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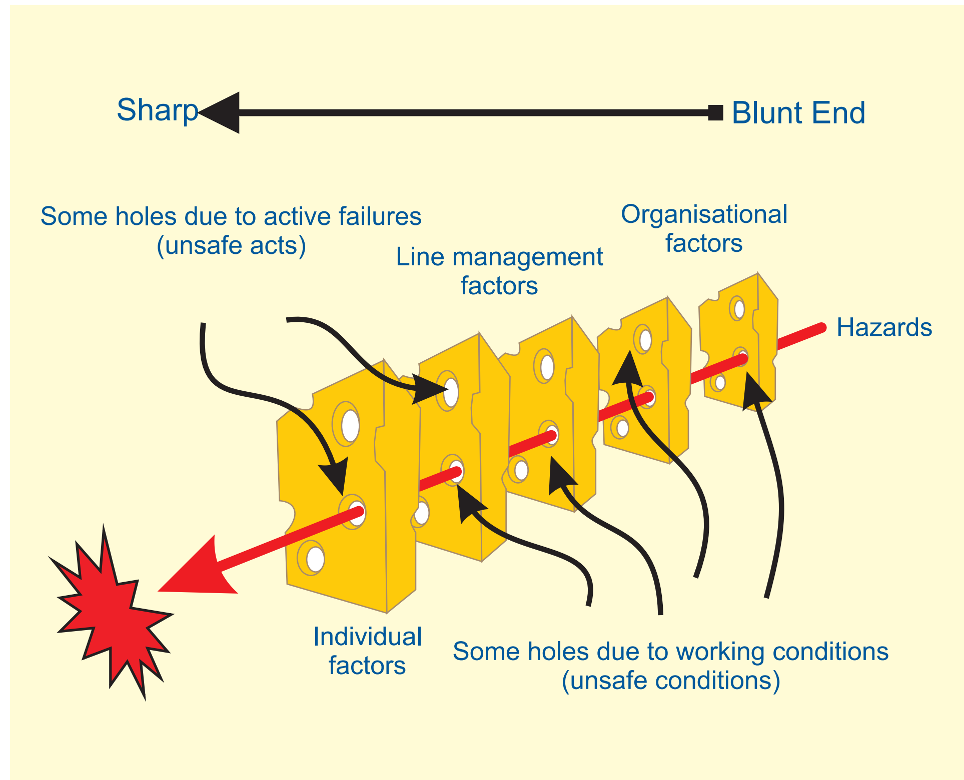
Theme - 6

Accident Causation : Models and Theories

industrial Disaster Risk Management



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Disaster Management Institute (DMI) Bhopal
The Disaster Management Institute (DMI) was set up in 1987 by the Government of Madhya Pradesh (GoMP) as an autonomous organization in the aftermath of the industrial disaster in Bhopal.
Since inception, DMI has built vast experience in preparation of both On-site and Off-site Emergency Management Plans, Safety Audit, Risk Analysis and Risk Assessment, Hazard and Operability Studies (HAZOP), etc.
The National Disaster Management Authority (NDMA) constituted under the chairmanship of the Prime Minister selected DMI as a member of the Core Group for preparation of the National Disaster Management Guidelines- Chemical Disaster.
It is a matter of pride that NDMA has selected DMI for conducting Mock Exercises on chemical (industrial) Disaster Management at key industrial locations in the country.
The Ministry of Environment and Forests, InWEnt and gtz-ASEM Germany have recognized DMI as a Nodal Training Institutes for capacity building in industrial Disaster Risk Management.

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Contents

This module is useful for :-

- Those who wants to know the accident models
- Accident investigating agencies and regulatory agencies who are responsible for accident investigation
- Administrators who are responsible for further action on accident investigation

1. History

Before we go for the serious business of accident or disaster causations we have to examine the Bhopal and Seveso chemical tragedies.

1.1 Bhopal, India

December 2/3 night, 1984 was very unfortunate for the city of Bhopal in Madhya Pradesh, India. In midnight, a poisonous gas cloud escaped from the Union Carbide India Limited (UCIL) pesticide factory. The cloud contained methyl isocyanate (MIC), covering a big area of Bhopal city. The gas leak killed thousands of local residents instantly and caused health problems for millions of people. These health problems killed again thousands of victims in the years that followed. It is said that people still suffer from chronic diseases consequential to gas exposure, till today. Research conducted by a number of agencies pointed out that this disaster will still cause people to fall ill every year. This event is now known as the worst industrial environmental disaster to ever have been occurred in the whole world.

The cause of the accident has been researched after the disaster. Apparently water ended up in MIC storage tanks, causing an exothermal reaction that released an amount of poisonous gas large enough to open the safety valves. Normally scrubbers would intercept escaping gas, but these were temporarily out of order for repair.

Research showed that factory personnel neglected a number of safety procedures. There were no valves to prevent water from entering the storage tanks. The cooling installation of the tanks and the flaring installation that might have flared the gas that was released were out of order (fig. 1).

Safety was very low in this factory of Union Carbide, compared to its other locations. The safety procedures were neglected because of budget cuts.

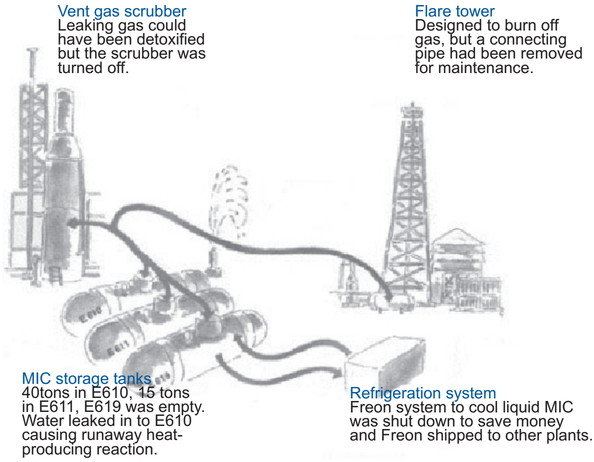


Fig 1: Overview of events that led to the Bhopal disaster

Union Carbide was accused of deliberate evasion of regular safety procedures. During lawsuits where victims demanded compensation, documents were revealed which proved that Union Carbide regularly used untested technology in the Bhopal factory. When the gas leak occurred doctors were not informed of the nature of the gas. This caused the correct treatment and emergency measures to be held off.

In 2001 Dow Chemical Company took control of Union Carbide. These take-overs led to a discussion on responsibility for cleaning up the tons of poisonous waste that are still present in the environment consequential to the 1984 disaster. Environmental activists are trying to convince Dow Chemical Company to clean up this potential minefield of toxic chemicals. These could cause nervous system failure, liver and kidney disease and possibly cancer for many years to come.

Photo-1

Today, the location is still polluted with thousands of tons of toxic chemicals, such as hexachlorobenzene and mercury. These chemicals are stored in open barrels. Rainfall causes rinsing out of pollution to local drinking water sources. Local residents still suffer from a number of diseases, which appear to be very uncommon among people that do not live in the disaster area.

The tank from which gas leaked is still laying in the premises and is shown as photo-1. Scrubber and flair tower are shown as photo-2 and 3 respectively.

Photo-2

Photo-3

1.2 Seveso, Italy

On midday of July 10, 1976 an explosion occurred in a TCP (2,4,5-trichlorophenol) reactor in one of the chemical companies in Meda, Italy. A toxic cloud escaped into the atmosphere containing high concentrations of TCDD, a highly toxic form of dioxin. Downwind from the factory the dioxin cloud polluted a densely populated area of six kilometres long and one kilometre wide, immediately killing many animals. A neighbouring municipality that was highly affected is called Seveso. The accident was named after this village. The dioxin cloud affected a total of 11 communities.

Seveso is a major disaster like Bhopal and Chernobyl, However, the Seveso story is remarkably different when it comes to handling the pollution and the victims because earlier accidents had shown dioxin to be an extremely dangerous substance. Polluted areas were researched and the most severely polluted soils were excavated and treated elsewhere. Health effects were immediately recognized as a consequence of the disaster and victims were compensated. A long-term plan of health monitoring has been put into operation. Seveso victims not only suffered from a directly visible symptom known as chloracne (see picture), but also from genetic impairments.

The Seveso accident and the immediate reaction of authorities led to the introduction of European regulation for the prevention and control of heavy accidents involving toxic substances. This regulation is now known as the Seveso Directive. This Directive is a central guideline for European countries for managing industrial safety. The Council of Ministers of The European Committee adopted the Directive in 1982. It obligates appropriate safety measures, and also public information on major industrial hazards, which is now known as the 'need to know' principle.
Bhopal tragedy happened in midnight while Seveso disaster in the midday.

2. Concept of safety

In order to understand the accident causation, it is necessary to consider what is meant by "safety".

Depending on one's perspective, the concept of safety may have different connotations, such as:

a) zero accidents (or serious incidents);
b) the freedom from danger or risks, i.e. those factors which cause or are likely to cause harm;
c) the attitude towards unsafe acts and conditions by employees (reflecting a "safe" corporate culture);
d) the degree to which the inherent risks in industry are "acceptable";
e) the process of hazard identification and risk management; and
f) the control of accidental losses (of persons and property, and damage to the environment).

Safety is the state in which the risk of harm by accident to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and risk management.

3. Basic models of accident causation

3.1 What people thought for accidents

Accidents theories and models have been developed by considering the following views from different groups about the accident causation:

➡ One group of professional proposes the theory of multiple causation and include the following reasons:

- Inadequate maintenance.
- Poorly designed equipments.
- Untrained employees.
- Lack of policy enforcement or standard procedures (management control).

➡ According to other group of professionals the following causes of accidents are advocated:

- Mechanical failure due to improper tools or equipments design, size or application.

- Health factors, physical limitations or physical incompatibility with the job.
- Mental inability to perform the task, which includes attention deficit caused by the tedium of mundane jobs that is aggravated by a higher intelligence or inquisitiveness.
- Lack or misuse of safety equipments or incorrect specifications for devices such as fire extinguishers, mechanical safeguards, personal protective equipments, fall protection equipments, rollover protection cages, handrails, warning labels and barriers.
- Inadequate ergonomic design.
- Physical stress induced by working in high noise environments, in prolonged temperature extremes and under conditions of labour fatigue.
- Inadequate operational controls.

➡ Other professionals are of the view of the following different set of opinions:

- Lack of management support.
- Poorly orchestrated downsizing or expansion.
- A management style that appoints a safety manager and committees to solve the accident problem. Such an arrangement is almost always indicative of weak management arising from a lack of accountability.
- Gloominess in the workplace.
- The use of incorrect management logic, as in the following examples: (i) management commitment is the key to success; in fact, management action is the key to success. (ii) poor employee attitudes cause accidents; actually, poor management practices cause poor employee attitudes. (iii) accidents drive costs; in fact, claims drive costs.
- Diminished employee confidence in management's ability to provide safety due to a lack of programmes, too many programmes or half-baked, half-hearted, ineffective programmes for regulatory compliance. Abandonment of major programmes or negligence regarding stated plans has a demoralizing effect.
- Not implementing total quality management (TQM) or implementing it incorrectly.
- Lack of personal job fulfillment, inadequate or ineffective training. Conversely, there is the myth that "trained people will work safely".
- Lack of safe working procedures implementation.
- Chemical impairment.
- Risk-taking behaviour among personnel who are either inherently high-risk takers or have risk-taking personalities.
- Lack of shared safety responsibility.
- Inadequate hiring strategies.
- Inadequate physical communication systems and personal communication skills.
- Physical and mental illness of workers, including such ailments as heart disease, untreated diabetes, untreated epilepsy, depression, homicidal or suicidal

tendencies or chemical dependency. Suicide, for example, performed at work in a way that appears to be an accident is better compensated than suicide away from work that is made to look accidental. Homicides at work are frequently more difficult to identify and prove than homicides outside of work.

- Sleep deficit and shift reassignment affecting the normal life.
- Fraud.
- No incentive programmes or inadequate incentive programmes.

➡ Other group is of the following views:

- "act of God"
- Some would claim that accidents can be caused by a lack of spiritual fitness. People who do not maintain a degree of spiritual fitness will find it difficult, if not impossible, to incorporate safety as part of their personal regimen.
- Luck.
- Weather.

The above views from different groups can be concluded by saying that accidents occur due to wrong decisions by senior management, lack of management's foresight for right policies and programmes, weakness in monitoring of the day to day safety issues, workers health, workers behaviour and working conditions, incentives, weak regulations and monitoring, missing communication in all tiers, lessons from past accidents, money savings, and so on, etc.

The Bhopal is probably the site of the greatest industrial disaster in history and was a result of a combination of failure of legal, technological, organisational, and human behaviour.

3.2 Development process

Accident causation models are originally developed in order to assist people who had to investigate accidents, so that such accidents could be investigated effectively. Knowing how accidents are caused is also useful in a proactive sense in order to identify what types of failures or errors generally cause accidents, and so action can be taken to address these failures before they have the chance to occur. The Incident Ratio Pyramid was developed by researchers, based on data from a wide range of industrial accidents. They suggested that for every serious major injury there were an increasing number of minor injuries, property damage events and incidents with no visible injury or damage. These incidents could be seen to display a fixed relationship. This relationship has been subsequently validated by other work, and although the ratios have varied to a small extent, this concept has formed the basis of safety management systems. However, more recent work by a number of groups indicates that there is a different ratio pyramid where process safety incidents are concerned

(Fig 2). Process safety incidents are typically less frequent, have greater potential for harm, and 'near misses' are not as obvious. The barriers that need to be defeated to result in a process safety incident are also different from those which are relevant for an occupational safety incident.

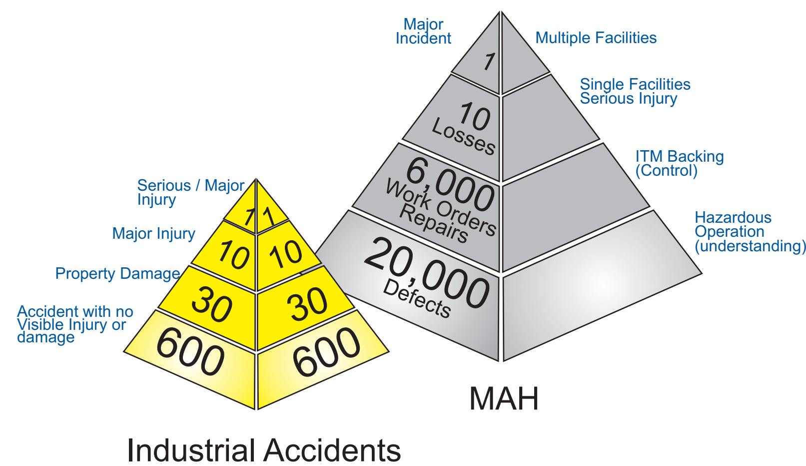


Fig 2: Incident ratio pyramid

In terms of incident investigation the approaches to occupational incidents need to be adapted to be able also to address process safety incidents. This adaption is necessary to allow the consideration of the complex people, plant and management system barriers that prevent, detect, control and mitigate process hazards.

Accident models provide a conceptualisation of the characteristics of the accident, which typically show the relation between causes and effects. They explain why accidents occur, and are used as techniques for risk assessment during system development, and for post accident analysis to study the causes of the occurrence of an accident and further measures to control the accidents.

Most of the engineering models originated before the introduction of digital technology; these models have been updated but have not kept pace with the fast change in technological revolution. Modern technology is having a significant impact on the nature of accidents, and this requires new causal explanatory mechanisms to understand them and in the development of new risk assessment techniques to prevent their occurrence.

3.3 Domino theory

Heinrich's Domino Theory states that accidents result from a chain of sequential events, metaphorically like a line of dominoes falling over (Fig 3). When one of the dominoes falls, it triggers the next one, and the next…but removing a key factor (such as an unsafe condition or an unsafe act) prevents the start of the chain reaction.

What are Unsafe Conditions and Acts?
According to Heinrich, all incidents directly relate to unsafe conditions and acts, which he defines as "unsafe performance of persons, such as standing under suspended loads ... horseplay, and removal of safeguards"; and "mechanical or physical hazards such as unguarded gears ... and insufficient light." These have been described in details in human behaviour and errors in the Theme 7.

The Dominoes
Heinrich posits five metaphorical dominoes labelled with accident causes. They are Social Environment and Ancestry, Fault of Person, Unsafe Act or Mechanical or Physical Hazard (unsafe condition), Accident, and Injury. Heinrich defines each of these "dominoes" explicitly, and gives advice on minimizing or eliminating their presence in the sequence.

- Social Environment and Ancestry: This first domino in the sequence deals with worker personality. Heinrich explains that undesirable personality traits, such as stubbornness, greed, and recklessness can be "passed along through inheritance" or develop from a person's social environment, and that both inheritance and environment (what we usually refer to now as "nature" and "nurture") contribute to Faults of Person.

- Fault of Person: The second domino also deals with worker personality traits. Heinrich explains that inborn or obtained character flaws such as bad temper, inconsiderateness, ignorance, and recklessness contribute to accident causation. According to Heinrich, natural or environmental flaws in the worker's family or life cause these secondary personal defects, which are themselves contributors to Unsafe Acts, or and the existence of Unsafe Conditions.

- Unsafe Act and/or Unsafe Condition: The third domino deals with Heinrich's direct cause of incidents. As mentioned above, Heinrich defines these factors as things like "starting machinery without warning ... and absence of rail guards''. Heinrich felt that unsafe acts and unsafe conditions were the central factor in preventing incidents, and the easiest way of accident avoidance is by lifting one of the dominoes out of the line. The theory didn't provide any space for modern factors like computer applications and networking failure or Information Technology failure.

Heinrich defines four reasons why people commit unsafe acts "improper attitude, lack of knowledge or skill, physical unsuitability, and improper mechanical or physical environment." He later goes on to subdivide these categories into "direct" and "underlying" causes. For example, he says, a worker who commits an unsafe act may do so because he or she is not convinced that the appropriate preventive measure is necessary, and because of inadequate supervision. The former he classifies as a direct cause, the latter as an underlying cause. This combination of multiple causes, he says, create a systematic chain of events leading to an accident.

- Accident: Heinrich says, "The occurrence of a preventable injury is the natural culmination of a series of events or circumstances which invariably occur in a fixed and logical order." He defines accidents as, "events such as fall of persons, striking of persons by flying objects are typical accidents that cause injury."

- Injury: Injury results from accidents, and some types of injuries, Heinrich specifies in his "Explanation of Factors", are cuts and broken bones.

To be fair to Heinrich, he does insist that "the responsibility lies first of all with the employer." Heinrich specifies that a truly safety-conscious manager will make sure his "foremen" and "workers" do as they are told, and "exercise his prerogative and obtain compliance ... follow through and see the unsafe conditions are eliminated." Heinrich's remedy for such non-compliance is strict supervision, remedial training, and discipline.

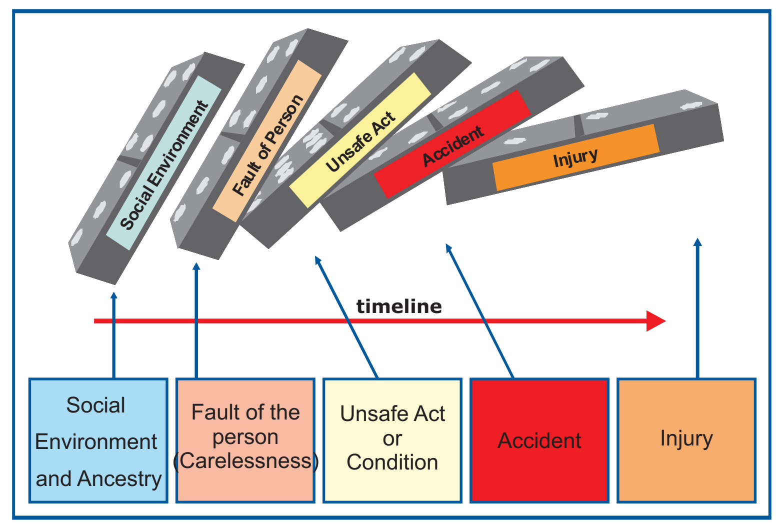


Fig 3: Heinrich's Domino Model of accident causation

3.4 Swiss Cheese Accident Models

An excellent account of this work has been provided by Reason, which emphasises the concept of organisational safety and how defences (protection barriers such as material, human and procedures) may fail. In this approach the immediate or proximal cause of the accident is a failure of people at the “sharp end” who are directly involved in the regulation of the process or in the interaction with the technology . Reason defines accident as situations in which latent conditions (arising from management decision practices, or cultural influences) combine adversely with local triggering events (weather, location, etc.) and with active failures (errors and/or procedural violation) committed by individuals or teams at the sharp end of an organisation, to produce the accident. The dynamics of accident causation are represented in the Swiss Cheese Model of Defences (Fig 4), which shows an accident emerging due to holes (failures) in barriers and safeguards at each level.

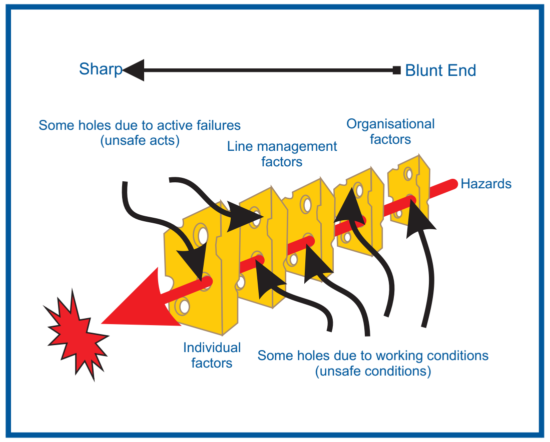


Fig 4: Reason's Swiss Cheese Model of Defences

The notion of latent factors supports the understanding of accident causation beyond the proximate causes, which is particularly advantageous in the analysis of complex systems that may present multiple-failure situations. Reason's model shows a static view of the organisation; whereas the defects are often transient i.e. the holes in the Swiss cheese are continuously moving. The whole socio-technical system is more dynamic than the model suggests.

The Swiss cheese model is well suited to complex chemical process production systems, where a hierarchical organizational structure tends to exist (managers, front-line personnel, physical and operational barriers, etc).

Fig 5. describes the basic structural elements identified further in the model, as:

Decision makers: These include high-level managers, who set goals and manage strategy to maximize system performance (e.g. Policy productivity and safety).
Line management: These include departmental managers, who implement the decision makers' goals and strategies within their areas of operation (e.g. Production, training, sales, etc).
Preconditions: These refer to qualities possessed by people, machines and the environment at the operational level (e.g. a motivated workforce, reliable equipments, organizational culture, environmental conditions, etc).
Productive activities: These refer to actual performance at operational levels.
Defence: These refer to safeguards and other protections that deal with foreseeable negative outcomes, for example by preventing such outcomes, protecting the workforce machines, environment etc.

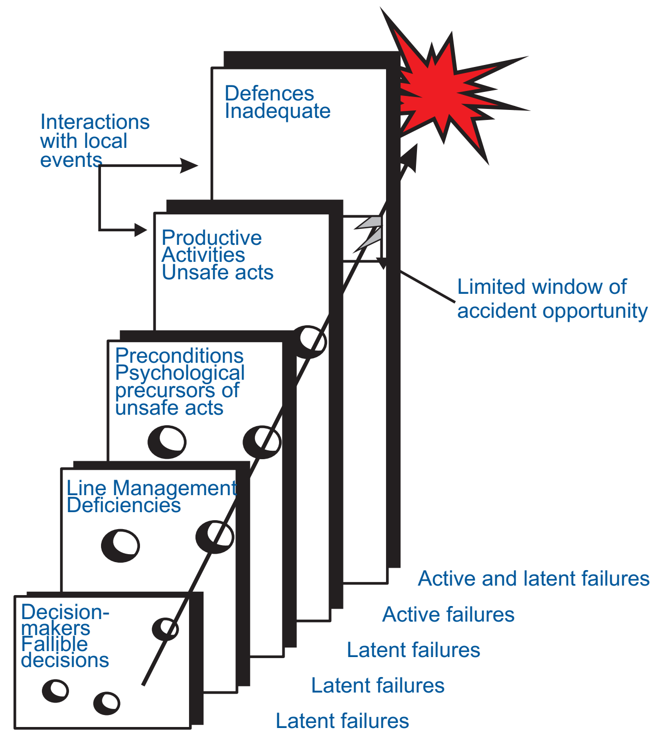


Fig-5: Structural elements of cheese model

Accidents occur because weaknesses or "windows of opportunity" open in all levels of the production system, allowing a chain of events to start at the upper echelons of the structure and move down, ultimately resulting in an accident, if it is not stopped at any level. Said otherwise, most (if not all) accidents can be traced back to weaknesses in all levels of the system, including the decision makers' level.

These weaknesses or "windows of opportunities" can be due to different factors, such as mechanical or technical failures, although, unfortunately, the human factor seems to be the most frequent or most traceable source of most accidents. These weaknesses, thus, map onto the normal structure, and, therefore, are particular to each organizational level. Human weaknesses in the system can be listed as follows:

- Fallible decisions at decision makers' level.
- Line management deficiencies at line management levels.
- Psychological precursors of unsafe acts at precondition levels.
- Unsafe acts at production levels.
- Inadequate defences at the defense level.

3.5 System model of accident causation

System model proposes the failure in coordination of three systems i.e. man, machine and environment as shown in Fig 6. This model has been used for many years by people at all levels in organisations from supervisors to safety managers to investigate incidents .

This model highlights the reliability of interaction of man, machine and environment. Understanding and addressing these causal factors that lead to accidents is necessary to develop effective accident prevention strategies. The model takes a system's view of accidents. It focuses on how the characteristics of the production system generates hazardous situations and shape, the work behaviours and analyzes the conditions that trigger the release of the hazards. The model is based on descriptive rather than prescriptive models of work behaviours and takes into account the actual production behaviors, as opposed to the normative behaviours and procedures that workers "should" follow. The model identifies the critical role of task unpredictability in generating unexpected hazardous situations, and acknowledges the inevitability of exposures and errors. The model identifies the need for two accident prevention strategies: (1) reliable production planning to reduce task unpredictability, and (2) error management to increase the workers' ability to avoid, trap and mitigate errors. This model contributes to safety research by increasing understanding of the production system factors that affect the frequency of accident. The practical benefit of the model is that it provides practitioners with strategies to reduce the likelihood of accidents and also guide to review the whole system for the suitable risk reduction options.

System Theory Model

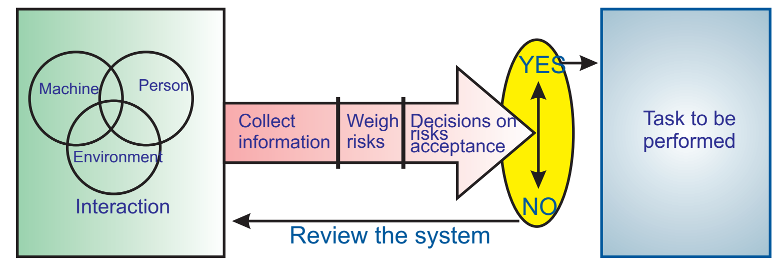


Fig 6: System model

The model advocates the proper assessment of cumulative hazards during the interaction of three systems and guides the risk assessment before taking decision of doing work.

3.6 The pure chance theory

According to the pure chance theory, every one of any given set of workers has an equal chance of being involved in an accident. It further implies that there is no single discernible pattern of events that leads to an accident. In this theory, all accidents are treated as corresponding to Heinrich's acts of God, and it is held that there exist no interventions to prevent them.

3.7 Biased liability theory

Biased liability theory is based on the view that once a worker is involved in an accident, the chances of the same worker becoming involved in future accidents are either increased or decreased as compared to the rest of workers. This theory contributes very little, if anything at all, towards developing preventive actions for avoiding accidents.

3.8 Accident proneness theory

Accident proneness theory maintains that within a given set of workers, there exists a subset of workers who are more liable to be involved in accidents. Researchers have not been able to prove this theory conclusively because most of the research work has been poorly conducted and most of the findings are contradictory and inconclusive. This theory is not generally accepted. It is felt that if indeed this theory is supported by any empirical evidence at all, it probably accounts for only a very low proportion of accidents without any statistical significance.

3.9 The energy transfer theory

Those who accept the energy transfer theory put forward the claim that a worker incurs injury or equipment suffers damage through a change of energy, and that for every change of energy there is a source, a path and a receiver. This theory is useful for determining injury causation and evaluating energy hazards and control methodology. Strategies can be developed which are either preventive, limiting or ameliorating with respect to the energy transfer. Control of energy transfer at the source can be achieved by the following means:

- elimination of the source
- changes made to the design or specification of elements of the work station
- preventive maintenance.

The path of energy transfer can be modified by:

- enclosure of the path
- installation of barriers
- installation of absorbers
- positioning of isolators.

The receiver of energy transfer can be assisted by adopting the following measures:

- limitation of exposure
- use of personal protective equipment.

3.10 Modern theory of accident

According to modern thinking, accidents require the coming together of a number of enabling-factors each one necessary but in itself not sufficient to breach system defences. Major equipment failures or operational personnel errors are seldom the sole cause of breaches in safety defences. Often these breakdowns are the consequence of human failures in decision-making. The breakdowns may involve active failures at the operational level, or latent conditions conducive to facilitating a breach of the system's inherent safety defences. Most accidents include both active and latent conditions.

Fig 7. portrays an accident causation model that assists in understanding the interplay of organizational and management factors (i.e. system factors) in accident causation.

Various “defences” are built into the plant system to protect against inappropriate performance or poor decisions at all levels of the system (i.e. the front-line workplace, the supervisory levels and senior management). This model shows that while organisational factors, including management decisions, can create latent conditions that could lead to an accident, they also contribute to the system's defences.

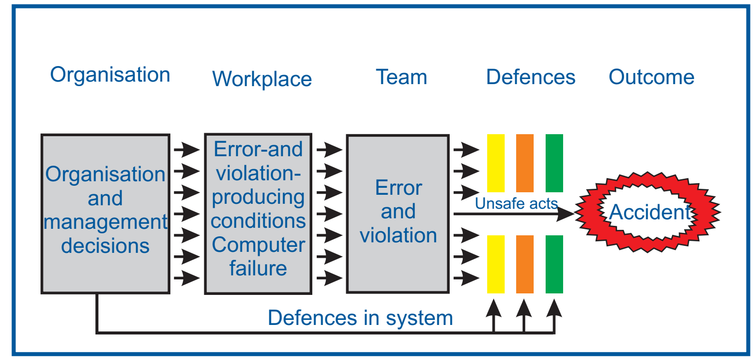


Fig 7: Modern theory of accident

Errors and violations having an immediate adverse effect can be viewed as unsafe acts; these unsafe acts may penetrate the various defences put in place to protect the system by company management, the regulatory authorities, etc., resulting in an accident. These unsafe acts may be the result of normal errors, or they may result from deliberate violations of prescribed procedures and practices. The model recognizes that there are many error- or violation-producing conditions in the work environment that may affect individual or team behaviour.

These unsafe acts are committed in an operational context which includes latent unsafe conditions. A latent condition is the result of an action or decision made well before an accident. Its consequences may remain dormant for a long time. Individually, these latent conditions are usually not harmful since they are not perceived as being failures in the first place.

Latent unsafe conditions may only become evident once the system's defences have been breached. They may have been present in the system well before an accident and are generally created by decision-makers, regulators and other people far removed in time and space from the accident. Front-line operational personnel can inherit defects in the system, such as those created by poor equipment or task design; conflicting goals (e.g. service that is on time versus safety); defective organisations (e.g. poor internal communications); or bad management decisions (e.g. deferral of a maintenance item). Effective safety management efforts aim to identify and mitigate these latent unsafe conditions on a system-wide basis, rather than by localized efforts to minimize unsafe acts by individuals. Such unsafe acts may only be symptoms of safety problems, not causes.

Even in the best-run organisations, most latent unsafe conditions start with the decision-makers. These decision-makers are subject to normal human biases and limitations, as well as to very real constraints of time, budget, politics, etc. Since some of the unsafe decisions cannot be prevented, steps must be taken to detect them and to reduce their adverse consequences.

Fallible decisions by line management may take the form of inadequate procedures, poor scheduling or neglect of recognizable hazards. They may lead to inadequate knowledge and skills or inappropriate operating procedures. How well line management and the organisation as a whole perform their functions sets the scene for error- or violation-producing conditions. For example, how effective is management with respect to setting attainable work goals, organizing tasks and resources, managing day to-day affairs, and communicating internally and externally? The fallible decisions made by company management and regulatory authorities are too often the consequence of inadequate resources. However, avoiding the costs of strengthening the safety of the system can facilitate accidents that are so expensive as to bankrupt the operator.

The domino theory found that 88 per cent of accidents are caused by unsafe acts of people, 10 per cent by unsafe conditions and 2 per cent by 'acts of God'.

4. Structure of accidents

After having a view of various models to understand the accidents or disasters we have to ask key questions on following to correlate the fig 8 of structure of accident:-

- Lack of control: Do a system has adequate programmes, standards, compliance and monitoring for all regulations of safety concerned?
- Basic causes: Do a proper system is placed to control immediate unsafe acts and unsafe conditions?
- Contributing/immediate factors: Do a system is in place to control substandard acts and practices, poor working conditions?
- In absence of the above an incident may happen and if not noticed in time with proper remedial actions it may incubate in a disaster.
- Do proper preparedness, response is in place to take care of victims, property and environment? If not then it should be ensured that proper post disaster plan should be in place including the arrangement for detailed investigation to know the causes of accident.

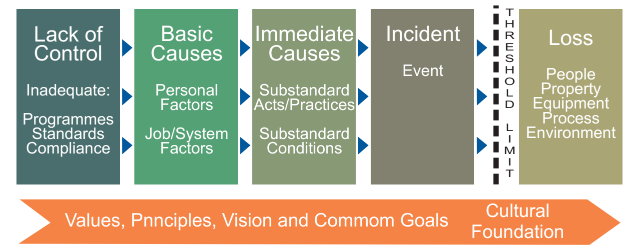


Fig 8: Structure of Accidents

The belief that accidents are caused and can be prevented makes it imperative for us to study those factors which are likely to favour the occurrence of accidents. By studying such factors, the root causes of accidents can be isolated and necessary steps can be taken to prevent the recurrence of the accidents. These root causes of accidents can be grouped as “basic” and “immediate” / “contributing”. The immediate causes are unsafe acts of the worker and unsafe working conditions. The contributing causes could be management-related factors, the environment and the physical and mental condition of the worker. A combination of causes must converge in order to result in an accident.

Fig 8. shows the structure of accidents, including the details of immediate causes, contributing causes, types of accidents and results of accidents. This accounting is not exhaustive by any means. However, an understanding of the “cause and effect” relation of the accident-causing factors is required before continuous improvement of safety processes can be undertaken.

5. Control of accidents

To control the accidents the following two theories are applied in general:-

5.1 Seven Avenues theory

After discussing all models it can be concluded that there are following seven avenues to initiate the counter measures:

- Safety management error
- Safety programme defect
- Management / Command error
- System defect
- Operating error
- Mishap
- Consequence

Safety management error: For this avenue the attention should be on

- Training
- Education
- Motivation
- Task design

Safety program defect: This avenue addresses about proper data collection and analysis before data are applied for removing the defects and hence the following should be the key issues:

- Information revision
- Data collection
- Data analysis and application in implementation

Management / Command error: For the management and control of any possible error or incidents the importance of training cannot be ignored. Training may not have desired impacts in error control mechanism if minimum basic education is missing. Various serious tasks of task design is needed with proper motivation. In brief, the effective management of error can be reduced with the following:-

- Training and education
- Review and monitoring
- Risk assessment and reduction
- Job safety design

System defect: To overcome the system defects either engineering modification is required at the early with revised and effective standard operating procedures (SOPs), or proper enforcement of national regulations and company policy/statements by circulars

- Design revision
- SOP
- Enforcement and monitoring of regulations and company policy

Operating error: It has been observed that operating errors lead to small accidents and if these small accidents have not been properly addressed, then any one of the small accident may become a major accident. The operating error can be controlled effectively by:

- Engineering control
- Training and awareness
- Motivation

Mishap: After having all avenues at their appropriate places when the accident occurs then only the following ways helps in reducing the damages of the accidents:

- Protective equipments
- Barriers
- Separations

Consequence: Any accident has certain short term and a few long term impacts on human lives, environment and property. Hence to reduce the effect of consequences the following issues should be reviewed rigorously by all stakeholders including the civil authorities:-

- Containment
- Firefighting
- Rescue, evacuation and rehabilitation
- First aid

5.2 Barriers theory for control accidents

A key stage in any accident model is establishing the barriers that failed as well as those that worked. Barriers can take a number of different forms; normally technical (physical), administrative (procedures), or people-based (training, competence, etc). There are also 'fortunate mitigating circumstances'. Time of day or night and weather (including wind direction) have played a part in reducing the effects of consequence of the release of hazardous chemicals of some major incidents but they should never be relied upon as a normal barrier as they cannot be controlled.

Once securing evidence, data collection, and interviews are completed, creating a time-line is normally the next stage in any Process Safety Incident Investigative Technique. From the time-line a probable sequence of events can be established and discrepancies, omissions and areas to explore further can be identified. It tracks the sequence of events and barriers present and therefore allows all the relevant barriers to be identified. It then identifies which barriers worked effectively, which worked partially, and which failed completely. In a typical process safety incident there will be barriers in all these categories. Further techniques can then be used to identify root causes for barrier failures and hence management system failures.

Barrier theory can be applied to understand the Bhopal disaster. Event was the leak of MIC gas from a tank and it could have been prevented to become disaster if this leak could have been controlled by proper effective barriers functioning. Technical barrier (physical) by ensuring the proper functioning of refrigeration, scrubber function and flair tower. All these three failed because proper technical thought was not given that if MIC comes out how it can be controlled.

For process safety there are multiple barriers of disparate types and therefore a more sequential approach is needed. The most powerful approach has been to apply a formal root cause technique to each failed barrier in turn. This may seem time-consuming, but experience has shown that each barrier failure is typically due to a small sub-set of management system failures. Therefore it is relatively quick to analyse each barrier with the benefit of more rigorous analysis. Bhopal accident can be understood in Fig 9. by applying barrier theory.

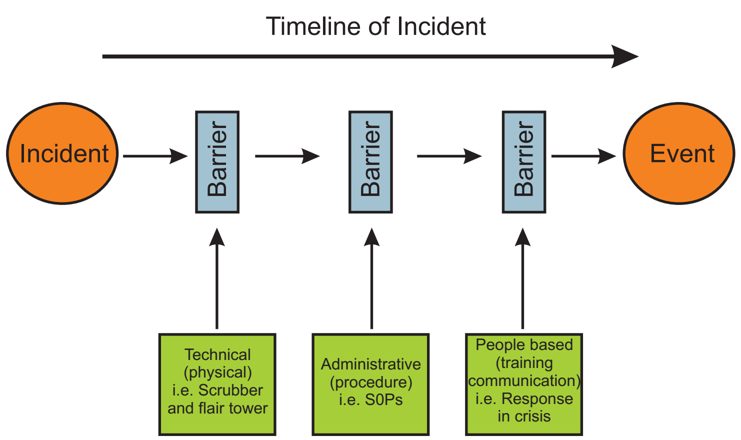


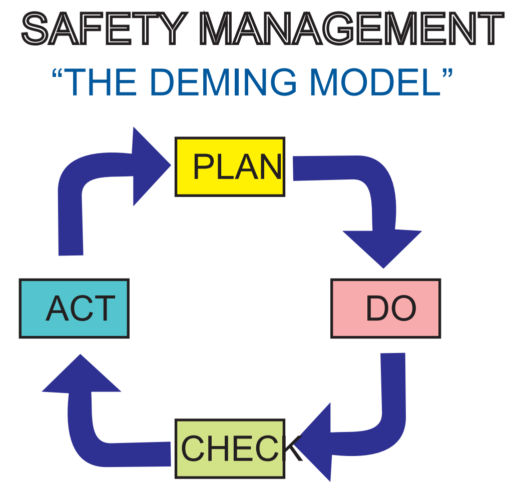
Fig 9: Elements of Barriers theory

Once all root causes for the individual barrier failure are determined, the results can be collated to provide the overall assessment. At this point an approach with a pre-worked checklist of specific, defined, root causes ideally linked to management system elements becomes a powerful tool, since common root causes (those which under-pinned several barrier failures) become immediately apparent. This is an important management insight because it highlights those areas which should be addressed to strengthen the management system. If this process is repeated over time for each incident that occurs, a repeating picture of the common management system failings can be identified. With sufficient data this can be applied retrospectively. Fig 9. shows a barrier pattern for all three types to control any accident.

5.3 Deming Model

"The Safety Management System" should set out the safety objective of the system by which the objectives are to be achieved, and the performance standards which are to be met and the means by which adherence to the standard is to be monitored.

The approach of Quality Management Model sometimes called "Deming Model" or "PDCA" , as shown below, is a complete loop system. This will ensure that the standard or quality will be achieved and the effectiveness of the management system is well monitored and improved continuously within the system.



The following checklist will help in understanding and implementing the PDCA:

a) Organizational issues: An organisation should review the following:-

1) time pressures to sustain on-time operations to achieve goals ;
2) ageing equipments requires intensive inspections for fatigue, corrosion, overall condition, etc.;
3) new technologies requiring new tools, new work procedures, retraining, etc.;
4) "fix-it" focus to stay on schedule (e.g. replacing broken parts without determination as to why);
5) outsourcing of services to subcontractors;
6) unwitting introduction of (lower cost, substandard) bogus parts, etc.; and
7) licensing and regulatory clearances.

b) Work site conditions: Work site conditions should also be examined thoroughly:-

1) plant designs that are not user-friendly from a maintenance perspective;
2) control equipments and calibration (which are continually subject to modifications) versus standardization of maintenance tasks and procedures;
3) availability (and accessibility) of spares, tools, documentation, etc.;

4) requirements for having ready access to voluminous technical information, and the need for maintaining detailed work records;
5) variable environmental factors (for example, too hot or noise or less illumination, etc. in the technical workshops and process areas); and
6) unique operating conditions created by concurrent activities and inclement weather.

c) Human Factors in maintenance: Human behavior can be influenced by :-

1) organizational and working conditions (as described above);
2) environmental factors (e.g. temperature, lighting and noise);
3) individual factors (e.g. workload, physical demands and maintenance);
4) scheduling (e.g. shift work, night work and overtime) versus adequacy of rest periods;
5) appropriateness of SOPs (e.g. correctness, understandability and usability);
6) quality of supervision;
7) proper use of job cards, etc. (i.e. do actual floor practices comply with SOPs?);
8) adequacy of formal training, on-the-job training (OJT), recurrent training and human factors training;
9) adequacy of handovers at shift changes and record keeping;
10) boredom; and
11) cultural factors.

6. Checklists

The following checklist will help in reducing accidents

The Management
Directors and Department Heads and Managers or any other person who has charge of a workplace or authority over a worker are responsible to :-

- Complete all documentation in accordance with regulatory requirements and procedures.
- Be informed of any accidents/incidents/near misses that occur in their area of responsibility and report these to the EHSO (environment, health and safety office) and local authorities in accordance with regulatory requirements.
- Ensure investigations are conducted in a respectful, responsive and sensitive manner as to effectively identify hazards and identify improvements.
- Listen carefully, act honestly and fairly and communicate openly in order to achieve effective and positive results.
- Ensure an investigation is conducted in a sensitive, responsive and effective manner in order to minimize the impact of the workplace injury.

- Conduct investigations into accidents/incidents/near misses in a timely manner.
- Ensure corrective actions and effective measures are identified and instituted as soon as is practicable to ensure the safety of other employees and community.

The Employees
Employees are responsible to:-

- Report promptly any accidents, incidents or near misses to their supervisor.
- To assist and cooperate with those persons undertaking an investigation, in order to identify causes and unsafe conditions.
- Complete all documentation in accordance with regulatory requirements and procedures.

Members of Health and Safety Committees
It is the responsibility of members of a Health and Safety Committee to:

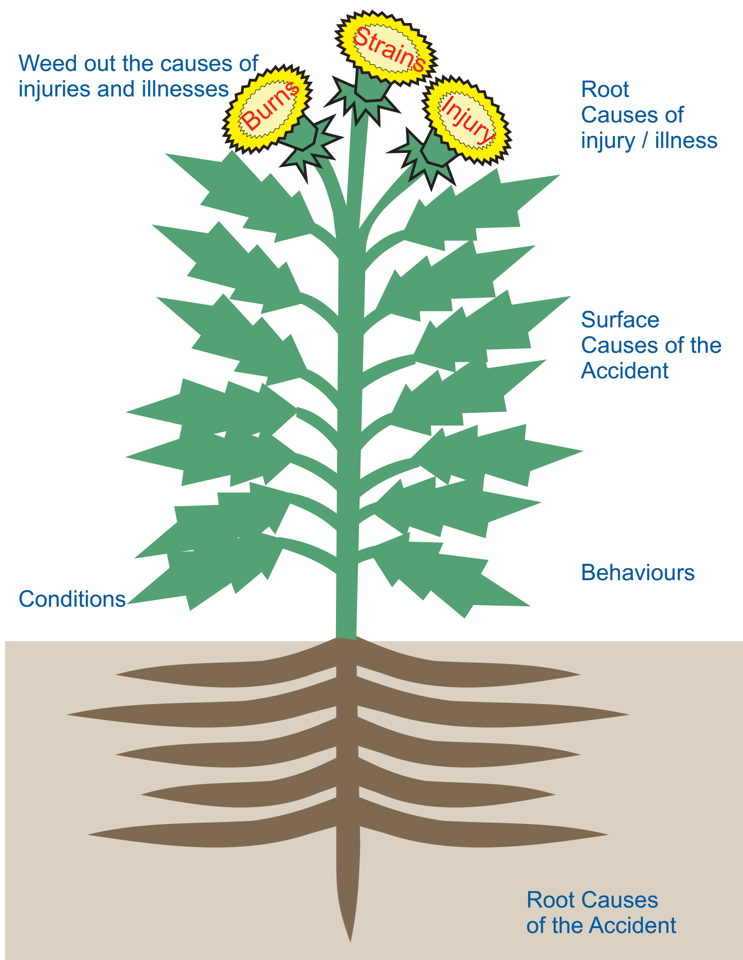
- Assist in conducting an investigation into an accidents/incidents/near miss, when requested by a supervisor or the EHSO.
- Participate in the investigation in a respectful, responsive and sensitive manner.
- Assists with identifying hazards and making recommendations for the improvement of workplace conditions.

Supervisor's Responsibilities
Supervisors are advised to see the following:-

- In the event of a serious accidents/incidents/near misses, ensure proper medical treatment is provided.
- Contact EHSO if emergency assistance is required and identify the type of assistance required.
- Report the incident immediately to Environmental Health and Safety Office (EHSO).
- Secure the accident scene and maintain it undisturbed, until a member of the Environmental Health and Safety Office arrives to assist . Security can provide tape to rope off the scene and assist to secure the area.
- If necessary, evacuate the area in accordance with emergency requirements.
- Supervisor is to complete and submit the following documentation as required:
  -Accidents/incidents/near misses Form.
  -Workers Compensation Claim and Employer Accident Report as per the format.
  -Worker's Capabilities Form to be given to Employees who are seeking a medical help for a sickness or injury and may require modified duties hours.
- Help should be sought for help from the District Collector and rehabilitation should be ensured.

7. Summary

We can conclude the whole module by the following diagram where all causes, injury and illness, surface causes, root causes are linked.
Workout and identify the root causes, working conditions and human behaviours in your workplace which may lead to causes of accidents and injuries.



8. Exercise on recent accidents

8.1 Case 1: Accident in USA

Incident:
On March 23, 2005, at 1:20 p.m., the BP Texas City Refinery suffered one of the worst industrial disasters in recent U.S. history. Explosions and fires killed 15 people and injured another 180, alarmed the community, and resulted in financial losses exceeding $1.5 billion. The incident occurred during the startup of an isomerization (ISOM) unit when a raffinate splitter tower was overfilled; pressure relief devices opened, resulting in a inflammable liquid geyser from a blowdown stack that was not equipped with a flare. The release of inflammables led to an explosion and fire. All of the fatalities occurred in or near office trailers located close to the blowdown drum. A shelter-in-place order was issued that required 43,000 people to remain indoors. Houses were damaged as far away as three-quarters of a mile from the refinery.

The BP Texas City facility is the third-largest oil refinery in the United States. Prior to 1999, Amoco owned the refinery. BP merged with Amoco in 1999 and BP subsequently took over operation of the plant.

Incident Description
On the morning of March 23, 2005, the raffinate splitter tower in the refinery's ISOM unit was restarted after a maintenance outage. During the startup, operations personnel pumped inflammable liquid hydrocarbons into the tower for over three hours without any liquid being removed, which was contrary to startup procedure instructions. Critical alarms and control instrumentation provided false indications that failed to alert the operators of the high level in the tower. Consequently, unknown to the operations crew, the 170-foot (52-m) tall tower was overfilled and liquid overflowed into the overhead pipe at the top of the tower.

The overhead pipe ran down the side of the tower to pressure relief valves located 148 feet (45 m) below. As the pipe filled with liquid, the pressure at the bottom rose rapidly from about 21 pounds per square inch (psi) to about 64 psi. The three pressure relief valves opened for six minutes, discharging a large quantity of inflammable liquid to a blowdown drum with a vent stack open to the atmosphere. The blowdown drum and stack overfilled with inflammable liquid, which led to a geyser-like release out the 113-foot (34 m) tall stack. This blowdown system was an antiquated and unsafe design; it was originally installed in the 1950s, and had never been connected to a flare system to safely contained liquids and combust inflammable vapors released from the process.

The released volatile liquid evaporated as it fell to the ground and formed a inflammable vapor cloud. The most likely source of ignition for the vapor cloud was backfire from an idling diesel pickup truck located about 25 feet (7.6 m) from the blowdown drum. The 15 employees killed in the explosion were contractors working in and around temporary trailers that had been previously sited by BP as close as 121 feet (37 m) from the blowdown drum.

Root cause of accident

BP Group Board did not provide effective oversight of the company's safety culture and major accident prevention programs.

- inadequately addressed controlling major hazard risk. Personal safety was measured, rewarded, and the primary focus, but the same emphasis was not put on improving process safety performance;
- did not provide effective safety culture leadership and oversight to prevent catastrophic accidents;
- ineffectively ensured that the safety implications of major organizational, personnel, and policy changes were evaluated;
- did not provide adequate resources to prevent major accidents; budget cuts impaired process safety performance at the Texas City refinery.
- did not create an effective reporting and learning culture; reporting bad news was not encouraged. Incidents were often ineffectively investigated and appropriate corrective actions not taken.
- did not ensure that supervisors and management modelled and enforced use of up-to-date plant policies and procedures.
- did not incorporate good practice design in the operation of the ISOM unit. Examples of these failures include:
- no flare to safely combust inflammables entering the blowdown system;
- lack of automated controls in the splitter tower triggered by high-level, which would have prevented the unsafe level;
- inadequate instrumentation to warn of overfilling in the splitter tower;
- did not ensure that operators were supervised and supported by experienced,

technically trained personnel during unit startup, an especially hazardous phase of operation;
- did not effectively incorporated human factor considerations in its training, staffing, and work schedule for operations personnel;
- Lacked an effective mechanical integrity program to maintain instruments and process equipment. For example, malfunctioning instruments and equipment were not repaired prior to startup; and
- did not have an effective vehicle traffic policy to control vehicle traffic into hazardous process areas or to establish safe distances from process unit boundaries.

Recommendations

A few of the strategic recommendations made are:

- Identify those facilities at greatest risk of a catastrophic accident by using available indicators of process safety performance and information;
- Establish the capacity to conduct more comprehensive PSM inspections by hiring or developing a sufficient cadre of highly trained and experienced inspectors;
- Management of change (MOC) review be conducted for organizational changes that may impact process safety including:
  a. major organizational changes such as mergers, acquisitions, or reorganizations;
  b. personnel changes, including changes in staffing levels or staff experience; and
  c. policy changes such as budget cutting.

- Issue management of change guidelines that address the safe control of the following:
  a. major organizational changes including mergers, acquisitions, and reorganizations
  b. changes in policies and budgets
  c. personnel changes
  d. staffing during process startups, shutdowns and other abnormal conditions.

- Ensure and monitor that senior executives implement an incident reporting programme throughout the refinery that
  a. encourages the reporting of incidents without fear of retaliation;
  b. requires prompt corrective actions based on incident reports and recommendations, and tracks closure of action items at the refinery where the incident occurred and other affected facilities; and
  c. requires communication of key lessons learned to management and hourly employees as well as to the industry.

Exercise 1: You have to do following after studying the case 1:-

- First discuss the accident
- Apply the Domino and Swiss Cheese model

8.2 Case 2: Accident in India

Incident:
M/S.Superfine Aromatics company limited is a chemical factory located at Nanjangud, in Mysore District of Karnataka state of India. This factory is engaged in manufacturing of perfumery chemicals using hazardous chemicals viz.,toluene, Alpha pinene, acetic acid, hydrogen peroxide, ethane di sulphonic acid, soda ash, etc.

On 17.8.2001 at around 9.45 am there was an explosion in Alpha Campholenine Aldehyde plant. The HDPE drum containing an intermediate of alpha penine which was decanted from a reactor exploded instantaneously. As a result, two employees got injured by the splinters due to the blast, the injuries were of minor nature. However the severity of the blast was of high intensity which caused flash fire and damaged the complete structure including the adjacent buildings.

Investigations
Investigations conducted by the department revealed that the main causes for the said blast in subject is presumably due to the presence of foreign oxidising material in the HDPE barrel into which highly explosive peracetic acid was decanted.

Recommendations
Recommendations made to prevent such accident includes strict compliance of safety rules in handling, storing, and usage of hazardous and explosive chemicals as envisaged in the respective Material Safety Data Sheets and establishment of proper work procedures in handling such chemicals.

Exercise 2: You have to do following after studying the case 3:-
- First discuss the accident
- Apply the Domino and Swiss Cheese model

8.3 Case 3: Accident in India

Incident:

There was a chemical accident in the Urea Plant at M/s. Mangalore Chemicals and Fertilizers Limited, Panambur, Mangalore on 9.2.2000. An 8" dia high pressure pipe line housing a weldolet was connected between autoclave (urea reactor) of 108MT capacity and the stripper to carry ammonium carbamate (Urea Solution). The pressure of pipe line was of the order of 141kg/cm^2 and the temperature of 180 degree C. The Solution

contained 29% of ammonia, 18% carbon di oxide and 32% of urea. The parameters such as temperature and pressure are required to be maintained at the same level throughout the pipe line for effective transfer of urea solution. For this purpose pressure gauges and thermocouples were introduced at regular intervals and the readings were recorded.

On 9th February 2000, a substantial quantity of ammonium carbamate solution leakage was noticed at the weldolet joint of the pipeline. A maintenance manager along with two operators, an engineer and two contract workmen were trying to plug the leakage by providing a proper clamping. In the process, the weldolet joint gave way resulting in sudden release of pressurized hot ammonium carbamate solution. As a result, the personnel on the job were exposed to hot solution and toxic gas. Consequent to which, 8 persons were affected amongst them 2 died on the spot and the other two at the hospital amounting to death of 4 persons including the maintenance manager and an engineer.

Investigation

Investigation conducted under the guidance of an expert committee revealed that the weldolet used in the high pressure pipe line had high carbon content which is not suggested for that kind of a process, maintenance/repair work was undertaken on line even after noticing the hazardous solution which amounts of non implementation of shutting down procedures envisaged in the on-site emergency plan. Further the high-pressure pipeline was not subjected to hydrostatic test, ultrasonic tests and examinations as required under relevant provisions of law for its soundness. The personnel who were on the job were not wearing any personal protective equipment in addition to non-adherence to work to permit system.

Recommendations

The expert committee constituted to investigate the incident went into the details of the causes and had made the following recommendations to avert any incident in future.

1. The pipe line, connected equipment and the accessories must be subjected to Hydrostatic test as required under the relevant provision of law;
2. Weldolet must be subjected to 100% examination to detect corrosion and the soundness;
3. Maintenance/repair works shall not be undertaken on line, it shall be done only as per standard maintenance procedure drawn up before hand;
4. Permit to work system shall be strictly adhered to along with suitable personal protective equipment;

5. The on-site emergency plan rehearsals shall be put to rigorous tests and practiced by updating the weaknesses noticed from time to time;
6. The personnel including the contract workmen shall be put to rigorous training in handling chemical emergencies particularly to bring a change in their attitudinal behaviour of over confidence.

Exercise 3: You have to do following after studying the case 4:-

- First discuss the accident
- Apply the Domino and Swiss Cheese model

9. Glossary

- Flare tower: The flare tower is designed to burn off inflammable/toxic gases Hazard: The inherent potential to cause injury or damage to people's health.
- Hazard assessment: A systematic evaluation of hazards.
- Incident: An unsafe occurrence arising out of or in the course of work where no personal injury is caused.
- Organisation: A company, operation, firm, undertaking, establishment, enterprise, institution or association, or part of it, whether incorporated or not, public or private, that has its own functions and administration. For organizations with more than one operating unit, a single operating unit may be defined as an organisation.
- Risk: A combination of the likelihood of an occurrence of a hazardous event and the severity of injury or damage to the health of people caused by this event.
- Risk assessment: The process of evaluating the risks to safety and health arising from hazards at work.
- Scrubber: The gas scrubber is a safety device designed to neutralize vented toxic gas from the storage tank with a water or caustic soda solution.
- Worker: Any person who performs work, either regularly or temporarily, for an employer.
- Worksite: Physical area where workers need to be or to go due to their work which is under the control of an employer.

10. References

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