balance sheet. Unfortunately, there is no single method, which is capable of measuring accident and loss statistics with respect to all required aspects. Three systems are commonly used in offshore industry, they are:

1. Occupational Safety and Health Administration, US Department of Labor (OSHA)
2. Fatal Accident Rate (FAR)
3. Fatality rate or deaths per person per year

All the methods report the number of accidents and/or fatalities for a fixed number of working hours during a specified period, which is unique and common among them (Chandrasekaran, 2015).

## 1.10 Frank and Morgan Logical Risk Analysis

Frank and Morgan (1979) proposed a systematic method of financing risk and presented a scheme for risk reduction. Their model is applicable to any process industries and therefore valid for oil and gas industries as well. Before applying this method for targeting risk reduction, the whole company

is subdivided into several departments. This division can be based on the functional aspects or administrative aspects. This method involves six steps of risk analysis, which are as follows:

*Step 1: Compute risk index for each department*

Each department inherently has a risk level, which is to be identified first. This can be done by evaluating the hazards present and the control measures available. This is also called as the first level of risk assessment. It is generally done by preparing a checklist, shown in Table 1.1. Control scores and hazard scores for all the departments are established from the checklist given in Table 1.2.

Hazard checklist has six groups of hazards. There are scores associated with each hazard, within each group. These scores are summed up for hazards applied within that group. The hazard score for a group is given by:

$$\text{Hazard score} = \text{sum} \times \text{hazard weightage} \quad (1.3)$$

Hazard score for each department is the sum of the scores computed for each of the six groups. Similarly one can estimate the control scores as well. Control score for each department is the sum of the scores of each of the six groups as tabulated above. Control score for a group is given by:

$$\text{Control score} = \text{sum} \times \text{control measure weightage} \quad (1.4)$$

After determining the hazard and control scores for each department, risk index can be calculated as given below. Risk index may be either positive or negative depending upon the control measures and hazard groups present in each department.

$$\text{Risk index} = \text{control score} - \text{hazard score} \quad (1.5)$$

*Step 2: Determine relative risk for each department*

The aim is to rank the departments and not the individual hazards present in the plant. This is due to the fact that the department with the highest risk index (highest positive value) is not likely to need much reduction in hazards. High risk index means that the controls are very effective. Those departments will need funds lesser than other department to mitigate/eliminate/reduce hazards. In fact, use the best department risk score as the base reference. All curves are normalized with respect to the best department. This is done by subtracting the risk score of the best department from risk scores of the concerned department. This adjustment will make the relative risk of best department as zero.

**Table 1.1** Hazard groups and hazard score

| Rating points                                     | Hazard group and hazard (Group hazard factor in parentheses)                                           |
|---------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| <b>Fire/explosion potential (10)</b>              |                                                                                                        |
| 2                                                 | Large inventory of flammables                                                                          |
| 2                                                 | Flammables generally distributed in the department rather than localized                               |
| 2                                                 | Flammables normally in vapor phase rather than liquid phase                                            |
| 2                                                 | Systems opened routinely, allowing flammable/air mix, versus a totally closed system                   |
| 1                                                 | Flammables having low flash points and high sensitivities                                              |
| 1                                                 | Flammables heated and processed above flash point                                                      |
| <b>Complexity of process (8)</b>                  |                                                                                                        |
| 2                                                 | Need for precise reactant addition and control                                                         |
| 2                                                 | Considerable instrumentation requiring special operator understanding                                  |
| 2                                                 | Troubleshooting by supervisor rather than operator                                                     |
| 1                                                 | Large number of operations and/or equipment monitored by one operator                                  |
| 1                                                 | Complex layout of equipment and many control stations                                                  |
| 1                                                 | Difficult to startup or shutdown operations                                                            |
| 1                                                 | Many critical operations to be maintained                                                              |
| <b>Stability of process (7)</b>                   |                                                                                                        |
| 3                                                 | Severity of uncontrolled situation                                                                     |
| 2                                                 | Materials that are sensitive to air, shock, heat, water, or other natural contaminants in the process. |
| 2                                                 | Potential exists for uncontrolled reactions                                                            |
| 1                                                 | Raw materials and finished goods that require special storage attention                                |
| 1                                                 | Intermediates that are thermally unstable                                                              |
| 1                                                 | Obnoxious gases present or stored under pressure                                                       |
| <b>Operating pressure involved (6)</b>            |                                                                                                        |
| 3                                                 | Process pressure in excess of 110lb/in <sup>2</sup> (gauge)                                            |
| 2                                                 | Process pressure above atmosphere but less than 110lb/in <sup>2</sup> (gauge)                          |
| 1                                                 | Process pressure ranges from vacuum to atmospheric                                                     |
| 3                                                 | Pressures are process rather than utility related                                                      |
| 2                                                 | High pressure situations are in operator                                                               |
| 1                                                 | Excessive sight glass application                                                                      |
| 1                                                 | Nonmetallic materials of construction in pressure service                                              |
| <b>Personnel/environment hazard potential (4)</b> |                                                                                                        |
| 3                                                 | Exposure to process materials pose high potential for severe burn or severe health risks               |

**Table 1.1** (Continued)

| Rating points                | Hazard group and hazard (Group hazard factor in parentheses)            |
|------------------------------|-------------------------------------------------------------------------|
| 2                            | Process materials corrosive to equipment                                |
| 2                            | Potential for excursion above Threshold Limit Value (TLV)               |
| 1                            | Spills and/or flumes have high impact on equipment, people, or services |
| 1                            | High noise levels make communication difficult                          |
| <b>High temperatures (2)</b> |                                                                         |
| 1                            | Equipment temperatures exist in <100°C range (low)                      |
| 2                            | Equipment temperatures exists in 100 < 170°C range                      |
| 3                            | Equipment temperatures exists in 170 < 230°C range                      |
| 2                            | High temperature situations are in operator-frequented area             |
| 2                            | Overflows and/or leaks are fairly common                                |
| 2                            | Heat stress possibilities from nature of work or ambient air            |

*Step 3: Compute percentage risk index for each department*

This indicates relative contribution of each department to the total risk of the plant. Relative risk of each department is converted to a percent of total risk by a simple procedure. Total risk of all departments is the sum of absolute value of relative risk of each department. The percent risk index is given by:

$$\% \text{ Risk index} = \frac{\text{relative risk}_i}{\sum_0^i \text{relative risk}} \times 100 \quad (1.6)$$

*Step 4: Determine composite exposure dollars for each department*

The estimated risk is subsequently converted to financial value now. This estimates the financial value of risk for each department. Composite exposure dollars are the sum of monetary value of three components: (i) property value; (ii) business interruption; and (iii) personnel exposure. Property value is estimated by the replacement cost of all materials and equipments at risk in the department. Business interruption is computed as the product of unit cost of goods and production per year and expected percentage capacity. Personnel exposure is the product of total number of people in the department during the most populated shift and the monetary value of each person.

**Table 1.2** Control scores and control group

| Rating points                      | Control group and control (Group control factor in parentheses)                                                                                                                               |
|------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Fire protection (10)</b>        |                                                                                                                                                                                               |
| 4                                  | Automatic sprinkler system capable of meeting demands                                                                                                                                         |
| 2                                  | Supervisors and operators knowledgeable in installed fire protection systems are trained properly                                                                                             |
| 1                                  | response to fire                                                                                                                                                                              |
| 1                                  | Adequate distribution of fire extinguishers                                                                                                                                                   |
| 1                                  | Fire protection system inspected and tested with regular frequency                                                                                                                            |
| 1                                  | Building and equipment provided with capability to isolate and control fire                                                                                                                   |
| 1                                  | Special fire detection and protection provided where indicated                                                                                                                                |
| <b>Electrical integrity (8)</b>    |                                                                                                                                                                                               |
| 3                                  | Electrical equipment installed to meet National Electrical Code area classification                                                                                                           |
| 1                                  | Electrical switches labeled to identify equipment served                                                                                                                                      |
| 1                                  | Integrity of installed electrical equipment maintained                                                                                                                                        |
| 1                                  | Class I, division 2 installations provided with sealed devices Explosion proof equipment provided or purged reliably and good electrical isolation between hazardous and non hazardous areas. |
| 1                                  | All electrical equipment capable of being locked out                                                                                                                                          |
| 1                                  | Disconnects provided, identified, inspected, and tested regularly                                                                                                                             |
| 1                                  | Lighting securely installed and facilities properly grounded                                                                                                                                  |
| <b>Safety devices (7)</b>          |                                                                                                                                                                                               |
| 3                                  | Relief devices provided and relieving is to a safe area                                                                                                                                       |
| 2                                  | Confidence that interlocks and alarms are operable                                                                                                                                            |
| 2                                  | Operating instructions are complete and current, and department has continued training and/or retaining program                                                                               |
| 1                                  | Safety devices are properly selected to match application                                                                                                                                     |
| 1                                  | Critical safety devices identified and included in regular testing program                                                                                                                    |
| 1                                  | Fail safe instrumentation provided                                                                                                                                                            |
| <b>Inerting and dip piping (5)</b> |                                                                                                                                                                                               |
| 2                                  | Vessels handling flammables provided with dip pipes                                                                                                                                           |
| 2                                  | Vessels handling flammables provided with reliable inerting system                                                                                                                            |
| 2                                  | Effectiveness of inerting assured by regular inspection and testing                                                                                                                           |
| 1                                  | Inerting instruction provided and understood                                                                                                                                                  |
| 1                                  | Inerting system designed to cover routine and emergency startup                                                                                                                               |
| 1                                  | Equipment ground visible and tested regularly                                                                                                                                                 |
| 1                                  | Friction hot spots identified and monitored                                                                                                                                                   |

**Table 1.2** (Continued)

| Rating points                              | Control group and control (Group control factor in parentheses)                                       |
|--------------------------------------------|-------------------------------------------------------------------------------------------------------|
| <b>Ventilation/Open construction (4)</b>   |                                                                                                       |
| 3                                          | No flammables exist or open air construction is provided                                              |
| 2                                          | Local ventilation provided to prevent unsafe levels of flammable, toxic, or obnoxious vapors          |
| 2                                          | Provision made for containing and controlling large spills and leaks of hazardous materials           |
| 1                                          | Building design provides for natural ventilation to prevent accumulation of dangerous vapors          |
| 1                                          | Sumps, pits, etc., nonexistent or else properly ventilated or monitored                               |
| 1                                          | Equipment entry prohibited until safe atmosphere assured                                              |
| <b>Accessibility and/or separation (2)</b> |                                                                                                       |
| 2                                          | Critical shutdown devices and/or switches visible and accessible                                      |
| 2                                          | Adjacent operations or services protected from exposure resulting from incident in concerned facility |
| 2                                          | Operating personnel protected from hazards by location                                                |
| 1                                          | Orderly spacing of equipment and materials within the concerned facility                              |
| 1                                          | Adjacent operations offer no hazard or exposure                                                       |
| 1                                          | Hazardous operations within the facility well isolated                                                |

*Step 5: Compute composite risk for each department*

For each department, composite risk is the product of composite exposure dollars and percentage risk index of that department. This value represents the relative risk of each department. Units for composite risk are in dollars. Composite risk for each department is given by:

$$\text{Composite risk} = (\text{composite exposure}) \times (\% \text{ risk index}) \quad (1.7)$$

*Step 6: Risk ranking*

This is the final step in the process. Risk ranking of the departments is done based on the composite risk as this will help the risk managers to decide the requirement of fund for each department either to mitigate risk or at least to control risk. Departments should be ranked from highest composite score to the lowest.

**Table 1.3** Data for each department of the process plant

| Exposure dept. | Hazard score | Control score | Property value (\$) ( $\times 10^3$ ) | Business interruption cost (\$) ( $\times 10^3$ ) | Composite score (\$) |                  |
|----------------|--------------|---------------|---------------------------------------|---------------------------------------------------|----------------------|------------------|
|                |              |               |                                       |                                                   | Personnel            | Exposure dollars |
| A              | 257          | 304           | 2900                                  | 1400                                              | 900                  | 5200             |
| B              | 71           | 239           | 890                                   | 1200                                              | 653                  | 2743             |
| C              | 181          | 180           | 1700                                  | 720                                               | 1610                 | 4030             |
| D              | 152          | 156           | 290                                   | 418                                               | 642                  | 1350             |
| E              | 156          | 142           | 520                                   | 890                                               | 460                  | 1870             |
| F              | 113          | 336           | 2910                                  | 3100                                              | 1860                 | 7870             |

**Example problem**

Now, let us consider an example to understand the application of Frank and Morgan risk analysis. Relevant data for each department is given in Table 1.3.

From the given input data, risk index is calculated using the Equation 1.5. For example, risk index of department A is given by:

$$\text{Risk index} = \text{control score} - \text{hazard score} \quad (1.8)$$

$$\text{Risk index}_A = 304 - 257 = 47$$

Similarly, risk index for all other departments are computed. For determining the relative risk, department risk index is subtracted from the maximum risk index. In this example, maximum risk index is for department F (223), which is considered as the *reference department*. Therefore, relative risk for department A is given by:

$$\text{Relative risk}_A = 47 - 223 = -176$$

The % risk index is then calculated for all the departments as:

$$\% \text{Risk index}_A = \frac{-176}{911} \times 100 = -19.31\%$$

After computing the % risk index for each department, composite risk is calculated:

$$\text{Composite risk}_A = 5200 \times 19.31\% = 1005$$

**Table 1.4** Computation of risk ranking

| Exposure dept. | Risk index | Relative risk | % Risk index | Composite exposure ( $\times 10^3$ ) | Composite risk ( $\times 10^3$ ) | Risk ranking |
|----------------|------------|---------------|--------------|--------------------------------------|----------------------------------|--------------|
| A              | 47         | -176          | -19.31       | 5200                                 | 1005                             | 1            |
| B              | 168        | -55           | -6.04        | 2743                                 | 166                              | 5            |
| C              | -1         | -224          | -24.59       | 4030                                 | 991                              | 2            |
| D              | 4          | -219          | -24.04       | 1350                                 | 325                              | 4            |
| E              | -14        | -237          | -26.02       | 1870                                 | 487                              | 3            |
| F              | 223        | 0             | 0            | 7870                                 | 0                                | 6            |
|                | Check      | 911           | 100%         |                                      |                                  |              |

After computing the composite risk for each department, risk ranking is done based on the department with the higher composite risk. Composite risk will be zero for the reference department in which the risk ranking will be the least. In the current example, composite risk is highest for department A. This implies that more amount of money is required to control risk and initiate risk control measures in department A. Amount of money allotted for safety is distributed among the department according to the risk ranking. Computations of risk rankings for other departments are shown in Table 1.4.

The goal is to reduce the potential losses within the plant while identifying the crucial department that is responsible for higher risk. This method also helps safety executives to pay attention to those departments that are crucial. Morgan's method is one of the best employed tools for such problems, as seen in the literature and possibly the easiest method to attempt financing risks (David Brown and William Dunn, 2007).

## 1.11 Defeating Accident Process

Different steps involved in an accident include initiation, propagation, and termination. Initiation is the event that starts the accident. This should be reduced to avoid a large accident. The procedures to control the initiation of the events are: grounding, inerting, maintenance, improved design and training to reduce human error. Propagation is the event that expands the accidents. These events should be curtailed effectively. Some of the procedures to control the propagation include emergency material transfer, fewer inventories of chemicals, use of nonflammable construction materials, installation of emergency and shutdown installation valves. Termination is the event that stops the accident. This should be increased to have a better

**Table 1.5** Fatality statistics for nonindustrial activities (Lees, 1996)

| Activities               | FAR (deaths/10 <sup>8</sup> h) |
|--------------------------|--------------------------------|
| Staying at home          | 3                              |
| Traveling by car         | 57                             |
| Traveling by cycle       | 96                             |
| Traveling by air         | 240                            |
| Traveling by motor cycle | 660                            |
| Rock climbing            | 4000                           |

control over the accident. Some of the procedures to control termination are: end of pipe control measures, fire-fighting equipment, relief system, and sprinkler systems.

### 1.12 Acceptable Risk

In offshore industries, risk cannot be avoided. Drilling, exploration, and production processes cannot be zero-risk zones as they have inherent factors that may lead to an unforeseen incident. Depending upon the environmental conditions prevailing, they can become an accident. It is therefore important to understand that risk is accepted in offshore industries up to a certain level. According to the regulatory norms, risk is acceptable and permissible in offshore industries. According to the United States Environmental Protection Agency, risk of one in million is acceptable for carcinogens. For noncarcinogens, acceptable risk is hazard index of lesser than one. According to the United Kingdom Health and Safety Executive, acceptable FAR is unity. It is also interesting to note that even nonindustrial activities, which are part of daily routine, have risk indicators. Fatality statistics for common non-industrial activities are given in Table 1.5.

### 1.13 Risk Assessment

Risk assessment is the quantitative or qualitative value of risk, which is related to a situation and a recognized hazard. Quantitative risk assessment involves in estimating both the magnitude of potential loss and the probability of occurrence of that potential loss. Therefore, risk assessment consists of two stages, namely: (i) risk determination; and (ii) risk evaluation. Risk determination deals with numbers and hence it is a quantitative approach. Risk evaluation deals with the events and hence it is a qualitative approach.

Risk is identified by continuously observing changes in risk parameters on the existing process and therefore a continuous process. Risk estimation is done by determining the probability of occurrences and the magnitude of consequences, which is post-processing of the data identified during the former stage.

Risk evaluation consists of risk aversion and risk acceptance. Risk aversion is determined by the degree of risk reduction and risk avoidance. Risk acceptance is the establishment of risk references and risk referents. Risk references are for comparing the values and the risk referents are standards with which the risk parameters are compared. For example, let us take a specific case for risk assessment of a chemical process plant. National Academy of Sciences identified four steps in chemical risk assessment, which includes hazard identification, dose–response assessment, exposure assessment, and risk characterization.

### *1.13.1 Hazard Identification*

It includes engineering fault assessment. Basically it is used to evaluate the reliability of specific segments of a process plant, which is in operation. It determines the probabilistic results. The method employed in hazard identification is fault tree analysis.

### *1.13.2 Dose–Response Assessment*

This involves describing the quantitative relationship between the amount of exposure and extent of toxic injury. Hazardous nature of various materials needs to be assessed before their effects are estimated. Outcome of the dose–response assessment is a linear equation relating exposure to the disease, which is obtained by the regression analysis of the dose–response data.

### *1.13.3 Exposure Assessment*

This describes the nature and size of population exposed to the dose agent, its magnitude, and the duration of exposure. This assessment includes the analysis of toxicants in air, water, or food.

### *1.13.4 Risk Characterization*

Risk characterization is the integration of data and the analysis. It determines whether or not the person working in the process industry and the general public in the nearby vicinity will experience effects of exposure. It includes estimating uncertainties associated with the entire process of risk assessment.

## 1.14 Application Issues of Risk Assessment

Risk assessment often relies on inadequate scientific information or lack of data. For example, any data related to repair may not be useful to assess newly designed equipment. It means that even though the data available is less, still all data related to that event cannot be considered as qualified data to do risk assessment. In toxicological risk assessment, the data related to use of them in animals is not relevant to predict their effects on humans. Therefore, to do risk assessment, one uses probabilistic tools for which data size is one of the main issues. Due to the limited data available in terms of occurrences of events (as the accidents are fewer) and their consequences, risk analysts use a conservative approach. They end up overestimating the risk by using statistical approach. Alternatively, one can also estimate risk on comparative scale. Conservative approach is a quantitative risk assessment, which identifies the frequency of event and its severity. After identifying the frequency and severity, risk rankings are determined to identify the critical events. Attention is paid on risk reduction or mitigation of these events instead of examining the whole process repeatedly. This is seen as one of the effective tools of risk reduction. Comparison technique is a qualitative risk assessment, which is done by conducting surveys and preparing a series of questionnaires. Based on the survey results, risk ranking is done.

## 1.15 Hazard Classification and Assessment

The first step in all risk assessment or Quantitative Risk Assessment (QRA) study is the hazard identification (HAZID). The purpose of HAZID is to identify all hazards associated with the planned operations or activities (Chandrasekaran et al., 2010). It provides an overview of risk, which is useful in planning further analysis of risk assessment. It provides an overview of different types of accidents that may occur in the industry with an assurance that no significant hazards are overlooked. Some of the terminologies commonly used in hazard classification and assessment are discussed next:

*Hazard* means a chemical or physical condition that has potential to cause damage to people, property or, environment. Hazard is a scenario, which is a situation resulting in more likelihood of an incident.

*Incident* means loss of or contamination of material or energy. All incidents do not propagate to accidents.

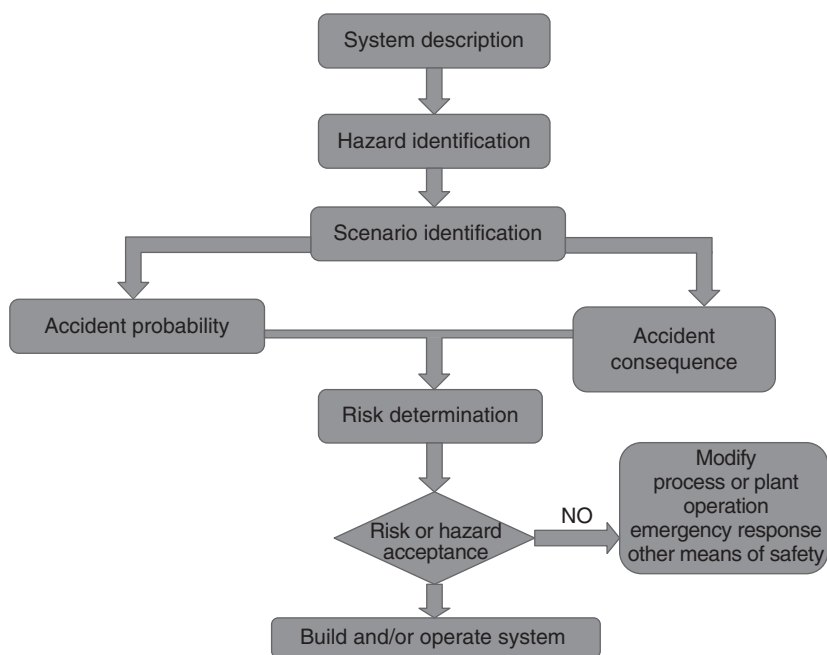
*Risk* is a realization of hazard. Incident becomes an accident.

*Hazard analysis* is the identification of undesired events that lead to materialization of a hazard. It includes analysis of the mechanisms by which these undesired events could occur. It also includes estimation of the extent, magnitude, and likelihood of any harmful effects.

### 1.15.1 Hazard Identification

Hazard identification deals with the engineering failure assessment. It evaluates the reliability of specific segments of a plant in operation to determine the probabilistic results of its operational and design failure. Fault tree analysis is one of the common forms of engineering failure assessment. Hazards that are common in oil and gas industries are not identified until an accident occurs. It is therefore essential to identify the hazards if one wants to reduce risk. Some of the frequently asked questions, which lead to hazard identification are: (i) what are hazards?; (ii) what can go wrong and how?; (iii) what are the chances that they can go wrong?; and (iv) what are the consequences, if they go wrong? Answer to the first question can be obtained by doing HAZID. The answer to the question of what can go wrong and how can be obtained by doing risk assessment, which will subsequently lead to the assessment of probability of failure. Answers to questions (iii) and (iv) will actually lead to a detailed risk assessment. It is important to document all the accidents and near-miss events occurring in the offshore industries to have a wider database. It is useful in estimating the frequency of occurrence of such accidents through detailed mathematical modeling with a higher accuracy. By documenting the accidents, consequences are also identified simultaneously, which subsequently helps in risk assessment. Hazard evaluation is a combination of HAZID and risk assessment, a flowchart is given in Figure 1.7.

Hazard evaluation can be performed at any stages of operation. It can also be performed during the preliminary stages of analysis and design of the process plant. During the initial design stages, hazard evaluation is done using Failure Mode Effective Analysis (FMEA), whereas during the ongoing operation stages, it is done using Hazard and Operability Study (HAZOP). If the hazard evaluation shows low probability and minimum consequences, then the system is called *gold-plated system*. Such systems are examples of implementation of potentially unnecessary and expensive safety equipments. As can be seen from Figure 1.7, layout of hazard evaluation, the most important step in hazard evaluation is risk acceptance. It is also complex because the level of risk acceptance is subjective to each organization and hence should be predefined. Fortunately, oil industries follow international



**Figure 1.7** Flowchart for hazard evaluation

standards to define or determine the level of risk acceptance (OISD-169, 2011; OISD-116, 2002; OISD-144, 2005; OISD-150, 2013; OGP-2010).

Potentially unnecessary and expensive safety equipment and procedures are implemented in the system. One of the important steps in hazard evaluation is to decide on the risk acceptance criteria. It is complex as the level of risk acceptance in oil and gas industries is subjective to each organization and the process methods they adopt for exploration and production. Therefore they should be predefined even before one attempts to perform hazard evaluation. But there are also standard procedures to define or determine levels of risk acceptance.

### 1.15.2 Hazard Identification Methods

- **Process hazard checklists:** Refers to a list of items and possible problems in the process that must be checked periodically.
- **Hazard surveys:** Refer to the inventory of hazardous materials.
- **HAZOP:** Refers to Hazard and Operability Studies, which is carried out generally to identify the possible hazards present in any given process plant.

- **Safety review:** Refers to a less-formal type of HAZOP study. The result depends upon the experience of the person conducting the review and hence the outcome of the review can be highly subjective.
- **What-if analysis:** This is a less-formal method that applies *what-if logic* to a number of investigations. For example, the question would be *what-if the power stops?* Answers to such questions yield a list of potential consequences and solutions.
- **Human error analysis:** Refers to a method used to identify parts and procedures of a process system. It is generally applied to the process that has higher probability of human error. For example, fire alarm/buzzer system in the control panel, etc.
- **Failure Mode, Effects and Criticality Analysis (FMECA):** This method tabulates the list of equipments and their possible mechanical failure under working conditions. This study is capable of identifying the possible failure modes of each component present in the system and their effects of failure on the overall performance of the process system.

## 1.16 Hazard Identification During Operation (HAZOP)

Hazards arise due to deviations from normal process. There always exist deviations from the design intent. This is applicable to the existing and new process plants. The main purpose of HAZOP study is to identify the potential hazards and the relative operability problems that arise due to the perceived deviations. HAZOP analysis identifies all possible hazards, operational problems, recommends changes, and identifies areas that require further detailed studies. For conducting a HAZOP analysis, up-to-date Process Flow Diagram (PFDs) is required. It also requires Process and Instrumentation Diagram (P&IDs), detailed equipment specifications, details of materials and mass and energy balances. A team of experts who are experienced in a similar plant, along with the technical and safety professionals conduct HAZOP study.

### 1.16.1 HAZOP Objectives

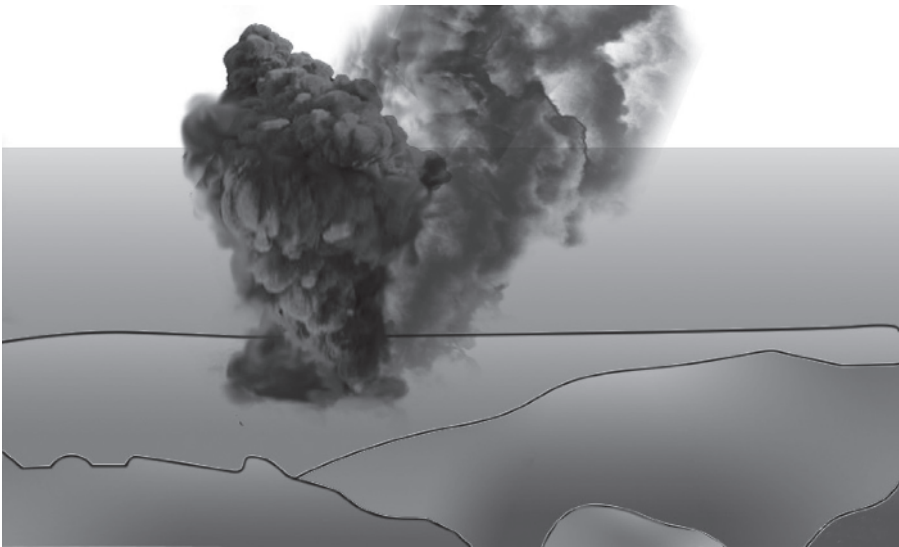
HAZOP studies are carried out to identify the following:

- Any perceived deviations from intended design/operation
- Causes for those deviations
- Consequences of those perceived deviations

- Safeguards to prevent the causes and mitigate consequences of the perceived deviations
- Recommend actions in the design and operation to improve safety and operability of the plant

### *1.16.2 Common Application Areas of HAZOP*

HAZOP is primarily used in chemical industries to estimate hazards that arise during operations; one such example can be seen in hazard studies carried out in Flixborough disaster, 1974. It is a chemical plant in the United Kingdom, which manufactures caprolactam that is required to manufacture nylon. This incident occurred due to the rupture of a temporary by-pass pipeline carrying cyclohexane at 150°C, which leaked and it set into a fire. Within few minutes, after the initiation of fire, about 20% of the plant's inventory got burnt and resulted in the spread of a vapor cloud over a diameter of about 200m. This resulted further in an explosion of a hydrogen production plant located nearby, which showed a cascading effect of the consequences. Another similar example where HAZOP studies were applied successfully was to study the consequences of explosion at a Rocket-fuel plant located at Nevada, Las Vegas, United States, as shown in Figure 1.8. The plant was destroyed in few seconds after the initiation of explosion. The wind storm



**Figure 1.8** Explosion at Rocket-fuel plant located at Nevada, Las Vegas

destroyed the roof structure and the glass. Fire was caused essentially due to the use of a welding torch in the wind-ward direction. Studies reported using HAZOP is seen to be useful in predicting the hazardous nature of the chemical release and their consequences.

### *1.16.3 Advantages of HAZOP*

HAZOP supplements the design ideas with imaginative anticipation of deviations. These may be due to equipment malfunction or operational error. In the design of new plants, designers sometimes overlook few issues related to safety in the beginning. This may result in few errors. HAZOP highlights these errors. HAZOP is an opportunity to correct these errors before such changes become too expensive or impossible. HAZOP methodology is widely used to aid loss prevention. HAZOP is a preferred tool of risk evaluation because of few reasons: (i) easy to learn; (ii) can be easily adapted to almost all operations in the process industries; (iii) is a common method in contamination problems rather than chemical exposure or explosions; and (iv) requires no special level of academic qualification to perform HAZOP studies.

HAZOP studies examine the full description of the process thoroughly. It systematically questions every part of it to establish the perceived deviations from that of the design intent. Once identified, an assessment is made to estimate the consequences of such deviations. If considered necessary, action is taken to rectify the situation in the beginning itself. Though the method is imaginative, but it still is systematic. It is more than a checklist type of review. It encourages the team to identify possible deviations and helps to trace all of them under the operational conditions. HAZOP penetrates into greater depth of risk analysis of any process plant. HAZOP, applied on the same type of plant, repeatedly improves safety, which is quite important. Potential failures that were not noticed in the earlier studies can be easily highlighted using HAZOP.

## **1.17 Steps in HAZOP**

### *Step 1: Define the design intent*

Defining the design intent is the first step in a HAZOP study. Let us explain the design intent using some examples. Consider the following:

1. Suppose there is a plant in operation, which has to produce certain tons of chemical per year.

2. an automobile unit has to manufacture certain number of cars every year.
3. a plant has to process and dispose certain volume of effluent per year.
4. an offshore plant has to produce certain barrel of oil every year.

In all the cases, equipments are designed and commissioned to achieve the desired production capacity. In order to do so, each item like the equipments, pump, length of pipe work will need to be consistently functional in a particular (desired) manner. This is the design intent for that particular item and not the machinery or production capacity.

#### *Step 2: Identify the deviations*

For understanding the deviation in design intent, let us consider another example. A plant requires continuous circulation of cooling water at temperature  $x^{\circ}\text{C}$  and at  $\text{xxx L/h}$ . Cooling of the process is done by heat exchanger. For effective functioning of the plant, effective working of heat exchanger is mandatory. The design intent is the effective working of the heat exchanger. If the water supplied for circulation becomes greater than  $x^{\circ}\text{C}$ , this would affect the production and hence this is the deviation. Note the difference between the deviation and its cause. For example, failure of pump would be a cause and not a deviation.

### **1.18 Backbone of HAZOP**

The backbone of HAZOP studies is the keywords that are used in the study. There are two types of keywords: primary and secondary. **Primary** keyword focuses the attention on a particular aspect of the design intent or an associated process condition. **Secondary** keywords suggest possible (perceived) deviations from that of the design intent; when combined with that of the primary keywords, they intent the required meaning. As HAZOP revolves around the effective use of these keywords, it is necessary to understand their meaning and usage.

Primary keywords reflect both the process design intent and operational aspects of the plant. Examples are : FLOW, TEMPERATURE, PRESSURE, LEVEL, SEPARATE, COMPOSITION, REACT, MIX, REDUCE, ABSORB, CORRODE, ERODE, etc. These keywords sometimes may be confusing. For example, let us take the word CORRODE. One may assume that the intention is that corrosion should occur as it refers to the design intent. Most of the plants are designed with the design intent that corrosion should not occur during the life span; or if it is expected, it should not exceed a certain rate. An increased corrosion rate would result in the deviation from the design

intent and therefore this word is a primary keyword. Some more primary keywords related to process are Isolate, Drain, Vent, Purge, Inspect, Maintain, Start-up, Shutdown, etc. These words are sometimes given secondary importance. For example, sometimes it is necessary to shutdown the entire plant just to re-calibrate or replace the pressure gauge in the process lines.

Secondary keywords are applied in conjunction with that of the primary to suggest the potential deviations. Examples: NO, LESS, MORE, REVERSE, ALSO, OTHER, FLUCTUATION, EARLY, etc. They convey the meaning of deviation from the design intent. For example, Flow/No indicates that there is no desired flow, which is a deviation from the design intent of FLOW. Another example could be on the operational aspect as Isolate/No. It should be noted that not all combinations of primary/secondary keywords are appropriate. For example, Temperature/No; Pressure/reverse could be considered meaningless. Results of HAZOP study are recorded in a desired format, which is termed as a HAZOP report as shown in Table 1.6.

Example problem

Let us consider an example problem of a flow line shown in Figure 1.9. FLOW/NO is applied to describe the deviation from the design intent. One of the reasons for no flow could be the blockage of the strainer S1 due to the impurities present in the dosing tank T1. Consequences that arise from the loss of dosing are incomplete separation in V1; additional causes may be cavitation in pump P1, which may result in the possible damage of the

Table 1.6 HAZOP report format

| Deviations | Causes | Consequences | Safeguards | Recommended action |
|------------|--------|--------------|------------|--------------------|
|------------|--------|--------------|------------|--------------------|

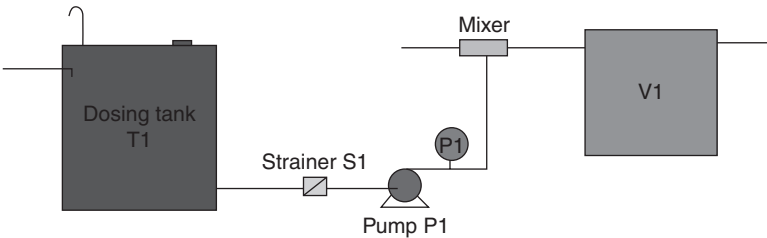


Figure 1.9 Example problem

pump, if prolonged. While recording consequences, one should be explicit. For example, instead of recording as “No dosing chemical to the mixer,” it is better to add a detailed explanation along with the reason for no dosing chemical to the mixture. When assessing the consequences, one should not account for any protective systems or instruments that are already included in the design. Let us consider a case where the HAZOP team identified a cause for FLOW/NO in a system as being spurious closure of an actuated valve. It is noticed that the valve position is displayed in the central control room and also there exists an alarm in the control panel, indicating spurious closure of the valve. Even in this situation, one may think of adding the details in assessing the consequences and then recommending a few additional control measures as safeguards against the identified cause. In the example under consideration, as the spurious closure of the valve could result in the increase in pressure in the upstream line, which can lead to other cascading consequences like fire etc., it is better to add additional safeguards in spite of the presence of an alarm system in the control room. Hence, while recording HAZOP reports, one should not take the credit of the existing protective systems or instruments that are already included in the design, but to recommend additional/alternative safeguards.

Any existing protective devices, which either prevent the cause or safeguard the adverse consequences should also be recorded in the HAZOP report. Safeguards need not be restricted only to hardware; one can also recommend periodic inspection of the plants as safeguard measures. If a credible cause results in a negative consequence, it must be decided whether some action should be taken along with its priority. If it is felt that the existing protective measures are adequate, then no action need be recommended in the report.

Recording of action falls in two groups: (i) action that removes/mitigates the cause; or (ii) that eliminates the consequences. Recommended actions that address the consequences are more (the latter) as this has a direct impact on the cost control toward risk reduction. But in general, former type is preferred against the latter, but not always possible when dealing with equipment malfunction. One of the probable actions that could be recommended for the present example is to provide a strainer on the road tanker itself, which can restrict the entry of impurities to the tanker T1. However, one should be careful in such recommendations as such recommendations may result in choking the pump at the inlet section.

While recommending actions in the HAZOP report, one should not always recommend for engineered solutions such as adding additional instruments, alarms, trip-off switches, etc. It is due to the fact that any failure

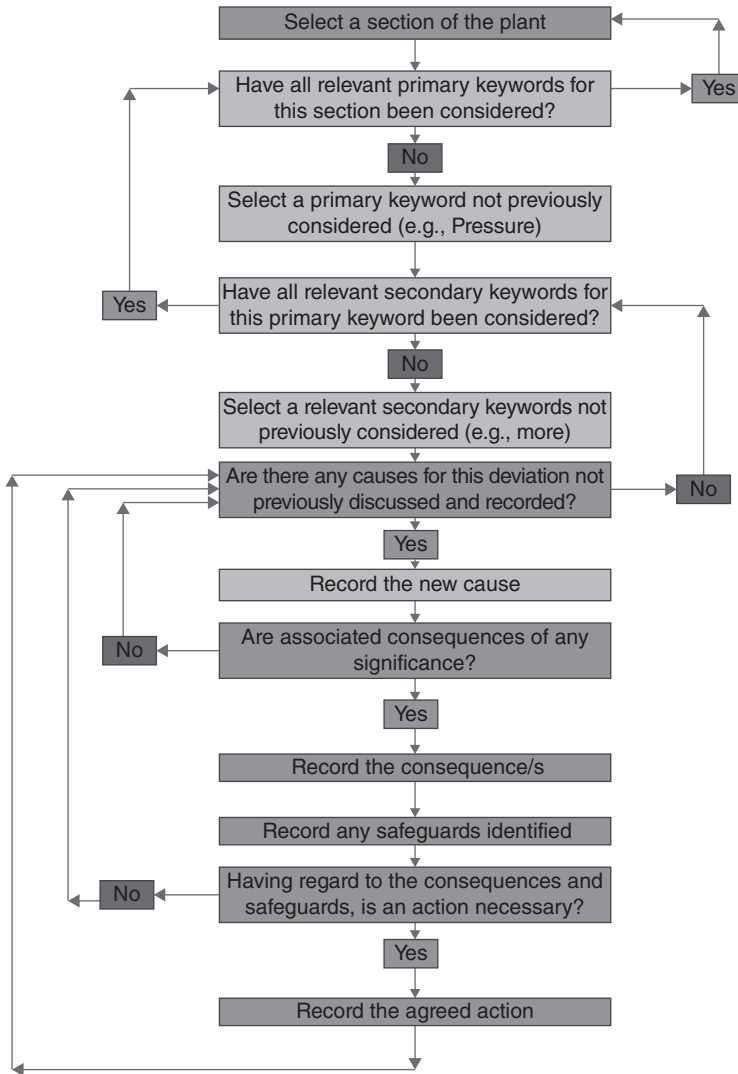
of mechanical systems does not resolve the actual hazard identified in the original process layout. With due regards to the reliability of such devices in operation, one should remember that their potential for spurious operation will cause unnecessary down-time. In addition, this may also result in increased operational cost in terms of maintenance, regular calibration, etc. Further complications arise if trained personnel are not appointed to operate the sophisticated protective systems; their maintenance is also equally complicated and expensive.

### **1.19 HAZOP Flowchart**

HAZOP studies are not carried out on the whole layout of the process plant but only on the chosen segments of the plant. Usually, such segments are identified through preliminary studies such as HAZID. HAZOP procedure is discussed in the flowchart given in Figure 1.10.

### **1.20 Full Recording Versus Recording by Exception**

HAZOP reports prepared some years ago contained partial recording of the potential deviations and the associated consequences. Some of the negative consequences were also found to be recorded as they were useful for the internal audit of the company. This method of recording reduces time and effort since they were handwritten records. Such methodology is called recording by exception. In this method, it is assumed that anything that is not included is deemed to be satisfactory. On the other hand, recent practices are to report everything in detail. Each keyword is clearly stated as applied to the system under study. Even statements like “no cause could be identified” or “no consequence arose from the cause recorded” are also seen in these statements. This is called full recording. Full recording reports verify the fact that a rigorous study has been undertaken as it is evident from the comprehensive document. This can assist in speedy assessment of safety and operability of modifications that are carried out later in the plant. With computer methods in practice, full recording has become more common these days. However, use of a few MACRO words reduces the reading time of such full records. For example, MACRO words like “no potential causes identified,” “no significant negative consequences identified,” “no action required,” etc. can be suitable for many studies that are carried out as a part of routine maintenance.



**Figure 1.10** HAZOP flowchart

## 1.21 Pseudo Secondary Words

Pseudo secondary word is used along with the primary keyword when no appropriate secondary keyword is found suitable. For example, let us consider FLOW as one of the primary words to be used in the report.

Some combinations have credible causes, such as: FLOW/NO, FLOW/REVERSE, etc. and a few combinations have no causes, such as FLOW/LESS, FLOW/MORE, FLOW/OTHER, etc. So FLOW/REMAINDER can be used as a MACRO word that substitutes the meaning of a group of negation as shown in the later set. Some of the pseudo secondary words are ALL, REMAINDER, etc. After exploring all possible combinations of primary/secondary keywords, if no potential deviations could be identified, then FLOW/ALL can also be used in the report. Use of pseudo keywords improves readability as this eliminates countless repetitive entries in the report. But HAZOP report should clearly mention a list of secondary keywords in the beginning; or else, use of pseudo keywords may have ambiguous meanings.

## 1.22 When to Do HAZOP?

HAZOP studies are generally carried out to identify potential hazards and operability problems caused by deviations that arise from the design intent. In particular, if there are major deviations made during any recent modifications made in the process line, then the changes should be verified for their safety through HAZOP studies. As a general practice in oil and gas industries, HAZOP studies are carried out at periodic intervals of not later than 6 months. HAZOP studies should preferably be carried out as early in the design phase as possible because this influences the changes in the design if deemed fit. But unfortunately, a good HAZOP study can be carried out only on the availability of a complete design. As a compromise, HAZOP is usually carried out as a final check when the detailed design is completed. HAZOP studies may also be conducted on an existing facility to identify the modifications that should be implemented to reduce risk and operability problems. Following situations generally necessitates HAZOP studies:

- At the initial concept stage when the design and detailed drawings are available.
- When the final P&ID are available.
- During the construction and installation to ensure that valid recommendations are implemented.
- During commissioning of the plant.
- During operation of the plant to ensure that the plant emergency and operating procedures are regularly reviewed and updated as required by OSID norms.

### 1.22.1 Types of HAZOP

Different types of HAZOP studies are conducted depending upon the objective of the said problem. HAZOP reports should follow a set of standard procedures to make it valid under legal challenges (IEC 61882; Crawley et al., 2000; Kyraikdis, 2003). The following list explains the types along with their applicability.

*Process HAZOP:* A technique that was originally developed to assess plants and process systems. This is quite a common type that is being practiced in oil and gas industries.

*Human HAZOP:* A “family” of specialized HAZOPs. More focused on human errors than technical failures. Usually conducted only on violations of work permits or report of a bulk of near-miss events.

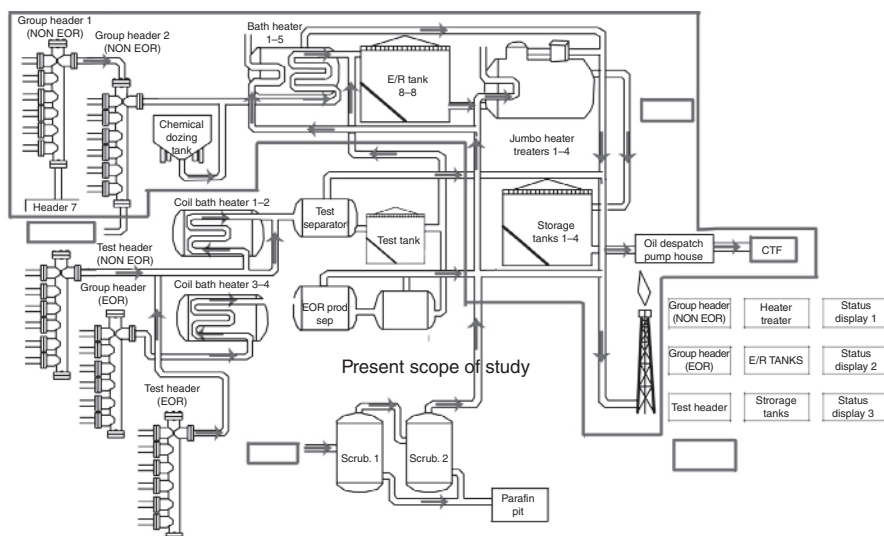
*Procedure HAZOP:* Review of procedures or operational sequences, sometimes denoted Safe Operation Study (SAFOP). This is usually carried out while a major deviation in the process line is proposed.

*Software HAZOP:* To identify possible errors in the development of software. This is useful to analyze the hazards that may arise from the failure of automated control systems. This is essential for all electric and electronic control systems and is often practiced in oil and gas industries.

## 1.23 Case Study of HAZOP: Example Problem of a Group Gathering Station

Let us consider a case study of a Group Gathering Station (GGS). Location and intrinsic details of the GGS are masked for strategic reasons but the study is actually carried out on a functional plant (Chandrasekaran, 2011c). The aim is to identify the hazards and operability problems of a GGS that has potential to cause damage to the operation, plant, personnel, and environment. The main objective is to eliminate or reduce the probability and consequences of incidents in the installation and operation of GGS. PHA-Pro7 software is used for preparing the HAZOP worksheet in the present study. Figure 1.11 shows the PFD of the GGS considered for the study. Working of the GGS is briefly explained in the following text to make the reader familiar with the process.

The well fluid emulsion, received at the limits of the GGS, is distributed into three production manifolds. From the Main Group Header, well fluid goes to the Bath Heat Treater for the first stage of separation of oil, gas, and



**Figure 1.11** Nodes marked in the PFD of GGS

water. Separated oil is subsequently stored in the Emulsion Receipt (ER) tanks, while the associated gas is separated out and taken to the flare stack. Separated water is then drawn to the Effluent Treatment Plant (ETP) from where it is disposed after proper treatment. From the ER tanks, oil is then fed to the Jumbo Heater Treaters through the Feed pumps for refinement. In the Jumbo Heater Treaters, further separation of oil and water takes place; separated oil is then pumped to the Common Tank Farm (CTF). Flow of the process line is shown in Figure 1.11.

*Methodology adopted in the present study:*

1. A section of the plant (NODE) on the P&ID is identified.
2. Design intent under normal operating conditions of the section is defined.
3. Deviations from the design intent or operating conditions are identified by applying a system of guide words, which are pre-defined.
4. Possible causes, related consequences, and available safeguards are identified and reported.
5. Action(s) are recommended to reduce/eliminate the deviations; focus is kept on the consequences.
6. Discussions and actions are recorded in full and detail.

### HAZOP WORKSHEETS

Node 1. Group header (12"-P-102-A3A)

Deviation 1: Low or no flow

Type : pipeline

Design

conditions/  
parameters:

1. Liquid rate: 2500 m<sup>3</sup>/day

2. Gas flow rate Negligible with  
GOR (MAX)10  
V/V

3. Pressure 10 kg/cm<sup>2</sup>

4. Temperature 50°C

5. Viscosity of  
pure oil at  
operating  
temperature

6. Density at 15 API: 966 kg/m<sup>3</sup>  
operating  
temperature

| Causes                                                      | Consequences                     | Risk matrix |   |    | Safeguards                               | Recommendations                                                                                    |
|-------------------------------------------------------------|----------------------------------|-------------|---|----|------------------------------------------|----------------------------------------------------------------------------------------------------|
|                                                             |                                  | S           | L | RR |                                          |                                                                                                    |
| 1. Leak or rupture of the group header line (12"-P-102-A3A) | 1. Fire and environmental hazard | 3           | 2 | C  | 1. Fire protection systems are available | 1. Pressure transmitter provided for the group header line (12"-P-102-A3A)                         |
|                                                             | 2. Loss of material              | 2           | 2 | C  |                                          | 2. Periodical hydro testing to be done for the pipeline                                            |
|                                                             | 3. Process upset                 | 1           | 2 | A  |                                          | 3. Periodical inspection and thickness measurement of group header line (12"-P-102-A3A) to be done |

| Causes                                                                                                                  | Consequences                                                                  | Risk matrix |   |    | Safeguards                                                                                                                                                                   | Recommendations                                                                                                                                                                                                       |
|-------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------------|---|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                         |                                                                               | S           | L | RR |                                                                                                                                                                              |                                                                                                                                                                                                                       |
| 2. Isolation valves in the inlet crude oil line to the group header (12"-P-102-A3A) are stuck in closed position        | 1. Pressurization in the upstream section of the pipeline<br>2. Process upset | 1           | 3 | C  | 1. Pressure gauge (PG) is available for each line from the wells<br>2. NRV is available for the inline to the group header (12"-P-102-A3A)<br>3. By-pass lines are available | 1. Pressure transmitter (PT) provided for the group header line (12"-P-102-A3A)<br>4. Periodical inspection and maintenance of the isolation valves in the inlet line to group header line (12"-P-102-A3A) to be done |
| 3. NRV in the inlet crude oil line to the group header (12"-P-102-A3A) is stuck in closed position                      | 1. Pressurization in the upstream section of the pipeline<br>2. Process upset | 1           | 3 | C  | 1. Pressure gauge (PG) is available for each line from the wells                                                                                                             | 1. Pressure transmitter (PT) provided for the group header line (12"-P-102-A3A)<br>5. Periodical inspection and maintenance of the NRV in the inlet line to the group header line (12"-P-102-A3A) to be done          |
| 4. Drain valve in the inlet crude oil line to the group header (12"-P-102-A3A) are stuck in open position or is passing | 1. Fire and environmental hazard<br>2. Loss of material                       | 13          | 2 | C  | 1. Fire protection systems are available                                                                                                                                     | 1. Pressure transmitter (PT) provided for the group header line (12"-P-102-A3A)<br>6. Periodical inspection and maintenance of the drain valve in the inlet line to the group header line (12"-P-102-A3A) to be done  |

(Continued)

| Causes                                                                                                  | Consequences                                                                  | Risk matrix |   |    | Safeguards                                                       | Recommendations                                                                                                                                                                                             |
|---------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------------|---|----|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                         |                                                                               | S           | L | RR |                                                                  |                                                                                                                                                                                                             |
| 5. Chocking of the inlet crude oil line to the group header (12"-P-102-A3A) due to the sludge formation | 1. Pressurization in the upstream section of the pipeline<br>2. Process upset | 1           | 3 | C  | 1. Pressure gauge (PG) is available for each line from the wells | 1. Pressure transmitter (PT) provided for the group header line (12"-P-102-A3A)<br>7. Periodical inspection and thickness measurement of the inlet line to the group header line (12"-P-102-A3A) to be done |

Node 1. Group header (12"-P-102-A3A)

**Deviation 2:**

**high flow**

Type: pipeline

Design

conditions/  
parameters:

1. Liquid rate: 2500 m<sup>3</sup>/day
2. Gas flow rate Negligible with GOR (MAX)10 V/V
3. Pressure 10 kg/cm<sup>2</sup>
4. Temperature 50°C
5. Viscosity of pure oil at operating temperature 270 cp
6. Density at operating temperature 15 API: 966 kg/m<sup>3</sup>

| Causes                                              | Consequences                                                                                 | Risk matrix |   |    | Safeguards                                                                                                                             | Recommendations                                                                 |
|-----------------------------------------------------|----------------------------------------------------------------------------------------------|-------------|---|----|----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
|                                                     |                                                                                              | S           | L | RR |                                                                                                                                        |                                                                                 |
| 1. High flow from the upstream section of this Node | 1. Possibility of pressurization inside the group header (12"-P-102-A3A)<br>2. Process upset | 1           | 3 | C  | 1. Pressure Safety Valve (PSV) is available for the Group header (12"-P-102-A3A)<br>2. By-pass lines are available for the header line | 1. Pressure transmitter (PT) provided for the group header line (12"-P-102-A3A) |

Node 1. Group header (12"-P-102-A3A)  
**Deviation 3: Reverse or misdirected flow**  
 Type: pipeline

Design conditions/ parameters:  
 1. Liquid rate: 2500 m<sup>3</sup>/day  
 2. Gas flow rate Negligible with GOR (MAX)10 V/V  
 3. Pressure 10 kg/cm<sup>2</sup>  
 4. Temperature 50°C  
 5. Viscosity of pure oil at operating temperature 270 cp  
 6. Density at operating temperature 15 API: 966 kg/m<sup>3</sup>

| Causes                                                                                                                               | Consequences           | Risk matrix |   |    | Safeguards | Recommendations                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------|------------------------|-------------|---|----|------------|----------------------------------------------------------------------------------------------------------------|
|                                                                                                                                      |                        | S           | L | RR |            |                                                                                                                |
| 1. Isolation valve in the first Group header or to the testing line is stuck in open position or is passing during normal operations | 1. Process upset       | 1           | 2 | A  |            | 1. Pressure transmitter (PT) provided for the group header line (12"-P-102-A3A)                                |
|                                                                                                                                      | 2. Loss of containment | 2           | 2 | C  |            | 8. Periodical inspection and maintenance of the isolation valve in the first group header line (12"-P-102-A3A) |
| 2. Butterfly valve connecting the two group headers is stuck in open position or is passing during normal operations                 | 1. Process upset       | 1           | 2 | A  |            | 1. Pressure transmitter (PT) provided for the group header line (12"-P-102-A3A)                                |
|                                                                                                                                      | 2. Loss of containment | 2           | 2 | C  |            | 9. Periodical inspection and maintenance of the Butterfly valve connecting the two group headers to be done    |

(Continued)

Node 1. Group header (12"-P-102-A3A)

**Deviation 4: Low pressure**

Type: pipeline

|                                                   |                                 |
|---------------------------------------------------|---------------------------------|
| Design conditions/ parameters:                    |                                 |
| 1. Liquid rate:                                   | 2500m <sup>3</sup> /day         |
| 2. Gas flow rate                                  | Negligible with GOR (MAX)10 V/V |
| 3. Pressure                                       | 10 kg/cm <sup>2</sup>           |
| 4. Temperature                                    | 50°C                            |
| 5. Viscosity of pure oil at operating temperature | 270 cp                          |
| 6. Density at operating temperature               | 15 API : 966 kg/m <sup>3</sup>  |

| Causes                                       | Consequences | Risk matrix                             | Safeguards | Recommendations |
|----------------------------------------------|--------------|-----------------------------------------|------------|-----------------|
|                                              |              | <div>S</div> <div>L</div> <div>RR</div> |            |                 |
| 1. Refer Low/ No flow deviation of this node |              |                                         |            |                 |

Node 1. Group header (12"-P-102-A3A)

**Deviation 5: High pressure**

Type: pipeline

|                                                   |                                 |
|---------------------------------------------------|---------------------------------|
| Design conditions/ parameters:                    |                                 |
| 1. Liquid rate :                                  | 2500m <sup>3</sup> /day         |
| 2. Gas flow rate                                  | Negligible with GOR (MAX)10 V/V |
| 3. Pressure                                       | 10 kg/cm <sup>2</sup>           |
| 4. Temperature                                    | 50°C                            |
| 5. Viscosity of pure oil at operating temperature | 270 cp                          |
| 6. Density at operating temperature               | 15 API: 966 kg/m <sup>3</sup>   |

| Causes | Consequences | Risk matrix |   |    | Safeguards | Recommendations |
|--------|--------------|-------------|---|----|------------|-----------------|
|        |              | S           | L | RR |            |                 |

1. Refer More  
flow deviation  
of this node

Node 1. Group header (12"-P-102-A3A)

**Deviation 6 : High temperature**

Type: pipeline

Design  
conditions/  
parameters:

- |                                                   |                                 |
|---------------------------------------------------|---------------------------------|
| 1. Liquid rate:                                   | 2500 m <sup>3</sup> /day        |
| 2. Gas flow rate                                  | Negligible with GOR (MAX)10 V/V |
| 3. Pressure                                       | 10 kg/cm <sup>2</sup>           |
| 4. Temperature                                    | 50°C                            |
| 5. Viscosity of pure oil at operating temperature | 270 cp                          |
| 6. Density at operating temperature               | 15 API: 966 kg/m <sup>3</sup>   |

| Causes | Consequences | Risk matrix |   |    | Safeguards | Recommendations |
|--------|--------------|-------------|---|----|------------|-----------------|
|        |              | S           | L | RR |            |                 |

|                  |                                                                          |   |   |   |                                                                                  |                                                                                    |
|------------------|--------------------------------------------------------------------------|---|---|---|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| 1. External Fire | 1. Fire and environmental hazard                                         | 3 | 2 | C | 1. Temperature gauge (TG) is available for each of the line from the wells       | 10. Periodical inspection and maintenance of the fire protection system to be done |
|                  | 2. Possibility of pressurization inside the group header (12"-P-102-A3A) | 1 | 3 | c | 2. Pressure Safety Valve (PSV) is available for the group header (12"-P-102-A3A) |                                                                                    |
|                  | 3. Process upset                                                         | 1 | 3 | A | 3. Fire protection systems are available                                         |                                                                                    |

(Continued)

Node 1. Group header (12"-P-102-A3A)

**Deviation 7 :Variation in composition**

Type: pipeline

Design

conditions/  
parameters:

1. Liquid rate : 2500 m<sup>3</sup>/day
2. Gas flow rate Negligible with GOR (MAX)10 V/V
3. Pressure 10 kg/cm<sup>2</sup>
4. Temperature 50°C
5. Viscosity of pure oil at operating temperature 270 cp
6. Density at operating temperature 15 API : 966 kg/m<sup>3</sup>

| Causes                                                   | Consequences                                                           | Risk matrix |   |    | Safeguards                                                           | Recommendations                                                                                |
|----------------------------------------------------------|------------------------------------------------------------------------|-------------|---|----|----------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
|                                                          |                                                                        | S           | L | RR |                                                                      |                                                                                                |
| 1. Presence of impurities in crude oil coming from wells | 2. Possibility of choking inside the group header line (12"-P-102-A3A) | 1           | 3 | C  | 1. Pressure gauge (PG) is available for the each line from the wells | 11. Ensure arrangements for analyzing the crude oil from the wells on a regular basis are made |

Risk matrix is prepared to indicate the acceptability of hazard in the GGS as per OSID norms, Figure 1.12 shows the risk matrix.

Following major conclusions are drawn from the study conducted:

- All the identified hazards of the given installation of GGS can be reduced or eliminated by implementing the suggested recommendations.
- Cost of implementation of recommendations (as calculated) influences the implementation of action significantly.
- Risk ranking of the installation is higher in Node 2 (Heater Treaters) and Node 5 (Jumbo Heater Treaters)

|                              |                                                     | Hazard severity (S)             |                                          |                                       |                            |
|------------------------------|-----------------------------------------------------|---------------------------------|------------------------------------------|---------------------------------------|----------------------------|
|                              |                                                     | No injury or health impacts (1) | Minor injury or minor health impacts (2) | Injury or moderate health impacts (3) | Death or severe injury (4) |
| Likelihood of occurrence (L) | Not expected to occur during facility life (1)      | A                               | A                                        | C                                     | C                          |
|                              | Could occur once during facility life (2)           | A                               | C                                        | C                                     | N                          |
|                              | Could occur several times during facility life (3)  | C                               | C                                        | N                                     | U                          |
|                              | Could occur on an annual basis (or more oflent) (4) | C                               | N                                        | U                                     | U                          |

A - Acceptable (no risk control measures are needed)  
N - Not desirable (risk control measures to be introduced within a specified time period)  
C - Acceptable with control (risk control measures are in place)  
U - Unacceptable

Figure 1.12 Risk matrix for the example problem (GGS)

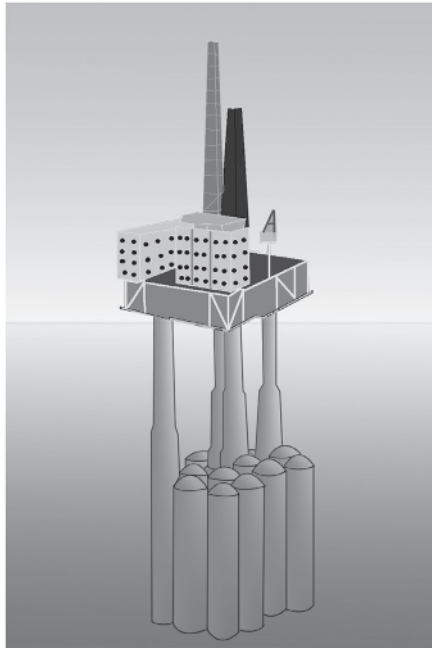
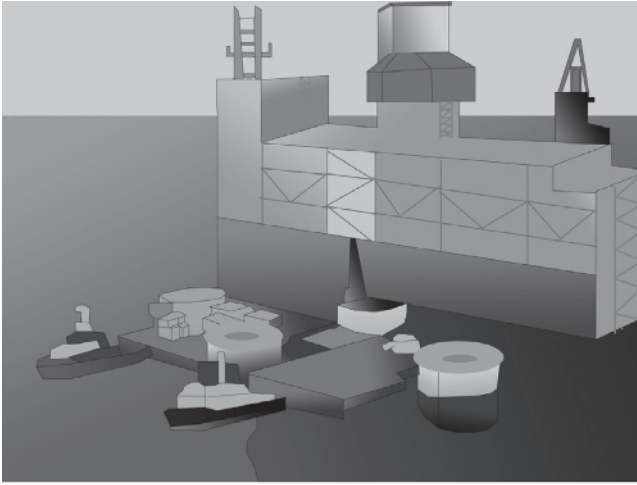
- Recommendations of category U and N are not available in this study. Only category A and C are available. While implementing these recommendations, priority should be given to category C

While recommendations made in the above study improved the safety of operation, cost toward their implications influenced the implementation of recommended action plans (Venkata Kiran, 2011). As this being a subjective issue under the jurisdiction of the head of the operation group, implication strategies are not further discussed.

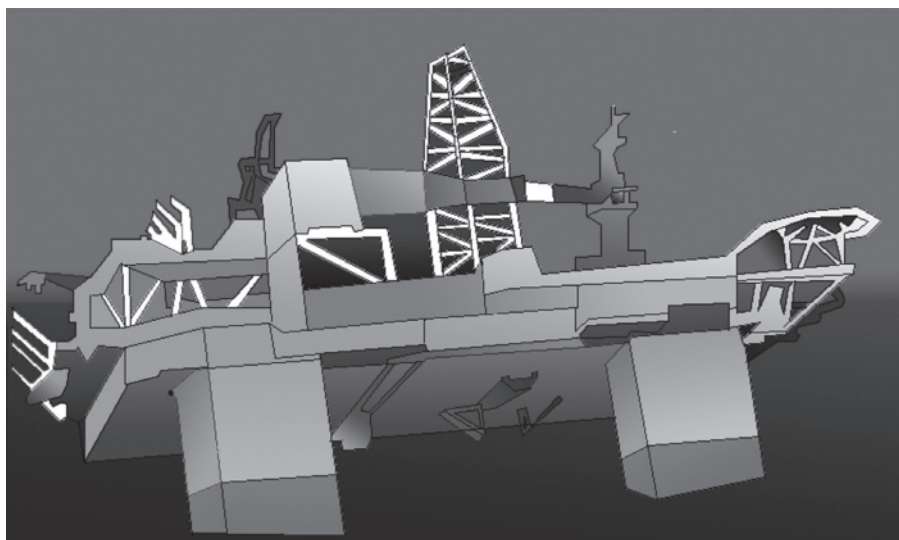
1.24 Accidents in Offshore Platforms

1.24.1 Sleipner A Platform

Consider an accident that is reported in Sleipner A platform in the North Sea. The Sleipner platform is shown in Figure 1.13. It is a condeeep-type platform with concrete gravity base structure, consists of 24 cells, and has a total base area of 16 000 m<sup>2</sup>, operating at a water depth of 82 m. The platform is producing oil and gas successfully in the North Sea. Failure of the platform caused



**Figure 1.13** The Sleipner A platform



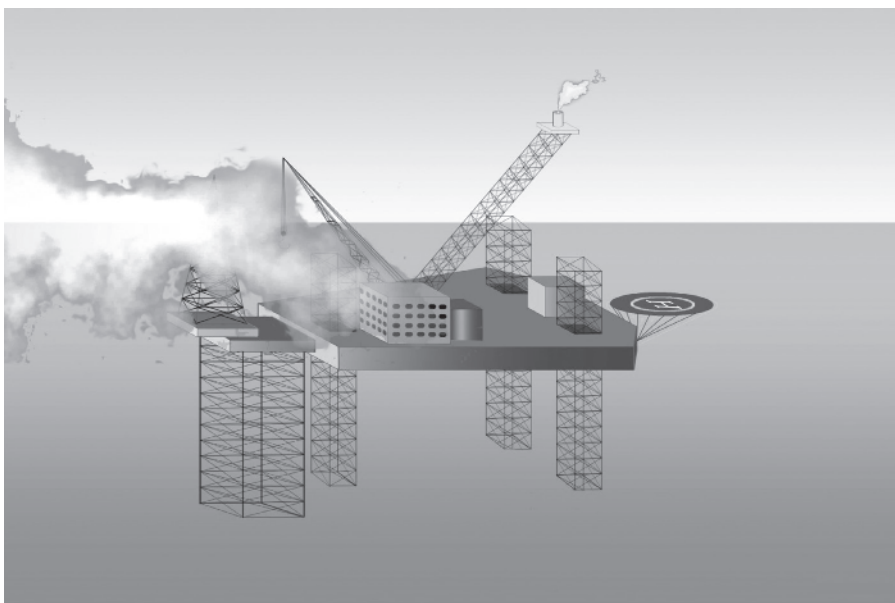
**Figure 1.14** Thunder Horse platform

a seismic event of magnitude 3.0 on the Richter scale. The failure resulted in a total economic loss of about \$700 million.

The conclusions of the investigations mentioned that the failure in a cell-wall resulted in a serious crack that propagated. Leakage was high such that the pumps were not capable to control the leakage. Wall failed as a result of the combination of a serious error in the finite element analysis and insufficient anchorage of the reinforcement in a critical zone. Shear stresses were underestimated by about 47%, leading to an insufficient design. Concrete wall thickness was reported to be inadequate.

### *1.24.2 Thunder Horse Platform*

Another example is the accident that occurred at the Thunder Horse platform, shown in Figure 1.14. Thunder Horse production platform is located in 1920 m of water in the Mississippi Canyon Block 778/822, about 150 miles (240 km) southeast of New Orleans. Construction costs were around US \$5 billion and the platform is expected to operate for about 25 years. The hull section was constructed in 2004. In July 2005, Thunder Horse was evacuated due to the threat caused by Hurricane Dennis. After the hurricane passed, the platform was inspected and assessment reports did not mention any damages to the hull of the platform. Interestingly, an incorrectly plumbed pipeline allowed



**Figure 1.15** Timor Sea oil rig

water to flow freely among the several ballast tanks, which initiated the platform to tip into water. As a serious consequence of the accident, world oil prices increased because of speculation of oil shortage. The platform was subsequently rehabilitated within a fortnight after Hurricane Dennis and subsequent hits by Hurricane Katrina, 6 weeks later, did not damage the platform.

#### *1.24.3 Timor Sea Oil Rig*

Another example is the accident that occurred in Timor Sea oil rig, shown in Figure 1.15. Leaking Timor Sea oil rig caught fire on November 2, 2009. While the oil spill resulted in severe environmental damage, the cause of fire was not known immediately; personnel onboard were moved out safely without any fatal injuries.

#### *1.24.4 Bombay High North in Offshore Mumbai*

A massive platform, Bombay High North (BHN) in offshore Mumbai High field was gutted in a devastating fire on July 27, 2005. In less than 2 hours, BHN was reduced to molten metal as shown in Figure 1.16. The platform remained a beehive of activity for 24 years, which was brought to a halt due to the accident; it was later retrofitted and made functional.

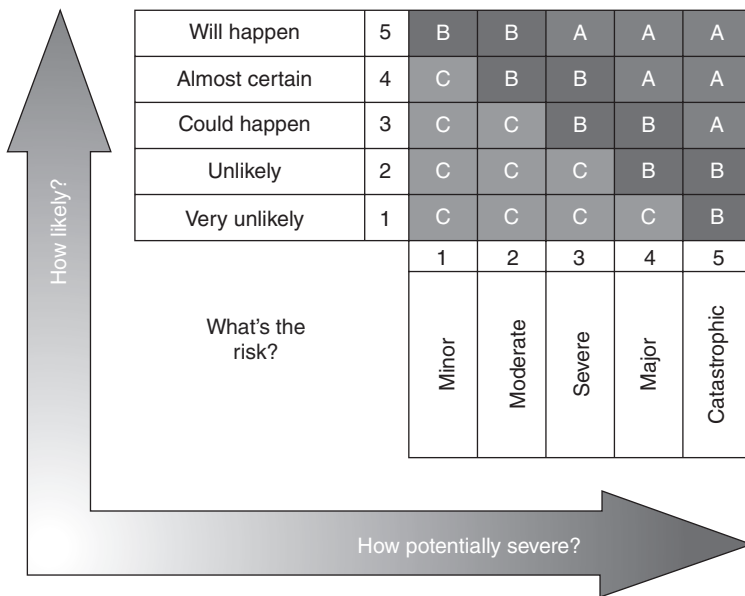


**Figure 1.16** Burnt out of Bombay High North platform

From the events discussed, it is important to know that the causes of failures are unknown in most of the cases. Even post-accident studies could not trace out the fundamental causes of the accident but hinted toward a set of complex reasons (Prem et al., 2010). However, from an engineering perspective, one can understand that the causes are mostly due to the oversight either in the design stage or during operation/maintenance (Valerie and Cary, 1991). As the consequences of such accidents lay serious impact on world's economy through oil pricing, it is imperative to note that risk analyses are becoming increasingly important to ensure that at least such events are not repeated (Terje and Jan Erik, 2007). It shows the importance or necessity of QRA tools (e.g., HAZOP) and their applicability to offshore platforms or any process industry in general at different stages: (i) front end engineering design stage; (ii) fabrication, construction, and commissioning stage; and (iii) operational stage etc.

## 1.25 Hazard Evaluation and Control

Every type of hazard is associated with some risk, which can potentially result in moderate to serious consequences. It is important to analyze the seriousness of the consequences in terms of operational, strategic, and economic perspectives. Subsequently, planning can be made to either mitigate or control the risk to an acceptable level. Hazard evaluation can be done at



**Figure 1.17** Hazard evaluation

any stage in a process plant. It can be either done during the initial design stages by conducting FMEA/FMECA or during the ongoing operation of the project through HAZOP. If the hazard evaluation shows low probability and minimum consequences, then the system is attributed as a gold-plated system, indicating that unnecessary and expensive safety equipments and procedures are implemented in the system (Skelton, 1997).

### 1.25.1 Hazard Evaluation

Hazards can be defined as physical or chemical conditions that have the potential to cause damage to people, property, or environment. The first step in controlling any hazard is to determine the magnitude of risk associated with it. This is often called as hazard evaluation. A simple way of evaluating hazard is assessing the total consequences associated with the hazard and the likelihood that those consequences will occur. Figure 1.17 illustrates the relationship between them.

### 1.25.2 Hazard Classification

**Class “C”** hazards pose relatively lesser risk.

**Class “B”** hazards pose serious risks, which means that immediate steps need to be taken to control such hazards.

**Class “A”** hazards are intolerable. This implies that the work should be immediately stopped until satisfactory level of hazard control is achieved.

The class into which hazards fall is the basis for deciding how to prioritize the plans for controlling them. An effective way of assessing risks and prioritizing plans for dealing with them depends on the hazard classification as shown in Figure 1.17. Other factors that influence hazard evaluation are: (i) frequency of exposure; (ii) duration of the exposure; and (iii) diagnosing additional circumstances that might affect risk like climatic conditions, etc.

### *1.25.3 Hazard Control*

As it is difficult to eliminate hazards completely from oil and gas industries, most often attempts are made to manage hazards efficiently. The steps to manage hazards efficiently are as follows:

The first step is toward eliminating the hazard. For instance, if any damaged equipment is causing a hazard, one can think of either replacing it or by-passing it in the process line.

The second step is toward substituting hazardous materials with safer ones. This deals with the inventory control and also linked with process. For example, one can plan to replace a cleaning solution that gives off toxic fumes by a nontoxic alternative.

The third step is to isolate personnel and public from perceived hazards. A variety of steps and measures can be planned in this line to minimize hazards that can be caused to people working onboard and also to the public who live in the vicinity.

The fourth step is to adopt engineering controls to minimize risks.

The fifth step is to use administrative tools to minimize hazards. This can be done by creating more warning signals and signboards.

The sixth step is to administer protective equipments or clothing in case all the other five steps fail. This is a line of defense and therefore not the first.

This step-by-step procedure is known as Hierarchy of Hazard Controls and helps in finding the most reasonable and effective way to minimize risk of injury. In any given situation in which a hazard cannot be brought fully under control, employers are required to provide written instructions to support safe work. It is also important to ensure that workers receive sufficient

level of training and supervision that is required to work safely. A Hazard Control Form will help to chalk the hazard control plan, which explains the roles and responsibilities of each team on duty to manage hazards under any unforeseen emergency.

#### *1.25.4 Monitoring*

Recommendations prescribed to control hazards need to be reviewed periodically to ensure that they are effective and appropriate. This can be a part of the ongoing regular safety inspection program. Alternatively, Joint Health and Safety Committee are formulated in many oil companies to review the control measures. Following points may be useful while reviewing the hazard controls:

- Is the hazard under control?
- Have the steps taken to manage it solved the problem?
- Are the risks associated with the hazard under control too?
- Have any new hazards been created?
- Are new hazards being controlled appropriately?
- Do workers know about the hazard?
- What has been done to control it?
- Do workers know what they need to do to work safely?
- If there is a new hazard, are workers trained properly to deal with it?
- Are there written records of all identified hazards, their risks, and the control measures taken?
- What else can be done?

### **Exercises 1**

1. Occurrence of single or sequence of events that produce unintended loss is called .....

Accident

2. Chemical or physical condition that has potential to cause damage to people, property, or environment is called .....

Hazard

3. Measure of expected effects of the results of an incident is called as:

(a) Hazard      (b) Consequence      (c) Failure      (d) Incident

(b) Consequence

4. The relationship between the frequency and number of people suffering a given level of harm from realization of hazard is called as .....

Societal risk

5. Estimation of uncertainties associated with the entire process of risk assessment is called as .....

Risk characterization

6. ....can be a suitable tool for evaluating industrial fire risk and prioritizing units in general level of an industrial complex especially chemicals company.

Frank and Morgan risk analysis.

7. The control score for a department in an oil and gas industry is given as 156 and hazard score is 152. Calculate the percentage risk index?

(a) 24.04            (b) 26.02            (c) -26.02            (d) -24.04

(d) -24.04

8. Action taken to control or reduce risk is called .....

Risk aversion

9. In the context of a risk assessment, what do you understand by the term risk?

(a) An unsafe act or condition  
(b) Something with the potential to cause injury  
(c) Any work activity that can be described as dangerous  
(d) The likelihood that harm from a particular hazard will occur

(d) The likelihood that harm from a particular hazard will occur

10. .... are used for representing societal risk.

FN curves

11. Prevention of hazard occurrence through proper hazard identification, assessment, and elimination is called .....

Safety

12. Define individual risk and societal risk.

**Individual risk:** Defined as frequency at which individuals may be expected to sustain a given level of harm from realization of hazard. It usually accounts only the risk of death. It is expressed as risk per year.

**Societal risk:** Defined as a relationship between the frequency and number of people suffering a given level of harm from realization of hazard. Societal risks are expressed as: FN curves, showing relationship between the cumulative frequency ( $F$ ) and number of fatalities ( $N$ ).

13. What is the difference between safety and risk?

**Safety or loss prevention:** Prevention of hazard occurrence (accidents) through proper hazard identification, assessment, and elimination.

**Risk:** measure of magnitude of damage along with its probability of occurrence.

14. What are the application issues of risk assessment?

Risk assessment often relies on inadequate scientific information or lack of data. For example, any data related to repair may not be useful to assess newly designed equipment. It means that even though the data available is less, still all data related to that event cannot be considered as qualified data to do risk assessment.

15. State a few golden rules of good HSE Management program.

Identifies and eliminates existing safety hazards

Safety knowledge, safety experience, technical competence, safety management support, commitment to safety

16. What do you understand by loss? What do you understand by acceptable risk? As an employee of an oil industry, how do you react to the term acceptable risk?

**Loss:** Severity of negative impact

**Acceptable risk:** Level of human and/or material injury or loss from an industrial process that is considered to be tolerable by a society or authorities in view of the social, political, and economic cost-benefit analysis.

17. Explain about safety assurance and safety assessment methods.

**Safety assurance:** Is the application of safety engineering practices intended to minimize the risks of operational hazards. Strategies include reactive, proactive, predictive, and iterative. Risk analysis is one of the methods.

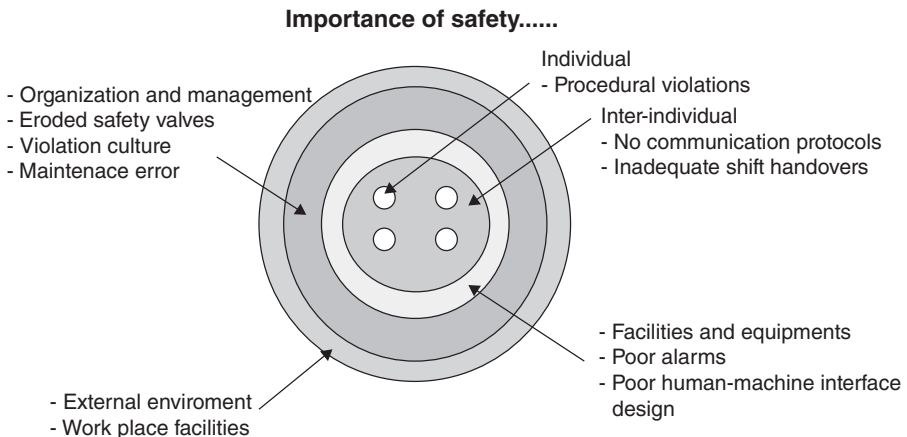
**Safety assessment:** Assessed to their potential severity of impact (generally a negative impact, such as damage or loss) and to the probability of occurrence. Methods: risk assessment, hazard identification, risk characterization, etc.

18. What are goal-setting regimes and rule-based regimes?

**Goal-setting regimes:** Dutyholder assesses risk. Should demonstrate its understanding, controls cover management, technical, and systems issues. Keeps pace with new knowledge. Opportunity for workforce engagement.

**Rule-based regimes:** Legislator sets the rules. Emphasizes compliance rather than outcomes. Slow to respond. Less emphasis on continuous improvement. Less workforce involvement.

19. Explain the importance of safety in HSE management through a schematic illustration.



20. Calculate the risk ranking for each department?

| Exposure dept | Hazard score | Control score | Property value ( $\times 10^3$ ) | Business interruption cost ( $\times 10^3$ ) | Composite score |                    |
|---------------|--------------|---------------|----------------------------------|----------------------------------------------|-----------------|--------------------|
|               |              |               |                                  |                                              | Personnel       | Exposure (dollars) |
| A             | 257          | 304           | 2900                             | 1400                                         | 900             | 5200               |
| B             | 71           | 239           | 890                              | 1200                                         | 653             | 2743               |
| C             | 181          | 180           | 1700                             | 720                                          | 1610            | 4030               |
| D             | 152          | 156           | 290                              | 418                                          | 642             | 1350               |
| E             | 156          | 142           | 520                              | 890                                          | 460             | 1870               |
| F             | 113          | 336           | 2910                             | 3100                                         | 1860            | 7870               |

A-1, C-2, E-3, D-4, B-5, F-6.

21. Influx of fluids from the formation into the wellbore is called as .....

Well kick

22. Offshore reserve that can't economically support installation of fixed drilling and production platforms is called as .....

Marginal field

23. What are the challenges in offshore drilling?

(a) Complex operations (b) Innovative equipments (c) Skilled labor (d) All of the above

(d) Complex operations, innovative equipments, skilled labor

24. Influx of fluid from the formations into wellbore is called:

(a) Dispersion (b) Diffusion (c) Well kick (d) Blowout

(a) Dispersion

25. ....maintain control over potential high-pressure condition that exists in the formation.

BOP

26. What are the important factors in drilling from a safety point of view?

System design is "complete integration of all parts into the whole which should be considered in the beginning itself." Consultations are required between field development engineers, equipment

manufacturers, service engineers, maintenance engineers, drilling companies, reservoir engineers, etc.

27. List different problems associated with offshore drilling operations. Also comment on the recent development of alternate drilling techniques to improve safety in operations.

- Highly complex and technically challenging operation.
- Uses innovative equipments and techniques.
- Require highly special individuals to design/execute the drilling operation.

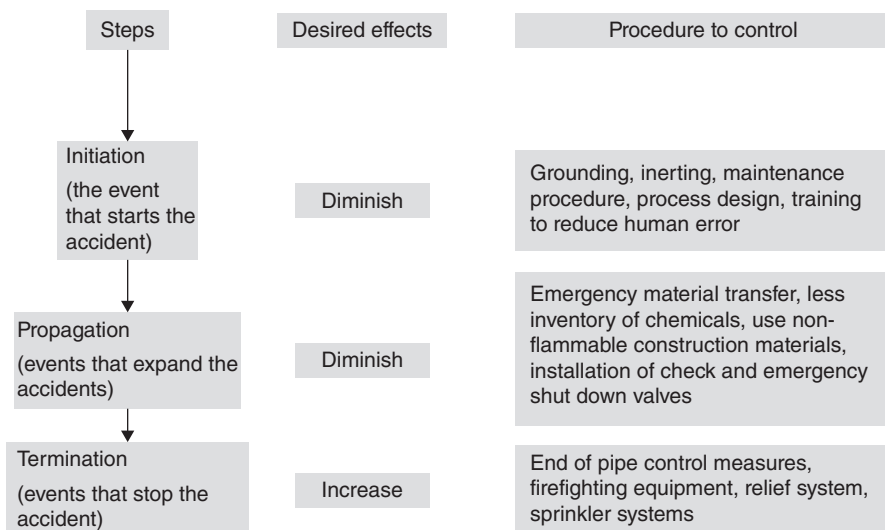
28. Three systems are commonly used as a measure of accident. What are they? Name them. Also indicate the most important common feature between them.

- OSHA (Occupational Safety and Health Administration, US Dept of Labor)
- Fatal Accident Rate (FAR)
- Fatality rate or deaths per person per year
- All three methods report number of accidents and/or fatalities for a fixed number of working hours during a specified period.

29. What are the steps taken to defeat an accident process? List different types of risk, as identified in risk analysis studies.

Different types of risk includes strategic, financial, compliance, operations.

#### Defeating accident process



30. What are the advantages and disadvantages of through the leg drilling?

**Advantages**

- Early production for improved cash flow
- Several wells in a leg can be completed and placed in production
- Drilling rig moves to a well cluster in another leg
- When wells in the 2nd leg are drilled and completed, they can be placed in production
- Continuous flow is maintained
- Time and money savings if two rigs are used
- Use a normal rig for drilling and lighter rig for completion works
- While completion rig completes the work while drilling proceeds in another leg well cluster
- Elapsed time can be reduced
- Cost savings—due to reduced on-site requirement of heavier drilling rigs

**Disadvantages**

- Limited to size of the completion equipment used
- Major limitation
- Number of wells that can be practically installed in a given leg

31. ....is first step in all risk assessment or QRA study.

HAZID

32. If the hazard evaluation shows low probability and minimum consequence, then the system is called as .....

Gold plated

33. ....identifies potential hazards and operability problems due to deviations.

HAZOP

34. ....is a logical, structured process that can help identify potential causes of system failure, such as causes of initiating events or failure of barrier systems.

FTA

35. .... is a most commonly used probabilistic analysis method used for hazard identification.

FTA

36. Which one of them is a primary keyword?

- (a) More            (b) Reverse            (c) Erode            (d) Fluctuation  
(c) Erode

37. What is a HAZARD?

- (a) Where an accident is likely to happen  
(b) An accident waiting to happen  
(c) Something with the potential to cause  
(d) The likelihood of something going wrong  
(c) Something with the potential to cause

38. What are the different hazard identification methods? Explain them briefly.

- Process hazard checklists
- Hazard surveys
- HAZOP
- Safety review

39. Explain about hazard control, hazard evaluation, and hazard monitoring.

**Hazard control:** Sometimes hazard can be eliminated altogether, but most often measures have to be put in place to manage hazard efficiently and it also helps to be systematic. This is a step-by-step procedure which starts from the big ones, like whether to repair or upgrade the equipment and working down until you find a practical solution.

**Hazard evaluation:** Hazard evaluation can be performed at any stage. If the hazard evaluation shows low probability and minimum consequence, then the system is called gold-plated. Potentially unnecessary and expensive safety equipment and procedures are implemented in the system.

**Hazard monitoring:** Hazard controls need to be reviewed periodically to make sure they are still effective and appropriate. This can be part of your

regular safety inspections. Talking with staff and the Joint Health and Safety Committee (if you have one) is an excellent way to start to get an idea about how well controls are working and what could be done even better. Some questions to consider when reviewing hazard controls are:

- Is the hazard under control?
- Have the steps taken to manage it solved the problem?
- Are the risks associated with the hazard under control too?
- Have any new hazards been created?

40. What is meant by hazard analysis?

- Identification of undesired events that led to materialization of a hazard
- Analysis of the mechanisms by which these undesired events could occur
- Estimation of the extent, magnitude, and likelihood of any harmful effects

41. .... is a rating corresponding to seriousness of an effect of a potential failure.

Severity

42. The objective of FMEA is on .....and not on.....

Failure prevention, and detection

43. Write short notes on HAZID and its limitations (if any).

- Deals with engineering failure assessment
- Evaluate the reliability of specific segments of a plant operation
- To determine probabilistic results of failure
- Faulty tree analysis is one such common form of engineering failure assessment
- Limitations: It is not identified until an accident occurs

44. Name one method of hazard evaluation used for mechanical and electrical systems.

FMEA

45. What do you understand by a weak link? This is required to be identified in what kind of hazard studies?

- Weak link will be the one that has the highest rank of failure
- Do a detailed analysis of the components present in the weak link
- One may also re-design to reduce the probability of failure of the components in the weak link.

This is identified while conducting FMEA

46. Name two types of FMEA.

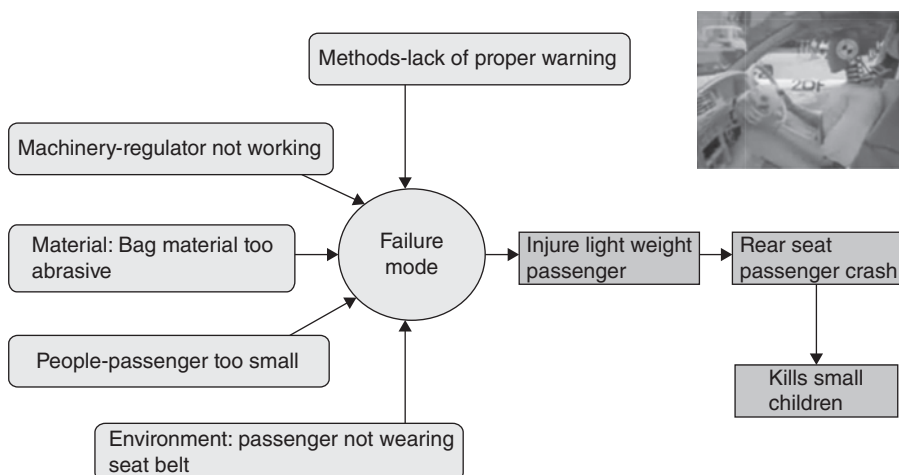
Design FMEA, Process FMEA

47. What advantages HAZOP has when applied to a new design?

- HAZOP supplements the design ideas with imaginative anticipation of deviations. These may be due to equipment malfunction or operation error.
- In the design of new plants, designers overlook few issues related to safety in the beginning. HAZOP highlights these errors.
- HAZOP is an opportunity to correct these errors before such changes become too expensive or impossible. HAZOP methodology is widely used to aid LOSS PREVENTION.
- HAZOP is a preferred tool of risk evaluation

48. Draw a FMEA cause and effect diagram for an airbag used in passenger car.

**FMEA cause and effect diagram**  
**Example 2 — air bag in passenger car**

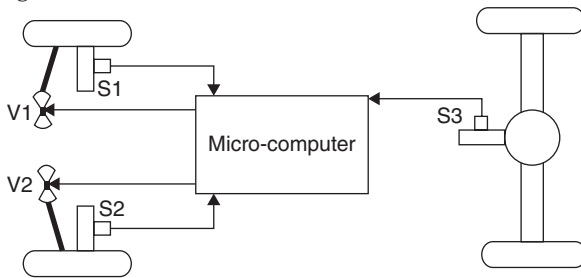


49. Explain full recording and recording by exception.

**Full recording:** Later practices were to report everything. Each keyword is clearly stated as applied to the system under study. Even statements like “no cause could be identified” or “no consequence arose from the cause recorded” are seen in these statements.

**Recording by exception:** In earlier HAZOP reports, only potential deviations with some negative consequences were recorded. Also, for handwritten records, it certainly reduces the time—both in study itself and subsequent production of HAZOP report. In this method, it is assumed that anything that is not included is deemed to be satisfactory.

50. Conduct FMEA analysis for the anti-skid braking system. The figure shows the layout plan of passenger car anti-skid braking system. Objective is to prevent locking of front wheels during heavy braking under bad road conditions. Speed sensors S1 and S2 measure the speed of two front wheels. S3 measures speed of the drive shaft. This also indicates speed of the rear wheel. Signals from three speed sensors are fed to a microcomputer. If the speed of front wheels fall significantly low, indicating application of brakes, then valves V1 and V2 are opened to reduce the braking force.



FMEA-anti-skid braking system of Car

| Component                 | Failure mode     | Failure effect                                                                                                                                           | Comment                                                                            |
|---------------------------|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| Front wheel sensor S1, S2 | No output signal | Computer will assume that one wheel has stopped.<br>Sends a signal to open relief valve on that wheel.<br>Results in partial loss of front wheel braking | Uneven braking on front wheels<br><br>Alarm system required to switch off computer |
| Front wheel valves V1, V2 | Fail to open     | One front wheel could lock on heavy braking                                                                                                              | Not desired.<br>Test facility required                                             |
|                           | Fail to close    | Partial loss of front brake                                                                                                                              | Uneven braking on front wheels<br>Additional stop valve required?                  |

| Component             | Failure mode                                   | Failure effect                                                                                                                                            | Comment                                      |
|-----------------------|------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|
| Rear wheel sensor, S3 | No output signal                               | Microcomputer will have no reference speed from rear wheel<br><br>Will not attempt to close V1 or V2<br><br>Both front wheels could lock on heavy braking | Alarm system required                        |
| Microcomputer         | No output signals to either front wheel valves | Both front wheels could lock on heavy braking                                                                                                             | Alarm system required                        |
|                       | No output signal to one front wheel valve      | One front wheel could lock on heavy braking                                                                                                               | Alarm system required                        |
|                       | Spurious output to both front wheel valves     | Total loss of front wheel braking                                                                                                                         | Alarm system required to switch off computer |
|                       | Spurious output to one front wheel valve       | Partial loss of front wheel braking                                                                                                                       | Alarm system required to switch off computer |

## Model Paper

1. Identify major ways to prevent accidents resulting from fire and explosions.
2. Three systems are commonly used as a measure of accidents. What are they? Name them. Also indicate the most important common feature between them.
3. Define individual risk and societal risk.
4. What do you understand by acceptable risk? As an employee of an oil industry, how do you react to the term acceptable risk?
5. You are given two options to reach Station A from Station B.
  - (a) You wish to drive the complete distance of 2200 km at an average speed of 45 km/h to reach Station A by road;
  - (b) alternatively you plan to fly and reach Station B by a commercial airlines in 2½ h.

*Answer the following questions:*

1. Which travel is the safest, based on the FAR in general? Explain. Refer table for fatalities of different modes of transport.
2. What is the fatality rate for the safest trip?
3. Suppose you travel by car at an average speed of 60 km/h, do you think FAR will change? Will it increase or decrease? Guess the answer to this question on the basis of calculations did for the previous questions.

Justify your answer without working out the FAR in detail.

| Activity          | FAR (deaths/10 <sup>8</sup> h) |
|-------------------|--------------------------------|
| Staying at home   | 4                              |
| Traveling by car  | 57                             |
| Bicycle riding    | 96                             |
| Traveling by air  | 240                            |
| Motorcycle riding | 660                            |
| Rock climbing     | 4000                           |

6. An employee works in a process industry with an FAR of 4. This industry has normal working hours. As the employee gained experience in his

trade, he wishes to change his job. Another oil and gas company abroad offered him a job. The work agreement of the new company says that his working hours are only 4 hours per shift and he will have to work only for 200 days in a year.

- For your reference, see table showing the FAR for different industries
- The employee is confused as he foresees a higher risk rate in oil and gas industry compared to the current process industry where he is employed. But he expects a good financial gain.

Answer the following:

- Should the employee opt for change in his job? Being an HSE consultant, should you advise him to do so, explain the basis on which you will work out his safety in the new job.
- Suppose the employee wants to shift back to his original employer after his abroad assignment is over, should you advise him to bargain toward his working hours so that he faces the same fatality rate as that of his recent abroad assignment? If so, state briefly your advice to him.

Table: FAR for industry

| Industry             | FAR |
|----------------------|-----|
| Chemical industry    | 2   |
| Factory work         | 4   |
| Coal mining          | 8   |
| sea fishing          | 40  |
| Offshore oil and gas | 62  |
| Steel fabricators    | 70  |