MINE SAFETY SCIENCE AND ENGINEERING

HEALTH AND DISASTER MANAGEMENT

FIRST EDITION

Debi Prasad Tripathy

CRC Press
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Health and Disaster Management

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Preface

Mining engineering is a dangerous profession, often associated with many health and safety hazards. Opencast and underground mines are sources of constant danger and risks to the mine workers and may result in disasters unless mining is carried out with due diligence and the strict adoption of safety legislation and safe practices. In the past few decades, great progress has been evident in the safety and health areas of the mining industry. Engineering and technical developments have contributed greatly to improvements in mining safety and health. However, the study of mine accident statistics worldwide indicates that accident and incident rates are still above the acceptable limits in many countries. This leaves scope for further improvement in reducing accident and incident rates and achieving a zero accident goal.

Mine safety engineers promote and enforce mine safety and health by developing mine safety standards, policies, guidelines, and regulations. They use their knowledge and skill of mine design and practices to ensure the safety of workers and minimize risks, thereby preventing accidents. Over the years, research in the area of mine safety has increased and there is a large number of published articles/reports available on mine safety, health, and disaster management online. However, to the best of the author's knowledge there is no text or reference book on the topic that covers recent developments in mine safety, health, and mine disaster management in any detail. This causes a great deal of difficulty for those who seek information on the subject because they have to consult many different and diverse sources. The main purpose of this book is to consolidate the desired safety information and to provide up-to-date information on the subject. The author has referred to the latest published material in the field of safety science and engineering and details of these are presented in the reference section.

This book consists of 13 chapters. Chapter 1 is devoted to important safety terms and definitions, principles of safety engineering, and the present challenging issues in mine safety. Chapter 2 presents safety issues in opencast coal and non-coal mines as well as in underground coal and non-coal mines. Chapter 3 and 4 cover the behavioral-based safety and safety culture strategies that are required to improve mine safety.

Chapter 5 presents a classification of accidents and their causes in coal and non-coal mines, methods to calculate frequency and severity rates, accident costs, and fatal and serious accident trends in Indian, South African, American, and Australian mines. This chapter also covers the process of accident investigation, accident reports, and accident prevention measures for opencast and underground mines.

Chapter 6 covers important aspects of safety risk assessment and management in mines including hazard identification, risk analysis, risk evaluation, and risk control measures. In this chapter, the qualitative, quantitative and hybrid risk assessment techniques that are suitable for managing risks in the mining industry are also discussed.

Chapter 7 presents the safety audit process and standards that are required to ensure that the legislative compliance in mining industry. Chapter 8 covers the status

of occupational health and safety in mines. This chapter also covers occupational health hazards relating to mining, occupational health and safety structure, and legislation for mines. Chapter 9 presents the types of safety education and training programs available and how they are provided in different countries.

Chapter 10 covers innovations in mine safety including virtual reality applications in the mining industry, electrical safety, the use of intrinsic safety and flameproof apparatus, the use of personal protective equipment, IT applications in the mining industry, and other safety practices followed in Indian mines as well as in other developed countries.

Chapter 11 is devoted to managing disasters in mines. This includes the classification of mine disasters, rescue operation procedures in case of disaster, emergency preparedness, and disaster management plans. Case studies of mine disasters that occurred in India and other countries are also discussed in this chapter.

The different types of rescue equipment used in mines, The Mines Rescue Rules, 1985, and methods of artificial respiration are outlined in Chapter 12. Chapter 13 presents the first aid procedures to be followed after various types accidents in mines, and the requirements for first aid training and facilities in various countries.

Mine safety engineers use innovative and practical methods for ensuring mining operations are safe and they need to constantly update their skills and knowledge in order to keep up with technological advancements in the field of mine safety science and engineering. This book will prove useful for engineering and safety professionals working in the mining industry, researchers, instructors, and undergraduate and graduate students in the field of mining engineering.

I would like to express my sincere gratitude to various authors and publishers, in particular: the Society of Mining, Metallurgy & Exploration, Colorado; the British Standards Institution, London, UK; Draeger, Lübeck, Germany; and Dr. Mehmet Kizil of the University of Queensland for granting permission to reproduce part of their published research work. I would like to thank Dr. Gagandeep Singh, Editorial Manager, and Mrs. Mouli Sharma of CRC Press for their support and help in producing this book. I would also like to thank CRC Press for agreeing to publish this book. And finally I would like to express my thankfulness to Dr. Charan Kumar Ala for his timely help and assistance in preparing and formatting this book.

Debi Prasad Tripathy
February 10, 2019

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Professor Debi Prasad Tripathy is Professor in the Department of Mining Engineering at the National Institute of Technology, Rourkela. He obtained his B.E. (Mining Engg.) from Visvesvaraya National Institute of Technology (VNIT), Nagpur; M.Tech. from the Indian Institute of Technology (IIT) (BHU), Varanasi; and Ph.D. from the Indian Institute of Technology (ISM), Dhanbad. He did his postgraduate diploma in Ecology and Environment at the Indian Institute of Ecology and Environment (IIEE), New Delhi; Master of Financial Management at Pondicherry University; and gained his postgraduate diploma in Personnel Management and Industrial Relations from Annamalai University. He acted as Head of Department, Mining Engineering during 2010–2012 and 2017–2019.

He has published around 200 research and technical papers in reputed international and national journals and conferences and has authored five books: *Noise Pollution* (APH Publishing Corporation, 2008), *Dictionary of Environmental Science*, (APH Publishing Corporation, 2013) *Dictionary of Quotations* (APH Publishing Corporation, 2012), *Dictionary of Earth Science* (APH Publishing Corporation, 2011), and *Environmental Pollution Research* (APH Publishing Corporation, 2002). His areas of teaching and research interests are mine environment and safety engineering, environmental management (air and noise), mine management, mine planning, and computer applications in the mining industry.

He is an active member of several professional bodies: Chartered Engineer (IE, India), FIE (I), FUWA, FISRMTT, LISTE, MMGMI, and LMEAI. He has visited the United States, Australia, Canada, Switzerland, South Africa, Papua New Guinea, Botswana, Thailand, Dubai, and Singapore on various academic assignments. He worked as Associate Professor at Papua New Guinea University of Technology, Lae, in 2007. He has supervised five Ph.D.s in Mining Engineering. He undertook international training for the EMCBTA project, World Bank, at the University of New South Wales, Sydney, Australia, in 2004, and Disposal and Management of Coal Combustion Residues at Southern Illinois University, Carbondale, IL.

He has been honored with: MSPI Outstanding Personalities Award, 2008; UWA Life Time Achievement Award, Chennai, 2002; Gannet Memorial Award, 2009, from IE (I); and his name is included in Marquis' *Who's Who in the World*, 2009. In view of his academic/research contributions, he has been honored with: the Abel Wolman Award of IE (I) in 2014; the URR Award, 2014 and 2015, Expert in Min. Env., MOEF; MEAI, Smt. Bala Tandon Award for significant contributions to improving Environment and Ecology in Mining, Hyderabad, in 2014; Smt. Veena Roonwal Memorial Award for contributions to Environmental Management, SGAT, Bhubaneswar, 2014; Geo-Minetech Excellence Award, 2015; MGMI, Smt. Bala Tandon Award for significant contributions to improving Quality of Life in Mine Environment, Kolkata, in September 2015. He was an examiner of PhD thesis of Monash University (Australia), Aalto University (Finland) as well as many IITs and NITs as well as being a selection committee member as subject expert in mining engineering in many state and central government bodies in India.

He was involved in a number of industrial and government sponsored R&D and consultancy projects. He conducted a good number of international/national executive training programs for industry participants in the areas of mine legislation, mine safety engineering, and mine environment. He is an editorial board member and reviewer of many prestigious international journals.

1 Basics of Mine Safety Engineering

1.1 INTRODUCTION

Ever since the beginning of industrial scale mining in the 19th century, safety has been a major concern in the mining industry. Mine workers face a number of risks to their well-being including physical, ergonomic, and psychological problems. The most common causes of fatal injuries in the mining industry include roof fall, explosion, and fire in underground mines. Over the last few decades, a great deal of effort has been put into research and practical work to understand how major accidents can be prevented. Many countries have continuously improved existing standards, framed new rules and regulations, and employed advanced technology to improve safety in mines. Yet today, the mining industry is considered as one of the most unsafe industries, due to the continuous reoccurrence of accidents around the world.

Since 1901, around 278 and 99 major accidents have taken place in Indian coal and non-coal mines, and 505 and 84 major accidents have taken place in US coal and non-coal mines respectively (DGMS, 2018b; MSHA, 2017a). The majority of these accidents were due to noxious gases, fire, explosion, inundation, and roof fall. Some of these accidents killed thousands of mine workers while some affected only a few. All accidents in mines may or may not affect the mine workers, depending on the number of workers present at the accident location. Therefore, it is necessary to understand all types of possible hazards and risks that lead to fatal, serious, and reportable accidents.

Mine safety refers to the management of operations and events within the mining industry, for protecting miners by minimizing hazards, risks, and accidents. Most of the pertinent safety issues related to mining are addressed through promulgation of the relevant legislation, compliance, and best practices that are to be considered for the best possible protection of the mine workers. Employers are expected to abide by these laws and practices to ensure the maximum observance of safety at the workplace (Safeopedia, 2018). Mine safety covers various issues that affect the safety of equipment and personnel in the mining industry. The various issues are as follows:

- general safety issues that are common to all types of mines
- workplace safety issues that are directly related to the workplace
- process and production safety issues within the processes associated with the mining
- occupational health and safety issues particularly associated with the mining
- environmental safety issues associated with underground and surface hazards
- structural safety issues associated with mine construction and geological characteristics.

Mine safety engineering is an engineering discipline that ensures that engineered systems provide acceptable levels of safety. In mine safety engineering, risk assessment concepts such as hazard identification, risk analysis, and risk evaluation are applied to mine safety issues to keep the risk level as low as reasonably possible. Therefore, to understand the structure, causes, prevention, and control methods of accidents, a knowledge of mine safety engineering concepts is required. It involves considerable planning, engineering analysis, and logical approach to manage these risks.

1.2 SAFETY NOMENCLATURE

Over the last four decades, although many international standards and guidelines have been framed to improve the safety in the mining industry, none of them have provided uniformity in the terminology to be used for safety management. The common definitions of terms used in the area of safety engineering and management are presented in Appendix A.

1.3 PRINCIPLES OF SAFETY ENGINEERING

Safety engineering is an engineering discipline that ensures that engineered systems provide acceptable levels of safety; it is a subset of system safety engineering. Safety engineering, like any applied science, is based upon fundamental principles and rules of practice. It supports risk management programming. It is the application of engineering and management principles, criteria, and techniques to optimize safety. Safety engineering involves: (i) establishing context, (ii) hazard identification, (iii) risk evaluation, and (iv) control of hazards in man-machine systems that contain a potential to cause injury to people or damage to property (Nelson & Associates, 2007).

1.3.1 Establishing Context

Establishing context is essential to define how the safety management and safety engineering tasks will be carried out to ensure that safety requirements are met. In the establishing context step, the scope and limits of the task are defined, and they must cover the entire life cycle of mining.

1.3.2 Hazard Identification

A hazard is defined as any source of potential damage, harm, or health effects to workers. Generally, a hazard when combined with some initiating event, will lead to harm. Therefore, the identification of hazards is the first and most important step in the risk assessment process. In hazard identification, all the hazards and risk factors that have the potential to cause harm are identified using system safety techniques. The most basic technique for identifying hazards is “energy analysis.” The damage or harm in any workplace cannot happen without the presence of some form of hazardous energy. Using the energy analysis technique, all the hazards related to the various

forms of energy of an activity or task can be identified by identifying the types of energies present. The energy analysis technique simplifies the task of hazard identification, as it allows the identification of hazards by means of a finite set of search paths, recognizing that the common forms of energy that produce the vast majority of accidents can be placed into only ten descriptive categories as shown in Figure 1.1.

The aim of the hazard identification step is to identify and prepare a list of potential hazards for the activity under study. Assessing and prioritizing the risk of the identified hazards will be done in the later stages of risk assessment process. The descriptions of the hazardous energy types are indicated below.

- **Chemical Energy Hazards**: Chemical energy hazards are associated with materials that are acidic, flammable, or toxic. The risks of the hazardous chemical energy are heat, pressure, fire, and explosion.

  Examples of chemical energy hazards in the mining industry are fire and explosion.
- **Electrical Energy Hazards**: Electrical energy hazards are commonly present in any workplace due to the use of electrically operated equipment and power lines. Electrical energy hazards can cause harm to workers in the following ways:
  - electric shocks
  - exposure to electric arc
  - electric burns

  Examples of electrical energy hazards in the mining industry are contact, induction, or arcing.
- **Mechanical Energy Hazards**: Mechanical energy hazards involve system hardware components that cut, crush, bend, shear, pinch, wrap, pull, or puncture. Such hazards are associated with components that move in circular, transverse (single direction), or reciprocating ("back and forth") motion. Traditionally, such hazards found in typical industrial machinery have been associated with the terms "power transmission apparatus," "functional components," and the "point of operation." Examples of mechanical energy hazards in the mining industry are being caught in moving equipment, being hit by moving machinery, and vehicle collisions.
- **Kinetic (Impact) Energy Hazards**: Kinetic energy hazards are associated with the collision of objects in relative motion to each other. This would include the impact of objects moving toward each other, the impact of a moving object against a stationary object, falling objects, flying objects, and flying particles. Examples of kinetic energy hazards in the mining industry are falling objects, falling tools, or flying rocks, etc.
- **Potential (Stored) Energy Hazards**: Potential energy hazards include things that are under pressure, tension, or compression; or things that attract or repulse one another. Potential energy hazards involve things that are susceptible to sudden unexpected movement. Examples of potential energy hazards in the mining industry are tire failure, spring pressure release, or hydraulic pressure release.

- **Thermal Energy Hazards**: Thermal energy hazards involve things that are associated with extreme or excessive heat, extreme cold, sources of flame ignition, flame propagation, and heat related explosions.
- **Radiant Energy Hazards**: As the particles moving from one source to another carry radiation, heat, and light, radiant energy is termed as a form of kinetic energy. Radiant energy hazards involve the relatively short wavelength-energy forms within the electromagnetic spectrum to include the harmful characteristics of visible, infrared, microwave, ultraviolet, x-ray, and ionizing radiation. Examples of radiant energy hazards in the mining industry are overheated mechanical equipment, refrigeration systems, radiation, or hot or cold surfaces.
- **Geological Hazards**: These hazards are associated with geological events, such as instabilities of the Earth's surface. Examples of geological hazards in the mining industry are ground collapse, and structure collapse.
- **Biomechanical Hazards**: These hazards occur when human bodies are exposed to high forces working against their own energy to move. The activities associated with biomechanical hazards are climbing, pushing, pulling, positioning, lifting, poor access, and poor housekeeping. The most common risk of biomechanical hazard is musculoskeletal disorder. Examples of biomechanical hazards in the mining industry are injury to musculoskeletal system like sprains, strains, slips, or trips.
- **Acoustic Energy Hazards**: Acoustic energy hazards involve excessive noise and vibrations. Both noise and vibration, when exposed to for a long time at the workplace will result in adverse health conditions. Noise can also be categorized as pressure energy hazards. Example of acoustic energy hazards in the mining industry involves heavy earth moving machinery and blasting.

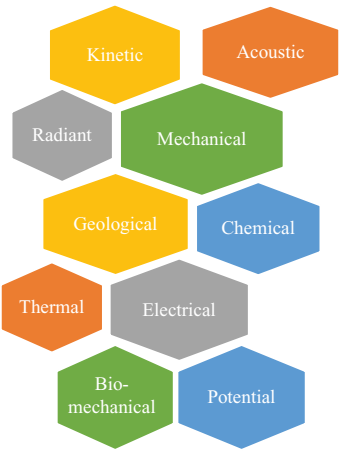

FIGURE 1.1 Types of hazardous energy sources.

1.3.2.1 Database of Identified Hazards

To develop a comprehensive database of potential hazards, record the types of energies present in the workplace and then describe the situations under which they might become a possible cause of an undesirable event. To identify the full list of energy sources and associated risks the following system safety techniques can be applied:

- brainstorming
- what-if analysis
- preliminary hazard analysis
- hazard mode and effects analysis
- fault tree analysis

The systematic understanding of "man-machine-environment" helps to identify all the hazards effectively.

- purposes and misuses of the system
- design, functions, and material properties of the system
- details of the system user, such as technical skills, physical, psychological, cultural capabilities, and education level
- details about the physical environment and administrative environment in which the system will be operated

1.3.3 Hazard Evaluation

The main purpose of the hazard evaluation step of the safety engineering process is to rank or list the potential hazards identified in the hazard identification stage. Mere identification of hazards in the identification stage does not provide information about the dangers associated with them. To understand the dangers associated with a particular hazard, the risk factors associated with the identified hazards should be examined. Risk can be measured as the product of three components: (a) the probability that an injury or damage producing mishap will occur during any one exposure to the hazard; (b) the likely severity or degree of injury or damage that will likely result should a mishap occur; and (c) the estimated number of times a person or persons will likely be exposed to the hazard over a specific period of time.

A detailed analysis of the likelihood of an accident can be expressed as the Probability (P), Exposure (E), and Consequence (C) of an accident.

Therefore,

$$R = (P \times E) \times C$$

The danger of an incident is a combination of hazard and risk.

$$D = H \cdot R$$

$$D = H(P \times E \times C)$$

where
H = Hazard
D = Danger of incident

Probability is the likelihood of an accident with a given hazard. Exposure is the extent to which the risk can have an effect, and consequence is determined as the most probable results of a potential accident, including injuries and property damage. Based on the assessment of these three elements the risks of the identified hazards (a hazard being a source, situation, or act with the potential for harm in terms of human injury or ill health, or a combination of these) are calculated and ordered. The equation $R = (P \times E) \times C$ must take into account every accident event, even when it has only a remote probability, a rare chance of exposure, or possibility of minor injury.

1.3.3.1 Acceptable vs. Unacceptable Risk

Practically, risk cannot be reduced to zero due to factors such as secondary risks and their associated costs. Based on the risk evaluation of the hazard, a risk can be categorized into an acceptable risk group or an unacceptable risk group. Acceptable risks are the risks that would be deemed tolerable by rational, well-informed, and ethical individuals, organizations, or community groups. Unacceptable risks are the risks that would be deemed intolerable by rational, well-informed, and ethical individuals, organizations, or community groups. Hazards associated with acceptable risks are traditionally called "safe" and hazards associated with the unacceptable risks are traditionally called "unsafe." Based on the risk evaluation, the unacceptable hazards and risks are dealt with in the hazard control step of the safety engineering process.

1.3.4 Hazard Control

The main aim of safety engineering is the control of system hazards, which may cause system damage or system user injury. Accidents can be prevented by adopting control measures at machine, human, or environment levels. The hierarchy of control measures was established by the authoritative safety literature as well as by logic and sound engineering practices. The hierarchy of controls is as follows

- **Eliminate hazards**: Complete elimination of hazards can be very expensive and may not be practical. If the complete elimination is not possible or economically feasible, then the next control technique should be followed.
- **Replace the hazard with less the hazardous substitute**: This control is similar to eliminating the hazard, but instead the high-risk equipment is replaced with less hazardous equipment. For example, in many mines it was recommended to replace risky rope haulages with belt conveyor systems for material transportation.
- **Isolate people from hazards using physical safeguards**: This control limits the exposure of workers to the hazards. Examples of physical safeguards in mines are barriers, safety devices, adequate lighting, fences, or lock-out tags.

If the above measures fail to remove the hazards and provide safety, the hazards can be controlled through the following measures:

- **Change the way people work by developing and using adequate warnings and instructions**: This control involves increasing awareness regarding the types of hazards present, developing safe operating procedures, providing effective communication, displaying warning signals, audio video alarms, etc.
- **Protect the workers with personal protective equipment (PPE)**: In this control method, the workers are provided with personal protective equipment such as hard hat, safety belt, cap lamps, boots, safety jacket, hand gloves, noise cancellation headphones, etc. This control is the least effective method of all the control methods.

The elimination of hazards is the most effective control measure and the use of personal protective equipment is the least effective control measure.

1.4 THEORIES OF ACCIDENT CAUSATION

An accident is defined as an unplanned and undesired event, typically resulting in injury or damage. Generally, dynamic events, including an amalgamation of causative factors, leads to accidents. The causative factors activate the pre-existing hazards, the activated hazards then move through the main system in a logical path of events, factors, and circumstances to result in a loss event or accident. From the accident process, it is clear that the probable causative factors are the main cause of accidents occurring. Therefore, properly controlling or preventing the probable causative factors at the early stage of the system life cycle could prevent the accidents. The unsafe conditions and the unsafe acts are the probable causative factors.

The causes of accidents can be producing or proximate. A producing cause means a cause that, in a natural or continuous chain of causes, produces an event; and without the producing cause, the accident would not have occurred. A proximate cause is a producing cause that is reasonably foreseeable before it produces an accident event. Based on this, accidents can be classified as foreseeable and unforeseeable. In foreseeable accidents, the system engineering applications for hazard identification, risk evaluation, and risk control can be used to predict and prevent the probable causes. In unforeseeable accidents, the system engineering applications for hazard identification, risk evaluation, and risk control cannot be used to predict and prevent the probable causes.

Over the last few decades, many theories have emerged to explain why accidents occur in industries. Each accident-causation theory has different explanations, and predictive values are used to prevent accidents (ELearning, 2006). In simple terms, accident-causation theory hypothesizes that injuries result from a series of different factors, in which one of them leads to an accident. The most common accident-causation theories are presented in Figure 1.2. Accident-causation models were originally developed

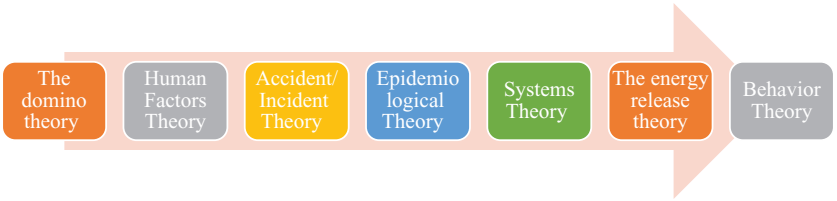

FIGURE 1.2 Accident-causation theories.

in order to assist people who had to investigate occupational accidents, so that such accidents could be investigated effectively. The prior knowledge of the causes of accidents helps to identify the types of errors or failures that could lead to the accidents and hence to take the necessary actions to control such errors proactively.

1.4.1 The Domino Theory

H. W. Heinrich, a safety engineer and pioneer in the field of industrial accident safety, developed the domino theory, as shown in Figure 1.3. This theory was prominent from 1950 to 1980. In the domino theory, various factors are considered as if they are a series of dominos standing on an edge and each factor is dependent on the past factor. When one factor falls, then the factors fall as a chain reaction. The final domino, i.e. personal injury, occurs only because of an accident. An accident occurs only because of an unsafe act or unsafe condition. An unsafe act or unsafe condition occurs because of the fault of a person's carelessness, or because of poor design or improper maintenance of equipment. Faults of persons are inherited from their social environment or ancestry. And social environment or ancestry is where and how a person was raised and educated.

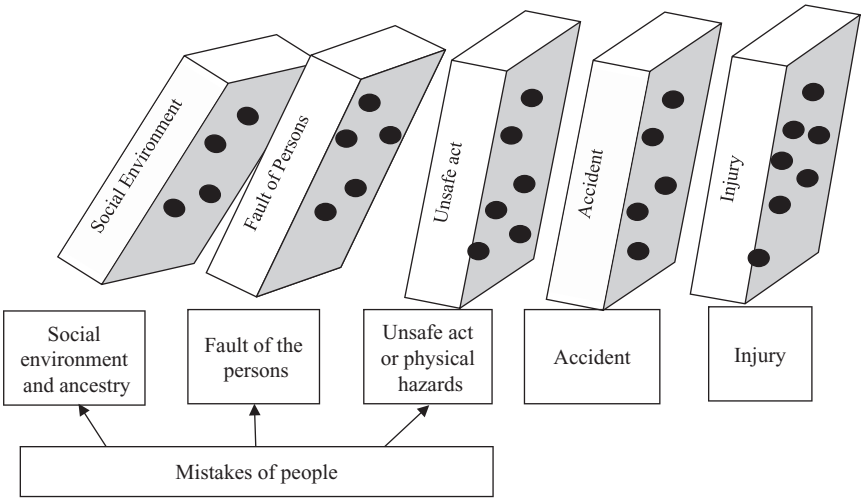

FIGURE 1.3 The domino theory.

Some experts claim that domino theory is the basis for behavior-based safety theory, which holds that as many as 88% of all accidents are caused by unsafe acts of people, 10% by unsafe actions, and 2% by "acts of God." Therefore, accidents can be avoided in the workplace by removing one of the dominos, especially the unsafe acts or unsafe conditions (Hollnagel, 2009). The suggested corrective actions are as follows:

- **Engineering**: Change the system design to control hazards.
- **Education**: Give workers training regarding all facets of safety. Impose on management the awareness that attention to safety pays off.
- **Enforcement**: Ensure that workers as well as management follow internal and external rules, regulations, and standard operating procedures.

1.4.2 Human Factors Theory

Dr. Russell Ferrell, Professor of Human Factors at the University of Arizona, has presented the human factors theory (Doshti, 2016). This theory portrays human errors as the causes that lead to a chain of events, which consequently lead to accidents. The human errors are categorized broadly as overload, inappropriate worker response, and inappropriate activities, as shown in Figure 1.4.

The factors affecting *overload* are as follows:

- **Load**: Work task is beyond the capability of the worker. The influencing factors are
  - internal factors – stress, worry
  - environment – noise, illumination
  - situational – uncertain goals, danger
- **Capacity**: State of mind, physical condition, training, drugs, pressure
- **State**: Motivational level and arousal level

The factors affecting *inappropriate worker response* are

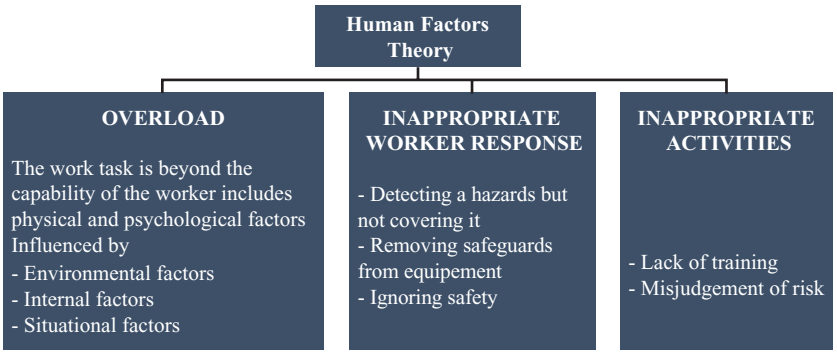

FIGURE 1.4 Human factor theory.

- **Incompatibility**: due to
  - **Stimulus response**: Due to control-display
  - **Stimulus**: Due to inconsistent display types
  - **Response**: Due to inconsistent control types or location

The main influencing factos affecting *inappropriate activites* are that the worker did not know how to do it.

1.4.3 Accident/Incident Theory

Accident/incident theory is an extension of the human factors theory. Three new elements were added to the human factors theory, as shown in Figure 1.5. The new elements are

- **Ergonomic traps**: Management failures
- **Decision to err**: Personal failures
- **Systems failure**: Management failures

In this theory, *system failure* and *ergonomic traps* are the most important steps as they aid in identifying the potential for a causal relationship between management behaviors or management decisions regarding safety. Ergonomic traps include management failures such as incompatible workstations and incompatible expectations. System failure includes failures such as failure to frame policy, improper training

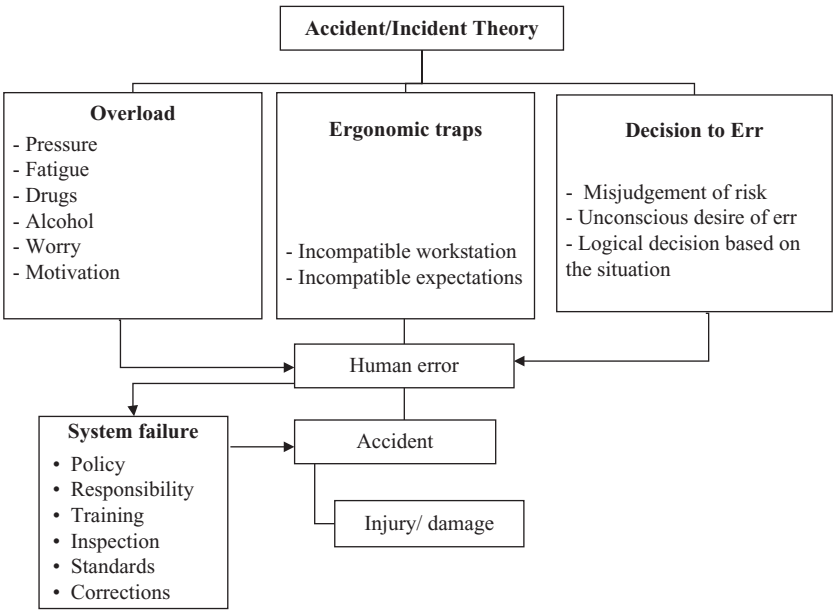

FIGURE 1.5 Accident/incident theory.

and retraining of employees, failure to comply with standards, improper responsibility assignment, and improper inspection.

1.4.4 Epidemiological Theory

The epidemiological theory studies the causal relationship between environmental factors and accident or disease. Two key components are

1. **Predisposition characteristics**: Perceptions, environmental factors, susceptibility of people
2. **Situational characteristics**: Peer pressure, poor attitude, risk taking, priorities of supervisor

These characteristics, taken together, can cause or prevent accidents as shown in Figure 1.6. For example, if a worker is susceptible (predisposition characteristics) to peer pressure (situational characteristics) to speed up his task, the result will be an increased possibility of an accident.

1.4.5 System Theory

This theory studies the systems. A system is a regularly interacting and interrelated component. In any workplace, the system is comprised of three components people, machine, and environment, as shown in Figure 1.7. Under normal circumstances the chances of an accident are low. The accident likelihood can be determined based on the interaction of the three components. Changing the interaction between the three components may increase or decrease the chance of an accident. Therefore, it is necessary to understand and address the components and their interactions in order to develop an effective accident prevention plan.

Systems theory supports the performance of risk assessment during the interaction of the three components in the system and helps in decision-making before performing the task.

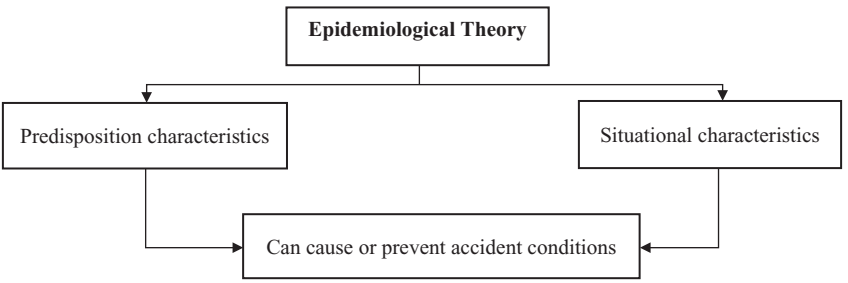

FIGURE 1.6 Epidemiological theory.

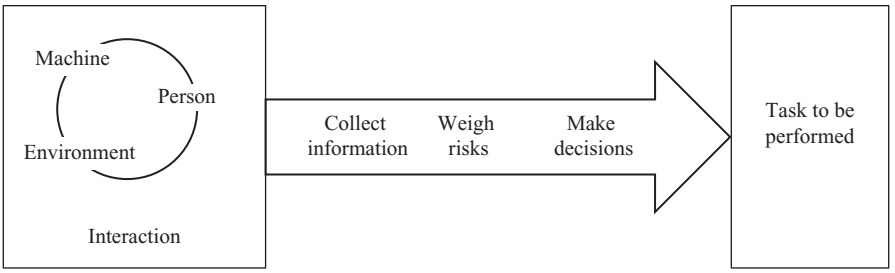

FIGURE 1.7 System theory.

1.4.6 Energy Release Theory

Energy release theory claims that injury to an employee or damage to equipment occurs when there is a change in energy. For every change in energy, there should be a source, a path, and a receiver. This theory helps in understanding injury causation and evaluating energy hazards and their control measures. The control measures can be implemented either at source for prevention or at path or target for limitation of the energy transfer, as shown in Figure 1.8.

1.5 CHALLENGING ISSUES IN MINE SAFETY

The mining industry is known worldwide for its high-risk and hazardous working environment. Technological advancement in ore extraction techniques for the enhancement of production levels has caused further concern for safety in this industry. Research in mine safety has revealed that the majority of incidents in this hazardous industry take place as a result of human error, the control of which would largely enhance safety levels in mining sites.

Working in any type of mine presents a variety of health and safety risks. Over the years, the advances in technology, legislation, and training have drastically reduced the number of accidents and injuries in the mining industry. However, many

Energy source	Barrier	Vulnerable target
• Prevent build-up of energy • Reduce the amount of energy • Prevent uncontrolled release of energy • Modify rate or distribution of the released energy • Modify the qualities of the energy	• Separate in space and time, the victims from the energy being released • Separate the victims from the energy by physical barriers	• Make the vulnerable target more resistant to damage from the energy flow • Limit the development of damage • Rehabilitate the victims

FIGURE 1.8 Haddon's energy release theory.

accidents are still occurring due to some issues that continue to cause problems (Safestart, 2017). The general challenging issues are

- lack of awareness of hazards
- inadequate assessment and management of hazards
- inadequate use of personal protective equipment
- human factors in accident causation
- improper organizational safety culture
- impact of working at depths on mine safety
- inadequate training in modern technology
- lack of proper communication when underground
- challenges in the implementation of occupational health, safety, and environmental legislation in mines
- environmental and safety problems in opencast/underground mines
- inadequate tracking of workers in emergency situations

1.5.1 Lack of Awareness of Hazards

The lack of knowledge on the part of employees, supervisors, and management about different types of hazards present in the site's working conditions is one of the major challenges in mine safety. In both underground and opencast mines, hazards vary due to different environmental conditions and machinery used. Until the 1990s, in the mining industry around the world, the training of workers was provided based on the statutory requirements of each country only. This led to a lack of awareness of hazards on the part of mine workers themselves. To improve hazard awareness, and consequently improve safety in mines, the application of risk management was recently made mandatory in the mining industries in India in 2017. Hazard identification in risk management involves identifying obvious and emerging hazards. However, a study conducted by Bahn (2013) in Western Australia revealed that workers having a high level of experience in underground mines did not guarantee their ability to identify hazards. The number of hazards identified varied from group to group. Both the experienced and new employees failed to identify most of the hazards of the workplace. Therefore, to identify obvious and emerging hazards, regular additional training should be provided to all employees and supervisors working in the mines. Additional training should also be provided when there is a change in the working conditions or working environment, or when working with new equipment or machinery, or with new working procedures.

1.5.2 Inadequate Assessment and Management of Hazards

Simple identification of hazards does not, in itself, help to improve the safety in the workplace. Managing the hazards to effectively control their risk is essential. This can be done using risk analysis techniques. Therefore, knowledge of risk analysis techniques by employees and supervisors is necessary. In the Indian mining industry, currently employed safety officers and engineers have no formal education and

insufficient training on safety concepts and risk management, which makes it difficult to conduct risk management in mines.

The rapid-ranking method that encompasses the multiplication of probability, exposure, and consequence of the hazard, is the only method used in Indian mining industry. This technique is a qualitative method that is often considered to give unstable output. To cover the wide variety of hazards and to assess their associated risks qualitatively and quantitatively, it is important to use suitable risk analysis techniques. Therefore, additional training should be given to employees and supervisors on how to use different risk analysis techniques, and how to manage hazards when they encounter them. Based on the risk assessment the following should be considered:

- safe operating procedures
- preventive measures to risk control
- follow appropriate code of practice
- allocate resources for eliminating or controlling the hazards based on the risk level

1.5.3 Inadequate Use of Personal Protective Equipment

It is the legal and moral responsibility of the owner of the mine to provide Personal Protective Equipment (PPE) and to ensure PPE is used all the time while working. PPE will help protect the workers from injuries or illness whilst at work. Due to the lack of knowledge of hazards and due to low safety budgets, the mining companies in India provide only the hard hats, cap lamps, belts, and boots. Other PPE, such as hand gloves, safety jackets, eye protection, and ear protection are not provided. Providing hand gloves could prevent accidents in mines like cuts and loss of fingers. Providing the safety jacket to all employees will reduce the machinery accidents caused by lack of visibility (of mine workers). Hearing loss caused by noise is another concern for miners. So, proper hearing aids should be provided when blasting, drilling, or performing any other load activities.

1.5.4 Human Factors in Accident Causation

Human factors are the most common cause of accidents in the mining industry around the world. And fatigue and complacency are the two most common human factors. As employees become comfortable with their routine and their surroundings, there is greater potential danger, as their lack of alertness will prevent them from being focused on the hazards. Due to production pressure or mixed messages about production and safety, employees may find themselves rushing through tasks, which will increase the likelihood of making errors. Whilst employees must be trained to identify and manage hazards, they should also be made aware of human factors that affect their ability to perform work safely at any point during their shift. This can be improved by changing safety culture and following behavior-based safety guidelines.

1.5.5 Improper Organizational Safety Culture

The majority of accidents in mines are due to human error. Human errors include improper training, negligence, and violations. One potential approach to prevent accidents involving human error is through improving safety culture in mines. The common assumption in the mining industry is that "the accidents in mines are inevitable, as mining is inherent of hazards." Such assumptions should be removed from the workers' minds by systematically improving the safety culture. To achieve this, first understand the existing safety culture; then identify the areas that need improvement; and improve the culture in the identified areas. All types of employees should share a fundamental commitment to safety as a value.

1.5.6 Impact of Working at Depth on Mine Safety

With the increasing demand for the supply of minerals, some mines are now operating at a greater depth. Slope stability is the major issue in opencast mines. However, with the increase in depth, there will be more challenging issues in underground mines. The challenging issues are rock bursts/violent fracture of pillars, roof falls, gassiness of mines, and heat and humidity, among others. The rock burst/violent fracture of pillars could be reduced by appropriate mine layout and mining sequence. Sufficient ventilation should be provided to dilute gases and reduce the heat and humidity in the deep mines. Effective strata control management along with the use of adequate supports in underground mines will reduce the risk of roof and side falls.

1.5.7 Inadequate Training in Modern Technology

The mining industry needs to develop high-quality training programs, and to strengthen and modernize training through collaboration with industry stakeholders. The mining industries need to ensure that all miners receive basic and annual refresher training, and that all mine operators maintain effective training plans. Modern technologies can be utilized in the future in the mining industry, such as virtual reality, the use of intrinsic safety and flameproof appliances, the use of remote control and automation, and the increased use of IT in safety management. Effective wireless communication systems must be used in underground mines for ensuring the safety of workers below ground and for effecting timely evacuation in emergencies. The use of state-of-the-art rescue equipment is absolutely necessary for rescue and recovery operations in underground coal mines.

Training is recognized as an essential element for developing an effective safety and health program in mines. A major challenge in the mining industry today is how to train the workers. Along with the initial and refresher training, the workers should be trained whenever there is a change in working method, equipment, or regulatory changes. The workers should also be trained in fire escape training, mobile vehicle driving, and other operations using virtual reality simulation, etc.

1.5.8 Lack of Proper Communication Underground

In every mine, communication is crucial for the smooth running of daily operations and especially at times of accidents. The communication systems used in underground mines are lagging behind those used in opencast mines. Establishing a reliable communication system in underground mines is very difficult due to hazardous and uneven environmental conditions. Most of the existing communication systems in underground mines are wired systems. Wired communication systems will be placed at fixed locations and may not be accessible in the case of a disaster or accident. Therefore, other methods of communication systems, such as wireless systems, RFID systems, which are more reliable, indispensable, and convenient, should be adopted in underground mines.

1.5.9 Challenges in Implementation of Occupational Health, Safety, and Environmental Legislations in Mines

Every mining company should operate by following the legal statutes framed by the safety policy of their own company as well as the health and safety standards framed by their country. However, the Mine Safety and Health Administration (MSHA), Directorate General of Mines Safety (DGMS), and other mine inspection agencies record many violations every year by the mining companies. The main challenges for compliance with the standards are safety culture, poor leadership, negligence, lack of materials, and production pressure. Ensuring compliance with the safety standards, training the workers, and making a change in safety culture could reduce the violations in mines to a great extent.

1.5.10 Environmental and Safety Problems in Opencast/Underground Mines

Mining ventilation is an important safety concern for mine workers. A poor mine ventilation system may directly affect the mine workers' safety and health. Poor ventilation inside an underground mine may have the following safety issues:

- The workers do not receive supply of fresh air, and this leads to asphyxiation
- The failure to flush out harmful gases and coal dust leads to explosion
- The workers will be exposed to heat, dust, and toxic gases, which can cause death, injury, and illness

The concentration of gases may also lead to either methane or coal dust explosion. The source of the explosion in mines can be from many sources like sparks from different machinery, frictional heat, live electrical wires, and cutting and welding. Water sprinkling in coal mines can help to keep dust levels down: by spraying the machine with water and filtering the dust-laden water with a scrubber fan, miners can successfully trap the dust. Gases in mines can poison the miners or displace the oxygen in the mine, causing asphyxiation. Continuous gas-monitoring systems (telemonitoring system) must be installed in large coal mines to get round-the-clock

information on gas, temperature, etc., so that timely prevention/control measures can be implemented to minimize the risk of gas explosion in mines. Further effective measures should be taken against coal dust generation, and the suppression of coal dust and the sources of ignition must be controlled/contained to minimize risk of coal dust explosion.

1.5.10.1 Noise

Heavy earth-moving machinery is commonly used in both opencast and underground mines for the extraction of minerals. The most familiar issue with such machinery is noise generation. Noise is generated in mines from both opencast and underground machinery, and when the threshold limit value (TLV) of 90 dBA is exceeded, it has the potential to cause noise-induced hearing loss and other non-auditory effects. Noise may not harm the worker instantly but continuous exposure can cause temporary or permanent hearing loss. The work done by the National Institute for Occupational Safety and Health (NIOSH) (2010) showed that roof bolters are among the loudest machines used in mines, followed by auger miners, bulldozers, continuous mining machines, front-end loaders, and shuttle cars and trucks. There should be noise control at source, on path, and at receiver through the provision of earplugs and muffs. Administrative and engineering controls must be implemented to minimize noise risk in mines.

1.5.10.2 Cave-Ins and Rock Falls

Since mining involves removing dirt and minerals from its natural location, ground movement issues in both opencast and underground mines have become a major concern for mine workers. The roof falls and side falls are one of the types of recurring accidents in the underground mines. Slope or bench failure is the major issue in opencast mines. Cave-ins and rock falls can lead to instant fatal, serious, or minor accidents in mines. Rock falls in mines can also trap mine workers underground.

1.5.10.3 Dust Exposure

Almost all the operations in mines generate significant amounts of dust. The respirable dust, which is less than 10 microns in size, can cause serious health effects. The respirable dust in mines can cause coal miners pneumoconiosis, silicosis, asbestosis, and other chronic obstructive pulmonary diseases. The use of water sprinklers is commonly employed to reduce dust levels in opencast mines. Water-spraying arrangements near the coal-cutting equipment and conveyors are used to reduce dust levels in underground mines.

1.5.10.4 Heat and Humidity

Heat exposure in mines can lead to heat-related illnesses, including heat stroke, which can be fatal. The increase in the amount of equipment used in mines, the depth of mines, and poor ventilation can result in high temperature and humidity in mines. Maintaining proper ventilation in mines can drastically reduce the problems arising from the heat generated. Mine workers should also have and use a regular supply of drinking water in order to reduce the chance of heat stroke and dehydration.

1.5.10.5 Inundation

The sudden inrush of water is one of the major issues in both underground and opencast mines. Inundation in underground mines can have effects varying from minor to catastrophic accidents, and inundation in opencast mines can completely disrupt the workings of the mine. The sources of inundation in mines are water-bearing strata, waterlogging in adjacent workings, water seepage from the surface, water leakage from subsidence cracks, and heavy flooding. Proper drain hole and sump design, and having sufficient pumping systems for pumping out accumulated water, can reduce the chance of inundation in underground mines. Along with the above measures, sealing the subsidence cracks and preparing a water management plan for the monsoon season can also aid in preventing inundation in mines.

1.5.10.6 Inadequate Tracking of Workers in Emergency Situations

A fire, explosion, inundation, or roof-fall accident in a mine may dislocate the mine workers from their workplace. The location information of the mine workers plays a key role in successfully rescuing the missing persons from the underground mine. Tracking systems such as zone-based active RFID, node-based personal area networks, and node-based local area networks aid the rescue team in effectively tracking the missing mine workers.

1.5.11 Inadequate Monitoring Equipment

Various monitoring equipment for keeping track of strata and gas levels can help in preventing roof fall and gas explosion accidents. The common types of strata monitoring equipment used for underground mines are borehole extensometers, load cells, stress meters, and telescopic convergence rods. Air quality sensors and alarms can be used to monitor the toxic gases, vapors, and fumes. Telemonitoring systems can also be used to continuously monitor the concentration of gases from the surface.

Along with the above issues, the main challenges specific to underground coal mines are as follows:

- methane gas explosion
- coal dust explosion
- poisoning due to gas
- roof fall
- coal fire
- side fall
- inundation due to water inrush
- shaft failure
- anoxia
- electrocution

The main challenges specific to underground non-coal mines are as follows:

- shaft failure
- carbon monoxide poisoning, mainly produced by blasting and heavy diesel-operated machines; the limit is 50 ppm for working

- fall of loose rock from sides and roof at the development faces
- fires in heavy machinery, like Load Haul Dumper (LHD), Side Discharge Loader (SDL), etc.
- inrush of water from underground reservoir
- heatstroke in working faces
- fall of boulders during production of mucks from stopes on LHD
- barricade failure of backfilled/paste-filled stopes
- noise
- lack of ventilation in blind headings

The main challenges specific to opencast coal/metal mines are as follows:

- ground vibration and fly rock problems for the mine workers as well as structural damages to housing in the vicinity of the mines
- noise pollution due to blasting and heavy earth-moving machinery
- mine drainage mixing with groundwater or river water creates water pollution
- air pollution due to movements of heavy earth-moving machinery
- failure of dump/bench slopes
- accidents during material transport
- mine fires

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2 Safety Issues in Opencast and Underground Mines

Irrespective of the minerals being mined, the mining industry is considered to be one of the most hazardous industries. The safety risks in mines vary from risks that are seldom catastrophic to those that are often serious, therefore the workers should be protecting themselves accordingly. Accidents are always a combination of hazards and causes, so understanding and being aware of the hazards and causes present in the mines helps to prevent injuries in the workplace. The causes of fatal and serious accidents from 2008 to 2017 in Indian coal mines are shown in Figure 2.1a and in non-coal mines is shown in Figure 2.1b.

The safety issues present in underground coal and non-coal mines and in opencast coal and non-coal mines are represented in the Figure 2.2.

2.1 SAFETY ISSUES IN UNDERGROUND COAL AND NON-COAL MINES

Underground mines are riskier than opencast mines, and underground coal mines are more dangerous than underground non-coal mines. In underground mining some hazards, such as ground movement, are inherent in the underground environment while other hazards are introduced through complex mining activities and processes, including hazards from transportation machinery. If these hazards are not managed properly using appropriate controls, they can result in serious traumatic injuries, deaths, or occupational illness (Ministry of Labour – Canada, 2015). The hazards do not differ greatly between underground coal and non-coal mines, with common hazards as follows.

2.1.1 Ground Movement

The safety hazards related to ground movement in underground coal and non-coal mines includes roof falls, side falls, overhang falls, rock bursts, air blasts, premature collapse of pillars, subsidence, and collapse of shafts.

2.1.1.1 Ground Movement Issue in Coal Mines

The ground movement accidents that killed ten or more workers in Indian coal mines are presented in Table 2.1.

From Table 2.1, it can be seen that roof falls have the highest frequency of accidents in underground coal mines. Unmitigated roof fall hazards have resulted in the greatest number of traumatic injuries in underground mining workplaces. Roof-fall accidents in underground mines can be as a result of inherent causes, human error, or other causes.

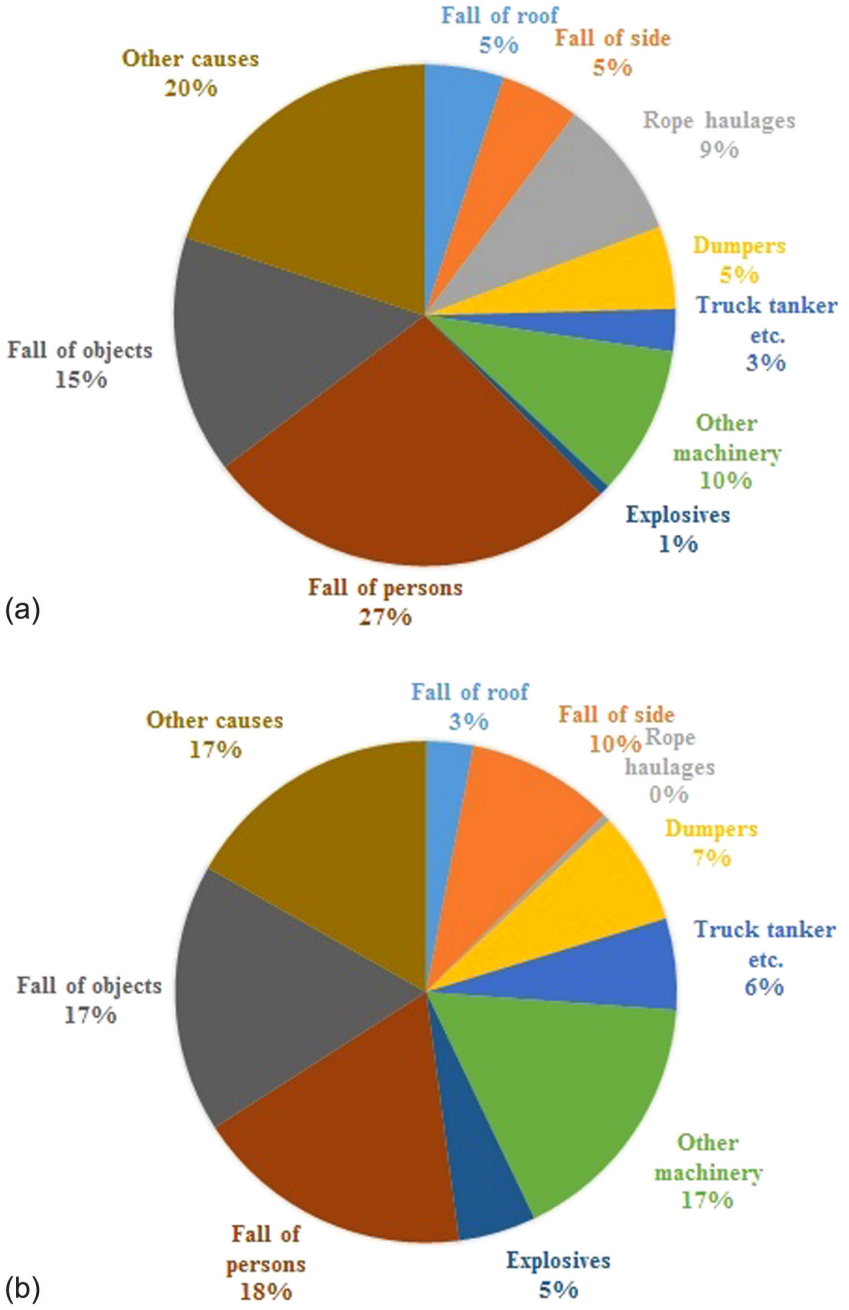

FIGURE 2.1 Causes of fatal and serious accidents during 2008 to 2017 in Indian mines (a) coal mines, (b) non-coal mines. (Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.)

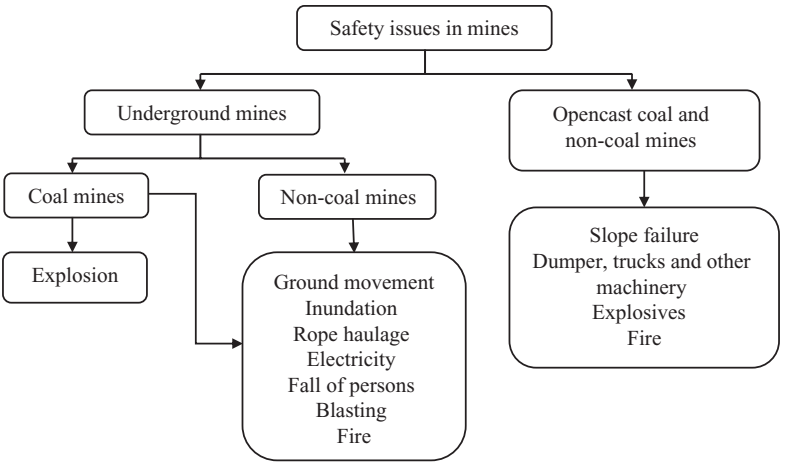

FIGURE 2.2 Safety issues in underground and opencast mines.

TABLE 2.1
Ground Movement Accidents in Indian Underground Coal Mines from 1901 to 2015

Date of Accident	Name of Mine	Killed	Cause
10-15-1910	Sitalpur	12	Roof fall
08-31-1915	Chanda	10	Collapse of pillars
02-04-1916	Bhowra	24	Collapse of pillars
04-14-1923	Rawanwara	16	Collapse of pillars
02-22-1943	Sodepur 9, 10 & 11 pits	13	Roof fall
10-08-1943	Jhamuria 7 & 8 pits	12	Air blast
07-12-1952	Dhemomain	12	Roof fall
04-11-1968	West Chirimiri	14	Collapse of pillars
08-08-1975	Kessurgarh	11	Roof fall
07-16-1982	Topa	16	Roof fall
06-24-2000	Kawadi Mine	10	Side fall
10-17-2003	Godavarikhani No 8 A	10	Roof fall

The inherent causes include the geological conditions and the presence of bodies of water. Other causes include

- supports are not set as specified
- improper training
- improper examination and testing of roof and sides
- poor quality of support materials
- lack of monitoring systems
- blasting

While the inherent causes are hard to manage, remedial measures can be applied to human error and other working methods. Remedial measures are as follows:

- Ensure that the systematic support rules are clearly understood and followed by overman, mining sirdar, and support men.
- Support men should not be allowed to go to freshly exposed working areas until they have been inspected by the supervisor and kept secure using temporary supports.
- Workers should be properly trained in testing the roof, cleaning roof falls, and methods in withdrawing props, cogs, or bars.
- Ensure good quality roof-bolting material is used for support.
- Anchorage testing should be carried out.
- No solid blasting should be carried out except with the correct types of delay detonators and explosives.
- Provide extra support at junctions and geologically disturbed areas.
- Strata monitoring should be carried out using stress meter and borehole extensometers.

2.1.1.2 Ground Movement Issues in Non-Coal Mines

Ground movement accidents that killed ten or more workers in Indian non-coal mines are presented in Table 2.2.

A rock burst is one of the dynamic hazards induced by mining excavation. From Table 2.2, it can be seen that rock bursts have the highest accident frequency rate in underground non-coal mines. A sudden, violent fracture of rock in mines is called a rock burst. The risk of rock bursts in mines increases with the depth. The first rock-burst accident in the world was recorded in Kolar Gold Mine, India in early 1900. Apart from depth, other factors responsible for the occurrence of rock bursts in mines are faults and the physico-mechanical properties of rock. The more the rock is capable of storing strain energy, the more prone it is to the phenomenon of bursting. The remedial measures for rock bursts are as follows (Cai, 2016):

- the assessment of risk of rock burst in an underground mine should be made at the mine design stage
- use the correct mining methods
- optimize the mining layout and excavation sequence
- avoid large stress concentration in the rock mass
- use suitable supporting measures
- use de-stress blasting techniques
- induce a slow relaxation movement of the rock
- avoid augmented abutment pressure.

2.1.2 Inundation

The sudden or gradual inflow of water from either the surface or from underground may lead to mine inundation. The gradual inflow of water can be easily managed by

TABLE 2.2
Ground Movement Accidents in Indian Underground Non-Coal Mines from 1901 to 2015

Date of Accident	Name of Mine	Killed	Cause
12-06-1910	Shivrajpur Manganese	12	Fall of sides
05-16-1929	Bawdwin Silver-Lead-Zinc	10	Fall of roof
04-19-1952	Champion Reef Gold	20	Rock burst
06-30-1952	Champion Reef Gold	10	Rock burst
05-27-1955	Champion Reef Gold	10	Rock burst
09-29-1957	Rajupalem Barytes	11	Fall of sides
02-25-1910	Hamsa Mineral Granite Mine	14	Fall of sides

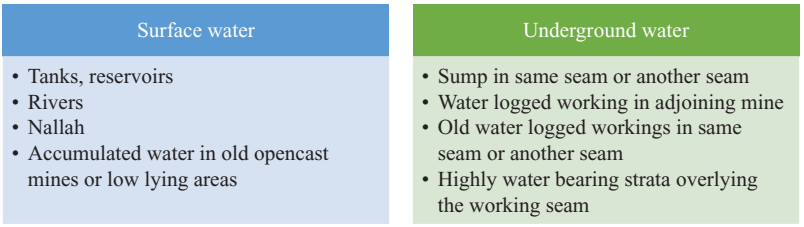

FIGURE 2.3 Sources of mine inundation.

pumping out water. However, the sudden inflow of water in mines is hard to control and creates maximum damage by drowning equipment, workings, and people.

2.1.2.1 Inundation Issues in Coal Mines

Although inundation hazards are present in both coal and non-coal underground mines, they occur more frequently in Indian underground coal mines. The source of inundation can be from the surface or from underground water as shown in Figure 2.3. Inundation accidents that killed ten or more workers in Indian underground coal mines are presented in Table 2.3.

2.1.2.2 Inundation Issues in Non-Coal Mines

The number of inundation accidents in underground non-coal mines is not as frequent as in underground coal mines, yet substantial damage has occurred due to inundation. Inundation accidents that killed four or more workers in Indian underground non-coal mines are presented in Table 2.4.

The remedial measures to prevent and control inundation accidents in both coal and non-coal mines are as follows:

- No work should be allowed in any mine vertically below any tank, reservoir, lake, or river.
- The entrance of mine should be designed, constructed, and maintained such that the lowest point of its mouth is not less than 1.5 m above the highest flood level at that point.

TABLE 2.3
Inundation Accidents in Indian Underground Coal Mines from 1901 to 2015

Date of Accident	Name of Mine	Killed	Cause
07-11-1912	Phularitand	21	Inundation
06-28-1913	Jotejanake	13	Inundation
01-16-1935	Loyabad	11	Inundation
07-06-1942	Makerwal	14	Inundation
08-05-1953	Majri	11	Inundation
12-10-1954	Newton Chikli	63	Inundation
09-26-1956	Burradhemo	28	Inundation
02-20-1958	Central Bhowrah	23	Inundation
01-05-1960	Damua	16	Inundation
11-18-1975	Silewara	10	Inundation
12-27-1975	Chasnala	375	Inundation
09-16-1976	Central Saunda	10	Inundation
09-14-1983	Hurriladih	19	Inundation
09-27-1995	Gaslitand	64	Inundation
02-02-2001	Bagdigi	29	Inundation
06-16-2003	Godavarikhani No 7 LEP	17	Inundation
06-15-2005	Central Saunda	14	Inundation

TABLE 2.4
Inundation Accidents in Indian Underground Non-Coal Mines from 1901 to 2015

Date of Accident	Name of Mine	Killed	Cause
11-05-14	Tadaiya Mica	5	Inundation
12-06-46	Pattabhirama & Margin Mica	8	Inundation
08-28-94	Rajpura Dariba (Galena & Sphalerite ore)	13	Inundation

- An embankment should be provided around the mine entrance, boreholes, or low-level areas that are below the highest flood level of the river.
- If there is an abnormal seepage of water, work should be stopped and people should be evacuated from the underground mines.
- A hydrogeological survey should be carried out to establish the presence of bodies of water.
- An adequate barrier against the mine boundary/fault plane should be provided.
- Provision should be made to check surveying quarterly.
- A sufficient sump area should be provided.
- A sufficient number of high-head pumps should be provided.
- Provision should be made to demarcate geological disturbances in different planes.

- Provision should be made for filling surface cracks, fissures, subsidence, and potholes to avoid any inrush of water to underground levels.
- Provision should be made for sealing boreholes.
- Barriers should be maintained around boreholes.
- Before a monsoon, an assessment should be made to identify the possible inundation dangers and adequate precaution measures should be identified and followed.
- Mining should be planned so that it does not disturbs water-bearing strata, if present.
- Suitable techniques for establishing the thickness of the barriers and the partings and detection of voids and abandoned water-bearing workings needs to be developed.

2.1.3 Rope Haulage

2.1.3.1 Rope Haulage Issues in Coal Mines

Rope haulage systems are one of the most common causes for transportation accidents in underground mines. Table 2.5 (DGMS, 2018b) presents the number of accidents due to rope haulage systems in Indian coal mines from 2005 to 2017. In 1979, the Gugnani Committee had recommended that mechanical conveyors should replace rope haulage in all mines and that new mines should be planned to have transport of coal by mechanical conveyors. While most of the new mines do have mechanical conveyors, the rope haulage systems in older mines are yet to be replaced.

TABLE 2.5
Rope Haulage Accidents in Indian Coal Mines from 2005 to 2017

	Coal	
Year	Fatal	Serious
2005	12	168
2006	9	178
2007	4	131
2008	4	90
2009	5	72
2010	3	37
2011	3	47
2012	2	46
2013	3	42
2014	1	29
2015	3	28
2016	5	26
2017	3	11

Source: Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.

From Table 2.5, it can be seen that at least one fatal accident occurs each year in coal mines and the serious accidents rate is substantially higher in coal mines than in non-coal mines. The main causes of rope haulage accidents are as follows:

- runaway tubs
- uncontrolled movement of tubs
- poor quality of ropes/rope breakage
- improper track layout/bad track condition
- traveling along haulage roadways
- non-provision of safety devices
- workers riding on tub buffers
- lack of communication
- no guarding of moving parts

2.1.3.2 Rope Haulage Issues in Non-Coal Mines

The number of accidents occurring due to rope haulage in non-coal mines from 2005 to 2017 are presented in Table 2.6 (DGMS, 2018b). From Table 2.6, it can be observed that there are no fatal accidents recorded in non-coal mines and that serious accidents are continuing. The main causes of rope haulage accidents in non-coal mines are same as in coal mines. Therefore, the remedial measures for both coal and non-coal mines are as follows:

- ropes should be inspected regularly by a foreman/engineer
- tubs should be lowered only when the motor is on
- safety devices should be used at the haulage track

TABLE 2.6
Rope Haulage Accidents in Indian Non-Coal Mines from 2005 to 2017

Year	Fatal	Serious
2005	0	1
2006	0	0
2007	0	2
2008	0	1
2009	0	0
2010	0	0
2011	0	3
2012	0	0
2013	0	0
2014	0	0
2015	0	0
2016	0	1
2017	0	0

Source: Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.

- a proper braking system should be provided
- regular inspections should be carried out
- track maintenance should be carried out at regular intervals
- there should be telephone communication and signaling systems at all coupling and decoupling points
- proper guards should be provided for all moving parts
- workers should be strictly prohibited to ride on tub buffers
- only authorized workers should be allowed to travel along the haulage roadways

2.1.4 Fire

2.1.4.1 Fire Issues in Coal Mines

Fire is considered as one of the most serious hazards present in underground coal mines. The rapid rate of spread coupled with the long period required to evacuate workers can make even a small fire a potential source of danger. Fire may also lead to explosion or the release of toxic gases in underground mines. In coal mines, 75–80% of the mine fires are caused by the spontaneous combustion of coal. The other common sources of fire in underground coal mines are

- friction due to defective bearings in conveyor drums, idlers, and wheels
- friction due to belt rubbing against tail-end structures
- sparks from cutting machinery picks, such as longwall shearer picks and continuous miner picks
- exhaust systems
- hot surfaces
- electrical sparks
- mechanical equipment
- short circuits and earth faults on electrical equipment
- explosives and detonators
- cutting and welding

The remedial measures for preventing fire in underground coal mines are as follows:

- prevention and control of spontaneous combustion in coal mines
- any defective bearings in the conveyor systems should be replaced or repaired
- the use of light metals and alloys should be prevented
- fire-resistant conveyor belts must be used
- fire extinguishers should be provided at required places
- conveyor belt systems should be properly inspected
- constant supervision should be provided around machinery
- proper ventilation should be provided and all the ventilation appliances should be fire-resistant
- electrical equipment should be protected against overload, low voltage, and earth leakage

TABLE 2.7
Fire-Related Fatalities in Indian Underground Coal Mines from 1901 to 2015

Date of Accident	Name of Mine	Killed	Cause
01-30-1936	Loyabad	35	Fire
06-24-1981	Jagannath	10	Fire
01-25-1994	New Kenda	55	Fire

- blasting should not be carried out if gases are detected
- shot holes should not be overcharged or undercharged
- cutting and welding should be carried out under supervision only

Fire accidents that killed ten or more workers in Indian coal mines are presented in Table 2.7.

Spontaneous combustion of coal in underground mines can occur due to

- the premature collapse of pillars in active workings
- the collapse of pillars in old workings
- goaved-out panels not being sealed properly
- coal not excavated within the incubation period
- the leakage of air through pillars

The preventive measures of spontaneous heating in coal seams/pillars are as follows:

- ensure long-term stability of pillars by using proper designs
- old workings should be inspected regularly to detect any weakening of pillars
- if weak pillars are identified, bolting should be carried out
- if possible, fire stoppings should be constructed around the old workings
- panels should be sealed with fire stoppings immediately after they have been goaved out
- coal must be extracted within the incubation period
- cracks in pillars should be sealed using suitable sealants; and sides should be plastered

For controlling fire, direct and indirect methods of firefighting strategies must be adopted in coal mines.

2.1.4.2 Fire Issues in Non-Coal Mines

The number of fire accidents that occur in underground non-coal mines is much lower than that of underground coal mines. However, the chances of occurring fire in non-coal mines are not any lower, due to the following hazards:

- oil or grease spillage
- fire in machinery due to fuel, hydraulic fluid leakage, or motor malfunction
- conveyor belt problems
- electrical short circuit or arching
- cutting or welding spark/flame

The preventive measures for fire in non-coal mines are as follows:

- oil, grease, or any other combustible material should not be allowed to be stored underground
- oil, grease, or any other combustible material spillage should be cleaned up immediately
- an operator should regularly inspect the excavation machinery to ensure there is no fuel leakage
- defective parts, such as rollers or idlers on the conveyor belt systems should be replaced or repaired
- fire-resistant conveyor belts must be used
- water-spraying arrangements should be provided at the conveyor loading and unloading points
- electrical equipment should be protected against overload, low voltage, and earth leakage
- damaged electrical cables and loosely connected joints should be replaced immediately
- cutting and welding should be done under supervision only
- fire extinguishers should be provided near conveyor belts, in areas where machinery is used, the oil room, cutting and welding areas, and other required places
- sand bags and water should be provided near cutting and welding area

2.1.5 Explosion Issues in Coal Mines

Explosion accidents have affected the mining industry around the world. Explosions are considered to be a low-frequency, high-consequence hazard. Explosions in underground coal mines are due to firedamp, coal dust, a combination of both, or water-gas formation. Firedamp explosion is also known as methane explosion. It is formed in mines when flammable gases, especially methane, mixes with the heat sources and there is not enough air to dilute the gas to levels below its explosion point. Coal dust can develop into explosion when ignited. Table 2.8 presents data for the number of explosion accidents that killed ten or more workers in Indian coal mines.

The remedial measures to prevent and control firedamp and coal dust explosion accidents in underground coal mines are as follows:

- adequate ventilation should be provided to dilute the firedamp mix to the level below explosion limits
- adopt methane drainage techniques

TABLE 2.8
Explosion Accidents in Indian Underground Coal Mines from 1901 to 2015

Date of Accident	Name of Mine	Killed	Cause
06-16-1908	Nadir Khas	20	Explosion
02-07-1910	Dishergarh	11	Explosion
11-26-1910	Namdang	14	Explosion
11-09-1911	Kendwadih	14	Explosion
10-22-1913	Chowrasi	27	Explosion
07-20-1916	Dishergarh	14	Explosion
11-18-1918	Dishergarh	10	Explosion
02-28-1921	Amlabad	11	Explosion
03-09-1922	Khost	13	Explosion
01-04-1923	Parbelia	74	Explosion
06-29-1935	Bagdigi	19	Explosion
07-24-1935	Kurhurbaree	62	Explosion
12-18-1936	Poidih	209	Explosion
03-19-1946	Begunia	13	Explosion
03-14-1954	Damra	10	Explosion
02-05-1955	Amlabad	52	Explosion
02-19-1958	Chinakuri 1 & 2 pits	176	Explosion
05-28-1965	Dhori	268	Explosion
03-18-1973	Noonodih Jitpur	48	Explosion
10-04-1976	Sudamdih Shaft	43	Explosion
01-22-1979	Baragolai	16	Explosion
03-03-1997	New Moghla	10	Explosion
09-06-2006	Bhatdee	50	Explosion
05-06-2010	Anjan Hill	14	Explosion

- continuous gas monitoring should be carried out using appropriate gas monitoring instruments and mine environment monitoring from surface
- if methane gas is detected, the power supply should be cut off to all electrical equipment
- sectionalization stoppings should be regularly monitored and maintained
- subsidence area should be monitored regularly
- surface cracks should be filled by dozing and the application of concrete, if required
- training and retraining of mining supervisors/officials should be provided
- main mine ventilator fans should be inter-coupled with underground power
- cutting and welding work should be carried out under supervision only
- sand and water should be kept near gas cutting/welding workplaces
- before blasting, ensure that no inflammable gas is present
- use P-5 explosive and delay detonators

- water spraying should be carried out before and after blasting
- stone-dust barriers should be provided
- stone dusting should be carried out regularly
- water-spraying arrangements should be provided at coal transportation points, such as the conveyor or haulage to prevent coal dust being airborne
- fire stoppings should be inspected regularly by a competent person
- sealed-off areas should be inspected regularly by a competent person
- old workings should be inspected regularly by a competent person
- fallen coal in return airways should be cleared up immediately
- return airways should be free from obstruction

2.1.6 Falls of Persons in Coal and Non-Coal Mines

The most frequent cause of accidents in coal and non-coal mines is the fall of a person. From 2013 to 2017, 23 people died and 517 people were seriously injured in coal mines, and 43 people died and 84 people were seriously injured in non-coal mines due to falls of persons. The main causes for the falls of persons are slippery roads, poor illumination, uneven walking surfaces, improper footwear, and debris on the walking path.

The remedial measures for preventing the falls of persons in underground coal and non-coal mines are as follows:

- the traveling road(s) should be free from debris – debris or minor falls should be cleared regularly
- water drainage should be provided at the sides of the traveling road(s) to prevent water seepage to enter the traveling road(s)
- the traveling road(s) should be maintained to be as flat as possible
- proper illumination should be provided in the accessible areas
- slip-resistant footwear should be used

2.1.7 Blasting-Related Issues in Coal and Non-Coal Mines

In underground coal and non-coal mines, miners being too close to the blast (fly rocks), explosive fumes poisoning, misfires, mine-induced seismicity, and premature blasts caused the most blasting explosive-related fatalities

- workers struck by fly rocks because they are too close to the blast area is one of the main causes of accidents in underground mines
- the explosive products used in underground blasting operations produce a variable quantity of toxic gases
- a misfire – the complete or partial failure of a blasting charge to explode – misfires are a major concern while blasting
- a premature blast – due to a faulty detonator, carelessness, accidental percussion, a faulty fuse, or degenerated explosives

The remedial measures for preventing blasting-related accidents are as follows:

- a blasting card system should be followed to ensure that no workers are present within the blasting area
- an efficient, well-designed, and well-maintained ventilation system is key to preventing or mitigating the concentration of toxic gases in underground mines
- drilling, stemming, and charging should be carried out properly to prevent misfires; after blasting, the shot-firer should check for any misfires
- the shot-firer should not engage in any other activity other than blasting
- the shot-firer should check the detonator, fuse, and explosives before using
- optimize blast design

2.1.8 Electrical Issues in Coal and Non-Coal Mines

With the advancement of technology, electrical usage has increased in underground coal and non-coal mines. In 2017, 4.92% and 1.81% of fatal and serious accidents in coal mines and 5.13% and 5.88% of fatal and serious accidents in non-coal mines were due to electricity. Though the percentage of accidents is relatively lower than from other causes, the presence of electrical hazards requires the constant monitoring and management of hazards. If not monitored properly, electrical hazards can become a source of ignition for fire, methane, or coal dust. The causes of electrical accidents in underground coal and non-coal mines are as follows:

- poorly maintained electrical devices
- improper shutdown of machine operation
- untrained and/or unskilled manpower
- the housing of power cables together with signaling and lighting cables

The preventive measures are as follows:

- electrical devices should be maintained properly
- proper protection should be used while maintenance work is carried out
- the strict implementation of shutdown procedures should be followed
- training and retraining should be provided to workers
- the correct isolation of different cables should be carried out
- the use of intrinsic safety and flameproof apparatus underground should be ensured
- the proper earthing of electrical appliances should be ensured

Numerous other hazards in coal and non-coal underground mines that can result in injury, illness, or death include the following:

- unsafe handling of materials
- inadequate training
- excessive temperatures/heat
- unguarded machinery
- lockout/tagout precautions not followed

- incorrect communication systems
- inadequate first aid, medical attention, emergency assistance
- inadequate inspection and prevention

2.2 SAFETY ISSUES IN OPENCAST COAL AND NON-COAL MINES

As the number of disasters occurring in opencast mines are low, opencast mines are considered to be safer than underground mines. However, accident statistics in Indian mines shows a different trend. The comparison of death rates per 1,000 persons employed in Indian underground and opencast mines, as shown in Table 2.9 and Figure 2.4, revealed that the trend of death rates is higher in opencast coal and non-coal mines than underground coal and non-coal mines. There are potential hazards present in opencast mines that can lead to disaster if they are not managed properly. The hazards do not differ much between opencast coal and non-coal mines. The common hazards in opencast non-coal and coal mines are as follows.

2.2.1 Slope Failure in Coal and Non-Coal Mines

Slope failure is the downslope movement of mineral, rock debris, and soil in response to the gravitational stresses. Slope failure is one of the most frequent causes of

TABLE 2.9
Comparison of Death Rate of 1,000 Persons Employed in Coal and Non-Coal Mines

Year	Coal Underground	Coal Opencast	Non-Coal Underground	Non-Coal Opencast
2001	0.43	0.38	0.46	0.63
2002	0.27	0.32	0.49	0.54
2003	0.33	0.35	0.52	0.45
2004	0.27	0.47	0.62	0.47
2005	0.34	0.42	0.38	0.43
2006	0.52	0.33	0.38	0.62
2007	0.13	0.46	0.35	0.48
2008	0.21	0.45	0.44	0.43
2009	0.25	0.4	0.61	0.32
2010	0.33	0.51	0.44	0.71
2011	0.13	0.35	0.20	0.34
2012	0.16	0.43	0.52	0.26
2013	0.14	0.46	0.39	0.55
2014	0.13	0.35	0.39	0.28
2015	0.13	0.29	0.29	0.29
2016	0.18	0.57	0.22	0.30
2017	0.16	0.36	0.15	0.47

Source: Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.

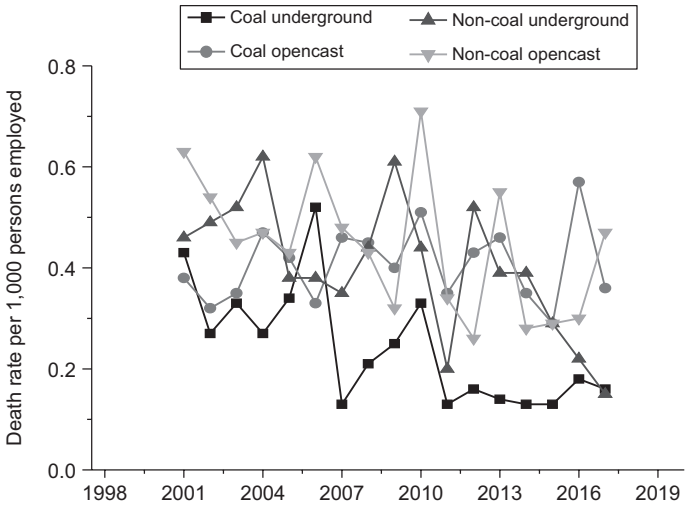

FIGURE 2.4 Death rate per 1,000 persons employed in Indian mines. (Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.)

accidents (Indo-US, 2005) in opencast mines. The factors that influence the stability of a typical opencast mine slope are the shear strength parameters of slope-forming material, the presence and characteristics of structural discontinuities in the slope mass, and the groundwater conditions (Singh and Monjezi, 2000; Singh et al., 2008). Unexpected weather patterns or seismic shock may also influence the stability of mine slopes. The causes of slope failure are

- improper slope design
- mine-induced seismicity
- water inrush due to the nearest river or heavy rainfall
- major geological disturbances
- blasting
- undercutting/toe-cutting
- presence of water in the rock mass
- improper drainage systems
- a decrease in cohesion and angle of internal friction of high-wall materials
- improper supervision and monitoring
- inadequate inspection of sides

The preventive measures for slope failure in opencast mines are

- ensure the optimum design of slopes (height, slope angle, etc.)
- ensure the safe geo-technical designs of benches: benches should be designed according to the regulations and instructions laid down by the Chief Inspector of Mines
- a rock-fall catchment system should be provided to minimize the consequences

- undercutting/toe-cutting of any face should not be allowed
- workers should not be allowed to work near any overhanging ledges
- slope monitoring devices for the advance warning of impending failures in stockpiles, overburden, and benches in mines.

Overburden is waste rock.

- The word overburden is very familiar among the mining (targeted) audience. So the explanation of overburden is not required.

The monitoring of slopes can be carried out using portable wire-line extensometers, inclinometers, time domain reflectometry, borehole extensometers, and piezometer.

2.2.2 Haul Road Issues in Coal And Non-Coal Mines

With the introduction of higher-capacity machinery and equipment, the number of incidents and accidents has increased in both opencast coal and non-coal mines. The various causes of accidents on haul roads are

- poor visibility on the haul road can lead to head-on collisions as well as front and rear collisions of dumpers
- a person crossing in a blind space
- a dumper coming off the haul road due to inadequate parapet walls or embankment
- poor visibility during the reversal of a dumper
- inadvertent movement of steering wheel along with tyre while maintenance of dumper where engine is "ON"

The preventive measures for reducing accidents on haul roads of opencast coal and non-coal are as follows:

- only permitted vehicles should be allowed to enter the mine area
- only authorized persons should operate the vehicles
- no person should be allowed to enter the haul roads
- proper illumination should be provided on haul roads
- adequate embankments should be provided on the haul roads
- various safety signs, warning signs, traffic signs, and speed limit boards should be provided on the haul roads
- water-sprinkling should be carried out regularly to prevent dust and improve visibility
- vehicle operators should follow the speed limits set by the mine management
- if the visibility or road conditions are poor, the operator should reduce the speed of the vehicle to maintain effective control
- a vehicle should not be parked in a position that will endanger other traffic, or opposite to another vehicle on a haul road
- a vehicle should not be parked within 30 meters of the working area of mobile equipment and swing radius of any shovel

- the vehicle operators should sound one blast of horn before moving off from a parked position
- the vehicles should be correctly illuminated during hours of darkness
- the operator should observe adequate clearance particularly when reversing, parking, and passing other vehicles

2.2.3 Dumpers, Trucks, and Other Machinery-Related Issues in Coal and Non-Coal Mines

The majority of fatal accidents in both coal and non-coal are caused by dumpers. In 2017, 53% of fatal accidents in opencast coal mines and 25% in opencast non-coal mines were due to dumpers, trucks, and other machinery (DGMS, 2018b). Other machinery in opencast mines includes drilling machines, shovels, dozers, draglines, etc. The remedial measures to prevent and control dumper and truck accidents are as follows:

- replace the dumpers and trucks with conveyor belt systems for in-pit transportation, if distances are small – this will eliminate the dumper and truck accidents in haul and associated roads
- no person other than the driver should be allowed to board the vehicle
- only authorized and properly trained drivers should be allowed to drive
- there should be separate roads for pedestrian and light vehicles
- no maintenance personnel should be present around the dumper when it starts to move
- no dumper movement should be allowed during manpower movement
- all dumpers should be parked in the field during lunch or other breaks
- fluorescent jackets should be provided to all workers
- speed limits should be adhered to throughout the haul road, especially at blind turnings
- wide roads should be provided
- haul roads should be well-illuminated
- sign boards should be provided at crossings
- flickering lights should be used at crossings
- no outside vehicle should be allowed to pass the crossings
- separate road for loaded and empty dumpers should be provided by use of a road divider
- the overtaking of other vehicles should be prohibited
- a supervisor should be present for all three shifts
- dumper and truck operators should educated through the use of regular safety talks
- the stock height should not exceed 10 meters; and dozers should be deployed regularly
- regular maintenance of dumpers and trucks should be carried out
- a pre-start check should be carried out by the operator before using any machinery

The remedial measures to prevent and control other machinery accidents are as follows:

- machinery should be properly guarded
- drilling machinery should be operated on a level surface
- no maintenance or any other personnel should be present around the drill machine when it is moved from one area to another
- a pre-start check should be carried out by the operator before using machinery such as a drill machine, shovel excavator, dragline, or dozer
- the operator cabin of excavator machinery should always have clear visibility
- no person should be allowed around excavator machinery while it is in operation
- no person other than the driver should be allowed to board any vehicle
- only authorized and properly trained drivers should be allowed to drive
- before leaving, the machinery should be parked on a level surface and the bucket should be emptied and lowered
- the shovel and dragline excavator buckets should be emptied before traveling/movement
- machinery should be shut down during blasting operations, in case of misfires or indications of slope failures
- the electrical cables of all machinery should be properly protected
- safety equipment, such as fire extinguishers, should be provided in the operator cabins of appropriate machinery

2.2.4 Explosives and Blasting Issues in Coal and Non-Coal Mines

The number of people who have died in opencast coal and non-coal mines due to blasting explosives is much lower than in underground mines. However, the accident rate is almost constant due to fly-rock hazards and misfires. Dozolme (2016) stated that the workers struck by rocks, either because they were too close to the blast or because the rock was thrown much further than expected, remains one of the main causes of accidents in opencast coal and non-coal mines. The fly-rock hazards include projectiles from deep-hole blasting and other projectiles. The main reasons for fly-rock hazards occurring in opencast mines are improper planning, judgment, and practices during blasting. The general preventive measure to control explosives accidents are as follows:

- separate vehicles for detonators and explosives should be provided
- special training to the drivers of the explosives vans should be provided
- low speed limits of the vehicles being used should be applied
- fire extinguishers should be provided and maintained regularly in the vehicle
- regular internal cleaning and washing of the explosives van should be carried out

- checking for contraband should be carried out regularly
- blasting should not be carried out when there is lightning

The remedial measure to prevent and control fly-rock hazards and misfires are as follows:

- Nonel/Excel should be used for controlled blasting
- blasting should only be carried out from a blasting shelter
- bench height, shot-hole diameter, spacing, burden, charge distribution, stemming, initiation system, sequence, and delay intervals should be determined scientifically after proper experimentation; good blast design can reduce blast-related hazards
- shot holes should not be overcharged
- adequate stemming column should be provided.
- all persons should be removed from the danger zone
- proper warnings should be given before blasting using powerful sirens
- rest shelters should be provided and used
- no person should be allowed to enter the blast zone immediately after blasting
- the blasting-in-charge must inspect the blasted area for determining any misfires
- drilling and inserting tools at the bottom of deep holes should be avoided, even if no explosives are found in them
- reduce charge/delay for preventing ground vibration problems

2.2.5 Fire Issues in Opencast Coal Mines

Due to the combustible nature of coal, the occurrence of fire is more common in opencast coal mines than opencast non-coal mines. Fire in opencast coal mines can occur due to spontaneous combustion in coal stockpiles or accidental fires. Accidental fire includes the burning of plants near exposed coal, the lighting of other fires near exposed coal, or dumping hot debris on coal stockpiles. The preventive measures for controlling fire in opencast mines are: use ash-water slurry to cover coal stockpiles; and the dumping of hot debris, burning of plants, and lighting of other fires near coal workings should be prohibited.

Safety hazards identified in opencast coal and non-coal mines are presented in Table 2.10.

TABLE 2.10
Safety Hazards Identified in Opencast Mines

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
Electrical Shovel	Machine/tool	Hoist break failure may to lead to accident
		Boom rope failure may cause injury to operator
		Leakage of air from break.
		Failure of compressor tank safety valve may lead to burst of hoses and compressor tank
		Boom stay rod failure – chances of falling on operator cabin
		Getting down of sprocket and counterweight during shovel shifting in ramp can cause injuries to operator
	Work environment/managerial	Invisibility of the boom end pins to the operator
	Human	Failure of horn resulting in accidents
		Improper communication between operator and helper resulting in cable damage and shock
Operation & Maintenance of Equipment/ Installations	Work environment/managerial	Damage to electrical cables
		Improper earthing of machinery
		Improper joints on high-tension lines
		Faulty safety appliances
		Loose connections of electrical cable may lead to short circuiting
		Poor illumination
	Human	Fall of objects
		Not following shutdown procedures
	Work method/procedural	Oil spillage may cause fire accident
		Spillage of acid while handling batteries may cause burn injury to person, fumes in battery room
		Contact with snapped wires/metal pieces may lead to an electrical accident
Dumper	Human	Slipping and falling while climbing on ladder
		Battery failure due to improper maintenance resulting in machine shutdown and heavy jerk to operator
		Application of breaks in rainy season may result in slipping and accidents
		Speeding while going downward
		Operators not following blasting cautions
		Direct hitting of tower lights at operator cabin resulting in invisibility and accidents

(*Continued*)

TABLE 2.10 (CONTINUED)
Safety Hazards Identified in Opencast Mines

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
		Overtaking of other heavy earth moving machinery and hence accidents
		Improper parking causing major accidents
		Improper handling of washing hoses
	Work method/procedural	Bursting of tire resulting in accidents
		Loosening and shearing of wheel bolts hence accidents
		Steering cylinder failure resulting in accidents
		Malfunctioning of retarder and service breaks
		Puncher in air tank resulting in brake failure
	Work environment/managerial	Accidents due to unavailability of bunds at the sharp edges
		Accidents or heavy jerks due to improper cleaning of road or boulders on road invisible to operator
	Machine/tool	Malfunctioning of gauges can cause an accident
		Failure of hoses due to friction resulting in heavy jerk/accident
		Accident due to usage of improper hoses
		Heavy jerk or boulders falling due to overloading in dumpers
		Physical damage/crack in chassis resulting in major accidents
		Failure of reverse camera
		Wiper failure may cause invisibility and accident
		Failure of dashboard indicator
		Failure of reverse/parking lights
		Failure of horns, head lights, indicators, or fog light resulting in dumper hitting other heavy earth moving machinery
		Failure of spherical bearing creating heavy jerk at operator cabin
		Failure of inch pin, bushes, crank-bearing resulting in accidents and heavy damage to dumper
		Heavy jerks to the operator due to loosening of rubber beading
		Insufficient charging of suspension resulting in falling of dumper or heavy jerks
		Failure of mounting bolts resulting in accidents
Hydraulic Shovel	Machine/tool	Engine blow out can damage nearby objects or persons
		Fire hazard because of engine fan belt snapping

(*Continued*)

TABLE 2.10 (CONTINUED)
Safety Hazards Identified in Opencast Mines

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
		Heavy jerk to operator in case of track chain cut
		Heavy jerk and injury to the dumper operator due to the shearing of cylinder mounting pin
		Hot oil getting sprayed due to hose puncher
		Panel board failure resulting in accidents
		Failure of cylinders and piston rods causing heavy injury
Drill machine	Machine/tools	Heavy jerk to operator in case of relief valve failure
		Shearing of feed chain resulting in accidents
		Breaking of drill rod causing heavy jerk to operator
		Snapping of feed chain
	Human	Accident because of not monitoring oil/air pressure
		Accident because of not monitoring high pressure meter
		Improper setting of rod carrier results in falling and can cause accidents
		Wrong positioning of drill near face
		Hand injury because of negligence during attachment/detachment of drill rod
	Work environment/managerial	Loose fittings/components of operator's cabin may lead to noise exposure and in turn lead to hearing loss
		Collapse of benches while drilling

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3 Behavior-Based Safety

3.1 INTRODUCTION

Behavior-Based Safety (BBS) is the "application of the science of behavior change to real world problems." BBS "focuses on what people do, analyzes why they do it, and then applies a research-supported intervention strategy to improve what people do." (Agnew and Ashworth, 2012)

Behavior-Based Safety is an approach to safety that focuses on workers' behavior as the cause of most work-related injuries and illnesses. Promoters of behavior-based safety programs maintain that 80–96% of workplace injuries are caused by workers' unsafe behavior. If the workers who are behaving "unsafely" are identified, they can be coaxed, cajoled, and/or threatened into behaving "safely" on the job or sacked.

The core features of BBS programs are as follows:

- the observation of workers by workers
- extensive training provided to those participating, particularly the observers
- the development of a list of "critical worker behaviors," often with input from workers themselves who are invited and welcomed into the process
- the development of "model behaviors," so that workers' behaviors are measured against their own standards – i.e. past behaviors
- substantial management commitment, including financial
- the use of reward systems, e.g. bonuses or acknowledgement of efforts and results
- the use of programs that are promoted as "voluntary" and encourage participation – for example, a program in health and safety will make clear that it is "everyone's responsibility"
- Utilize appropriate current participative and representative structures – e.g. elected Health and Safety (H&S) representatives, union delegates, and occupational health and safety (OHS) committees

3.2 PRINCIPLES OF BEHAVIOR-BASED SAFETY

Fully engage employees in understanding the importance of behavioral safety. Standards must be set for all employees at all levels for participation in safe behavior (Cagle, 2017).

- careless small behaviors can lead to accidents and injuries of much greater magnitude – targeting specific behaviors and creating a checklist approved by all employees creates workplace involvement with safe behavior
- training employees, active observation, and reporting promotes employee engagement and compliance

- the historical review of previous injuries and accidents provides data-driven results for decision-making and helps implementation
- the introduction of improvements can be facilitated through the systematic observation by employees, with regular meetings and brainstorming
- provide evaluations to employees on individual practices and safety behavior
- key leadership commitment is important in order to provide mentoring and set examples for employees so that they commit to a working environment dedicated to safe behavior

3.2.1 Principle 1: Focus Intervention on Observable Behavior

The behavior-based approach to safety is founded on behavioral science as conceptualized and researched by B. F. Skinner. Whatever the intervention strategy used to improve a human aspect of safety, the process should target behavior, whether using training, feedback, injury investigation, coaching, or incentives to benefit safety and focus on behavior. Why? Well, such a focus means you can be objective and impersonal about behavior (Karmis, 2001).

Behavior-based intervention encourages people to *think* differently, whereas person-based intervention encourages people to *act* differently. To be effective, person-focused intervention requires extensive one-to-one interaction between a client and a specially trained intervention specialist. Even if the time and facilities were available for an intervention to focus on internal and unobservable attitudes, few safety professionals or consultants have the education, training, and experience to implement such an approach. Internal person factors can be improved indirectly, however, by directly focusing on behaviors.

The key is to focus on behavior, and you will be on the right track, whatever the intervention approach: behavior-based commitment, behavior-based goal-setting, behavior-based feedback, behavior-based training, behavior-based recognition (Geller, 1997), behavior-based incentives and rewards (Geller, 1996b), and so on.

3.2.2 Principle 2: Look for External Factors to Improve Performance

Internal person dimensions such as attitudes, perceptions, and cognitions are difficult to define objectively and change directly. Instead, you should look for external factors influencing behavior, independent of individual feelings, preferences, and perceptions. When you empower people to analyze behavior from a systems perspective and implement interventions to improve behavior, you will indirectly improve their attitude, commitment, and internal motivation.

Careful observation and analysis of ongoing work practices can pinpoint many potential causes of safe and at-risk behaviors. Those causes external to people – including reward and punishment contingencies, policies, or supervisory behaviors – can often be altered for the improvement of both behavior and attitude. In contrast, internal person factors are difficult to identify, and if defined, they are even more difficult to change directly. Therefore, with behavior-based safety the focus is placed on external factors – environmental conditions and behaviors – that can be changed upstream from a potential injury.

3.2.3 Principle 3: Focus on Positive Consequences to Motivate Safety Improvement

The antecedent, behavior, and consequence (ABC) contingency is a basic tenet of behavior-based safety. "A" stands for "activators," or the antecedent events that direct behavior "B," and "C" refers to the "consequences," or the environmental stimuli that motivate behavior. Recognizing people's safe behavior will facilitate greater learning and more positive motivation than criticizing people's at-risk behavior will. Remember that it is only with positive consequences that you can improve both behavior and attitude at the same time.

Geller et al. (2001) proposed four essential processes to employ in a behavior-based system for mine safety: (i) define target behaviors, (ii) observe critical behaviors, (iii) intervene for instruction, support, motivation, or safety self-management, and (iv) test the impact of the process (Karmis, 2001).

3.2.4 The DO IT Process

The "DO IT" process puts people in control of improving behaviors and thereby preventing injuries. It is a general method for solving the behavioral dimensions of safety problems. It provides objective data for exploring why certain safety-related behaviors occur or do not occur, and for evaluating the impact of interventions designed to increase safe behavior or decrease at-risk behavior. If an intervention does not produce the desired effect, it is either refined or replaced with a completely different behavior-change approach.

3.2.4.1 *"D" for Define*

The process begins by defining certain behaviors to work with. These are the targets of the behavior improvement process: they are the safe behaviors that need to increase, or the at-risk behaviors that need to decrease. Avoiding at-risk behaviors often requires certain safe behaviors, and therefore safe targets might be behaviors that substitute for particular at-risk behaviors.

On the other hand, a safe target behavior can be defined independently of an associated at-risk behavior. Deriving a precise definition of a DO IT target is facilitated with the development of a checklist that can be used to evaluate whether a certain target behavior or process is being performed safely. Just developing such behavioral definitions can lead to valuable learning. When people get involved in developing a behavioral checklist, they own a training process that can improve human dynamics on both the outside (behaviors) and the inside (feelings and attitudes) of people.

3.2.4.2 *"O" for Observe*

When people observe each other for certain safe or at-risk behaviors, they realize everyone performs at-risk behaviors at time. The observation stage is not fault-finding, but is a fact-finding process to facilitate the discovery of behaviors and conditions that need to be changed or continued in order to prevent injuries.

The behavioral observations are only carried out with the awareness and permission of the person being observed. Unannounced observations might give a more

realistic picture of the at-risk behaviors, but such audits reduce interpersonal trust and give the impression that behavior-based safety is a negative program. It is easy to fall into a mindless job routine, and become incapable of handling unexpected events in a safe and timely manner. In addition, some mindless behavior can put a person in immediate risk of personal injury. We need to understand that this can happen to anyone and warrants a concerted effort to increase people's mindfulness when on the job. A behavior-based observation and feedback process provides the mechanism for making this happen.

Regarding the development of an observation process, teams of workers need to decide

- What kind of checklist to use during observations?
- Who will conduct the behavioral observations?
- How often will the observations be conducted?
- How will data from the checklist be summarized and interpreted?
- How will people be informed of the results from an observation process?

There is not one generic observation procedure for all situations, and the customization and refinement of a process for a particular setting should never stop. It is often advantageous to begin with a limited number of behaviors and a relatively simple checklist. This reduces the possibility that some people will feel overwhelmed at the start. Starting small also enables the broadest range of voluntary participation, and provides numerous opportunities to successively improve the process by expanding its coverage of both behaviors and work areas.

3.2.4.3 *"I" for Intervene*

During this stage, interventions are designed and implemented in an attempt to increase safe behavior and/or decrease at-risk behavior. As reflected in Principle 2 above, intervention means changing external conditions of the system in order to make safe behavior more likely than at-risk behavior. When designing interventions, Principle 3 is your guide. Specifically, the most motivating consequences are soon, certain, and sizable. Moreover, positive consequences are preferable to negative consequences.

In addition to behavioral feedback, researchers have found a number of other intervention strategies to be effective in increasing safe work practices. These include worker-designed safety slogans, "near hit" and corrective action reporting, safe behavior promise cards, individual and group goal-setting, actively caring thank-you cards, safety coaching, as well as incentive/reward programs for individuals or groups. These are described elsewhere (Geller, 1996a, 1998), some having been applied in mining settings (Fox et al., 1987; Rhoton, 1980). Later in this chapter, we offer guidelines for matching the intervention strategy with the behavioral target and situation.

3.2.4.4 *"T" for Test*

The test phase of DO IT provides work teams with the information they need to refine or replace a behavior-change intervention, and thereby improve the process. If observations indicate significant improvement in the target behavior has not occurred, the work team analyzes and discusses the situation, and refines the

intervention or chooses another intervention approach. Every time the participants evaluate an intervention approach, they learn more about how to improve safety performance.

3.3 THE SEVEN PRINCIPLES OF BEHAVIOR-BASED SAFETY

- Fully engage employees in the significance of behavioral safety. Set standards for all employees at all levels for participation in safe behavior (Arunagirinathan, 2013).
- Careless small behaviors lead to accidents and injuries of much greater magnitude. Targeting specific behaviors and creating a checklist approved by all employees creates workplace involvement in safe behaviors.
- Training employees to lead as safety monitors and carry out active observation and reporting promotes employee engagement and compliance.
- A historical review of previous injuries and accidents provides data-driven results for decision-making addressing the implementation of changes.
- The introduction of improvements through systematic observation by employees, with regular meetings and brainstorming, will incorporate the continuity of safety-based behavior.
- Ensure the provision of evaluations to employees on individual practices and safety behavior.
- Key leadership commitment is important to provide mentoring and examples in order for employees to commit to the idea of working in an environment dedicated to safe behavior.

3.4 WHAT IS A BEHAVIOR-BASED SAFETY APPROACH?

A behavior-based safety approach promotes interventions that are people-focused and typically incorporate one-to-one or group observations of employees performing routine work tasks, setting goals carefully, and giving timely feedback on safety-related behavior, as well as coaching and mentoring. The initiatives have a proactive focus, encouraging individuals and their work groups to consider the potential for incident involvement, (accidents) and to assess their own behavior as safe or unsafe always, no matter what.

A BBS approach is one that (HAS, 2013)

- Is based on solid principles about engaging, motivating, assisting, reinforcing, and sustaining safe behaviors.
- Takes a systematic approach, examining the motivation underlying behaviors, in order to increase safe behavior.
- Is an ongoing effort; not making “once-off” provisions, but giving a new way of working that the safety leader must continually promote for sustainable, positive results?
- May take time to achieve; however, some results can be observed immediately due to the nature of measurement involved.

- Emphasizes the implementation of increasingly safe behaviors rather than focusing on length of time without injury. BBS programs do not depend solely on "lagging indicators" (after the fact), and instead shift the focus to "leading indicators" (preventative).
- Is not a substitute for an already existing comprehensive health and safety program; it is a supplementary tool that will enhance the effect of already existing practices, and will allow for an objective measurement system.
- Aims to understand causes of incidents and near misses and correct them through the behavior of relevant people; for example, reducing hazards often requires a behavior change in managers and frontline workers, and equipment redesign may involve a behavior change in engineers.

BBS is a proactive process that helps to get changes in a work group's safe behavior levels *before* incidents happen. All incidents are preceded by some kind of behavior – BBS seeks to change a person's mind-set, habits, and behaviors so that these "at-risk" behaviors will no longer occur.

3.5 TYPES OF BEHAVIOR AND INTERVENTION STRATEGIES

Safety professionals intervene every day in an attempt to improve safety performance. When they target people's behavior they are implementing a behavioral intervention. They are intervening to increase safe behavior or to decrease at-risk behavior with the intention of preventing injury.

Whether behavioral intervention works depends upon many factors, including the type of behavior targeted, the personal characteristics of the individual performing the behavior, and the context or environmental setting in which the behavior is occurring. Also important, of course, is the type of intervention used to affect the target behavior. All of these factors interact in complex ways so that certain intervention strategies work better for certain behaviors, and some strategies may be affected by particular circumstances determined by both environmental and personal dynamics.

There are three types of at-risk behavior:

1. conscious
2. habitual
3. unintentional

BBS is about unintentional behavior and habitual behavior. To be more specific, it's about how to prevent mistakes or errors people didn't want to make in the first place.

There are differences between other-directed, self-directed, and automatic behaviors. All voluntary behavior starts out as other-directed, in the sense that we follow someone else's instructions, as reflected, for example, in a training program, operation manual, or policy statement. After learning what to do, essentially by memorizing or internalizing the appropriate instructions, our behavior enters the self-directed stage. After performing some behaviors frequently and consistently over a period of time they become automatic. A habit is formed. Some habits are good and some are

not good, depending on their short- and long-term consequences. If implemented correctly, some behavioral interventions can facilitate the transfer of behavior from the self-directed stage to the habitual stage.

3.5.1 Three Kinds of Behavioral Intervention

Behavior-based safety trainers and consultants teach the ABC model (or three-component contingency) as a framework to understand and analyze behavior, or to develop interventions for improving behavior. As above (Section 3.2, Principle 3), the "A" stands for activators or antecedent events, that precede behavior "B," and "C" refers to the consequences following the behavior, and produced by it. Activators typically direct behavior, whereas consequences motivate behavior.

BBS is a process that applies the principles of the ABC model. This assumes that all behaviors have one or more antecedents or activators or prompts, which initiate the behavior and one or more consequences that either encourage or discourage repetition of the behavior.

Antecedent	Behavior	Consequence
• A stimulus or event that occurs before a behavior in time • This stimulus or event may result in the behavior • Work examples include goals, policies, training, job aids, and guides	• Anything that we can see an individual do or say	• A stimulus or event that occurs after a behavior in time • This consequence could increase or decrease behavior in the future, depending on its reinforcing or punishing properties • Work examples include feedback, recognition, task completion, goal achievement, rewards

Despite the fact that we rely heavily on antecedents, it is consequences that have the greatest influence on behavior.

3.5.2 The ABC Model of Behavior Change

3.5.2.1 Three Elements

- **Activator** – is a person, place, or thing coming before a behavior that encourages that behavior.
- **Behavior** – is something a person can be seen doing.
- **Consequence(s)** – is an event or events that follow behaviors and may change the probability that they will recur in the future

3.5.2.1.1 Activators

- always come before behaviors
- communicate information
- consequences can also be activators

- prompt or activate behavior
- in most worksites we try to modify behaviors using activators
- activators only prompt behaviors, they do not reinforce it

3.5.2.1.2 Behaviors

- behaviors are any observable and measurable acts
- anything a person can be seen doing

3.5.2.1.3 Consequences

- are events that follow behaviors and change the probability that those behaviors will recur in the future
- have the greatest influence on behaviors

3.5.2.1.3.1 Consequences that Decrease or Stop Behavior

- **Punishment** – is getting something we don't like; anything that happens to people that decreases behavior
- **Extinction** – is when people do something but get no reinforcement; the withholding or non-delivery of reinforcement for previously reinforced behavior
- **Positive Reinforcement** – is the only consequence that maximizes performance; it captures "discretionary effort
- **Negative Reinforcement** – only produces a level of performance necessary to escape or avoid punishment; performance to the level necessary to stay out of trouble

3.5.2.1.3.2 Consequences that Increase Behavior

- consequences that people will work hard to avoid
- people will do what they must to avoid

Activators and consequences can be external to the performer (as in the environment), or they can be internal (as in self-instruction or self-recognition). They can be intrinsic to a behavior, meaning they provide direction or motivation naturally, as a task is performed (as in a computer game), or they can be extrinsic, being added to the situation in order to improve performance. A behavioral intervention is external and extrinsic. It adds an activator and/or a consequence to the situation in order to direct and/or motivate desirable behavior.

3.5.3 Instructional Intervention

Instructional interventions are typically activators or antecedent events used to move behavior away from the automatic (habit) stage to the self-directed stage, or to improve behavior already in the self-directed stage. The aim is to get the performer's attention and instruct them to transition from unconscious incompetence to conscious competence. The assumption is that the person wants to improve, so external motivation is not needed – only external and extrinsic direction.

This type of intervention consists primarily of activators, as exemplified by education sessions, training exercises, and directive feedback. Since the purpose is to instruct, the intervention comes before the target behavior and focuses on helping the performer internalize the instructions. As we have all experienced, this type of intervention is more effective when the instructions are specific and given one-to-one. Role-playing exercises provide instructors with opportunities to customize directions specific to individual attempts to improve.

3.5.4 Supportive Intervention

Once a person learns the right way to do something, practice is important in order for the behavior to become part of a natural routine. Continued practice leads to fluency and in many cases to automatic or habitual behavior. This is an especially desirable state for safety-related behavior. However, practice does not always come easily, and can benefit greatly from supportive intervention. We need supportive intervention to encourage us to keep going and to reassure us we are doing the right thing.

While instructional intervention consists primarily of activators, supportive intervention focuses on the application of behavioral consequences. Thus, when we give people rewarding feedback or recognition for particular safe behavior, we are showing our appreciation for their efforts and increasing the likelihood, they will perform the behavior again. Moreover, each occurrence of the desired behavior facilitates fluency and helps build a good habit.

After people know what to do, they need to perform the behavior many times before it can become a habit. Therefore, the supportive consequences we give people for their safety-related behavior can go a long way toward facilitating fluency and their transition to the automatic or habit stage. Such supportive intervention is often most powerful when it comes from one's peers – as in peer support.

3.5.5 Motivational Intervention

Note that an activator typically does not precede supportive intervention. In other words, when you support self-directed behavior you do not need to provide an instructional antecedent. The person knows what to do. Moreover, you do not need to activate desired behavior with a promise (an incentive) or a threat (a disincentive). The person is already motivated to do the right thing.

When people know what to do and do not do it, however, a motivational intervention is needed. In other words, when people are consciously incompetent about safety-related behavior, they require some external encouragement or pressure to change. Instruction alone in this situation is clearly insufficient because they are knowingly doing the wrong thing. In safety, we refer to this as a calculated risk.

We usually perform calculated risks because we perceive the positive consequences of the behavior to be more powerful than the negative consequences. This is because the positive consequence is immediate and certain, while the negative consequence of such behavior (an injury) is improbable and seems remote. Furthermore, typically, the safe alternative is relatively inconvenient, uncomfortable, or inefficient,

and these negative consequences are also immediate and certain. As a result, we often need to add both activators and consequences to the situation in order to move people from conscious incompetence to conscious competence.

An incentive/reward program attempts to motivate a certain target behavior by promising people a positive consequence if they perform it. The promise is the incentive and the consequence is the reward. In safety, this kind of motivational intervention is used much less than a disincentive/penalty program. This is when a rule, policy, or law threatens to give people a negative consequence (a penalty) if they fail to comply or take a calculated risk.

However, a disincentive/penalty intervention is often ineffective because, like an injury, the negative consequence or penalty seems remote and improbable. The behavioral impact of these enforcement programs are enhanced by increasing the severity of the penalty and catching more people taking the calculated risk. However, the large-scale implementation of this kind of behavioral intervention can seem inconsistent and unfair. And because threats of punishment appear to challenge individual freedom and choice, this approach to behavior change can backfire and activate further calculated risk-taking, even sabotage, theft, or interpersonal aggression.

Motivational intervention is clearly the most challenging, requiring enough external influence to get the target behavior started without activating a desire to assert personal freedom. Remember that the objective is to motivate a transition from conscious incompetence to a self-directed state of conscious competence. Powerful external consequences might improve behavior only temporarily, as long as the behavioral intervention is in place. Hence, the individual is consciously competent, but the excessive outside control makes the behavior entirely other-directed. Excessive control on the outside of people can limit the amount of control or self-direction they develop on the inside.

It is possible that a long-term implementation of a motivational intervention, coupled with consistent supportive intervention, can lead to a good habit. In other words, with substantial motivational and supportive intervention, other-directed safe behavior can transition to unconscious competence without first becoming self-directed.

Thus there are three types of behavioral interventions with respect to their application for helping people transition between five states of safety competence: (i) unconsciously incompetent, (ii) consciously incompetent (self-directed and/or other-directed), (iii) consciously competent/other-directed, (iv) consciously competent/self-directed, and (v) unconsciously competent. The three types of interventions: instructional, supportive, and motivational. At-risk behavior might be other-directed, self-directed, or influenced by a combination of external and internal factors.

Both activators and consequences are needed to change the behavior of consciously incompetent individuals. These behavioral interventions usually take the form of incentive/reward or disincentive/penalty programs, although peer pressure can also have a marked motivational influence on this state. When the controlling contingencies of an activator/consequence intervention are obvious to an individual,

a transition to conscious competence is likely to be perceived as other-directed. In other words, the individual will perform the desired behavior as long as the intervention program is in effect, but might revert to earlier at-risk behavior if the incentive/reward or disincentive/penalty program is removed. This will not happen if the individual's conscious competence changes from other-directed to self-directed.

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4 Safety Culture in the Mining Industry

4.1 CONCEPT OF SAFETY CULTURE

Safety culture is the attitude, beliefs, perceptions, and values that employees share in relation to safety in the workplace. It is defined by The UK Health and Safety Commission as: "The product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management." The International Atomic Energy Agency (IAEA) defines a strong safety culture as "the assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance" (IAEA, 2015). In simple terms, safety culture in an organization is the way that safety is seen, understood, valued, and formulated, when no one is watching. A positive safety culture in an organization is important for successfully creating and executing an effective safety program (Miller, 2018). The main elements of safety culture are human factors, leadership, environment, systems, and human behavior as shown in Figure 4.1.

"Safety culture" is a sub-section of the overall company culture. The safety outcome of an organization depends mainly on the culture of the organization. Management systems and their associated policies and procedures depend upon the actions of

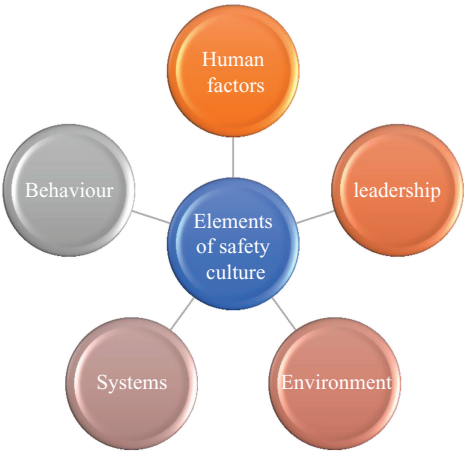

FIGURE 4.1 Elements of safety culture.

employees for their successful implementation (CCPS, 2018). If the employees of any organization do not operate in a safe environment, the failure of the management systems and the resultant financial effects could become apparent (Olphin, 2017). Therefore having a positive safety cultural environment is essential in an organization. Building a safety culture in the organization can (PSS, 2014)

- improve safety performance
- reduce accidents and injuries
- reduce absenteeism
- reduce financial losses
- improve the reputation of the organization
- improve the workers' productivity

The indications of poor safety culture in an organization can include (HSE, 2018b; Denis, 2012)

- failure to comply with the company's own safety management system
- repeated, routine procedural violations
- when accident prevention programs, injury, and illness prevention programs become just paperwork
- management decisions that appear consistently to put production or cost before safety

4.1.1 Important Characteristics of an Effective Safety Culture

The common safety culture characteristics are shown in Figure 4.2.

- **Safety is clearly a recognized value**: Safety should be given priority over all other demands in an organization. Managers should consider safety when framing strategies, plans, and goals, and should arrange the declared priorities and objectives when allocating resources.
- **Accountability for safety is clear**: There should be strong respect for the rules and importance of safety in the organization. Workers in the

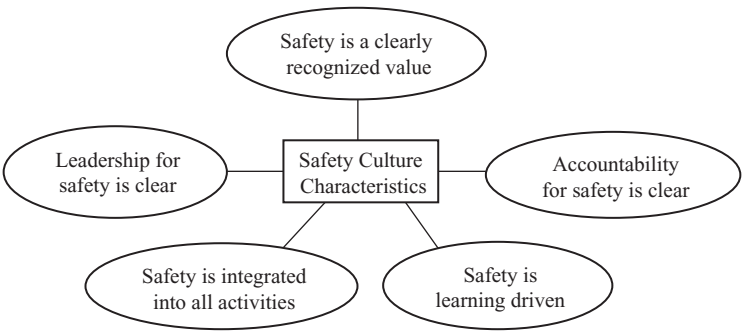

FIGURE 4.2 Safety culture characteristics.

organization should clearly know the tasks assigned to them. If the individual is unable to complete the task as expected, they should report this to their supervisors.

- **A safety leadership process exists**: Safety culture cannot be controlled, but good leadership can influence it. Leaders should set clear examples when it comes to safety. Good leaders should appear regularly at the workplace, talk about safety, and prove their commitment by their actions.
- **Safety is assimilated into all activities**: A positive safety culture will show that safety is assimilated in all activities in the organizations.
- **Safety culture is learning driven**: An organization should be learning from the previous experiences and continuously make every effort to improve performance.

The main organizational behavior impacting safety culture and their correlation are presented in Table 4.1 (IAEA, 2015; Kosmoski, 2016).

4.2 BUILDING SAFETY CULTURE IN THE MINING INDUSTRY

As safety reaches all levels of the workforce in an organization, building a safety culture is very essential. Establishing safety within the culture of an organization is not only a requirement, but it also has many operational benefits. The Occupational

TABLE 4.1
Relationship between Safety Culture Characteristics and Organizational Behavior

Organizational Behavior	Safety Culture Characteristics
Attention to safety	Safety is a clearly recognized value
Resource allocation	
Time urgency	
Goal prioritization	
Decision-making	
Roles and responsibilities	Accountability for safety is clear
Performance quality	
Communication	
Organizational culture	A safety leadership process exists
Communication	
Coordination of work	Safety is assimilated into all activities
Formalization	
Training	
Organizational knowledge	
Organizational learning	Safety culture is learning driven
Problem identification and resolution	
Performance evaluation	
Personnel selection	

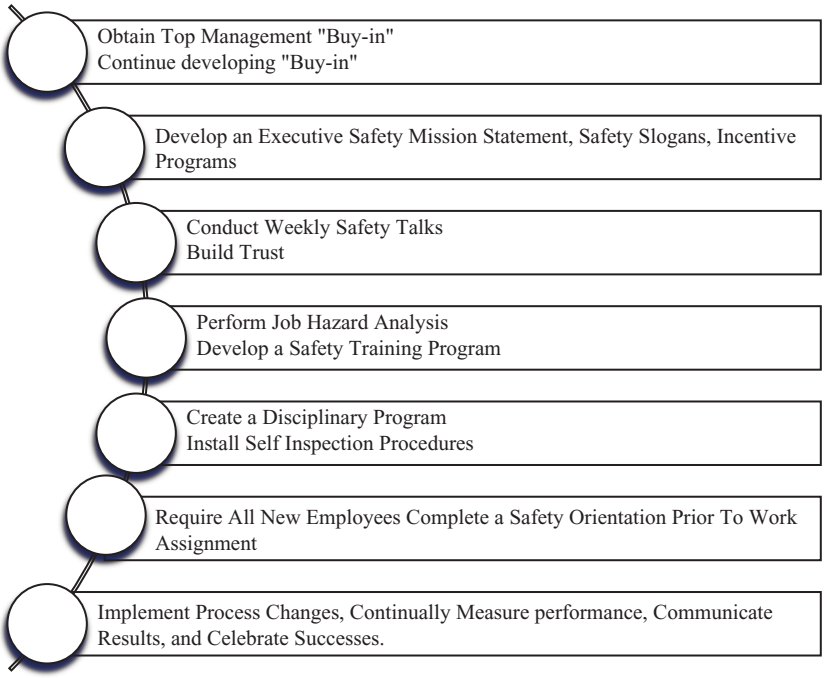

FIGURE 4.3 Steps for building safety culture.

Safety and Health Administration (OSHA) has reported that creating a safety culture has the single greatest impact on accident reduction of any process (Lanz, 2016). The key steps for building a safety culture are shown in Figure 4.3 (Chaparro, 2015; Kosmoski, 2016).

4.2.1 Ten Steps to Build a Positive Safety Culture

Building a positive safety culture is no mean feat. It requires real commitment from all levels of a company, as well as a plan and leaders to drive it toward success (WSG, 2018).

4.2.1.1 I. Set Goals

To build a positive safety culture, make sure that everyone is involved in setting goals, from senior managers down to the newest employee. When goals are collectively set it encourages engagement.

4.2.1.2 I. Talk and Listen

It is also extremely important that everyone is on the same page with safety practices, and that everyone recognizes it is as important to talk as it is to listen. The leaders need to talk to set out what the initial goals are, however they also need to listen and to make sure that all ideas are heard and incorporated where appropriate.

4.2.1.3 III. Be Involved

Single members of the team need to be held accountable for their involvement. Safety and leadership must go hand-in-hand.

4.2.1.4 IV. Be Responsive

There should be varied and open channels of communication and one should be held accountable for his inaction.

4.2.1.5 V. Report Near Misses

Near misses should also be properly reported: they can be a great way to build on existing safety measures.

4.2.1.6 VI. Investigate Accidents

The investigation should be done in such a way that it leads to further solutions. The investigation of accidents in an organization should aim to "find facts" rather than to "find faults."

4.2.1.7 VII. Training and More Training

Proper training should be given to all sections of employees. When there is no training, risks increase substantially.

4.2.1.8 VIII. Make Safety a Center Value

Developing safety as a center value level brings change throughout the company. It also helps the staff to trust the organization when it shows it values its staff and treats them as a most important asset.

4.2.1.9 IX. Have a Specialized Team

To provide guidance on how to have a successful workplace, every organization needs a specialized safety team.

4.2.1.10 X. Celebrate Success

It will be motivating for the workers to know that their efforts toward the company's safety culture do not go unnoticed and it is important to celebrate small and big successes alike with regard to the safety performance of the company.

4.3 STRATEGIES TO CHANGE THE SAFETY CULTURE

The idea of changing the current safety culture at a mining or any other organization can be alarming because the workplace may have fallen into a pattern of complacency. The effects of such complacency can vary from the occurrence of minor accidents to catastrophic accidents (Core Safety, 2018c). The possible reasons for resisting change are misunderstanding, habit, a different perception of the situation, low capacity for change, and low tolerance to change.

The changes in the safety culture of an organization cannot materialize instantaneously, they need to form a continuous process. A series of continuous improvement steps need to be framed and followed to create a safety culture. The levels of commitment of the owners and the workers are the true indications of a safety culture

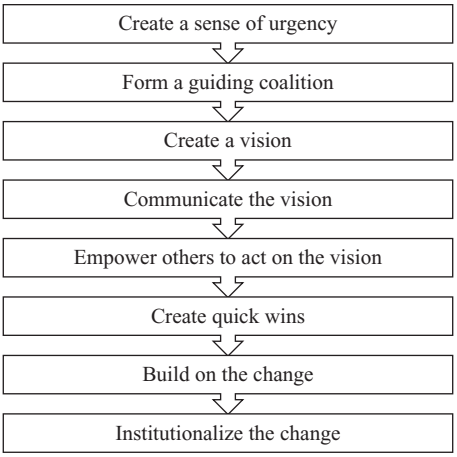

FIGURE 4.4 Steps for changing safety culture.

where safety is an important part of daily operations (GWM, 2016). Managing cultural change within an organization indicates a need to follow certain steps as shown in Figure 4.4 (Core Safety, 2018a; Duke, 2013).

- **Create a sense of urgency**: Any loss of life is unacceptable. If major or minor accidents are happening in an organization, then there is the need to create a sense of urgency in changing safety culture.
- **Form a guiding coalition**: It is necessary to form an alliance between driving parties to coordinate activities.
- **Create a vision**: The driving parties should create the goals, plans, and agenda.
- **Communicate the vision**: The goals, plans and agenda should be communicated to all the staff.
- **Empower others to act on the vision**: The management should authorize supervisors to properly implement the set goals.
- **Create quick wins**: Make visible changes at management level and ensure that all other staff can see them and feel them.
- **Build on the change**: Make sure the intentions are implemented and transformed with time.
- **Institutionalize the change**: Standardize the changes made over time by regulating the rules.

4.4 LEADERSHIP COMMITMENT FOR IMPROVING SAFETY CULTURE

Good safety leaders know that strong safety performance is what drives the company's results. So they encourage a culture of safety in their organization, and try to incorporate prevention measures into the company's strategies and performance

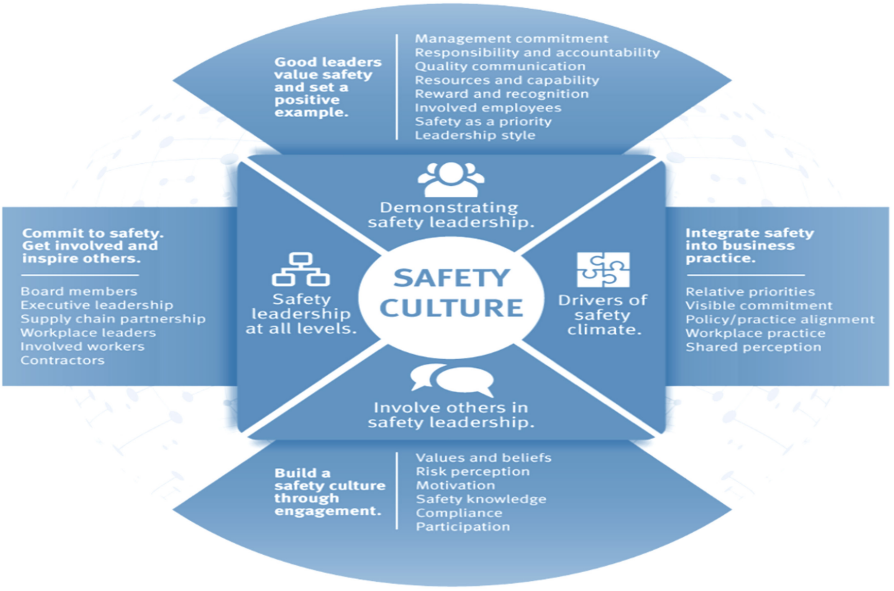

FIGURE 4.5 Safety leadership and culture model.

measures (WSPS, 2018). A safety leadership and culture model is shown in Figure 4.5 (Worksafe, 2016).

Leadership is defined as a multifaceted area, one aspect of which deals with the capacity of an individual to guide and influence other individuals. Leaders are individuals who have the ability to guide other individuals, teams, or even a complete organization. Leaders are individuals who influence the attitudes and behavior of other individuals. They can influence workers in many ways, sometimes through their official role and sometimes by their personal influence. Leaders in an organization can be at all levels: they can at the head of an organization's management, or middle managers at work sites, or first-line supervisors. The critical role of the leadership is to give support for the workers' safety, which is fundamental and achievable. A good leader clearly defines the goals and presents the ways to achieve the goals (Peterson, 1996). The achievement of creating a safety culture in an organization clearly depends on the leadership actions, measures and rewards, and systems.

4.4.1 The Importance of Leadership Commitment

Since the responsibility for safety starts with the top management, leadership commitment is the key in any organization (Worksafe, 2018). Everyone knows that a safe workplace is important, but it will not happen unless the top leaders commit to making the workplace as safe as it can be. Therefore, the main responsibility for creating a safe workplace depends on the leadership commitment. There is strong evidence that the performance of an organization improves when the leadership is committed to addressing workplace safety risks along with other important business

risks (SafeWork, 2017). A few other commitments by the leaders can also improve the safety culture in the organization. They are, for example: strictly following the procedures, rules, and laws; managing risks in a systematic way; regularly meeting with workers; providing proper training to workers; providing retraining if required; establishing two-way communication; and establishing a positive leadership and management style. When workers recognize that their leaders place a high level of importance on workplace safety, they are more likely to be inspired to follow safety procedures and raise safety issues with their supervisors (SafeWork, 2017).

4.4.1.1 The Qualities of Visible Safety Leadership

Good, visible safety leadership takes place when the leader and/or leadership team (Safetyworks, 2018; Core Safety, 2018b)

- promote safety
- get personally involved in workplace health and safety and communicate their ongoing commitment to the workplace health and safety vision
- demonstrate they mean what they say about workplace health and safety through their actions
- consistently take a strong uncompromising stand for workplace health and safety
- ask questions to understand how improvements can be achieved
- create an environment where people are encouraged to speak up
- consciously consider workplace health and safety impacts when making business decisions
- encourage workers to report hazards and near-miss incidents
- never be satisfied – always look forward to their employees to continuously improve in workplace health and safety
- demonstrate to people outside the organization that workplace health and safety is part of the culture for everyone

Leaders and senior managers must act as role models. They must show how to create a safe work environment. Their support and commitment also shows employees that their organization cares about their well-being. Overall, an organization's safety management system grows stronger and becomes more apparent when leaders and managers visibly support their safety management system. A strong safety and health culture generally leads to lower injury and illness rates, increased production, and better attitudes. If the leaders and managers do not hold safety and health commitment as a primary objective, it may shift the safety management system in an undesirable direction. Steps for leaders and managers to visibly show commitment to safety and health are as follows (SMCX, 2017):

4.4.1.1.1 Top Leaders

- set the organizational safety vision
- draft, sign, and communicate a safety and health commitment letter
- establish action plans to address identified trends
- set organizational-level safety and health goals

- participate in safety meetings
- acknowledge safety and health excellence during award ceremonies
- conduct safety walkthroughs in all work areas
- develop and communicate an open-door policy

4.4.1.1.2 Middle Managers

- promote and execute the organizational safety vision and goals
- set safety and health objectives (to meet established safety and health goals)
- encourage employee involvement
- hold personnel accountable for following safety and health rules
- participate in safety inspections and safety meetings
- recognize safety excellence

4.4.1.1.3 First-Line Supervisors

- set the safety culture for the workforce
- lead employees in accomplishing safety and health objectives
- ensure employees understand and follow safety and health rules
- inform leaders and managers when employee recognition is due
- actively involve employees in the safety management system (in at least three meaningful ways)
- implement a stop work program for hazardous conditions

4.4.2 Improve Safety Culture Through Leadership

Building a strong culture of safety in an organization requires active leadership from the top down. A safety culture is one where everyone in an organization is part of the group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to health and safety management. Safety managers and other organization leaders need to demonstrate a positive attitude toward health and safety in order to have a cascading effect on fellow employees and staff. By taking a proactive approach to safety, managers set the example for employees and positively influence safety culture. Having a strong culture of safety is one where all levels of the organization are visibly committed to safety. Everyone takes ownership of the organization's health and safety. Safety managers play a key role in helping achieve this (Safetypros, 2016).

Safety managers can promote a strong safety culture by setting the example. Leaders who communicate the importance of health and safety objectives influence employees to take the initiative and observe safe practices. A manager's role should not simply be restricted to directing work and monitoring compliance with rules and regulations, but should show initiative and proactivity in creating a safety culture. Managers acting as leaders facilitate safety communication and encourage employees to be part of the conversation.

Engaging with employees is the best way to foster the growth of safety culture. Managers should implement an open-door policy that allows employees to openly discuss issues and provide feedback on policies and procedures. Leaders should

invite employees to make suggestions and motivate them to help identify hazards. They engage with their employees and extend recognition to those who are an active part of solving health and safety challenges.

Proactive communication by managers and employees should make safety goals and objectives clear to everyone in the organization. Safety managers can communicate with employees through regular planned meetings, face-to-face discussions, health and safety briefings, and so on. Active involvement from the organization's leaders empowers employees to become actively involved with health and safety, which is a positive step toward preventing and controlling hazards.

Safety managers need to make continuous efforts to ensure that new safety objectives take hold and that employees are always up-to-date on safety requirements within the organization. Managers who are positive and demonstrate a commitment to health and safety set the example for employees to follow. Managers working at improving factors will have a positive influence on their organization's health and safety culture.

4.5 SAFETY MATURITY MODELS

Safety maturity models are useful to determine the current level of safety culture in an organization and the ability of the organization for continuous improvement. One of the most popular maturity models is Hudson's model (Hudson, 2003; Parker et al., 2006) as shown in Figure 4.6.

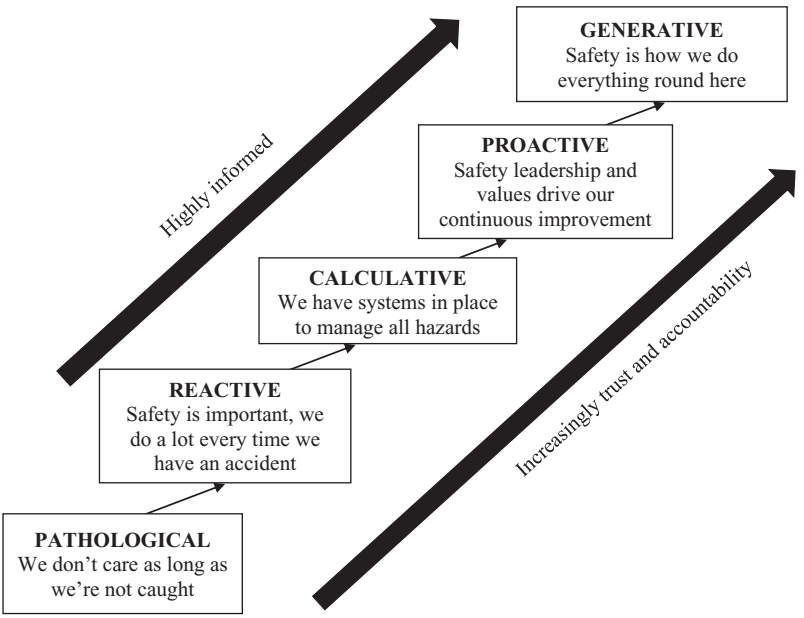

FIGURE 4.6 Hudson's model.

4.5.1 Safety Maturity Models in the Mining Industry

The state of safety culture and the safety management in the mining industry is different from organization to organization. Many mining companies are trying to improve the level of safety in their organization by introducing new techniques and tools. However, the poor state of an organization's safety culture can limit the effectiveness of the newly introduced technique. Therefore, to measure the current state of safety culture and the effectiveness of the safety management process in an organization, safety maturity models started to be developed (Foster and Hoult, 2013). The Minerals Industry Risk Management (MIRM) maturity chart, Anglo American Plc maturity model, and the UK coal journey model are the few safety maturity models that have been developed exclusively for use in the mining industry.

4.5.1.1 The Minerals Industry Risk Management Maturity Chart

A team from the University of Queensland developed the MIRM maturity chart. To clearly understand the journey based on a description of the culture and the risk management system a model is developed by modifying the Hudson model and a similar approach used by Bayside Aluminum, a BHP Billiton site in Richards Bay, South Africa (Department of Resources, Energy & Tourism, 2008; The University of Queensland, 2008; NSWDPI, 2011). The MIRM maturity chart is shown in Figure 4.7.

The MIRM maturity chart has a ladder with five rungs. After assessment, the site that falls on the lowest rung, "Vulnerable," will "accept the incidents happen," the site that falls on the next rung, "Reactive," will "prevent a similar incident from happening again," the site that falls on the "Compliant" rung will "prevent the incidents before they occur," the site that falls on the "Proactive" rung will "improve the systems," and the site that falls on the last rung, "Resilient," has "successfully integrated safety and risk management into its operations."

4.5.1.2 Anglo American Plc Maturity Model

In 2007, Anglo American Plc developed a maturity model based on the MIRM maturity chart that involves both people and systems (Morris, 2013) as shown in Figure 4.8.

The model shows an image of spiral staircase that is used in all courses, with discussions, and it used to identify current status and plans to improve. In this model, assessments are made against 6 people elements and 17 system elements, as shown in Table 4.2. The Anglo American model, the MIRM ladder, and the Hudson model all suggest a strong relationship between the culture of an organization and the development of a systems approach (Foster and Hoult, 2013).

4.5.1.3 UK Coal Journey Model

In 2010 this model was introduced in UK Coal Production Ltd (formerly UK Coal Plc), and it is shown in Figure 4.9 (UK Coal Plc, 2011). In this model, assessments are made against integrated "culture" and "system" elements. The "basic" level in the maturity model has no standards in place. With the improving level of maturity, the requirements of the standards increase. The elements used in this model

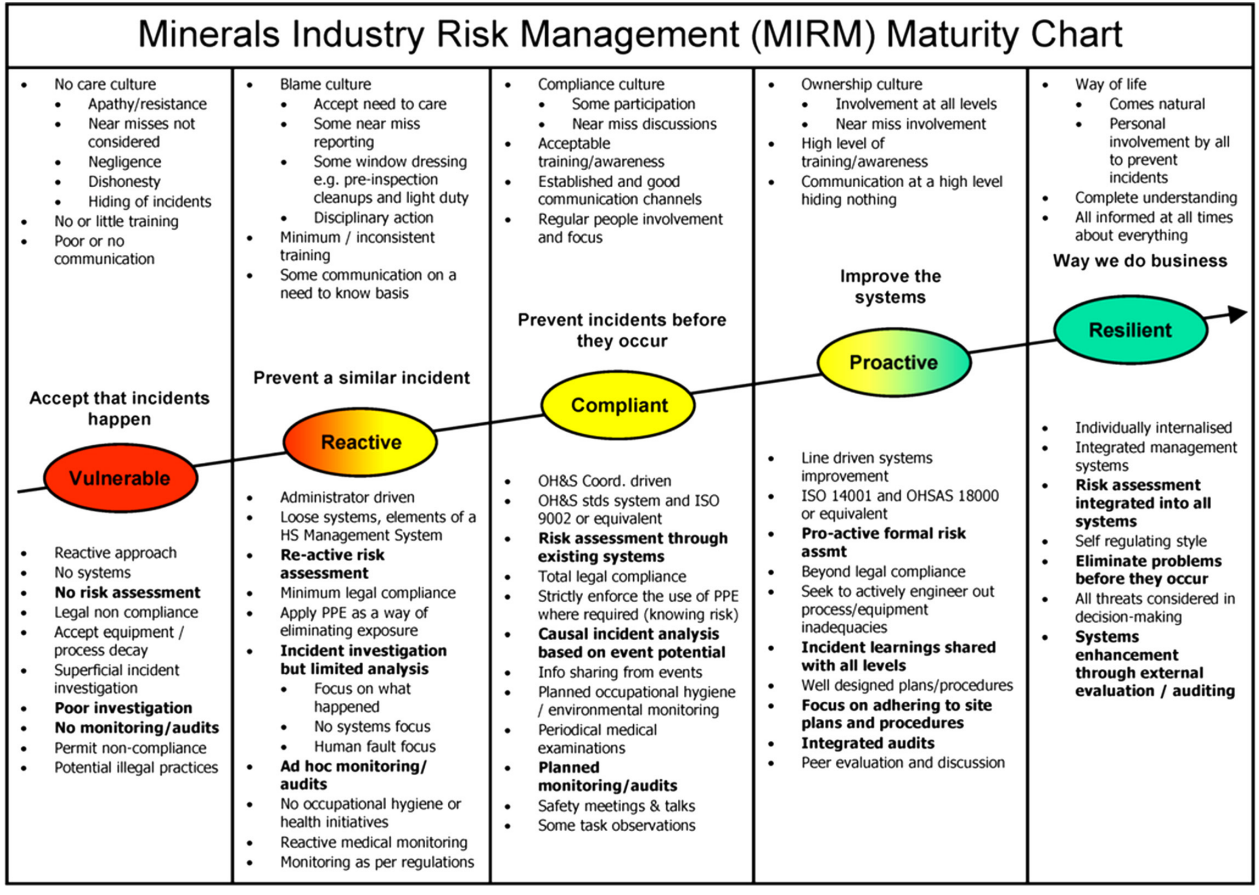

FIGURE 4.7 The MIRM maturity chart.

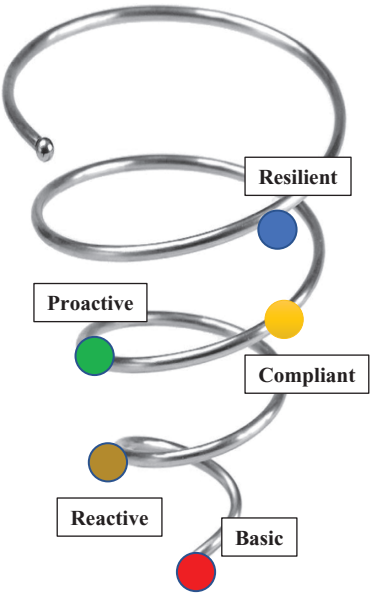

FIGURE 4.8 Anglo American Plc maturity model.

TABLE 4.2
Elements used for Assessment in Anglo American Plc Maturity Model

People	Systems
Personal risk attitude	Risk management adoption
Caring and recognition	Strategic planning
Management leadership and commitment	Project and process design management
Safety accountability	Major hazard identification and risk management
Employee involvement and consultation	Incident investigation and analysis
Coaching and mentoring	Job and task planning
	Hazard identification and reporting
	Training and competency
	Procurement
	Change management
	Knowledge management
	Communications
	Contractor management
	Safety performance measurement
	Emergency response
	Auditing and monitoring
	Maintenance

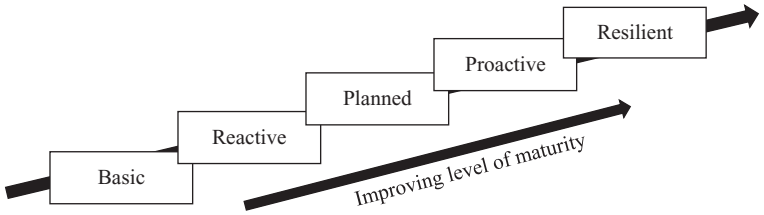

FIGURE 4.9 UK coal journey model.

are leadership and accountability; policy and commitment; risk and change management; legal requirements; objectives, targets and performance measurement; training, competence and awareness; communication and consultation; control of documents; operational controls; emergency procedures; incident investigation; monitoring, auditing and reviews.

5 Accident Statistics, Analysis and Prevention in Coal and Non-Coal Mines

5.1 ACCIDENTS AND THEIR CLASSIFICATION

An accident is an unplanned and unexpected event that results in mishap. Accidents may result in property damage, interruption of work, loss of life, or injury. Accidents are the result of the failure of people, equipment, materials, or the environment to react as expected. All accidents have consequences. Nevertheless, the consequences may vary based on the type of accident, working environment, location, workers' experience, protective equipment used, etc. Harms-Ringdahl (2003) presented types of accidents as follows:

- **Accidents with direct consequences** – the negative consequences will become evident in a short period of time. Almost all accidents in mines have direct consequences, for example, being stuck between equipment, electrocution, explosion, or roof fall.
- **Accidents giving an increased probability of injury or damage** – the negative consequences will become evident after continuous exposure for long period. This type of accident often leads to diseases. The likelihood of this type of accident depends on the exposure time. In mines, continuous exposure to dust by workers leads to various diseases such as coal workers' pneumoconiosis, asbestosis, silicosis, etc.

In mines, the accidents are classified as follows (DGMS, 2018b; Biswas, 2016; Kejriwal, 2002):

- **Fatal accidents**: involving at least one death
- **Serious bodily injury**: defined as any injury that involved or in all probability will involve
  - the permanent loss of any part or section of a body or
  - the permanent loss of or injury to sight or hearing or
  - any permanent physical incapacity or
  - the fracture of any bone or joints
- R**eportable injury**: an injury, other than serious bodily injury, that requires absence of the injured from work for a period of 72 hours or more

- **Minor injury**: an injury, other than serious bodily injury and reportable injury, that requires absence from work for a period exceeding 24 hours
- **Dangerous occurrences**: an incident that do not involve loss of life or any injury; however, could have happened, if any worker is present at the place of accident.

5.2 BASIC CAUSES OF ACCIDENT OCCURRENCE

The Directorate General of Mines Safety (DGMS) has analyzed the types of accidents and classified them in nine categories according to their causes. The accidents were also classified according to the location of their occurrence. To ease the computerization of accident data, from 1989, the DGMS has assigned a specific code for each cause and each location of fatal and serious accidents. The causes and their codes are shown in Table 5.1, and the classification according to the location of occurrence is shown in Table 5.2.

Figure 5.1 shows the number of accidents in Indian mines during 2017 with their causes. The basic hazard elements identified for different causes of accidents in underground coal mines are presented in Table 5.3.

5.3 FREQUENCY RATE AND SEVERITY RATE

The safety performance of a mine is often judged according to the number of accidents happening at that mine. The number of accidents can be expressed using various types of rates, that is the frequency rate and the severity rate. Along with the evaluation of safety standards in mines, the frequency and severity rates also help to compare the safety status of one mine with another or one company's mines to another company's mines, or to make international comparisons (Kejriwal, 2002; Tripathy and Reddy, 2016). Accident rates are evaluated in order to determine the causes and effects of accidents for the further improvements of safety measures in mines. To promote uniformity and comparability of mine accident statistics, the Bureau of Indian Standards (BIS) (IS 3786, 1983) and lately ISO (ISO 19434, 2017) have recommended basic methods for recording and classifying accidents. In India, the usual practice is to calculate the frequency rate and severity rate based on

- Rate per 1,000 persons employed
  - Death rate per 1,000 persons employed = (Number of accidents $\times 10^3$)/(Total number of persons employed)
  - Injury rate per 1,000 persons employed = (Number of persons injured $\times 10^3$)/(Total number of persons employed)
- Accident frequency rate per one lakh man-shifts worked
  - Frequency rate = Number of accidents $\times 10^5$/(Total number of man-shifts worked)
- Death rate per million tons output
  - Death rate = Number of accidents $\times 10^6$/(Total output of mines)

The accident frequency and severity rates in Indian coal mines during 2017 is shown in Figure 5.2.

TABLE 5.1
Causes of Accidents

Ground Movement

0111 Fall of roof
0112 Fall of sides (other than overhangs)
0113 Fall of overhang
0114 Rock burst/bumps
0115 Air blast
0116 Premature collapse of workings/pillars
0117 Subsidence
0118 Landslide
0119 Collapse of shaft

Transportation Machinery (Non-Winding)

0331 Aerial ropeway
0332 Rope haulage
0333 Other rail transportation
0334 Conveyors
0335 Dumpers
0336 Wagon movements
0339 Wheeled trackless (truck, tanker, etc.)

Explosives

0551 Solid blasting projectiles
0552 Deep hole blasting projectiles
0553 Secondary blasting projectiles
0554 Other projectiles
0555 Misfires/sockets (while drilling into)
0556 Misfire/socket (other than drilling into)
0557 Delayed ignition
0558 Blown through shots
0559 Other explosive accident

Dust, Gas & Other Combustible Material

0771 Occurrence of gas
0772 Influx of gas
0774 Explosion/ignition of gas/dust, etc.
0775 Outbreak of fire or spontaneous heating
0776 Well blowout (with fire)
0777 Well blowout (without fire)
0778 Other combustible material
0779 Other accidents due to dust/gas/fire

Other Causes

0991 Irruption of water
0992 Flying pieces (except due to explosives)
0993 Drowning in water
0994 Buried in sands, etc.
0995 Bursting/leakage of oil pipe lines
0999 Unclassified

Transportation Machinery (Winding)

0221 Overwinding of cages/skip, etc. (up going)
0222 Breakage of rope, chain, draw/suspension gear
0223 Falls of persons from cages, skip, etc.
0224 Falling of objects from cages, skip, etc.
0225 Hit by cages, skip, etc.
0228 Overwinding of cages/skip (down going)
0229 Other accident due to winding operation

Machinery Other than Transportation Machinery

0441 Drilling machines
0442 Cutting machines
0443 Loading machines
0444 Haulage engine
0445 Winding engine
0446 Shovel, dragline, frontend loader, etc.
0447 Crushing and screening plants
0448 Other heavy earth moving machinery
0449 Other non-transportation machinery

Electricity

0661 Overhead lines
0662 Trailing cables
0663 Switchgears, gate end boxes, pommel, etc.
0664 Energized machines
0665 Power cables other than trailing cables
0669 Other electrical accidents

Falls (Other than Fall of Ground)

0881 Fall of person from height/into depth
0882 Fall of persons on the same level
0883 Fall of objects including rolling objects
0889 Other accident due to falls

TABLE 5.2
Place of Accidents

Below Ground

Development Area
111 < 10 m of development face
112 > 10 m and within working district

Longwall Panel
121 > 10 m of longwall face
122 Gate roads in longwall panels

Depillaring/Stoping
131 < 10 m of face
132 > 10 m but < 30 m
133 > 30 m but within working district

Outside Working District
141 Traveling roadways
149 Unclassified

Tramming Roadways
151 Within district
152 Outside district

Haulage Roadways (Within District)
161 Rope haulage roadways
162 Conveyor roadways
163 Loco roadways
169 Unclassified

Haulage Roadways (Outside District)
171 Rope haulage roadways
172 Conveyor roadways
173 Loco roadways
179 Unclassified
180 Shaft
199 Other below ground places

Opencast

Benches
211 Waste/overburden alluvium
212 Waste/overburden float
213 Waste/overburden hard rock
214 Coal/ore benches

Quarry (Other than Benches)
221 Top of the quarry
222 Bed of the quarry

Roads
231 Haul roads
232 Rope haulage roads
239 Other transportation roads

Other Opencast Places
241 Waste dump
249 Other places (specify)

Above Ground
Transportation road/sites
311 Aerial ropeways
312 Rope haulage roads
313 Wheeled trackless transportation roads
314 Railway lines belonging to mines
315 Petroleum pipelines
319 Unclassified

Plant Sites
321 Site of ore handling plants
322 Workshop, powerhouse, engine room, etc.
323 Erection/rigging site
324 Gas col station/gas comp station/group gather.
325 Oil wells/water inject wells
329 Unclassified

Other Above Ground Places
331 Depot
332 Waste dump
333 Water reservoir
339 Unclassified

The different ways of representing accident frequency rate in India and abroad are

- The frequency rate should be calculated for both lost-time injury and reportable lost-time injury
  - Frequency rate = Number of lost-time injuries $\times 10^6$/(Total number of man-hours worked)

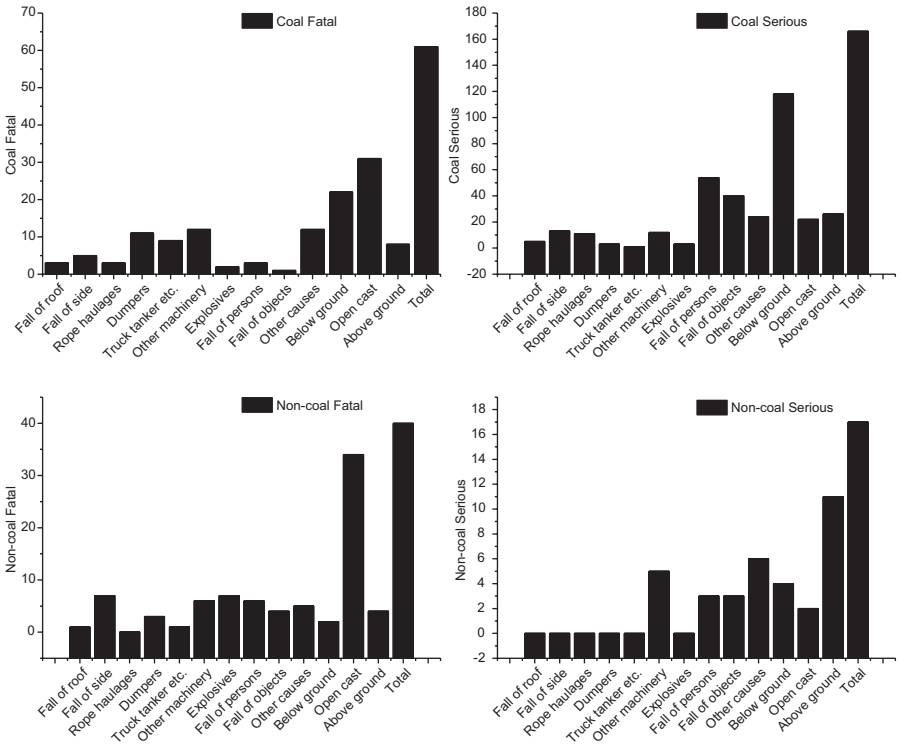

FIGURE 5.1 Number of accidents in Indian mines, with their causes, in 2017. (From DGMS standard note, 2018b. Retrieved from http://www.dgms.gov.in/writereaddata/UploadFile/Standard_Note_2018.pdf.)

It is called "Lost-time injury frequency rate" in Australia

- Frequency rate = Number of reportable lost-time injuries × 10^6/(Total number of man-hours worked)

The severity rate should be calculated from man-days lost both for lost-time injury and reportable lost-time injury.

- Severity rate = Man-days lost due to lost time injuries × 10^6/(Total number of man-hours worked)
- Severity rate = Man-days lost due to reportable lost time injuries × 10^6/(Total number of man-hours worked)

The incidence rate should be calculated for both lost-time injuries and reportable lost-time injuries as follows:

- Lost-time injury incidence rate = Number of lost time injuries × 1,000/(Average number of persons employed)
- Reportable lost-time injury incidence rate = Number of reportable lost time injuries × 1,000/(Average number of persons employed)
- Accidents per 10^6 man-hours worked

TABLE 5.3
Safety Hazards Identified in Underground Coal Mines (Tripathy and Ala, 2018)

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
Ground Movement (Geo-Mechanical)	Human	Rock mass rating not determined and systematic support rules not framed properly
		Poor knowledge of approved systematic support rules
		Delay in supporting the freshly exposed roof
		Deployment of an unauthorized or untrained support crew
		Poor supervision
	Work methods/ procedural	Improper roof/side testing and dressing
		Less than adequate grout in the column
		Non-vertical alignment of galleries
		More height and width of galleries
	Work environment/ managerial	Poorly supported or unsupported roof/side
		Lack of indicators in strata monitoring
		Unavailability of support material
		Poor quality of cement capsules, bearing plates and drill rods
		Presence of subsidence cracks and fissures on the surface above development panel
		Geologically disturbed areas or weak old supports
		Weak roof/side conditions
		Water seepage
Rope Haulage System (Mechanical)	Human	Deployment of an unauthorized or untrained trammer or clip-man
		Overloading of tubs
		Lack of precaution while haulage track line crosses the traveling road
		Failure to inspect and maintain haulage road regularly
		Deployment of an unauthorized or untrained operator
	Machine/tool	Defective or improper clips or lashing chain
		Failure of drawbar
		Defective rope, rope splicing, rope capel, or shackles
		Failure of sprags
	Work methods/ procedural	Unexpected movement of tubs
		Improper laying and maintenance of track line
		Improper maintenance of tubs and their fittings
		Improper maintenance of engine room
		Lack of proper illumination and whitewash at coupling and uncoupling points
		Improper signaling
		Failure to display safety labels and code of signals at all stopping places along the roadway

(*Continued*)

TABLE 5.3 (CONTINUED)
Safety Hazards Identified in Underground Coal Mines (Tripathy and Ala, 2018)

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
Rope Haulage System (Mechanical)	Work methods/ procedural	Improper condition or maintenance of brakes
		Improper condition or maintenance of the engine
		Improper condition or maintenance of drum, surge wheel, clutch, and gears
		Improper condition of automatic catches and buffers
		Non-functioning of speed limit switch and distance indicator
	Work environment/ managerial	Non-provision of safety buffers
		Non-provision or improper maintenance of safety appliances such as stop blocks, runway switches, backstay, drags, catches, safety hooks, jazz rails, friction rollers, re-railers
		Non-provision of guards around all moving parts
Belt Conveyor System (Mechanical)	Human	Deployment of an unauthorized or untrained operator
		Pre-start check not performed by the operator
		Irregular maintenance of a weak or damaged belt joint
		Inadequate cleaning of spillage coal in belt sides, drive heads and tail-ends
		Inattentive chute opening and improper screen of the chute
		An operator wearing loose clothing
		Worker crossing the belt to the other side or inadvertent entry of a worker while the belt is moving
	Machine/tool	Improper condition of belt and belt line
		Breaking of coupling or bolts of coupling and non-provision of coupling guard
		Bearing failure of the drive head
		Failure of pre-start alarm
		Failure of pull cord and lockout switches
		Damaged idlers or rollers
	Work methods/ procedural	Improper signaling
		Cleaning belt or checking gear-box and coupling while the conveyor is in motion
		Failure to display safety labels and code of signals
		Lack of proper illumination near drive head, discharge, and tail-end drums
		Improper shovel for cleaning the coal near tail-end drum
	Work environment/ managerial	Non-provision of guards around drive head, tail-end, and tensioning unit
		Friction in the running belt due to spillage coal and belt structure

(*Continued*)

TABLE 5.3 (CONTINUED)
Safety Hazards Identified in Underground Coal Mines (Tripathy and Ala, 2018)

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
Load Haul Dumper (Mechanical)	Human	Deployment of an unauthorized or untrained operator
		Pre-start check not performed by the operator
		Plying of the machine in disturbed or unsafe areas
		Workers standing around the machine or unexpected movement of a trailing cable
	Machine/tool	Front or rear light not working
		Audiovisual alarm or bell not working
		Footswitch or dead man switch not working
		Improper oil tank condition
		Bad condition of the tire
		Improper condition of parking or service brakes
		Improper condition of lift or tilt cylinder
		Improper canopy or canopy not provided
		Bypassed dump valve or dump valve not in order
		Poor condition of the front or rear frame
		Pilot switch not in order
		Pressure relief valve not in order
		Temperature switch not in order
		Poor condition of bucket
		Oil leakage
		Improper condition of the engine
	Work methods/ procedural	Parking or standing of the machine at a gradient
	Work environment/ managerial	Non-provision of lockout warning tags on the machine
Shot-firing and blasting (Chemical)	Human	Deployment of an unauthorized or untrained blasting crew
		Not following the blasting card system
		Priming of explosives in unauthorized places
		Improper or poorly maintained blasting tools
		Carrying of explosives and detonator together
		Shot-firing from a source other than the exploder
		Shot-firer engaged in other work
		Improper drilling, cleaning, charging, and stemming of shot holes
		Failure to warn before blasting
		Failure to spray water before and after blasting
		Failure to cover the entrance with a fence, in case of misfire
		Failure to recover cartridge or detonator, in case of misfire
	Work methods/ procedural	Drivage of joining gallery from both ends
		Multiple operations at face while charging

(*Continued*)

TABLE 5.3 (CONTINUED)
Safety Hazards Identified in Underground Coal Mines (Tripathy and Ala, 2018)

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
Electricity (Electrical)	Human	Improper maintenance of flameproof features of machinery
		Improper insulation of electric cables
		Improper permanent cable joints (compounding)
		Improper shutdown procedure
		Improper fencing of installations
		Improper maintenance of electric apparatus of equipment (without proper precaution)
		Improper reeling or unreeling of trailing cable
		Failure to inspect all the electrical parts of the energized machines daily for frayed cords, induction, arcing
		Failure to connect plugs or sockets to gate end box
	Machine/tool	Failure of protective devices
		Faulty power cables
		Unsatisfactory flexible trailing cable
		Improper condition of signaling wires and its clamping
		Improper condition of gate end circuit breaker
	Work methods/ procedural	Improper grounding system or earth pit and neutral pit
		Housing of power cable along with signaling cable and lighting cable jointly
	Work environment/ managerial	Failure to display danger boards on all electrical equipment
		Non-intrinsic signaling and telephonic communication circuits
Dust, Gas & Other Combustible Material (Geochemical)	Human	Deployment of untrained supervisors
		Improper monitoring or inspection of gases in sealed-off areas and old working areas that are not sealed-off
		Failure to examine the rate of emission of gas as per statutory norms
		Contraband
		Failure to check speed, amperage, and fan drift
		Failure to clean fallen coal or debris in return airway
		Failure to clean fallen coal, wood cuttings, oil, and greasy waste
		Improper monitoring of fire stoppings
	Machine/tool	Inadequate or non-functioning of gas detecting apparatus
		Insufficient fan capacity
		Leakage in ducts
		Non-availability or improper condition of auxiliary fans
		Improper condition or maintenance of safety lamp

(*Continued*)

TABLE 5.3 (CONTINUED)
Safety Hazards Identified in Underground Coal Mines (Tripathy and Ala, 2018)

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
Dust, Gas & Other Combustible Material (Geochemical)	Work methods/ procedural	Improper sealing of extracted panels
		Improper sampling of gases by supervisors
		Non-inter coupling of underground power with the main mine ventilator fans
		Gas cutting and welding work near a dusty area or any unauthorized area
		Irregular stone dusting
		Irregular ventilation survey
		Obstruction of the return airway or insufficient intake
		Improper condition or maintenance of main mechanical ventilator
		Improper condition or maintenance of stoppings
		Non-provision of the interlocking arrangement of auxiliary fans
		Non-provision of access for the inspection of stoppings, doors, airways, and air crossing
		Improper panel size
	Work environment/ managerial	Leakage from sectionalization stoppings
		Failure to provide sand, flashback arrester, and water near gas cutting and welding workplace
		Stone dust barrier not provided at panel entry
		Accumulation of coal dust at the working panel and loading points
		Non-provision of explosion-proof stoppings where CH4 exceeds 2%
		Presence of surface cracks, fissures, subsidence
		Inadequate ventilation
		Blind heading
		Heat and humidity
		Lengthy ventilation route
		Lack of dust suppression arrangements
		Non-provision of a fire-resistant mechanical ventilator, ducts, ventilation doors, and air crossings
		Non-provision or improper maintenance of firefighting equipment
		Susceptibility of spontaneous heating due to low cross point temperature and high moisture content
		Shallow depth of cover
		Huge de-pillared area
		Geological disturbance affecting the panel
		Thick seam
		Improper early fire detection system

(*Continued*)

TABLE 5.3 (CONTINUED)
Safety Hazards Identified in Underground Coal Mines (Tripathy and Ala, 2018)

Hazard Group	Type of Hazard Elements	Details of Hazard Elements
Inundation (Environmental)	Work methods/ procedural	Old boreholes that are not sealed effectively
		Inaccurate drivage of face
		Borehole not marked in the underground plan
		Failure to prepare and regularly update water danger plan
	Work environment/ managerial	Insufficient number of pumps or failure of pumps
		Working near geological disturbance faults, folds, slips, etc.
		Presence of surface cracks, fissures, subsidence
		Unexpected heavy rains and power failure
		Failure of barriers
		Non-provision of side drains
		Insufficient sump area
		Failure of water dams
		Presence of old waterlogged areas or abandoned workings

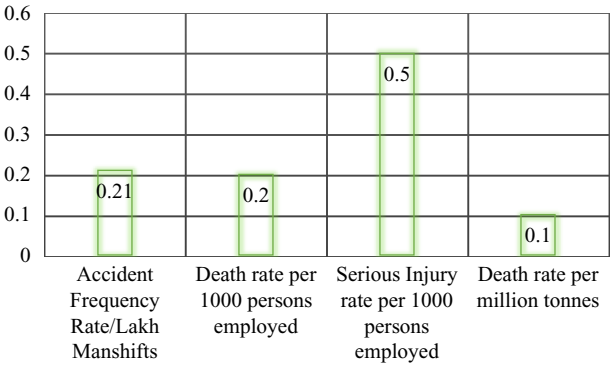

FIGURE 5.2 Accident frequency and severity rates in Indian coal mines in 2017. (From DGMS standard note, 2018b. Retrieved from http://www.dgms.gov.in/writereaddata/UploadFile/Standard_Note_2018.pdf.)

Frequency rate = Number of accidents $\times 10^6$/(Total number of man-hours worked)

- Severity rate = Number of days disability $\times 10^6$/(Total man-hours work exposure)
- Fatal accident frequency rate = Number of fatalities $\times 10^6$/(Total number of man-shifts worked)
- Accident severity rate = Lost time in workdays (LT) $\times 10^6$/(Total number of man-shifts worked)

- Severity measure (SM) = Sum of days × 2 × 10^5/Hours of exposure
- Severity index (SI) = (300F + 10S + R) × 10^5/Number of man-shifts worked
  - F = Number of death
  - S = Number of serious injuries
  - R = Number of reportable injuries
- Severity index (SI) = (50F + S) × 10^5/Total man-shifts worked

5.4 ACCIDENT COST

When an accident occurs, it may have different consequences, such as property damage, interruption of work, loss of life, or injury, and all these consequences present great costs to management, to the injured, and to society. To explain the true costs, accidents are often compared with an iceberg, as shown in Figure 5.3. When we look at the iceberg, the visible part is what we see, but this is only about 10% of the entire iceberg. The rest is under water and out of our view. In the same way, the direct costs of an accident are just the tip of the iceberg: the indirect costs of an accident are not visible. Therefore, accident costs to the management can be divided into direct costs and indirect costs (Preston, 2018).

5.4.1 The Direct Costs of an Accident

The direct costs of an accident include medical costs and compensation payments made to the injured employee. These costs are easy to calculate, as they are accrued directly from the accident.

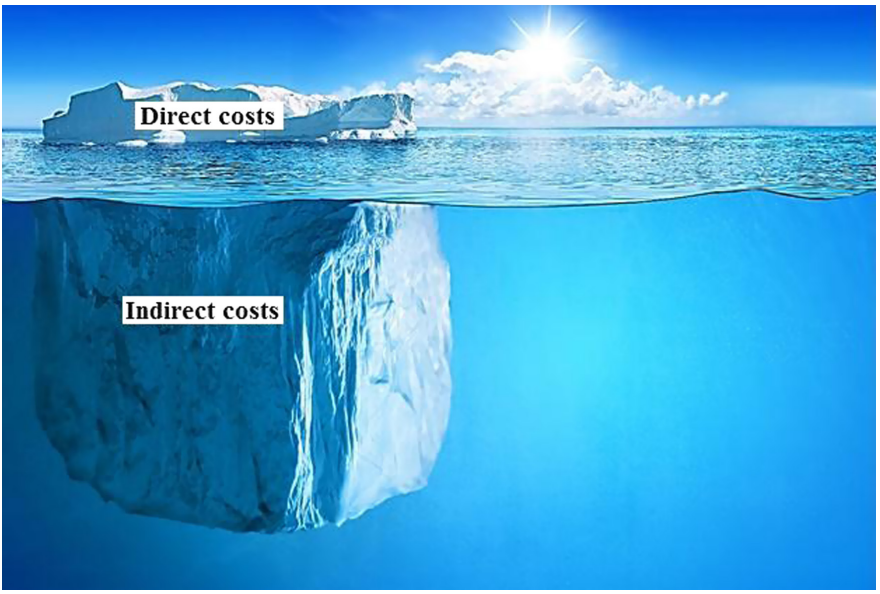

FIGURE 5.3 Comparison of accident cost with iceberg.

5.4.2 The Indirect Costs of an Accident

The indirect costs are hard to calculate, as they stem from the less obvious results of an accident, and they can often be hidden. The indirect costs include

- loss of production
- lost time of the injured
- lost time of co-workers and officials
- lost time for inspection and inquiry
- lost time of managers in investigating
- damage to property, equipment, or machine(s) involved in the accident
- cost of wages for additional supervision
- cost of processing claim forms and related paperwork
- cost of imposed remedial works
- cost of prosecution fines

Along with the costs to management, there will be indirect costs to the injured and society (Biswas, 2016). The pain and suffering of the victim and his family, the loss of wages, possible permanent disability, or loss of earning capacity are indirect costs to the injured. The costs of providing hospital and rehabilitation facilities for the injured and the maintenance of the dependents of the injured/killed are indirect costs to society.

5.5 ACCIDENT STATISTICS

To prevent accidents in mines, it is necessary to have a knowledge of the causes of accidents, locations of accidents, types of accidents, times of accidents, operations, employees, and supervisors responsible for the accident. Analyzing the accident statistics helps to

- estimate the causes and the magnitude of the accident problem
- identify, evaluate, and prioritize the preventive measures
- monitor the causes and the safety measures implemented

The analysis of the number of accidents in mines revealed that a total of 12,263 in coal and 2,273 fatal and serious accidents in metal mines have occurred during 2001 to 2017. The comparison of coal and metal mine accidents is presented in Figure 5.4.

The death rates per 1,000 persons employed in coal and metal mines are presented in Table 5.5. The in-depth analysis of the number of fatal accidents during 2001 to 2017 reveals that the number of fatal accidents is higher in coal mines (1,332) than in metal mines (778). In coal mines, it is observed that the number of fatal accidents below ground (597) is higher than in opencast (510) and above ground (225) locations. In metal mines, it is observed that the number of accidents in opencast mines (574) is higher than below ground (60) and above ground (144). The comparison of death rates per 1,000 persons employed is shown in Figure 5.5. The trend of death rates per 1,000 persons employed is observed to be higher in metal mines than coal mines.

TABLE 5.4
Fatal and Serious Accidents in Coal and Metal Mines, 2001–2017

	Coal			Metal		
Year	Fatal	Serious	Total	Fatal	Serious	Total
2001	105	667	772	62	178	240
2002	81	629	710	50	174	224
2003	83	563	646	51	147	198
2004	87	962	1,049	55	150	205
2005	96	1,106	1,202	47	93	140
2006	78	861	939	54	63	117
2007	76	923	999	53	63	116
2008	80	686	766	49	63	112
2009	83	636	719	33	76	109
2010	97	480	577	50	45	95
2011	65	533	598	41	65	106
2012	79	536	615	34	35	69
2013	77	456	533	54	37	91
2014	59	379	438	34	34	68
2015	54	302	356	41	22	63
2016	71	268	339	31	30	61
2017	61	166	227	39	10	49

Source: Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.

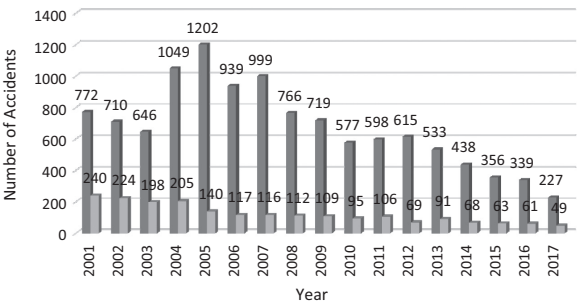

FIGURE 5.4 Comparison of coal and metal mine accidents in Indian mines. (Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.)

The serious injury rates per 1,000 persons employed in coal and metal mines are presented in Table 5.6. The in-depth analysis of the number of serious accidents during 2001 to 2017 reveals that the number of serious accidents is higher in coal mines (10,153) than metal mines (1,285). In coal mines, it is observed that the serious

TABLE 5.5

Death Rates per 1,000 Persons Employed in Coal and Metal Mines, 2001–2017

	Coal								Metal							
	Number of Fatal Accidents				Death Rate per 1,000 Persons				Number of Fatal Accidents				Death Rate per 1,000 Persons			
Year	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
2001	67	26	12	105	0.43	0.38	0.1	0.32	5	45	12	62	0.46	0.63	0.36	0.53
2002	48	22	11	81	0.27	0.32	0.11	0.23	5	33	12	50	0.49	0.54	0.28	0.45
2003	46	23	14	83	0.33	0.35	0.13	0.27	3	31	17	51	0.52	0.45	0.42	0.45
2004	49	32	6	87	0.27	0.47	0.05	0.24	5	36	14	55	0.62	0.47	0.32	0.43
2005	50	28	18	96	0.34	0.42	0.15	0.29	3	34	10	47	0.38	0.43	0.23	0.36
2006	44	24	10	78	0.52	0.33	0.09	0.36	3	42	9	54	0.38	0.62	0.19	0.47
2007	25	35	16	76	0.13	0.46	0.14	0.21	3	38	12	53	0.35	0.48	0.25	0.40
2008	32	29	19	80	0.21	0.45	0.18	0.25	3	35	11	49	0.44	0.43	0.42	0.43
2009	39	29	15	83	0.25	0.4	0.14	0.25	4	25	4	33	0.61	0.32	0.08	0.26
2010	41	40	16	97	0.33	0.51	0.15	0.32	4	35	11	50	0.44	0.71	0.21	0.53
2011	23	29	13	65	0.13	0.35	0.13	0.18	2	32	7	41	0.20	0.34	0.15	0.27
2012	25	37	17	79	0.16	0.43	0.17	0.23	5	26	3	34	0.52	0.26	0.05	0.20
2013	19	40	18	77	0.14	0.46	0.17	0.23	4	45	5	54	0.39	0.55	0.08	0.37
2014	20	31	8	59	0.13	0.35	0.08	0.17	4	25	5	34	0.39	0.28	0.08	0.22
2015	21	25	8	54	0.13	0.29	0.09	0.16	4	32	5	41	0.29	0.29	0.08	0.22
2016	26	29	16	71	0.18	0.57	0.2	0.29	1	26	4	31	0.22	0.30	0.06	0.22
2017	22	31	8	61	0.16	0.36	0.11	0.2	2	34	3	39	0.15	0.47	0.09	0.32

Key: 1. Below ground. 2. Open cast. 3. Above ground. 4. Overall.

Source: Data compiled from DGMS standard notes available from http://www.dgms.gov.in/.

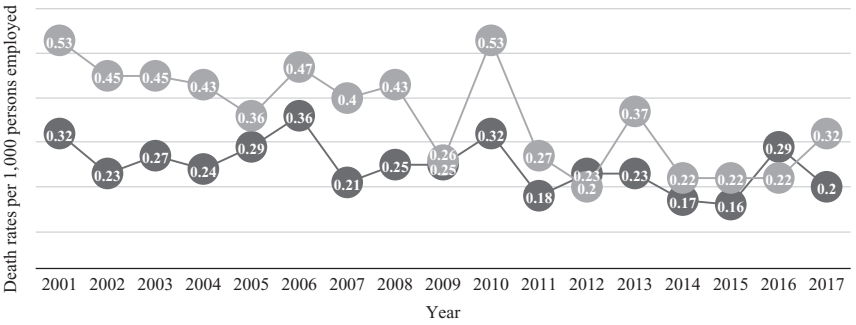

FIGURE 5.5 Comparison of death rates per 1,000 persons employed in coal and metal mines. (Data compiled from DGMS standard notes available from http://www.dgms.gov.in/.)

accidents below ground (7,414) is higher than in opencast (1,174) and above ground (1,565) locations. In metal mines, it is observed that the number of accidents above ground (536) is higher than in below ground (435) and opencast (314) locations. The comparison of the serious injury rates per 1,000 persons employed is shown in Figure 5.6. The trend of serious injury rate per 1,000 persons employed is observed to be higher in coal mines than in metal mines.

5.6 ACCIDENT TREND AND ANALYSIS IN INDIA AND ABROAD

The comparison of the trend of death rates per 1,000 persons employed in Indian mines with those of the US, Australian, and South African mines is presented in Table 5.7 (MCA, 2017; MCSA, 2017) and Figure 5.7.

From Figure 5.7, it is clear that the trend of death rates per 1,000 persons employed is higher in Indian mines than in those of other countries. The trend of fatal accidents occurring in Indian underground coal mines is higher than in the US and Western Australian underground coal mines, as shown in Figure 5.8 (Department of Mines, Industry Regulation and Safety, 2018; DGMS, 2017b; MSHA, 2017b).

5.7 INVESTIGATIONS INTO ACCIDENTS AND ACCIDENT REPORTS

Accident investigation is an analysis of the facts that occurred during an accident. It is necessary to investigate the accidents that have occurred in a mine in order to

- determine the sequences of events leading to an accident
- identify the cause of the accident
- expose deficiencies in equipment or operation process
- find ways to prevent a similar accident from recurring

The steps involved in the accident investigation process are presented in Figure 5.9 and the types of questions to be asked are shown in Figure 5.10 (DGFASLI, 2017).

According to Regulation Nos 8 and 9 of CMR, 2017 (CMR, 2017), all the dangerous occurrences, accidents, and diseases seen in a mine should be notified to the

TABLE 5.6

Serious Injury Rate per 1,000 Persons Employed in Coal and Metal Mines, 2001–2017

	Coal								Metal							
	Number of Serious Accidents				Serious Injury Rate per 1,000 Persons				Number of Serious Accidents				Serious Injury Rate per 1,000 Persons			
Year	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
2001	464	73	130	667	2.1	1.12	1.07	1.64	59	37	82	178	5.57	0.53	1.82	1.36
2002	434	92	103	629	2.07	1.43	0.8	1.57	52	40	82	174	5.07	0.53	1.89	1.30
2003	380	82	101	563	1.85	1.3	0.77	1.42	57	25	65	147	7.36	0.43	1.56	1.19
2004	757	82	123	962	3.69	1.24	1.02	2.45	54	34	62	150	6.70	0.52	1.36	1.14
2005	843	98	165	1,106	4.23	1.45	1.37	2.85	27	22	44	93	3.41	0.30	0.99	0.70
2006	646	88	127	861	3.4	1.3	1.11	2.31	24	13	26	63	3.20	0.25	0.55	0.51
2007	717	83	123	923	3.91	1.1	1.15	2.51	19	14	30	63	3.51	0.29	0.64	0.59
2008	516	74	96	686	2.87	0.98	0.92	1.92	14	13	36	63	1.65	0.24	1.21	0.63
2009	490	50	96	636	2.72	0.67	0.93	1.76	33	13	30	76	4.36	0.19	0.60	0.54
2010	348	62	70	480	2.03	0.83	0.68	1.38	12	16	17	45	1.44	0.21	0.32	0.31
2011	379	73	81	533	2.23	0.91	0.79	1.52	20	30	15	65	2.15	0.32	0.36	0.44
2012	374	61	101	536	2.22	0.74	1.03	1.53	16	14	5	35	1.67	0.17	0.08	0.22
2013	336	56	64	456	2.03	0.68	0.66	1.31	15	11	11	37	1.45	0.21	0.18	0.27
2014	250	64	65	379	1.6	0.7	0.67	1.11	12	16	6	34	1.25	0.26	0.14	0.27
2015	185	67	50	302	1.19	0.82	0.58	0.93	10	5	7	22	0.74	0.08	0.11	0.13
2016	177	47	44	268	1.14	0.55	0.51	0.81	7	9	14	30	0.52	0.15	0.23	0.21
2017	118	22	26	166	0.77	0.25	0.28	0.5	4	2	4	10	0.44	0.09	0.12	0.13

Source: Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.

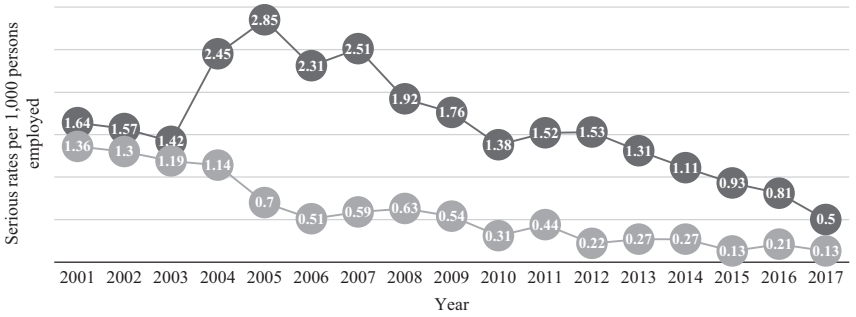

FIGURE 5.6 Comparison of serious injury rates per 1,000 persons employed in coal and metal mines. (Data compiled from DGMS standard notes and Annual accident reports available from http://www.dgms.gov.in/.)

TABLE 5.7
Death Rates per 1,000 Persons Employed in Different Countries, 2001–2016

Year	India	USA	Australia	South Africa
2001	0.32	0.37	0.15	0.17
2002	0.23	0.25	0.07	0.21
2003	0.27	0.29	0.12	0.21
2004	0.24	0.26	0.11	0.19
2005	0.29	0.20	0.08	0.13
2006	0.36	0.38	0.08	0.13
2007	0.21	0.28	0.1	0.12
2008	0.25	0.22	0.03	0.15
2009	0.25	0.13	0.1	0.12
2010	0.32	0.35	0.04	0.08
2011	0.18	0.14	0.04	0.07
2012	0.23	0.15	0.021	0.06
2013	0.23	0.16	0	0.04
2014	0.17	0.14	0.047	0.05
2015	0.25	0.12	0.037	0.04
2016	0.21	0.10	0.038	0.03

Sources: MCA (Minerals Council of Australia). (2017). Safety performance report of the Australian minerals industry. Retrieved from "http://www.minerals.org.au" www.minerals.org.au

CSA (Minerals Council South Africa). (2017). Facts and figures. Retrieved from www.mineralscouncil.org.za/industry-news/publications/facts-and-figures

DGMS. (2017b). Standard notes, 2017. Retrieved from http://dgms.gov.in/writereaddata/UploadFile/Standard_Note_01-01-20176362197732330444487.pdf

MSHA. (2017b). Preliminary accident reports, fatality alerts, and fatal accident reports. Retrieved from https://arlweb.msha.gov/fatals/

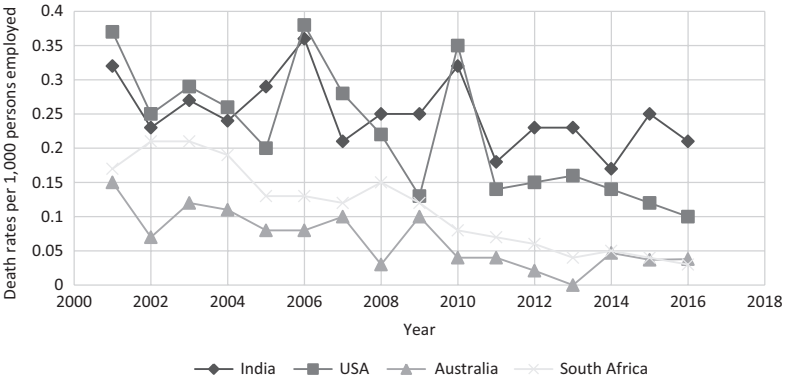

FIGURE 5.7 Comparison of death rates per 1,000 persons employed in Indian mines with U.S., Australia, and South African mines. (Data from the following: MCA (Minerals Council of Australia) 2017. Safety performance report of the Australian minerals industry. Retrieved from www.minerals.org.au; CSA (Minerals Council South Africa) 2017. Facts and figures. Retrieved from www.mineralscouncil.org.za/ industry-news/publications/facts-and-figures; DGMS, Standard notes. 2017b. Retrieved from http://dgms.gov.in/writereaddata/UploadFile/Standard_Note_01-01-201763621977323304448 7.pdf; MSHA Preliminary accident reports, fatality alerts, and fatal accident reports. 2017b. Retrieved from https://arlweb.msha.gov/fatals/.)

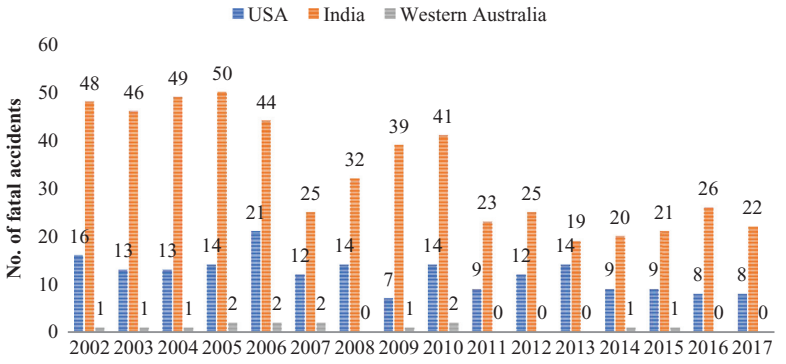

FIGURE 5.8 Comparison of number of fatal accidents in Indian underground coal mines with the US and Western Australian Mines. (Data from the following: DGMS, Standard notes. 2017b. Retrieved from http://dgms.gov.in/writereaddata/UploadFile/Standard_Note_01-01-201763621977323304448 7.pdf; Department of Mines, Industry Regulation and Safety, Australia. Safety regulation system. 2018. Retrieved from https://srs.dmp.wa.gov.au/SRS/Public/PublicationSearch?publicationTypeEnum=FatalitySummary; MSHA, Coal fatalities for 1900 through 2017. 2017a. Retrieved from https://arlweb.msha.gov/stats/centurystats/coalstats.asp.)

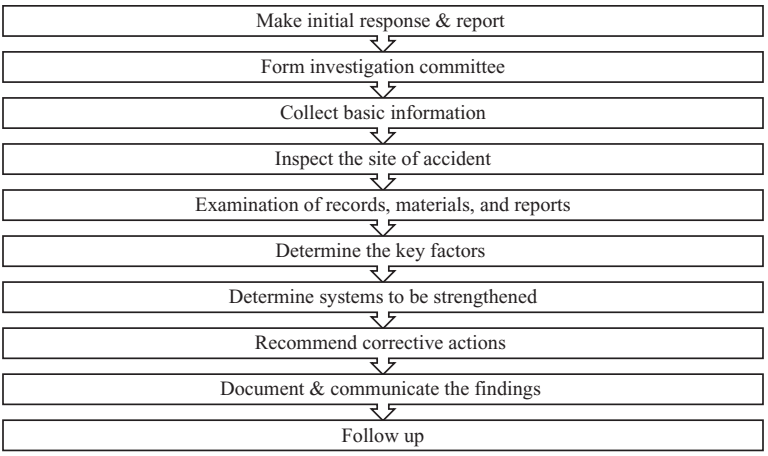

FIGURE 5.9 Accident investigation process.

Regional Inspector using the accident reports. These accidents includes loss of life or permanent disability. Dangerous occurrences in mines include the following:

- an explosion or ignition
- fire in any part of workings or in any machinery
- the spontaneous heating or outbreak of fire, or appearance of smoke, or other indication of heating or outbreak of fire
- a premature collapse of any part of the workings
- the instantaneous failure of a pillar, part of a pillar or several pillars of coal (i.e. a "bump") in working below ground
- a fall from height of any excavation or loading or transport machinery
- the bursting of equipment under pressure
- a breakage or fracture of rope, chain, headgear, pulley, or axle or bearing thereof, or other gear by which persons or materials are lowered or raised
- an influx of inflammable or noxious gases
- an irruption or inrush of water or other liquid matter
- any accident due to explosives
- the overwinding of cages or other means of conveyance while men or materials are being lowered or raised
- the breakage or fracture of an essential part of a winding engine, crankshaft, coupling, bearing, gearing, clutch, drum, or drum shaft, or the failure of an emergency brake
- the bursting of any equipment containing steam, compressed air, or other substance at high pressure
- the breakage, fracture, or failure of an essential part of any machine or apparatus whereby the safety of persons may be endangered
- a slide causing injury to any person, damage to any machinery, or interruption of normal mining operations
- the failure of a dump or side in opencast workings

FIGURE 5.10 Questions to be asked in an accident investigation.

- the failure of any structure or installation whereby the safety of persons may be endangered
- a spark generated due to electrical flashover causing a burn injury to any person

The accident report should be brief but all the important information about the accident should be covered as required by the Coal Mines Regulation (CMR) 2017.

The accident or dangerous occurrence report should include

- the name of the mine
- the particulars of the mine
  - the status of mineral excavation
  - the name and address of the owner
- the date and time of the accident
- the place and location of the accident in the mine
- the number of workers killed or injured
- the classification of the accident or dangerous occurrence
- particulars of the victims
  - the names of the victims
  - the nature of their employment
  - their ages
  - their gender
- the nature of their injuries
- if fatal, the cause(s) of death

The structure of the detailed accident report should include

- a statement of the accident
- a description of the workings
- the events prior to the accident
- the occurrence of the accident
- the rescue and recovery
- the inspection and inquiry
- an analysis of the evidence
- responsibilities
- recommendations

An example of a detailed accident report is presented below.

SAMPLE ACCIDENT REPORT

Mine name: Gaslitand Opencast Mine
Owner: Western Coalfields Ltd (WCL)
Place: Maharashtra
Date of accident: 01-23-2002
Number of persons killed: 1
Cause of accident: Fly rock

- **Statement of the accident**: When blasting was done in an opencast mine, a flying fragment flew to a distance of 210 meters and hit a mazdoor (laborer) who was sitting in an open place and killed him (WCL, 2002).
- **Description of the workings**: In quarry number 3, on 4 seam, 8 meters thick is being quarried out. Blasting is done in deep holes with slurry explosives and loading is done into dumpers with the help of mechanical shovels.
- **Events prior to the accident**: On January 23, 2002, shot-firer charged 20 holes with explosives. He deputed his three helpers to ensure that no one

was present in danger zone, namely within a radius of 300 meters of firing shots.

- **Occurrence of the accident**: The shot-firer then fired the shots at about 10.30 a.m. A mazdoor who had been lying down under a tree was hit by a piece of coal that was ejected because of blasting.
- **Rescue and recovery**: The mazdoor was immediately removed to colliery hospital on stretcher and was attended by the doctor on duty at 11 a.m. but was found dead.
- **Inspection and inquiry**: The officials inspected the place of accident the same day at 1 p.m. and observed that the place of accident was 210 meters away from the place of shot-firing. Because of blasting a piece of coal, weighing about 2 kg, was ejected and hit the mazdoor. The officials conducted further enquiry the next day and recorded statements of witnesses.
- **Analysis of evidence**: Shot-firer stated that he was not aware of mazdoor's presence in the danger zone. He said that he had deputed his assistants to check that no one was present in danger zone.
- **Responsibility**: Under the provisions of Regulation 170 of CMR, 1957, it is required that shot-firer shall not fire shots unless persons in a radius of 3,000 meters have taken proper shelter. He had deputed his assistant to ensure that no one was in danger zone near the place of accident. Therefore, shot-firer helper was held responsible for the accident.
- **Recommendations**: All employees working in the mine should be given proper training and education about the dangers from flying fragments.

ACCIDENT REPORTS OF SOME FATAL ACCIDENTS

Accident 1

Mine name: Godavarikhani No. 7 LEP
Owner: Singareni Collieries Company Ltd (SCCL)
Place: Andhra Pradesh
Date of accident: 06-16-2003
Number of persons killed: 17
Cause of accident: inundation

- **Statement of the accident**: In the first shift, top section development workings of No. 3 seam got connected with bottom section workings of the same seam that had been extracted in conjunction with hydraulic sand stowing and was containing water. This led to inundation of the top section working and drowning of seventeen workers (Novamining, 2014a).
- **Analysis of evidence**: The following observations were made after analyzing the evidence.
- **Inadequate stowing**: Large quantity of water, estimated to be several thousand gallons, had accumulated in panel No. 3 S/SS-1A in No. 3 seam bottom section, which was extracted in the year 2000 by splitting as final operation in conjunction with hydraulic sand stowing. The accumulation was due to inter-granular space in sand, shrinkage of stowed sand with time.

- **Working without taking prior permission from the Regional Inspector of Mines**: In an area, which was declared non-workable by the owner in 1999, development in 2-dip district in No. 3 seam top section was started in April, 2003. This 2-dip development district in No. 3 seam top section was being worked within 60 meters of the No. 3 seam bottom section workings in panel No. 3 S/SS-1A. This work was done without taking prior permission from the Regional Inspector of Mines and without taking due precautions against the danger of inundation arising out of working close to waterlogged workings.
- **Parting between sections**: The parting between top and bottom sections of 3 seam, which was to be kept at least 5 meters, got reduced by roof falls occurring in 3 seam bottom section along the 2 meters throw fault plane. The parting must have been reduced to a few centimeters just before the rupture. The head of water, which was calculated to be about 15 meters, was enough to cause the rupture leading to sudden inrush in top section.

  The water rushed along 18 L through the puncture in the form of a wall of a height of about 1 meter. After traveling southward, it entered No. 2 dip where 17 workers who were working in and below 19 L and who were drowned in the inrushing water.
- **Lack of supervision**: in mining in general and stowing of sand in particular.
- **Lack of certifying authority**: There is no system in place whereby after stowing any responsible officer would certify that stowing was proper and adequate before the district could be closed.
- **Responsibility**: Based on preliminary enquiry, SCCL management had held Agent, Manager, Safety Officer and officiating Manager, and Surveyor as responsible for the accident.
- **Recommendations**: All the stowed panels are proposed to be treated as "likely water bodies." The following measures were proposed to prevent recurrence of such inundation accidents.

1. The preparatory stopping in bottom-most level of the stowing panel shall be so constructed as to provide good drainage, until the panel is finally sealed-off and shall be closed at the last stage of isolating the panel with specially built water seals.
2. While working over the stowed panels, the parting shall be continuously ascertained by drilling boreholes at every junction and at an interval of 10 meters.
3. All the minor faults known while working the bottom section shall be clearly marked with throw in the combined plan so that boreholes of adequate length can be put for ascertaining thickness of parting as well as presence of water.
4. These test holes shall be reamed to top-up sand to ensure that the voids are filled if at all found. Proper stowing has to be ensured.
5. For every stowing district, there should be positive drainage at the bottom-most level for each panel.
6. Awareness program and precautions against the inundation shall be taken up among all the officers of the company.

Accident 2

Mine name: Anjan Hill Mine
Owner: South Eastern Coalfields Ltd (SECL)
Place: Chhattisgarh
Date of accident: 05-06-2010
Number of persons killed: 14
Cause of accident: Explosion

- **Statement of the accident**: On May 6, 2010, at about 11:30, an accident occurred at Hill Mine of M/s South Eastern Coalfields Ltd in Chhattisgarh, India. In this accident, 14 workers were dead, 5 were seriously injured and 26 had minor injuries (Mine accidents and disasters, 2010a).
- **Events prior and occurrence of the accident**

Date	Prior events
2/5/2010	Routine gas samples from the sealed area detected 416 ppm CO and 43 ppm C_2H_4 (ethylene) and 0.09% H_2
3/5/2010	0.27% H_2 (2746 ppm) 138 ppm C_4H_4 and 1,262 ppm CO were detected
3/5/2010	At 7 p.m., around 2,000 ppm CO was detected
3/5/2010	Rescue team started to strengthen the panel seal and construct a second row of seals to isolate the panel
5/5/2010	At 1:05 p.m., 5521 ppm CO, 0.26% CH_4, 1% CO_2, 100 ppm C_2H_6, 68 ppm C_2H_4 were detected from the main return
5/5/2010	At 4:20 p.m., there was a sudden gust of air that came out under pressure for approximately 1 minute with no smell of any noxious gases
5/5/2010	At 8:15 p.m., a second gust of air occurred
5/5/2010	At 10:10 p.m., a third gust of air came out of the mine adits A and B with a burning smell of coal
6/5/2010	At 1:20 a.m., a rescue team entered the mine to take gas samples. They had barely gone 30 m when they were hit with a gust of air and dust cloud. Visibility was nil for 1 minute and there was no noxious gas in the cloud and the dust was not as hot.
6/5/2010	It was observed that the potholes in the subsided area were found to be in take air and one pothole had a flame burning
6/5/2010	At 11:30 a.m., the pothole erupted and a 20 m flame burnt for approximately 5 minutes before subsiding to only 1 m.
6/5/2010	At 11:30 a.m., there was a violent explosion in the mine, which propagated out to the surface. Killing 6 men underground, and 8 standing who were around Adit B. 28 were injured standing around the Adit.

- **Rescue and recovery**: Rescue teams were sent underground on the 7th of May at 7.40 p.m.
- **Cause of the accident**: After analyzing the evidence, the following causes were identified
  - failure to flush the extracted goaf by carbon dioxide/nitrogen gas
  - failure to fill the potholes and subsidence cracks effectively
  - inaccurate mine plan
  - failure to procure safety-related items

- **Recommendations**: The following recommendations were made to avoid accidents of similar nature in future.
  - mine plan should be prepared accurately
  - safety items shall be procured, stored and provided to workmen
  - flushing goaf with nitrogen or carbon dioxide
  - install effective communication system in all mines
  - telemonitoring system should be installed in all mines, for monitoring the mine environment.
  - provide refresher training and updating technical skills of the officers, staff and workmen
  - provide guidelines for rescue operations
  - proper design and maintenance of stoppings

Accident 3

Mine name: Upper Big Branch Mine-South (UBB)	**Date of accident**: 04-05-2010
Owner: Performance Coal Company (PCC)	**Number of persons killed**: 29
Place: Montcoal, West Virginia	**Cause of accident**: Coal dust explosion

- **Statement of the accident**: A coal dust explosion occurred at Upper Big Branch Mine-South, on 5th April 2010 at about 3:02 p.m. causing death of 29 workers and injury to two workers (MSHA, 2011).
- **Description of the workings**: The average thickness of the coal seam at UBB was 1.3 meter, including sandstone partings and the mining height was 2.13 meter. Longwall method was employed by PCC at UBB. The longwall was operated seven days per week and development sections were operated five to six days per week. There were two overlapping 10-hour longwall production shifts and a 9-hour maintenance shift. According to company records, PCC employed 186 underground and 4 surface employees at UBB on the day of the accident.
- **Events prior to the accident**: There are four entrances to enter the mine and four sections producing coal. The coal-producing sections are Headgate 22, Tailgate 22, north Longwall Panel, and one advancing room-and-pillar section. Pumps were used to clear the water from the water accumulated areas mainly from behind the longwall.

  The production stared at 7.30 a.m. The longwall was running until 11 a.m., and was down from 11 a.m. to 1.30 p.m., due to a lost "B-Lock" on the ranging arm of the longwall shearer. Investigation revealed that the longwall shearer was operating near the tailgate up until a minute or two prior to the explosion. Someone shut down the shearer operation at 3 p.m. using a side remote control at tailgate. The water supply and power supply to the shearer was cut off by headgate operator. Prior to the explosion, the longwall workers realized that an uncontrollable event had occurred and started traveling away from the tailgate.

- **Occurrence of the accident**: At approximately 3:02 p.m., a massive coal dust explosion occurred in the northern portion of UBB. Due to the explosion, the electrical power in the Ellis portal and the power communications in different sections were interrupted.
- **Rescue and recovery**: Rescue operations were started immediately after the accident had occurred on April 5 by more than 20 rescue teams. Due to the presence of flammable gases in the mine rescue efforts were continued till April 9 to locate the last victim.
- **Inspection and inquiry**: MSHA (Mine Safety and Health Administration) began the accident investigation in the accessible underground areas of the mine affected by the explosion on April 12, 2010. The accident investigation included detailed mine mapping, collecting evidence, and analyzing evidence. Along with MSHA, the West Virginia Office of Miners' Health Safety and Training is also involved in preparing accident investigation protocol.
- **Analysis of evidence**: The analysis of evidence revealed that PCC has committed the following violations
  - failed to identify, record, and correct hazards
  - failed to reduce hazardous levels of loose coal
  - failed to disperse coal dust and float coal dust
  - failed to apply stone dust to the mine
  - operated shearer with missing and clogged water sprays
  - failed to maintain the longwall shearer
  - failed to adequately train its miners
  - failed to comply with its approved ventilation plan, roof control plan
- **Responsibility**: PCC was held responsible for ignoring evident safety hazards that consequently led to a massive coal dust explosion.
- **Recommendations**: The following are a few corrective measures suggested by MSHA to administrator:
  - minimize rock dust data input errors.
  - complete evaluation of the effectiveness of the Inspection Tracking System.
  - to conduct complete audit of ventilation plans
  - to modify the existing Mine Emergency Responsiveness Development program

Accident 4

Mine name: Pike River Mine
Owner: Pike River Coal Ltd.
Place: Greymouth, New Zealand
Date of accident: 11-19-2010
Number of persons killed: 29
Cause of accident: Explosion

- **Statement of the accident**: On 19 November 2010, at 3:45 p.m., the 29 men working in Pike River underground mine died immediately, or shortly afterward. The exact reason of death is still unknown; it is assumed that the

death was due to either explosion or toxic atmosphere. Two men working at some distance from the incident managed to escape. The mine was sealed, as it was exploded three more times over next nine days. Currently, there is no access to the mine (Mine accidents and disasters, 2010b).

- **Description of the workings**: The Pike River underground coal mine workings were not extensive, as the mine was new and shipped its first coal in early 2010. The mine lies under the rugged Paparoa Range on the West Coast of New Zealand's South Island.
- **Events prior to the accident**: The exact events prior to the incident were unknown due to incomplete investigation of the incident. On the day of the incidents, three A, B, C shifts and a day shift were running. Three men from the day shift and workers of C shift, a total of 31 men, were working at the time of the incident.
- **Occurrence of the accident**: At 3:44 p.m. on 19 November 2010, an unidentified noise was recorded on the digital access carrier (DAC) system. After the unidentified noise, alarms in the control room were activated and ventilation, pump, gas, and power feed to the control room was stopped.

  The explosion incident was recorded on CCTV footage, which was not seen until later. The CCTV coverage revealed that there was a pressure wave after the explosion and also showed the velocity of the explosion.
- **Rescue and recovery**: The emergency response was held back due to lack of information on the number of workers missing and the mine environment. It came clear, only on Sunday morning, about the exact number. The mine environment samples were not available due to feed stoppage. A shaft was drilled in the middle of the mine to collect samples. But, due to a second explosion, rescue operations were not made.

5.8 ACCIDENT PREVENTION IN MINES

Multiple factors contribute to accidents in mines. The factors can be management failures, supervisory failures, and employees' failures. The frequent number of accidents in opencast mines are related to machinery, such as dumpers and shovel equipment, blasting, and electricity – see Table 5.8 for a list of the causes and their prevention measures.

The frequent numbers of accidents in underground mines are related to ground movement, fire and explosion, inundation, electricity, conveyor systems, and haulage see Table 5.9 for a list of the causes and their prevention measures.

For preventing the accidents in mines, DGMS (2018b) has taken the following measures:

- National Conference on Safety in Mines
- National Safety Award (Mines)
- provision of safety training to managers and supervisors
- celebration of safety week and safety campaigns such as "Safety is My Responsibility"

TABLE 5.8
Accident Prevention Measures in Opencast Mines

	Causes	Prevention
Dumper	• Worker run over by dumper	• Separate road for pedestrian and light vehicles should be provided • No maintenance personnel should be present around the dumper as its movement starts • No dumper movement should be allowed during manpower movement • All dumpers should be parked in the field during lunch • Florescent jackets should be provided to workers
	• Collision with other dumpers	• Educate dumper operators through safety talks • Dumper operators should drive slowly and carefully at blind turnings • Wide roads should be provided • Haul roads should be well illuminated • Sign board should be provided at crossing • Flickering light should be used at crossing • No outside vehicle should be allowed to pass the crossing • Separate road for loaded and empty dumpers should be provided by road divider • Overtaking other vehicles should be prohibited
	• Toppling of dumper due to undercut of stockyard	• Supervision should be provided for all three shifts • Educate dumper operators regularly • Stock height should not exceed 10 m • Dozers should be deployed regularly • Adequate lighting should be provided
Shovel	• Overhead lines and poles	• Face height should be less than the boom height of the shovel
	• Hitting with/by dumper nearby	• Adequate training should be provided to dumper and shovel operators
	• Breakage of hoist/boom rope • Failure of boom/damage to other vital parts	• Regular checking of boom and other vital parts should be carried out by the maintenance department and operator
	• Fall of stones/loose materials from bucket	• Proper loading of material should be done • Boulders if any should not be placed on top of the bucket
	• Toppling of machine	• Marching should be done under the supervision of the engineer/foreman
Blasting	• Hitting with other vehicles on road	• Separate vehicles for detonators and explosives should be provided
	• Possibility of damage or toppling of the vehicle	• Special training for the drivers of the explosives van should be provided • Speed of the vehicle should be limited to 25 km/h

(*Continued*)

TABLE 5.8 (CONTINUED)
Accident Prevention Measures in Opencast Mines

	Causes	Prevention
Blasting	• Fire and explosion	• Fire extinguishers should be provided and maintained regularly • Regular cleaning and washing of the explosives van should be done • Checking for contraband should be done
	• Flying fragments	• Rest shelters should be provided and used • Nonel/Excel should be used for controlled blasting • Blasting should be carried out from the blasting shelter
Electricity	• Fall of persons	• Safety belts should be used when a person works on the electric pole and they should be secured firmly
	• Electrocution	• A proper shutdown procedure should be followed while working on electric poles • A proper shutdown procedure should be followed before shifting of field switch
	• Toppling of shifting equipment/field switch	• Field switches/equipment that are to be shifted frequently shall be kept at sufficient free area • Approach road of minimum gradient shall be provided before doing any shifting work. • The correct capacity of crane should be selected for handling field switches/equipment

- introduction of risk assessment techniques to control risks
- safe operating procedures framed to avoid unsafe practices in mines

The remedial measures to be taken by the mine owners or managers are

- the communication of working policy
- providing equipment that is fit for purpose
- providing a controlled work environment
- providing suitable working methods
- promoting a positive work culture
- ensuring safe operating procedures are reviewed regularly
- ensuring mines have prepared their safety management plan
- identifying unsafe acts and unsafe conditions
- ensuring safety audits of the mines are conducted periodically
- planning steps to prevent disasters such as inundation, explosion, fire
- providing two-way communication systems
- ensuring periodical inspections of working operations, machines, or equipment
- providing retraining and special training to officers and supervisors.

TABLE 5.9
Accident Prevention Measures in Underground Mines

	Causes	Prevention
Ground Movement	• Roof fall or side fall	• Geologically disturbed areas should be identified and marked in the mine plan • Accurate and precise surveying should be done • Freshly exposed roofs should be supported in every shift • The rock mass rating should be determined and the SSR (Systematic Support Rules) should be framed based on the rock mass rating • The quality of materials and supports should be checked properly • Training and retraining and on-the-spot guidance should be provided for support workers
	• Subsidence	• The presence of subsidence cracks and fissures on the surface above the development panel should be identified • Subsidence cracks should be filled with cement or any other suitable material
Conveyor	• Fire	• The conveyor belt should be of fire-resistant type • Metals and alloys that likely to emit sparks should not be allowed in the conveyor installation • A conveyor belt that is torn or badly worn, or has bad joints, should not be used • Wood or other inflammable materials should not be used for the support of the conveyor structure except for training the belt
	• Coal dust	• Adequate water spray arrangements should be installed at suitable places on the conveyor for the effective suppression of coal dust • The removal of spillage coal around the belt rollers, drums, tensioning units, and roads should be done regularly • At all loading, discharge, and transfer points, adequate arrangements should be made to avoid spillage of coal and formation of coal dust
	• Person caught by the running belt or any moving part	• Drive, return, or tensioning units should be kept substantially fenced or guarded • No person should be permitted to clean or oil any dangerous part whilst the belt is in motion
	• Improper signaling	• Along the length of the conveyor, effective means of signaling should be provided so that a distinct signal can be given to the attendant from any point along its length in order to stop the conveyor belt • Each conveyor installation should be regularly inspected once in every 8 hours when in use, for belt slip, fast idlers or rollers, torn belt, frayed ends, non-alignment, heating, flubbing against road or its supports, and any other defect

(*Continued*)

TABLE 5.9 (CONTINUED)
Accident Prevention Measures in Underground Mines

	Causes	Prevention
Rope Haulage	• Poor quality of ropes/ rope breakage	• Ropes should be inspected regularly by the foreman or engineer
	• Runaway of tubs	• Tubs should be lowered only when the motor is on • Safety devices should be used at track plane and haulage • A proper braking system should be provided • Regular inspections should be carried out
	• Improper track layout/ bad track condition	• Maintenance of track should be carried out regularly
	• Lack of communication	• There should be telephonic communication and signaling at all coupling and decoupling points
	• No guarding of moving parts	• All moving parts should be fenced off
Electricity	• Poorly maintained electrical devices	• Electrical devices should be maintained properly • Proper protection should be used during maintenance
	• Improper shutdown of machine operation	• Strict implementation of shutdown procedure should be followed
	• Untrained, unskilled manpower	• Training and retraining should be provided to workers
	• Housing of power cable along with signaling cable and lighting cable jointly	• Proper isolation of different cables should be carried out
Inundation	• Wrong surveying	• Proper surveying should be carried out • Survey plans should be updated regularly • Inspection should be carried out periodically
	• Insufficient pumping capacity	• Ensure that sufficient pumps are available • All boreholes should be sealed properly
	• Presence of geological disturbance faults, folds, slips, etc.	• Additional support in geological disturbance area should be provided • Soil compaction should be carried out on the surface • Cracks should be filled to prevent the accidental inrush of water
Fire and Explosion	• Fire characteristics and nature of coal with regards to proneness to heating	• Proper ventilation should be provided • Air sample analysis should be carried out regularly
	• No vertical correlation between different lifts	• Proper surveying should be carried out
	• Low incubation period/improper size of panel	• Panel size should be designed properly based on the incubation period of coal • Isolation stoppings should be provided
	• Poor quality of isolation stoppings	• Ensure that the isolation stoppings are in a good state

(*Continued*)

TABLE 5.9 (CONTINUED)
Accident Prevention Measures in Underground Mines

	Causes	Prevention
Fire and Explosion	• Inadequate gas detecting equipment	• An adequate quantity of gas detecting equipment should be provided • All the equipment should be maintained and calibrated regularly
	• Poor firefighting arrangement	• All firefighting arrangements should be maintained properly
	• Huge coal dust deposition in return airway	• Adequate suppression of dust by sprinkling of stone dust and proper cleaning and dusting of return airway should be carried out regularly
	• Leakage from sectionalization stoppings	• Regular monitoring and maintenance of sectionalization stoppings should be carried out • Erection of stopping outbye of previous stopping if required and balance pressure to avoid leakage of stoppings
	• Subsidence crack and fissures on surface above development panel	• Filling of cracks by dozing should be done • Cracks should be filled with concrete if required • Regular monitoring of subsidence area should be carried out
	• Stone dust barrier not provided at panel entry	• Stone dust barriers should be provided according to the statute
	• Accumulation of coal dust at working panel and loading points	• Regular cleaning of coal dust should be carried out • Water spraying and stone dusting should be carried out according to the statute
	• Gases in sealed-off area and old working areas that are not sealed-off	• Sealed-off area should be inspected once every 7 days by a competent person • Old workings should be inspected every 7 days by a competent person

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6 Safety Risk Assessment and Management

6.1 SAFETY MANAGEMENT SYSTEM

6.1.1 Introduction

A safety management system (SMS) is commonly defined "as the management activities, procedures and elements specially aimed at improving safety performance of the organization." SMSs have been successfully applied to manage safety risks in various industries, such as nuclear, space, chemical, petroleum, and others. The literature review carried out by Li and Guldenmund (2018) showed that there is no single standard definition for SMS and there are many models to choose from in order to outline the components of an SMS. The basic component of the SMS presented in International Labour Organization (ILO-OSH, 2001) are Policy, Organizing, Planning and Implementation, Evaluation, and Action for improvement. The Bureau of Indian Standards has formulated the Occupational Health and Safety (OHS) Management Systems (IS 18001, 2007) to provide guidelines on the identification of hazards, evaluation of risks, and control of risks in an organization. The basic components presented in IS 18001 are

- **Policy**: The organization shall frame, document and endorse its OHS policy.
- **Planning**: The organization shall review the existing arrangements for managing OHS it shall lay out guidelines for identifying hazards, risk assessment, and risk control.
- **Implementation and Operation**: The roles, responsibilities, and authorities of personnel shall be framed, documented, and communicated to facilitate effective OHS management; training shall be provided about workplace hazards.
- **Checking**: The performance of the OHS shall be measured on regular basis.
- **Management Review**: The management shall review the OHS management system at regular intervals.

Risk management plays an important role in safety management systems. It allows a thorough analysis of what, in the activity, could cause harm, so that one can review the current precautions taken and increase them if required, to prevent harm. Komljenovic and Kecojevic (2007) carried out an in-depth bibliographic review of various risk management and assessment techniques used in different industries and stated that a few standards and guides are generic in nature and can be applicable to any industry branch (DOE G 450.3-3, 1997; AS/NZS 4360 1999, 1999; ANSI/AAMI/ISO 14971 2000, 2000; CAN/CSA Q850-97, 2000; BS BIP 2033 2003,

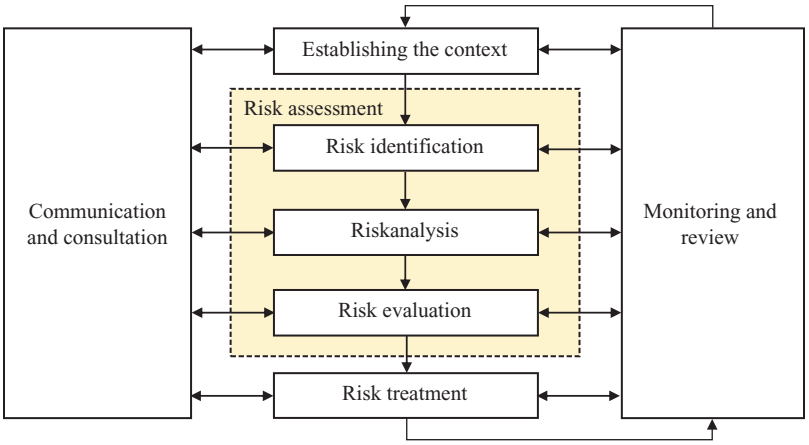


FIGURE 6.1 Risk management process model.

2003). The risk management process presented in International Organization for Standardization (ISO) 31000 (ISO 31000, 2009) is shown in Figure 6.1.

Establishing the context, the risk assessment, and the risk treatment are the three major processes in the risk management system. The risk assessment is the process of risk identification, risk analysis, and risk evaluation. In the context establishment step, the objectives, limitations, and scope of the task should be clearly defined (AS/NZS, 2004). The aim of the risk assessment is to systematically evaluate the potential risks associated with an activity. The output of the risk assessment will be the input into the decision-making process of the industry (IEC 31010, 2009). The risk treatment involves identifying and evaluating treatment options for modifying risks and preparing and implementing treatment plans. The following are the risk treatment options, also known as the "Hierarchy of Controls" (NSW DPI, 2011):

- **Elimination**: Completely remove the hazard
- **Substitution**: Replace the hazard
- **Engineering**: Isolate people using engineering devices from hazards
- **Administration**: Control hazards using training procedures
- **Personal protective equipment**: Isolate people from hazards by the use of hard hats, boots, gloves, safety glasses, etc.
- **Safe human behavior**: Control hazards with awareness, instructions, and compliance with rules and procedures

6.1.2 Safety Management System and Risk Management in Mines

During the past few years, the legislative requirements for the implementation of safety management systems and for effectively carrying out risk management in mines have been increasing. The implementation of risk management is essential in hazardous industries, especially the mining industry, because of the presence of inherent hazards associated within mining operations. Different countries and

TABLE 6.1
Risk Management Guidelines in Various Countries/Organizations

Country/Organization	Year	Standards/Guidelines
New South Wales	1997	Risk Management Handbook for the Mining Industry: How to conduct a risk assessment of mine operations and equipment and how to manage risk (NSWDPI, 1997)
New South Wales	2011	Mineral industry safety and health risk management guideline (NSWDPI, 2011)
New South Wales	2014	Safety Management Systems in Mines (NSWDPI, 2014)
Queensland	1998	Recognised Standard for Mine Safety Management Systems (QDME, 1998)
Queensland	1999	Information paper – safety and health management for Queensland mines and quarries (QMC, 1999)
Mineral Industry Safety and Health Centre (MISHC), Queensland	2007	National minerals industry safety and health risk assessment guideline (Joy and Griffiths, 2007)
Alberta, Canada	2003	Occupational health and safety regulations (GOA, 2003)
Alberta, Canada	2009	Occupational health and safety code (GOA, 2009)
ILO	2009	Code of practice on safety and health in underground coal mines (ILO, 2009)
India	2002	Safety management system – a guideline for implementation (DGMS, 2002)
India	2011	Provision for audit and review of SMS (DGMS, 2011)
India	2016	Integrated approach for development of SMP for coal and metalliferous mines (DGMS, 2016)
South Africa	2003	South African mining industry guide to hazard identification and risk assessment (HIRA, 2003)
UK	2014	The mines regulations 2014 (HSE, 2014)
USA	2008	The application of major hazard risk assessment (MHRA) to eliminate multiple fatality occurrences in the US minerals industry (Iannacchione et al., 2008)

organizations have framed risk management guidelines according to their requirements to manage risks in the mining industry, as shown in Table 6.1.

In India, the preparation of a Safety Management Plan (SMP) is mandatory for all coal mines (CMR, 2017). The requirements of an SMP are

All the coal mine owners, agents, and managers are required to

1. identify the hazards related to the health and safety of the persons employed in the mine
2. assess the risks of the identified hazards
3. record the identification and assessment of risk

4. consult the safety committee and the internal safety organization of the mine to determine the required control measures, such as eliminate any recorded risk, control the risk at source, minimize the risk, provide personal protective equipment, and monitor the risks
5. periodically review the identified hazards and risks assessed in order to determine the further requirements of control measures

A completed SMP should contain

1. the mine safety and health policy of the company
2. a plan to implement the defined safety and health policy
3. how the mine or mines intend develop capabilities to achieve the policy
4. principal hazard management plans
5. standard operating procedures
6. ways to measure, monitor, and evaluate performance of the safety management plan and to correct matters that do not conform with the safety management plan
7. a plan to regularly review and continually improve the safety management plan
8. a plan to review the safety management plan if significant changes occur
9. details of involvement of mine workers in its development and application

6.2 RISK ASSESSMENT

6.2.1 Hazard Identification

The aim of the hazard identification step is to generate a complete list of hazards and their associated risks that might have an impact on the success of each of the objectives identified in the context stage (ISO 31000, 2009). To identify a risk, one must first know what hazards are present and the potential harm associated with them. Therefore, hazard identification is used instead of risk identification.

As hazards are the main identifiable causes of the risks in the workplaces, controlling hazards offers a good chance of reducing the levels of injury or accident. The process of hazard identification is possibly the most crucial step of the whole risk assessment process, as this is where the main causes are identified, and when a cause is not identified, it cannot be actively dealt with. A hazard may originate from different sources and can take many forms. Therefore, it is important to identify the sources of the hazards and the scenarios in which they may originate. There are two types of approaches for hazard identification (Henley and Kumamoto, 1996): (i) an informal approach based on previous data and history; and (ii) a formal approach based on hazard identification techniques. The common hazard identification techniques are (Glossop et al., 2000):

- historical accident and incident records
- personal observations, interviews
- safety committee meetings, informal meetings
- personal experience

- brainstorming
- consultation with workers
- checklists and completed audits
- fault tree analysis

As most of the hazard identification techniques are generic in nature, they can be used to identify hazards in any workplace. However, the hazards may vary from workplace to workplace, so skilled, expert experience is essential to accurately identify all the hazards in a given workplace. The hazard identification process should consider the entire life cycle of a job and its potential impacts on workers, machines, and the environment. To generate a comprehensive list of hazards, a systematic process should start with the objectives of the context establishment step. The general steps in hazard identification are as follows (AS/NZS 4360, 2004):

- select the job to be evaluated
- divide the job into basic steps
- develop a list of expected hazards associated with each step of the job
- develop a list of risks associated with the identified hazards

6.2.2 Risk Analysis

Risk analysis is about developing an understanding of the risks associated with the hazards identified during the hazard identification process (ISO 31000, 2009). Risks associated with the identified hazards need to be assessed to find out the severity of the risk with the current controls employed. Risk should be assessed considering the following three elements:

- the probability (P) of the accident
- the exposure (E) of the hazard causing an accident
- the consequences (C) arising from the accident

Based on the assessment of these three elements, the risks of the identified hazards are calculated and ranked. The risk analysis process provides an input to the risk evaluation step and helps employers to make decisions about which risks or hazards need to be controlled, and hence to select the appropriate risk treatment strategies and methods. Risk analysis may be carried out to varying degree of detail, depending upon the risk, purpose of the analysis, and the data, information, and resources available (AS/NZS 4360, 2004). The risk analysis methodologies are categorized into two groups: qualitative and quantitative techniques. Qualitative risk assessment techniques use relative values for the consequences and probability methods in order to evaluate the level of risk in terms of high, medium, and low level. Such techniques are based both on a systematic estimation process and the experience of an expert, and they are more suitable for calculating low-level, complex systems. On the other hand, quantitative risk assessment techniques use the actual statistical values for the consequences and probability methods in order to evaluate the level of risk. They are suitable for high-level, complex systems.

6.2.3 Risk Evaluation

The aim of risk evaluation is to make decisions based on the results of risk analysis about which risks need treatment and treatment priorities (ISO 31000, 2009). In the risk evaluation process, the level of risk found during evaluation is compared with the risk criteria established in the context stage. If the level of risk is low or negligible, then the risk evaluation can lead to a decision to continue the existing controls and not to treat the risk. If the level of risk is medium or high, however, then the risk evaluation can lead to a decision about the risk treatment controls to be implemented in order to reduce or eliminate the risk. In some cases, further analysis may be needed (AS/NZS 4360, 2004; ISO 31000, 2009).

6.2.4 Risk Control

The aim of the risk control stage is to manage the risk level of the identified risk. The types of control measures to be adopted depend on the level of risk obtained in the risk evaluation stage. If the risk level of an activity is "high," then irrespective of the benefits associated with the activity, it should be discontinued until the risk level is reduced to minimum level possible. If the risk level of an activity is "medium," then the activity should be continued only when the control measures have been implemented and workers have been educated about the hazard(s) associated with the activity. If the risk level of an activity is "low," then the activity can be continued only of reasonable, practicable measures are available. Usually risk control is carried out using the hierarchy method; see the hierarchy of controls presented in Figure 6.2 (DGMS, 2002).

6.3 RISK ASSESSMENT TECHNIQUES

To date, quite a lot of techniques have been developed and applied for assessing risk in various high-hazard industries, including the mining industry. Each has its own purpose and outcome. Some of them are popular and commonly applied and some of them are hardly ever used. The selection of proper risk assessment techniques

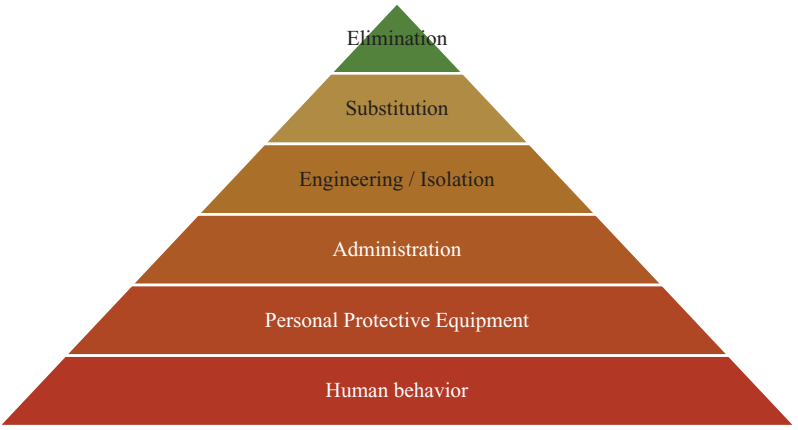


FIGURE 6.2 Hierarchy of controls.

depends on factors such as the types of hazards, the types of risks to be assessed, the availability of data, and the availability of expertise and other resources. Following ISO 31000 (2009), a suitable technique should exhibit the following characteristics:

- it should be justifiable and appropriate to the situation or organization under consideration
- it should provide results in a form that enhances understanding of the nature of the risk and how it can be treated
- it should be capable of use in a manner that is traceable, repeatable, and verifiable

The risk assessment techniques are classified as (i) qualitative, (ii) quantitative, and (iii) hybrid. The qualitative techniques are based on a logical estimation process and the experience of the engineer, and they are suitable for low-level complex systems. The quantitative techniques are based on the actual statistical values. and they are suitable for high-level complex systems. The hybrid techniques combine qualitative and quantitative techniques in the risk-ranking step (Joy, 2004; Marhavilas et al., 2011; Ramona, 2011). The classification of different risk analysis tools is presented in Figure 6.3.

A brief overview, including information on the procedures used for common techniques and their application in the mining industry, is presented in this chapter. Detailed information on these techniques can be found in numerous publications (Arunraj and Maiti, 2007; Bahr, 2014; Ericson, 2015; Glossop et al., 2000; ISO, 2009; Lees, 2012; Sheng et al., 2010).

6.3.1 Qualitative Techniques

The qualitative techniques explained here are job safety analysis (JSA), sequentially timed event plotting (STEP), hazard and operability study (HAZOP), failure mode and effects analysis (FMEA), and workplace risk assessment and control (WRAC).

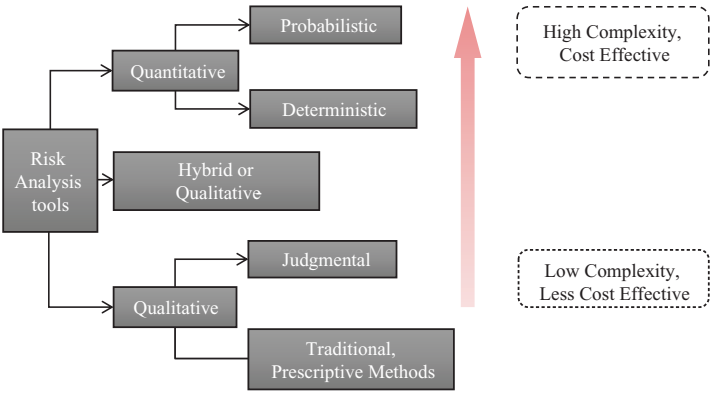


FIGURE 6.3 Classification of risk analysis tools. (Courtesy of Rasche and Wooley, 2000. Importance of risk based integrity management in your safety management system: Advanced methodologies and practical examples. In: Queensland Mining Industry Health & Safety Conference, Queensland Mining Council, Townsville, January/February 2000.)

6.3.1.1 Job Safety Analysis

Job safety analysis is a qualitative technique that helps to identify the hazards of particular tasks and recommend the safest ways to do the job. JSA is also termed as job hazard analysis or job hazard breakdown. The procedural steps involved in the performing JSA are shown in Figure 6.4 (CCOHS, 2016).

Before performing JSA, a team should be selected. Normally, the team comprises the management of the organization, manager, safety officer, and workers. The success of the JSA depends on the experience of the team members. The construction of JSA is explained using Example 1.

Example 1

Perform a JSA for "cleaning coal spillage on conveyor belt system."

Step 1 is to break the "cleaning coal spillage on conveyor belt system" job into its basic steps by asking what is to done first, what is to be done next, and so on. In step 2, for each basic step, ask what accidents could happen to workers while performing the job. Finally, for each hazard identified, ask what safety measure should be provided for the workers or what workers should do to avoid the accidents. The completed JSA worksheet is shown in Table 6.2.

6.3.1.2 Sequentially Timed Event Plotting

Sequentially timed event plotting is a multilinear systems safety approach developed by Hendrick and Benner (1986). In multilinear systems approaches, accidents are viewed as multiple possibilities of causal factors that react to previous factors and may interact with others throughout the system to ultimately lead to an accident. The STEP procedure is a comprehensive approach to reconstructing an accident

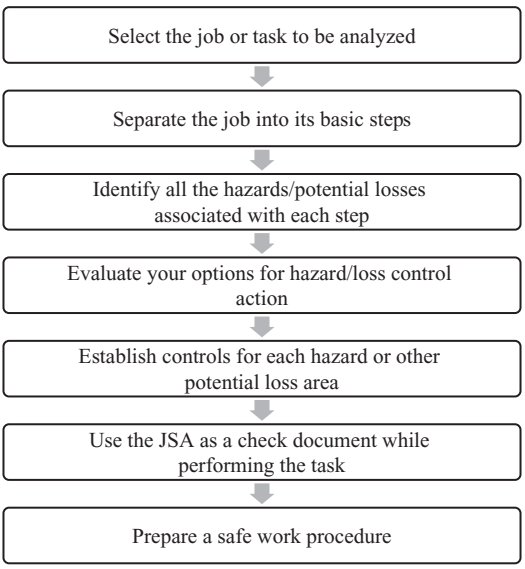


FIGURE 6.4 Steps for performing JSA.

TABLE 6.2

JSA Worksheet for Cleaning Coal Spillage on Conveyor Belt System

Job Safety Analysis

Job No. 1	**Job Title**: Cleaning coal spillage	**Job Location**: **56 L/4 D**	**Page**: 1
Operation Description: Cleaning of coal around idlers and drums			**Date**: 25-5-2018
Team Leader: *ABC*		**Team Members**:	**Recorded by**:

Step No.	Steps in Operation	Potential Hazards	Recommended safe job controls
1.	Stop the conveyor belt	The conveyor may draw in the operator if not stopped, with chance of electrocution	Stop the conveyor and test for dead Properly maintain conveyor switches
2.	Place lockout tag on conveyor start switch	Accidental starting of conveyor and other workers may start the conveyor without knowing the cleaning work is in progress	Provide safe operating procedures and proper training to operator
3.	Clean the coal spillage around idlers	Injury to operator while cleaning, if proper shovel is not provided	Provide long handled shovel, strictly prevent the operator from cleaning the coal when the conveyor belt is in motion
4.	Clean the coal spillage around drums	Injury to operator while cleaning, if proper shovel is not provided	Provide long handled shovel, strictly prevent the operator from cleaning the coal when the conveyor belt is in motion
5.	Perform a pre-start check	Injury to other workers	Provide safe operating procedures and proper training to operator
6.	Blow an alarm	Injury to other workers, if fails to blow the alarm	Provide safe operating procedures and proper training to operator
7.	Remove lockout tag from conveyor start switch	Miscommunication between workers	Remove lockout tag before starting the conveyor
8.	Start the conveyor belt	Chance of electrocution	Properly maintain conveyor switches

(Kontogiannis et al., 2000; Munson, 2000). In other words, the STEP method provides an overview of the timeline of the events and the sequence of events/actions that contributed to the accident. The main component of the accident reconstruction process is the STEP worksheet. In the worksheet, the timeline is recorded in a horizontal direction and the actors in the accident sequence are recorded in a vertical direction. The actors may include people, objects, and things. The procedure for the STEP process is shown in Figure 6.5.

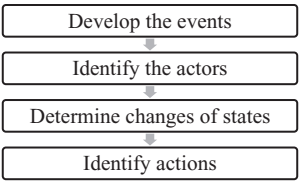


FIGURE 6.5 Steps in STEP process.

6.3.1.3 The HAZOP Study

The HAZOP study method was initially developed in the 1960s for analyzing hazards in the chemical industry but since then it has been extended to other industries, such as nuclear, mining, etc. HAZOP (ICI, 1974; Kletz, 1983) is a formalized methodology to identify and document potential hazards and operability problems through imaginative thinking. The basic principle of a HAZOP study is that normal and standard conditions are safe, and hazards occur only when there is deviation from normal conditions (Khan and Abbasi, 1997).

An experienced multidisciplinary team is required to conduct a HAZOP. To cover all the possible malfunctions in a plant, procedure, system, or process, the HAZOP study team members use a set of guide words for generating the process variable deviations to be considered in the HAZOP study. A list of guide words with their meanings is presented in Table 6.3 (McDermid et al., 1996). The procedural steps involved in conducting HAZOP are shown in Figure 6.6. Marhavilas et al. (2011) briefly summarized the main characteristics of HAZOP as follows:

- it is a systematic, highly structured assessment relying on HAZOP guide words to generate a comprehensive review and ensure that appropriate safeguards against accidents are in place
- it is applicable to any plant, process, system or procedure
- it is used most as a system-level risk-assessment technique
- it generates primarily qualitative results, although some basic quantification is possible

The construction of HAZOP is explained using Example 2.

Example 2

Find the deviations in the hydraulic fluid system of a powered roof support shield used in longwall mining.

The hydraulic cylinder is one the main components of the powered roof support. Its purpose is to operate shield legs, push the chain conveyor and advance the shield, stabilize the position of the canopy with respect to the caving shield, and operate the base-lifting device and side shields.

In the first step, the hydraulic cylinder is divided into different nodes and guide words are applied to each node to find the deviations. The causes and the consequences of the deviations are also recorded. The completed HAZOP study is presented in Table 6.4.

TABLE 6.3
List of Guide Words and Their Meaning

Guide Words	Meaning	Parameter	Deviation
No/None	Complete negation to design intention	Flow Level	No flow Zero level
More	Quantitative increase	Flow Level Temperature Pressure Concentration	High flow rate High level High temperature High pressure High concentration
Less	Quantitative decrease	Flow Level Temperature Pressure Concentration	Low flow rate Low level Low temperature Low pressure Low concentration
Part of	Only part of intention is fulfilled	Concentration Flow Level	Concentration decrease Flow decrease Level decrease
As well as	In addition to design intention, something else occurs	Concentration of impurity Temperature of substance Level of impurity Pressure of substance Flow of impurity	Concentration increase Temperature increase Level increase Pressure increase Flow increases
Reverse	Logical opposition of design intention occurs	Flow Pressure	Reverse flow rate Reverse pressure
Other than	Complete substitution	Concentration of desired substance Level of desired substance Flow of desired substance	Concentration zero Level zero Flow rate zero

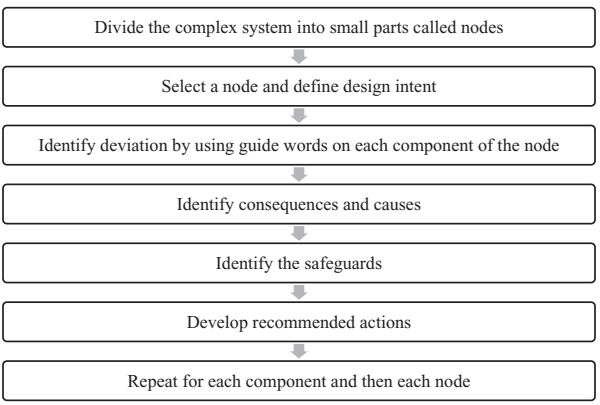


FIGURE 6.6 Steps for conducting HAZOP study.

TABLE 6.4

HAZOP Study of Hydraulic Cylinder

Hazard and Operability Study

Project No. 1 **Project Title**: Powered roof support shield **Page**: 1

Operation Description: Support system **Location**: 56 L/4 D **Date**: 25-5-2018

Team Leader: *ABC* **Team Members**: **Recorded by**:

Sl. No.	Guide Word	Deviation	Cause	Consequence	Safeguards	Actions
1.	More	High pressure	Return lines blocked	Hydraulic cylinder may split	Regular maintenance	Proper ventilation shall be provided
2.			Check valve leaking	Sudden increase of pressure in bottom stage	Regular maintenance	Replace check valve whenever required
3.	Less	Low pressure	Worn piston seals	No load carrying capacity	Regular maintenance	Replace the worn seals whenever required
4.			Bad check valve	No load carrying capacity	Regular maintenance	Replace check valve whenever required
5.	Less	Low temperature	Cooling of hydraulic fluid	Load carrying capacity decreases	Regular maintenance	No action proposed
6.	Other than	Hydraulic fluid Contamination	Dirt	Pressure loss	Regular maintenance	No action proposed

6.3.1.4 Failure Mode and Effects Analysis

FMEA (MIL, 1977; Lees, 2012) is a step-by-step approach for identifying all possible failures in a design, a machine, a manufacturing, or an assembly process. "Failure mode" means the ways in which something might fail, and "effect analysis" refers to studying the consequences of those failures. FMEA is a qualitative inductive method and is easy to apply. It is an efficient method of analyzing elements that can cause failure of the whole, or of a large part of a system. It is also good for generating the failure data and information at the component level. FMEA needs a highly skilled team with sufficient experience and time to carry out the study. It has been said that FMEA can be a laborious and inefficient process unless carefully applied (Prajapati, 2012). One of the main drawbacks of FMEA is that it is restricted up to component level, while the actual hazards may start at subcomponent level.

FMEA is usually a qualitative or semi-quantitative method, but it may be quantified using actual failure rates. The procedural steps involved in conducting FMEA are shown in Figure 6.7.

The construction of FMEA is explained using Example 3.

Example 3

The conduct of an FMEA study of a longwall shearer and powered roof support system.

The failures associated with a longwall shearer and powered roof support system are gear wheel wear, damaged picks, coupling breaking off, cylinder legs leaking, malfunction of valves, mechanical failures, software error, and operator failure. The total risks of all the failure modes of a longwall shearer and powered roof support system are calculated and presented in Table 6.5.

6.3.1.5 Workplace Risk Assessment and Control

WRAC is a risk-ranking approach that allows the user to focus on the highest risk. It is a very powerful tool for identifying potential production and operational losses (Joy

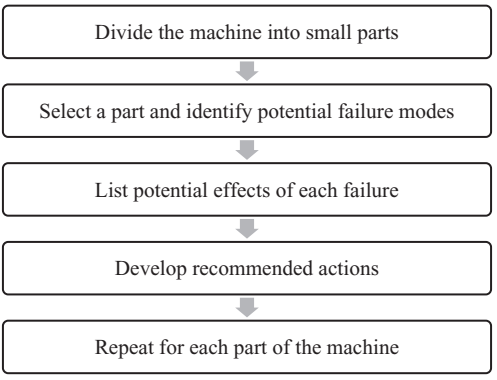


FIGURE 6.7 Steps for conducting FMEA study.

TABLE 6.5
FMEA of Longwall Shearer and Powered Roof Support System

Components	Failure Mode	Failure Effect	Recommendations
Shearer	Gear wheel wear	Drive unit failure	Replace gear
	Gear wheel tooth broke	Drive unit failure	Replace gear
	Damaged picks	Create sparks, potential ignition	Inspection of cutting drum should be increased
	Coupling breaks off	Shear shaft comes out of cutter motor	Use safe work procedures
Powered roof support	Cylinder legs external leak	Gradual drop in pressure	Installing yield valves with a lower operating value
	Cylinder legs internal leak	Load carrying capacity decreases	Maintenance should be carried out periodically
	Stage valves debris	Reduce shield capacity	Maintenance should be carried out periodically
	Yield valves malfunction	Leg pressure to increase beyond design levels	Change filters as needed to maintain a clean emulsion Chemical analysis of the fluid should be carried out periodically
	Check valve malfunction	Drop in pressure	Change filters as needed to maintain a clean emulsion Chemical analysis of the fluid should be done periodically
	Worn seals malfunction	Drop in pressure	Maintenance should be done periodically
	Canopy wrinkling	Permanent deformation of canopy	Corrosion resistant painting Lubrication of joints Stiffeners should be properly welded
	Canopy bend	Permanent deformation of canopy	Corrosion resistant painting Lubrication of joints Stiffeners should be properly welded
	Base fatigue	Leg socket breaks loose, Support suddenly becomes inoperable	Corrosion resistant painting Lubrication of joints Stiffeners should be properly welded
	Base bend	Failure of base structure	Corrosion resistant painting Lubrication of joints Stiffeners should be properly welded
	Crack formation of links	Horizontal support failure	Use sherardizing links
	Solenoid valves failure	Unplanned movement	Maintenance of sticking solenoid valves should be carried out periodically
	Moisture entry	Unplanned movement	Improve sealing of the control unit
	Software error	Unplanned movement	Add error diagnostic features

and Griffiths, 2007; Iannacchione et al., 2008). Before starting a WRAC study, a clear objective should be established, as well as the boundaries of the system to be reviewed. After a preliminary analysis, the team then should consider the breakdown of each segment of the mining process and identify the potential unwanted events associated with the identified hazards. The likelihoods and consequences of each stage are determined using a risk matrix followed by risk-rating calculations. The in-depth details of the risk matrix are presented in Section 6.3.2.2. The final product of the exercise is a list of current, planned, or potential new controls to reduce priority equipment risks (Thompson, 1999). The WRAC technique is suitable for identifying multiple failures. The procedural steps involved in conducting a WRAC analysis are shown in Figure 6.8.

The construction of WRAC is explained using Example 4.

Example 4

The conduct of a WRAC analysis for strata control in underground coal mines.

The risks of all the failure events associated with strata control are calculated and presented in Table 6.6. In this example, the likelihood and consequence values were assigned using the scale presented in a decision matrix risk assessment. If the scales used are developed using the real-time accident data, then the WRAC analysis is said to be a quantitative analysis, otherwise it is said to be a qualitative analysis.

6.3.2 Quantitative Techniques

The quantitative techniques explained here are the proportional risk assessment technique (PRAT), the decision matrix risk assessment (DMRA), the quantitative risk assessment (QRA), and the weighted risk analysis (WRA).

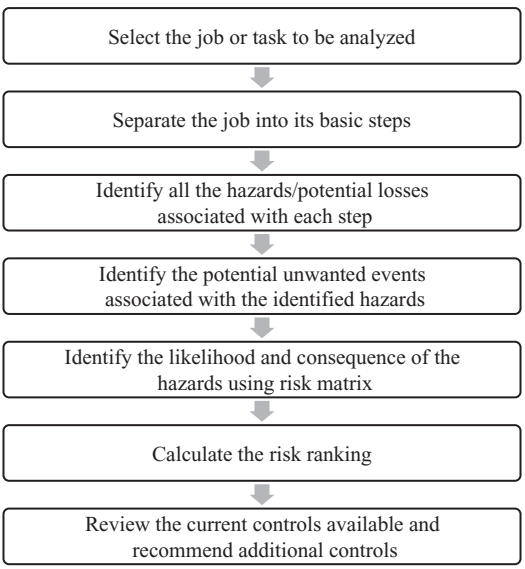


FIGURE 6.8 Steps for conducting WRAC analysis.

TABLE 6.6

Risk Ranking of Hazards Related to Roof/Side Fall Using WRAC Tool

Sl. No.	Hazards	Associated Risks	Likelihood (L)	Consequence (C)	Risk Ranking (R)	Current Control	Recommended Control
1.	Geological disturbances and weak roof, sides	Roof side fall	4	4	16	Identifying geologically disturbed area	Marking geological disturbances on plan
2.	More height and width of galleries	More stresses and chances of fall	3	3	9	Accurate and precise surveying	Control on blasting parameters
3.	Unsupported/poorly supported roof	Chance of roof fall	3	4	12	Timely supporting in shifts	Ascending advance support gang
4.	Delay in support and support lag	Injury due of fall	2	3	6	Timely supporting	Proper follow-up in all three shifts
5.	RMR (Rock Mass Rating) not determined and SSR (Systematic Support Rules) not framed	Improper support under supported working	4	4	16	RMR determined and framed SSR send for approval	Same control to continue
6.	Poor quality of support material	Poor quality of support	3	3	9	Proper check on quality of material and support	Present control to continue
7.	Poor quality of workman/shift	Poor quality of support	2	3	6	Training, retraining, on-the-spot guidance	Weekly discussion and guidance by officers and supervisors
8.	Manual drilling	Non verticality of holes	2	2	4	Ensuring verticality by proper follow-up	Present control to continue
9.	Non-availability of support material	Unsupported workings	4	4	16	Ensuring proper supply of support material	No work without support

(*Continued*)

TABLE 6.6 (CONTINUED)

Risk Ranking of Hazards Related to Roof/Side Fall Using WRAC Tool

Sl. No.	Hazards	Associated Risks	Likelihood (L)	Consequence (C)	Risk Ranking (R)	Current Control	Recommended Control
10.	Unskilled/untrained support crews	Poor quality of work	3	3	9	Training and retraining	Weekly orientation at mine
11.	Poor knowledge of approved SSR	Under or over support improper support	3	3	9	Imparting knowledge using safety talks	Weekly review
12.	Poor supervision	Chances of accident	3	3	9	No work without supervisors	Supervisors not to be overloaded
13.	Non verticality of galleries over galleries in different lifts	Uneven distribution of stresses, crushed top and sides	3	3	9	Proper surveying	Timely extension of center line
14.	Voids presents in bottom section	Risk of machine/men falling in voids	3	3	9	Checking by drilling boreholes before every blast	Present controls to continue

6.3.2.1 The Proportional Risk Assessment Technique

This technique, PRAT, uses a proportional formula for evaluating the quantitative risk of the identified hazards. Generally, the risk is defined as the product of the probability, exposure, and consequence of the accident (Fine and Kinney, 1972). Marhavilas and Koulouriotis (2008) modified the risk defined by Fine and Kinney (1972) and proposed a proportional formula for risk as follows:

$$R = P \times S \times F$$

where

R = risk
P = probability factor
S = severity of harm factor
F = frequency or exposure factor

This method is also known as the rapid-ranking method. The proportional formula provides a logical system for management to set priorities for attention to hazardous situations. The scales for the probability factors, severity factors, frequency factors, and risk values developed by Marhavilas and Koulouriotis (2008) are presented in Tables 6.7 and 6.8 respectively.

TABLE 6.7
Scales for Probability, Severity and Frequency Factors

P	Description of Undesirable Event	S	Description of Undesirable Event	F	Description of Undesirable Event
10	Unavoidable	10	Death	10	Permanent presence of damage
9	Almost assured	9	Permanent total inefficiency	9	Presence of damage every 30 sec
8	Frequent	8	Permanent serious inefficiency	8	Presence of damage every 1 min
7	Probable	7	Permanent slight inefficiency	7	Presence of damage every 30 min
6	Probability slightly greater than 50%	6	Absence from work >3 weeks, and return with health problems	6	Presence of damage every 1 hr
5	Probability 50%	5	Absence from work >3 weeks, and return after full recovery	5	Presence of damage every 8 hr
4	Probability slightly less than 50%	4	Absence from work >3 days and <3 weeks, and return after full recovery	4	Presence of damage every 1 week
3	Almost improbable (or remote)	3	Absence from work <3 days, and return after full recovery	3	Presence of damage every 1 month
2	Improbable	2	Slight injuring without absence from work, and with full recovery	2	Presence of damage every 1 year
1	Impossible	1	No one human injury	1	Presence of damage every 5 years

TABLE 6.8
Scale for Risk Values

R	Urgency Level of Required Actions
700–1,000	Immediate action
500–700	Required action earlier than 1 day
300–500	Required action earlier than 1 month
200–300	Required action earlier than 1 year
<200	Immediate action is not necessary but it is required the event surveillance

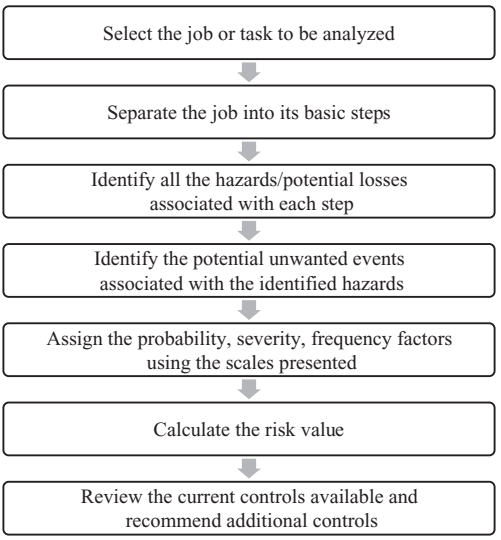


FIGURE 6.9 Steps for conducting PRAT.

The procedural steps involved in PRAT are shown in Figure 6.9. The first four steps in PRAT are carried out using FMEA, WRAC, or any other hazard identification technique.

The construction of PRAT is explained using Example 5.

Example 5

Calculate the risk level of hazards associated with inundation risk in underground coal mines using PRAT.

The risks of all the failure events associated with inundation in underground coal mines are calculated and presented in Table 6.9.

Based on the risk values obtained using the PRAT techniques, the order of the priorities of hazards can be presented. The hazards "presence of surface cracks, fissures, subsidence, potholes" and "presence of geological disturbance faults, folds, slips, etc." have the highest risk levels of 320 and 240 respectively, and require action in less than one year.

TABLE 6.9
Risk Level of Hazards Associated with Inundation Calculated Using PRAT

Sl. No.	Hazards	Associated Risks	P	S	F	R	Recommended Control
1.	Exposure to noise in area of pumps	Temporary hearing loss may occur	3	2	5	30	Personal protective equipment's such as earplugs or noise cancellation headphones should be used
2.	Sudden inrush of water/ unconsolidated free flowing materials	Flooding of working area, injury to persons, and loss of property	4	9	1	36	Stoppage of working in case of abnormal seepage of water, advance check borehole, and hydrogeological survey to be carried out to establish presence of water body
3.	Presence of geological disturbance faults, folds, slips, etc.	Sudden inrush of water	3	8	10	240	Provision of geological disturbances are demarcated on different plans and 15 m barrier is left against such disturbances
4.	Presence of surface cracks, fissures, subsidence, potholes	Flooding of mine	4	8	10	320	Provision for filling surface cracks, fissures, subsidence, potholes to avoid any inrush of such water to the underground
5.	Water entering from old boreholes that have not been sealed effectively	Flooding of mine	3	7	5	105	Provision for sealing boreholes; barrier is maintained around the borehole
6.	Unexpected heavy rains and power failure	Flooding of mine	3	8	1	24	Evacuation of persons from the underground
7.	Failure of pumps	Flooding of mine	3	10	3	90	Stoppage of working in case of abnormal seepage of water

6.3.2.2 Decision Matrix Risk Assessment

The DMRA technique is used to measure the risks' magnitudes and categorize them on the basis of likelihood and consequence (Woodruff, 2005). The relationship between the risks and their components can be evaluated using DMRA, either qualitatively or quantitatively. In the qualitative analysis the scales of the likelihood and the consequences need not be linear (AS/NZS 4360, 2004). In the case

of quantitative analysis mathematical manipulation may be used. A simplified risk matrix developed and intended to be used for risk estimation and evaluation in the mines of Coal India Limited is given in Table 6.10 (Srinivas, 2012; Tripathy, 2014).

The above matrix is used only to prioritize the risk for initiating the action.

6.3.2.2.1 Consequence criteria

Based on the identified four criteria of personal injury, loss of property (damage of equipment, infrastructure, or property), the duration of process interruption and the impact on the environment, the consequence matrix has been categorized into five classes. The scale of consequences is presented in Table 6.11.

TABLE 6.10
5 × 5 Risk Matrix

		Consequence Severity				
	Risk	**Insignificant (C_1)**	**Minor (C_2)**	**Moderate (C_3)**	**Major (C_4)**	**Catastrophic (C_5)**
Likelihood	Rare (L_1)	1	3	6	10	15
	Unlikely (L_2)	2	5	9	14	19
	Possible (L_3)	4	8	13	18	22
	Likely (L_4)	7	12	17	21	24
	Almost certain (L_5)	11	16	20	23	25

Note: Risk Score.

TABLE 6.11
Scale of Consequences (C)

	Criteria			
Category	**Personal Damage**	**Damage Cost**	**Process Interruption**	**Environmental Impact**
Insignificant (C_1)	No treatment	<5,000	<1 hour	Potential impact
Minor (C_2)	First aid treatment	5000–50,000	1 hour–1 shift	Local impact
Moderate (C_3)	Medical treatment	50,000–100,000	1 shift–1 day	On-site impact
Major (C_4)	Extensive injuries, single fatality	100,000–250,000	1 day–1 week	Off-site impact
Catastrophic (C_5)	Multiple fatality	>250,000	>1 week	Community alarm

6.3.2.2.2 Likelihood criteria

The likelihood of risk is classified into five categories based on four qualitative descriptions, as presented in Table 6.12.

The procedural steps involved in DMRA are shown in Figure 6.10.

The construction of DMRA is explained using Example 6.

Example 6

Determine the relationship between the risk(s) and their components for strata control analysis conducted in Example 4.

The risks of all the failure events associated with strata control are graphically presented in Table 6.13.

The DMRA results reveal that, except for the hazard events "manual drilling," "delay in support and support lag," "poor quality of workman-shift," all the other events require appropriate action to reduce the risk level to the lowest level possible.

6.3.2.3 Quantitative Risk Assessment Tool

The QRA tool was developed for assessing dust explosion hazards in industrial plants. This tool is useful for analyzing individual risk and societal risk. The overview of the QRA tool is represented in Figure 6.11 (Van der Voort et al., 2007). The first step is to divide the industrial plant into different parts. Then the explosion scenario of all the parts along with the frequency of occurrence can be determined. In this model, the consequences of debris and fragments throw, blast and flame effects, and outflow of bulk material, on unprotected people and external objects are taken into account. Finally, the risk counters and the societal risks are calculated.

TABLE 6.12
Scale of Likelihood (L)

Category	Description-1	Description-2	Safety Example	Health Example
Rare (L_1)	Almost impossible	Consequence may occur under exceptional circumstances	Occurs once every 1,000–10,000 years	1 case per 1,000,000 person years
Unlikely (L_2)	Not likely to happen	Consequence could occur at some time	Occurs once every 100–1,000 years	1 case per 100,000 person years
Possible (L_3)	Heard of it happening	Consequence should occur at some time	Occurs once every 10–100 years	1 case per 10,000 person years
Likely (L_4)	Has happened	Consequence will probably occur in most circumstances	Occurs once every 1–10 years	1 case per 1,000 person years
Almost Certain (L_5)	Common/ repeating	Consequence expected to occur in most circumstances	High-frequency of occurrence, occurs once every year	1 case per 100 person years

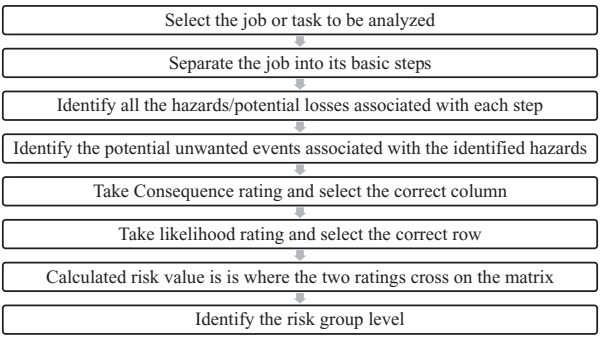


FIGURE 6.10 Steps for conducting DMRA.

TABLE 6.13
5 × 5 Risk Matrix

		Consequence Severity				
Risk		**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
Likelihood	L_1			• Delay in support and support lag • Poor quality of workman/shift		
	L_2			• More height and width of galleries • Poor quality of support material • Unskilled/untrained support crews • Poor knowledge of approved SSR • Poor supervision • Nonverticality of galleries over galleries in different lifts • Void presents in bottom section		
	L_3	• Manual drilling				
	L_4		• Unsupported/poorly supported roof			
	L_5		• Geological disturbances and weak roof/sides • RMR not determined and SSR not framed • Non-availability of support material			

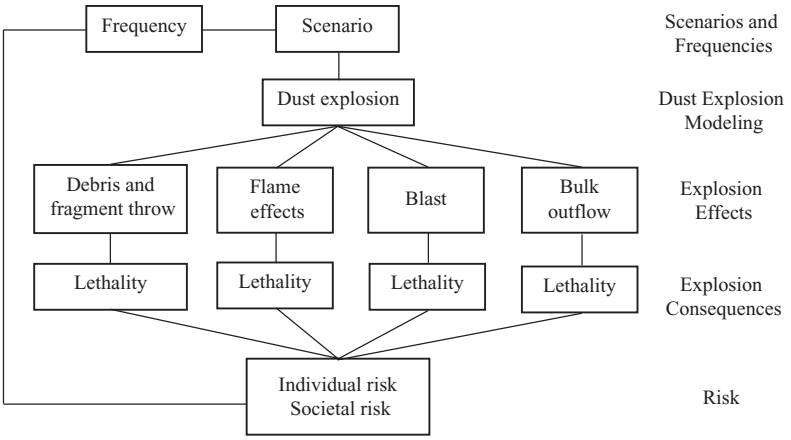


FIGURE 6.11 Overview of QRA tool. (Courtesy of Van der Voort et al., 2007 A quantitative risk assessment tool for the external safety of industrial plants with a dust explosion hazard. *Journal of Loss Prevention in the Process Industries*, 20(4–6), 375–386.)

6.3.2.4 The Weighted Risk Analysis

In order to balance safety measures with aspects such as environmental, quality, and economical, a weighted risk analysis methodology was used (Marhavilas and Koulouriotis, 2008). The weighted risk analysis is a tool comparing different risks, like investments, political losses, economic losses, loss of human lives, and environmental losses in terms of financial cost, since both the investment and risks could be expressed solely in financial terms (Suddle, 2009). Suddle and Waarts (2003) stated that, along with the technical aspects, different types of risks, such as economic, environmental, political, psychological, and societal acceptance, are the aspects that play a major role in the risk analysis phase, and they recommended that the different risks should be integrated in terms of financial cost, as follows (Suddle, 2004):

$$R_w = a_1 \sum_{i=1} R_{\text{human},i} + a_2 \sum_{j=1} R_{\text{economic},j} + a_3 \sum_{k=1} R_{\text{environmental},k} + \ldots$$

where R_w is the weighted risk (cost per unit year), a_1 is the (monetary) value per fatality (cost unit), a_2 is the (monetary) value per economical risk (cost unit), a_3 is the (monetary) value per environmental risk (cost unit), and so on. The weighted risk analysis is performed after the quantitative risk analysis as a complementary tool for different types of risk that affect the risk analysis process. The methodological steps for dealing with safety are shown in Figure 6.12 (Suddle, 2009).

6.3.3 Hybrid Techniques

The hybrid techniques explained here are fault tree analysis (FTA) and event tree analysis (ETA).

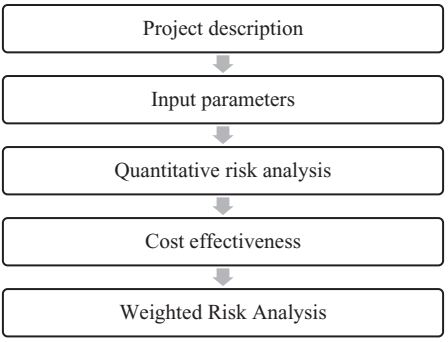


FIGURE 6.12 Steps for dealing with physical safety.

6.3.3.1 Fault Tree Analysis

Fault tree analysis (Lapp and Powers, 1976; Hauptmanns, 1988) is a deductive technique focusing on one particular accident event and providing a method for determining causes of that event. In other words, FTA is an analysis technique that visually models how logical relationships between equipment failures, human errors, and external events can combine to cause specific accidents. FTA is based on reliability theory, Boolean algebra, and probability theory (Ericson, 1999). FTA yields both qualitative and quantitative information.

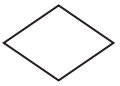
Fault trees are constructed from events and gates. Basic events can be used to represent technical failures that lead to accidents while intermediate events can represent operator errors that may intensify technical failures. The gates of the fault trees can be used to represent several ways in which machine and human failures combine to give rise to the accidents. For instance, an AND gate implies that both initial events need to occur in order to give rise to the intermediate event. Conversely, an OR gate means that either of two initial events can give rise to the intermediate event (Reniers et al. 2005, Yuhua and Datao, 2005). The common symbols used in the construction of FTA are shown in Table 6.14 and the procedure for FTA is shown in Figure 6.13 (Stamatelatos et al., 2002). In-depth literature on FTA can be found in (Fussell, 1976; Vesely et al., 1981; Lee et al., 1985; Tanaka et al., 1983; Henley and Kumamoto, 1996; Suresh et al., 1996; Andrews and Moss, 2002; Ericson, 2015; Ruijters and Stoelinga, 2015).

The application of FTA is popular in various high-hazard industries, such as nuclear, chemical, space, and transport, however its application in the mining industry is yet to gain popularity. A literature study showed that FTA was applied in the mining industry to investigate the following types of accidents: dozer fall (Iverson et al., 2001), failure logic of longwall shearer (Gupta et al., 2006), coal spontaneous combustion (Beamish et al., 2010), mine water inrush (Fan et al., 2011), roof fall (Jiang et al., 2012), coal mine fire (Shaojie, 2013), haul truck-related (Zhang et al., 2014), and methane gas explosion (Kumar and Ghosh, 2017).

6.3.3.1.1 Qualitative FTA

The construction of FTA is explained using the following examples.

TABLE 6.14
Common Symbols Used in the Construction of FTA

	EVENT	A rectangle is used to represent the top event and any intermediate fault events in a fault tree
	BASIC EVENT	A basic initiating fault requiring no further development
	CONDITIONAL EVENT	Specific conditions or restrictions that apply to any logic gate
	UNDEVELOPED EVENT	An event that is not further developed because further information is unavailable
	"OR" GATE	Output fault occurs if a least one of the input faults occurs
	"AND" GATE	Output fault occurs if all of the input faults occur
	"INHIBIT" GATE	Output fault occurs if the (single) input fault occurs in the presence of an enabling condition (the enabling condition is represented by a CONDTIONING EVENT drawn to the right of the gate)
	TRANSFER EVENT	Transfer symbols are used to indicate that the fault tree continues on a different page

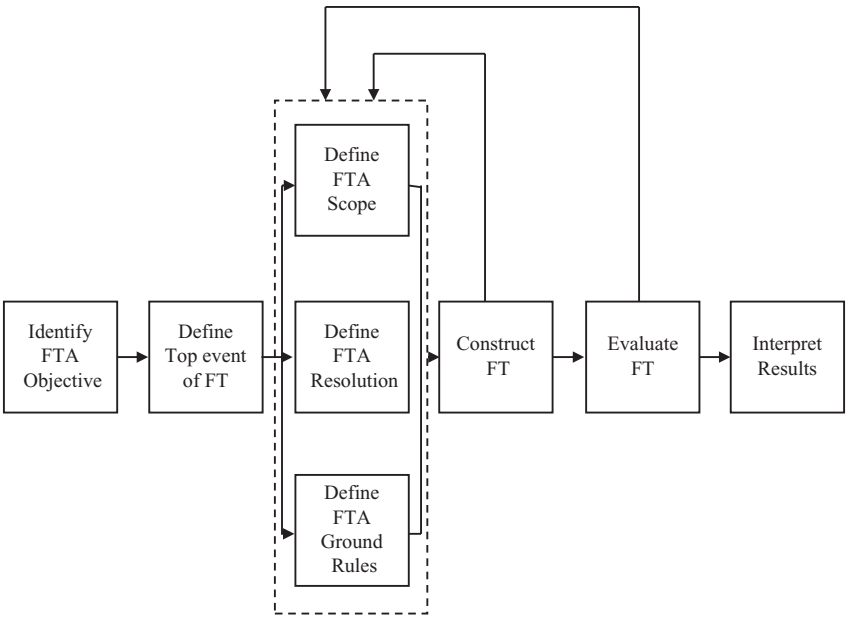


FIGURE 6.13 Fault tree analysis steps.

Example 7

Spontaneous heating is one of the common risks in underground coal mines. Construct a fault tree for the occurrence of top event "spontaneous heating" using the symbols in Table 6.14.

The aim of the FTA is to identify the root causes of the top event. The FTA investigates "how" the spontaneous heating can occur in underground coal mines. In this case, spontaneous heating occurs only when there is self-heating or when there is less than adequate dissipation heat. The fault tree of spontaneous heating is shown in Figure 6.14.

6.3.3.1.2 Probability evaluation of FTA

The probability of the occurrence of an output fault event of an AND gate is expressed as

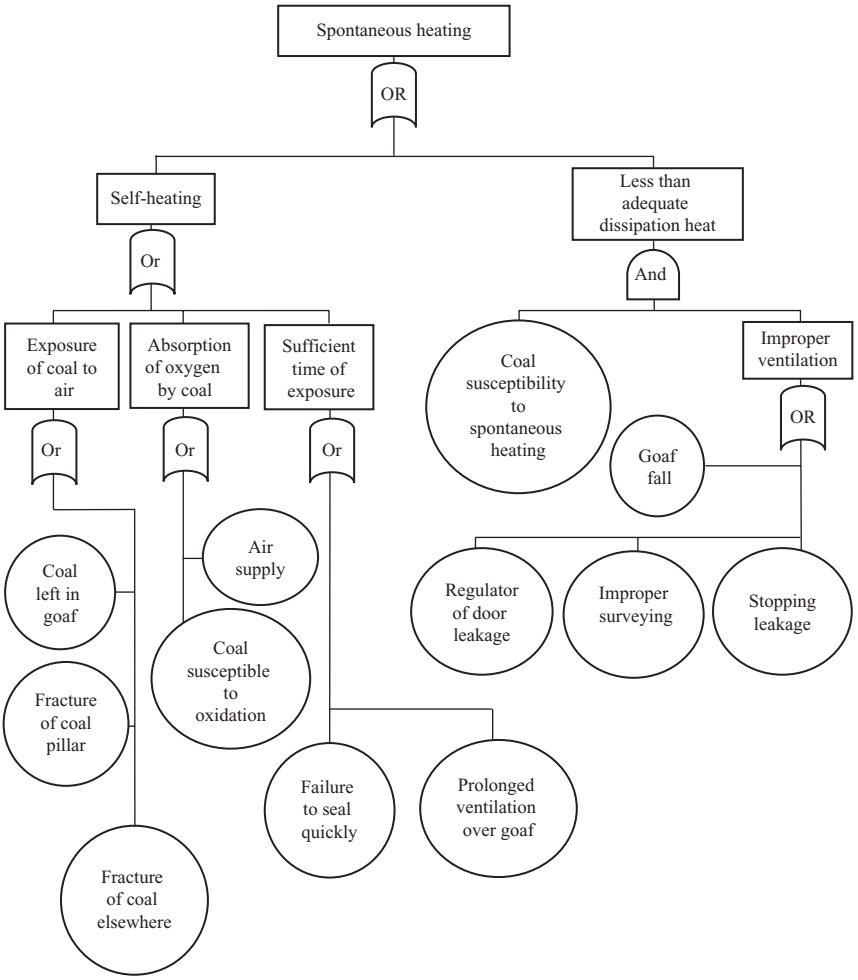


FIGURE 6.14 Fault tree for spontaneous heating.

$$P_{AND}(E) = \prod_{j=1}^{m} P(E_j) \tag{6.1}$$

where,

$P_{AND}(E)$ is the probability of occurrence of the AND gate's output fault event, E
$P(E_j)$ is the probability of occurrence of input fault event E_j, for $j = 1,2,\ldots m$
m is the number of input fault events.

Similarly, the probability of occurrence of an output fault event of an OR gate is expressed as

$$P_{OR}(E) = 1 - \prod_{j=1}^{m} \left(1 - P(E_j)\right) \tag{6.2}$$

where,

$P_{OR}(E)$ is the probability of occurrence of the OR gate's output fault event, E.

6.3.3.1.3 Quantitative FTA

Quantitative fault tree analysis requires the application of certain rules of Boolean algebra, logic, and probability theory. When the probability data of root cause events are available, the data can be used to predict the probability of the occurrence of the top event.

Example 8

Assuming the probability rates of the basic events are as shown in Table 6.15, calculate the probability of the occurrence of spontaneous heating in underground coal mines.

TABLE 6.15
Probability Values of Root Causes

Basic events	Base 1	Coal susceptible to spontaneous heating	3.00E-02
	Base 2	Stopping leakage	3.00E-02
	Base 3	Regulator of door leakage	1.00E-02
	Base 4	Goaf fall	2.00E-03
	Base 5	Improper surveying	2.00E-03
	Base 6	Coal left in goaf	3.00E-01
	Base 7	Fracture of coal pillar	4.00E-02
	Base 8	Fracture of coal elsewhere	3.00E-03
	Base 9	Failure to seal quickly	5.00E-02
	Base 10	Prolonged ventilation over goaf	4.00E-02
	Base 11	Prolonged ventilation over goaf air supply	2.00E-01
	Base 12	Prolonged ventilation over goaf air supply coal susceptible to oxidation	3.00E-02

By substituting the given values from Table 6.15 in Equation (2), we get the following value for the probability of occurrence of the following events:

Gate 4: "Exposure of coal to air"

$$P_{G4} = 1-(1-0.3)(1-0.04)(1-0.003)$$

$$= 0.33$$

Gate 5: "Absorption of oxygen by coal"

$$P_{G5} = 1-(1-0.2)(1-0.03)$$

$$= 0.224$$

Gate 6: "Sufficient time of exposure"

$$P_{G6} = 1-(1-0.05)(1-0.04)$$

$$= 0.088$$

Gate 2: "Self-heating"

$$P_{G2} = 1-(1-0.33)(1-0.224)(1-0.088)$$

$$= 0.526$$

Gate 7: "Improper ventilation"

$$P_{G7} = 1-(1-0.03)(1-0.01)(1-0.002)(1-0.002)$$

$$= 0.043$$

By substituting the Gate 7 and Base 1 values in Equation (1), we get the following value for the probability of occurrence of the event:

Gate 3: "Less than adequate dissipation heat"

$$P_{G3} = 0.0436 \times 0.03$$

$$= 0.0013$$

By substituting the calculated values in Equation (2), we get the probability value of the top event "spontaneous heating"

$$P_{G1} = 1-(1-0.526)(1-0.0013)$$

$$= 0.52$$

Thus, the chance of the occurrence of spontaneous heating in underground coal mines is 0.52. The fault tree analysis showing the probability of the top event is shown in Figure 6.15.

6.3.3.2 Event Tree Analysis

Event tree analysis is a forward, bottom-up, logical modeling technique that uses decision trees and logically develops visual models of the possible outcomes of an initiating event (Diamantidis et al., 2000; Hong et al., 2009). ETA is a graphical representation of the logic model that identifies and quantifies the possible outcomes following the initiating event. This technique can be applied to a system early in the

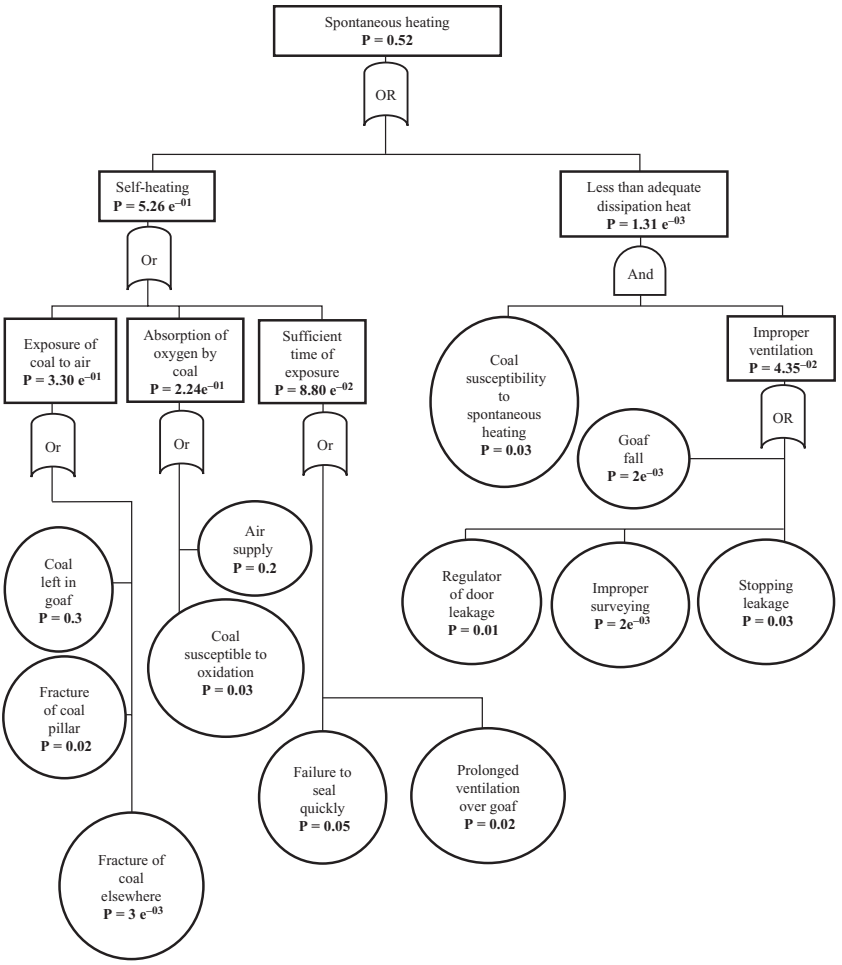


FIGURE 6.15 Fault tree for spontaneous heating with probability values.

design process to identify potential issues that may arise rather than correcting the issues after they occur (Beim and Hobbs, 1997).

In this method, an initiating event, such as the failure of an item of equipment or task is considered as the starting point and the predictable accidental results, which are sequentially propagated from the initiating event, are presented graphically. An event tree consists of an initiating event, probable subsequent events, and final results caused by the sequence of events. Probable subsequent events are independent of each other, and the specific final result depends only on the initiating event and the subsequent events following. Therefore, the occurrence probability of a specific path can be obtained by multiplying the probabilities of all subsequent events existing in a path (Marhavilas et al., 2014). The procedure for conducting ETA is shown in Figure 6.16 (Clemens and Simmons, 1998; Ericson, 2015). The construction of ETA is explained using Examples 9 and 10.

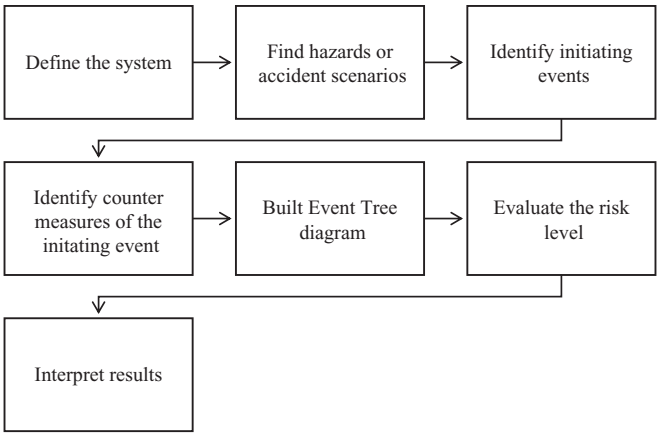


FIGURE 6.16 Steps in event tree analysis.

Example 9

Underground mine fire accidents are one of the most serious types of accidents, and they have high catastrophic consequences. Electric sparks are one of the most frequent hazards of mine fire accidents. Construct an event tree for the initiating event "electric spark."

Electric spark is the ignition source of the fire in underground mines. The general countermeasures employed by mines to control the consequences of mine fires are gas/fire monitoring systems, providing fire extinguishers at the required places, providing proper ventilation, and providing clear escape routes. The event tree for electric spark hazards is shown in Figure 6.17.

Example 10

Assume that the frequency of the initiating event, "electric spark," is 0.35, and the failure rates of the countermeasures – monitoring system, fire extinguisher, proper ventilation system, and escape route – are 0.51, 0.3, 0.3, and 0.94 respectively. Calculate the probability of the event paths.

$$\text{Success rate} + \text{failure rate} = 1$$

Since the failure rates of the events are given, we can calculate the success rates of the events using Equation (3)

Success rate of monitoring system = (1−0.51) = 0.49
Success rate of fire extinguisher = (1−0.3) = 0.7
Success rate of ventilation system = (1−0.3) = 0.7
Success rate of escape route = (1−0.94) = 0.06
Probability of path, $ES_a = 0.35 \times 0.49 \times 0.7 \times 0.7 \times 0.06 = 0.005$
Probability of path, $ES_b = 0.35 \times 0.49 \times 0.7 \times 0.7 \times 0.94 = 0.078$
Probability of path, $ES_c = 0.35 \times 0.49 \times 0.7 \times 0.3 \times 0.06 = 0.0021$
Probability of path, $ES_d = 0.35 \times 0.49 \times 0.7 \times 0.3 \times 0.94 = 0.033$

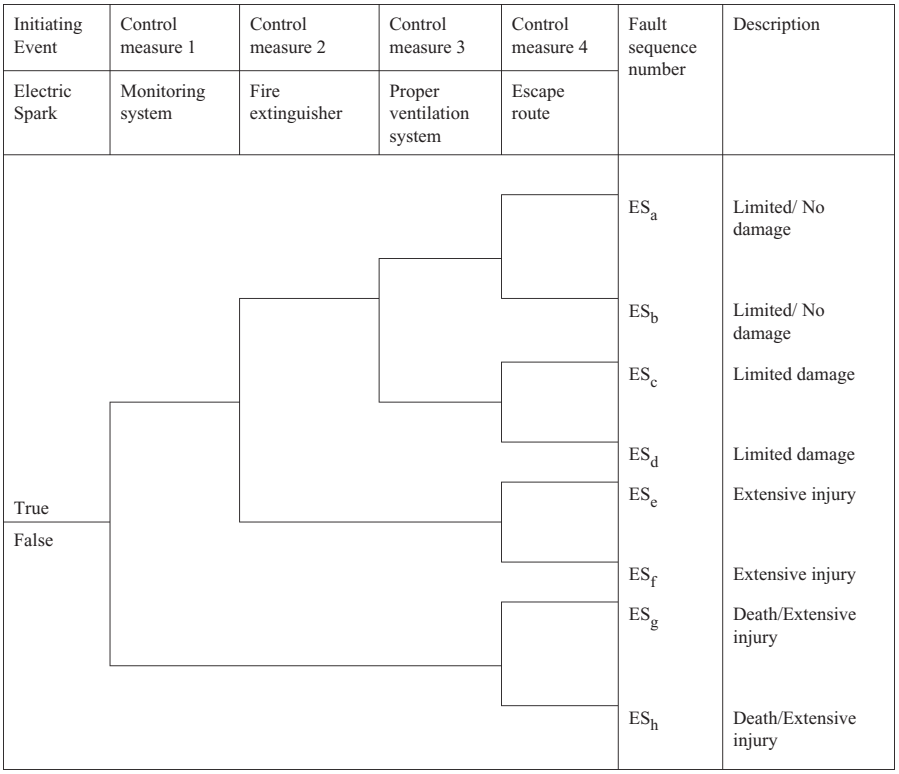


FIGURE 6.17 Event tree for electric spark.

Probability of path, $ES_e = 0.35 \times 0.49 \times 0.3 \times 0.06 = 0.003$
Probability of path, $ES_f = 0.35 \times 0.49 \times 0.3 \times 0.94 = 0.048$
Probability of path, $ES_g = 0.35 \times 0.51 \times 0.06 = 0.01$
Probability of path, $ES_h = 0.35 \times 0.51 \times 0.94 = 0.167$
The event tree with the calculated probability values is shown in Figure 6.18.
The order of probability paths are $ES_h > ES_b > ES_d > ES_g > ES_a > ES_e > ES_c$.

6.4 CASE STUDIES

These case studies provide a summary of risk assessment methods adopted in the Indian mining industry. Due to the practicality and ease of application, the WRAC technique is widely adopted in the mining industry. The risk matrix and rapid-ranking methods are commonly used to evaluate risk in the WRAC technique. However, there is no standard scale for the risk matrix and rapid-ranking methods for application to the mining industry. Therefore, depending on the requirement, many researchers and companies have developed their own scales. Queensland's Safety in Mines Testing and Research Station (SIMTARS) center for mining safety and health research has developed illustrative scales for evaluating risk in Indian mines

Initiating Event	Control measure 1	Control measure 2	Control measure 3	Control measure 4	Fault sequence number	Description	Frequency
Electric Spark	Monitoring system	Fire extinguisher	Proper ventilation system	Escape route			
Frequency = 0.35	Prob True = 0.49	Prob True = 0.7	Prob True = 0.7	Prob True = 0.06			
					ES_a	Limited/ No damage	5.04 e^{-03}
					ES_b	Limited/ No damage	7.90 e^{-02}
					ES_c	Limited damage	2.16 e^{-03}
					ES_d	Limited damage	3.39 e^{-02}
True					ES_e	Extensive injury	3.09 e^{-03}
False					ES_f	Extensive injury	4.84 e^{-02}
					ES_g	Death/Extensive injury	1.07 e^{-02}
					ES_h	Death/Extensive injury	1.68 e^{-01}

FIGURE 6.18 Event tree for electric spark with probability values.

(SIMTARS, 2001). The scales for risk parameters proposed by SIMTARS are represented in Table 6.16.

In 2002, the DGMS, India, has modified the scales developed by SIMTARS and issued guidelines for implementing SMSs in Indian mines (DGMS, 2002). The scales for risk parameters proposed by the DGMS (2002) are shown in Table 6.17.

The DGMS (2016) has issued a technical circular explaining the application of the risk assessment procedure using DGMS scales. The risk assessment given in the circular is presented in Table 6.18.

TABLE 6.16
Scales for Risk Parameters

C	Rank	E	Rank	P	Rank
Catastrophe	100	Continuous	10	May well be expected	10
Disaster	40	Frequent (daily)	5	Quite possible	7
Very serious	15	Seldom (weekly)	3	Unusual but possible	3
Serious	5	Unusual (monthly)	2.5	Only remotely possible	2
Minor	2	Occasional (yearly)	2	Conceivable but possible	1
Insignificant	1	Once in 5 years	1.5	Practically impossible	0.5
		Once in 10 years	0.5	Virtually impossible	0.1
		Once in 100 years	0.02		

TABLE 6.17
Scales for Risk Parameters

C	Rank	E	Rank	P	Rank
Several dead	5	Continuous	10	May well be expected	10
One death	1	Frequent (daily)	5	Quite possible	7
Significant chance of fatality	0.3	Seldom (weekly)	3	Unusual but possible	3
One permanent disability/ least chance of fatality	0.1	Unusual (monthly)	2.5	Only remotely possible	2
Many minor injuries	0.01	Occasionally (yearly)	2	Conceivable but unlikely	1
One lost time injury	0.001	Once in 5 years	1.5	Practically impossible	0.5
Small injury	0.0001	Once in 10 years	0.5	Virtually impossible	0.1
		Once in 100 years	0.02		

CASE STUDY 1

This risk assessment study was performed at Mine A, a mechanized underground coal mine, a public sector coal company located in Telangana, India. The mining block covers an area of 3.4 sq. km. The distance along the strike and dip are 2.75 km and 1.25 km respectively. The project consists of seven seams, in which only the top four seams have a workable thickness. The thickness of the seams is 19–39 m, the gradient varies from 1 in 6 to 1 in 7.8, and the coal grade varies from C to E. The method of working is the "longwall method."

The risk assessment team includes the manager, additional managers, safety officers, deputy managers, ventilation officer, pit engineer, surveyor, mining sirdar, workmen inspector, training officer, and safety committee member. The team identified and recorded the principal hazards in the mine. The risk evaluation of the identified hazards was performed using the DGMS scales. A sample of the risk assessment conducted is shown in Table 6.19.

TABLE 6.18

Risk Assessment for Inundation in Underground Coal Mines

Hazard No.	Hazard	Mechanisms	Calculated risk				Comments
			C	E	P	R	
1.	Lack of knowledge on procedures	Documents available are sketchy and inadequate	05	10	10	500	Workshop on development of SMP need to be conducted
2.	Lack of knowledge on procedures	Workers and supervisors not trained to follow procedures	05	10	10	500	Specialized refresher training required
3.	Lack of knowledge on procedures	Surveillance to implement procedures	05	10	10	500	Specialized process(es) to be devised
4.	Sudden inrush of water in underground mine workings from surface	Failure of coal pillars due to existence of fire underground, allowing connection through subsidence cracks with shallow surface rainwater accumulation and flooding of underground	05	10	07	350	
5.	Sudden inrush of water in underground mine workings from surface	Failure of embankment constructed at river bank due to heavy rain, and entry of water from surface through old workings and subsidence area to underground mine workings	05	10	07	350	
6.	Sudden inrush of water from workings of one seam to another seam in underground	Failure of dam constructed in the connection drift between workings of two seams, causing sudden inrush of water from workings of one seam to another seam in underground	05	10	07	350	
7.	Sudden inrush of water in underground mine workings from surface	Flooding of river due to heavy rain and water finding its way to underground workings through subsided area over goaf or mine entries	05	05	07	175	
8.	Sudden inrush of water from workings of same seam or from one seam to another seam in underground	Barriers against water-logged old workings failing under hydrostatic pressure causing inrush of water in underground workings	05	10	07	150	

(*Continued*)

TABLE 6.18 (CONTINUED)
Risk Assessment for Inundation in Underground Coal Mines

Hazard No.	Hazard	Mechanisms	Calculated risk				Comments
			C	E	P	R	
9.	Sudden inrush of water from workings of same seam or from one seam to another seam in underground	Sudden inrush of water from old water-logged workings of same seam or from one seam to another seam in underground due to accidental connection	05	05	02	50	
10.	Sudden inrush of water in underground mine workings from surface	Failure of river bank/embankment due to damage from mine subsidence	05	10	01	50	
11.	Sudden inrush of water in underground workings from adjacent strata	Pillar failure or creep allows goaf formation to connect with subsurface water body/aquifer	05	10	01	50	
12.	Sudden inrush of water in underground workings from adjacent strata	Roof fall in development workings taps overlying aquifer or subsurface water accumulation	05	1.5	02	15	
13.	Sudden inrush of water in underground workings from adjacent strata	Mine workings intersect geological structure providing water flow channel	01	02	01	02	
14.	Sudden inrush of water in underground workings from adjacent strata	Existing mine workings intersect open boreholes	0.1	2.0	07	1.4	
15.	Sudden inrush of water trapping mine workers in underground	Proper emergency response protocol including effective communication surface to underground not in place	05	02	10	100	Workshop on Emergency Preparedness and Response systems needs to be conducted
16.	Sudden inrush of water trapping mine workers in underground	Lack of exposure and practice of workers and supervisors to follow emergency response protocol	05	02	10	100	

TABLE 6.19
Risk Assessment for Inundation in Mine A

Sl. No.	Hazards	Associated Risks	C	E	P	R	Controls	Responsibility
1.	Water entering through exploration boreholes	Workers and machine may be drowned	5	1.5	3	22.5	• Boreholes should be plugged and collar height should be more than 3 m • All boreholes should be checked for every 3 months and before monsoon	Safety officer, surveyor
2.	Borehole not marked in underground plan	Chance of sudden inrush of water	5	2	1	10	• Borehole should be marked on the plan • Precautions shall be taken according to Coal Mines Regulations (CMR) 127 • Plugs should be made available in the district for the plugging of holes • All supervisors should be educated regarding boreholes	Surveyor, safety officer/ shift under-manager
3.	Monsoon water entering into the mine	Water may enter and drown the mine	5	10	3	150	• Formation of committee for checking/ inspecting before onset of monsoon and issue a check list for inspection • Inspect all the possible dangers in the mine according to the checklist and submit report • Rectify deficiencies found, if any, and authorize according to Annex 5	Manager

(*Continued*)

TABLE 6.19 (CONTINUED)
Risk Assessment for Inundation in Mine A

Sl. No.	Hazards	Associated Risks	C	E	P	R	Controls	Responsibility
4.	Failure of sump	Water will overflow and enter into pit working endangering machinery	0.01	5	2	0.1	• Adequate capacity pumps and motors should be available for replacement in case of breakdowns	Pit engineer
5.	Water entering into punch entries from surface	Water may enter and drown the mine	5	0.5	10	25	• A drain should be made around the punch entries • Regular inspection and cleaning to be ensured • Nala should be made in front of punch entry mouth • Nala should be made on artificial benches to divert water coming from surface	Manager (operations) deputy manager

CASE STUDY 2

This risk assessment study was performed at Mine B, a semi-mechanized underground coal mine, a public sector coal company located in Maharashtra, India. There is one working seam with one major fault, having a throw of 40 to 70 m and a hade of 27° on prevailing northern side of the property. The method of working is bord-and-pillar.

The risk assessment team includes the manager, safety officers, deputy managers, ventilation officer, pit engineer, mining sirdar, and workmen inspector. The team identified and recorded the principal hazards in the mine. The risk evaluation of the identified hazards was performed using the risk matrix developed by Coal India Limited. A sample of the risk assessment conducted is shown in Table 6.20.

CASE STUDY 3

In this case study, a fault tree analysis is used to determine the root causes of the accident. The following accident has occurred in a semi-mechanized underground coal mine, situated in Bilaspur, India. The accident description is as follows:

After dressing of development face at 15R/75LW, the bolting gang was about to start drilling holes for roof bolting. At 9.30 a.m. suddenly a piece of shaly coal measuring about 1.3 m × 0.4 m × 0.3 m fell from a hidden slip at the roof causing fatal injury to 54-year-old General mazdoor (working as a supports man).

The fall of a freshly exposed roof was taken as the top event (T) for the accident. After that, the different reasons that caused the top event were studied and analyzed. The top event was broken up into two intermediate events, such as geological disturbance and improper strata control. These intermediate events were further broken up to develop the fault tree, as shown in Figure 6.19.

The chance of roof fall is 0.803/year.

All the root causes identified in the fault tree analysis can be used to determine the impact of control measures using event tree analysis. The event tree analysis for initiating event “roof dressing” is shown in Figure 6.20.

TABLE 6.20
Risk Assessment for Electricity in Mine B

Sl. No.	Hazards	Associated Risk	L	C	R	Current Controls	Proposed Additional Controls	Responsibility	Residual L	Residual C	Residual R
1.	Improper earth leakage, over current protection	Breakage, shutdown and accident	L3	C3	13	Work with proper protection	Scheduled maintenance	Electrical supervisor	L2	C1	2
2.	Improper shutdown procedure	Chance of electrocution	L2	C4	14	Strict implementation of shutdown procedure	Present controls to continue	Electrical supervisor	L1	C1	1
3.	Untrained, unskilled manpower	Chance of electrocution	L2	C3	9	Training and retraining	On-the-job training	Electrical supervisor, engineer, safety officer, manager	L1	C1	1
4.	Poorly maintained electrical device	Breakage shutdown and accident	L3	C2	8	Proper maintenance	Scheduled maintenance	Electrical supervisor	L1	C2	3
5.	Housing of power cable along with signaling cable and lighting cable jointly	Chance of electrocution	L2	C2	5	Proper isolation	Present controls to continue	Electrical supervisor	L1	C1	1

(*Continued*)

TABLE 6.20 (CONTINUED)
Risk Assessment for Electricity in Mine B

Sl. No.	Hazards	Associated Risk	L	C	R	Current Controls	Proposed Additional Controls	Responsibility	Residual L	Residual C	Residual R
6.	Unplanned work on overhead line by inexperienced electricians	Chance of electrocution	L2	C4	14	Proper planning standard operating procedure	Safety talks	Electrical supervisors, engineer, safety officer, manager	L1	C1	1
7.	Improper tools of isolation	Chance of electrocution	L3	C4	18	Providing proper tools	Present controls to continue	Electrical supervisor	L1	C1	1
8.	Non-use of personal protection equipment	Personal injury	L2	C3	9	Work only with personal protective equipment	Present controls to continue	Electrical supervisor, safety officer, manager	L1	C1	1
9.	Improper tools and testing apparatus	Chance of electrocution	L2	C2	C5	Use of proper apparatus	Present controls to continue	Electrical supervisor, safety officer, manager	L1	C1	1
10.	Working without the knowledge of complete circuit	Chance of electrocution	L2	C3	9	Imparting proper education	Safety talks	Electrical supervisor, engineer, safety officer, manager	L1	C2	3

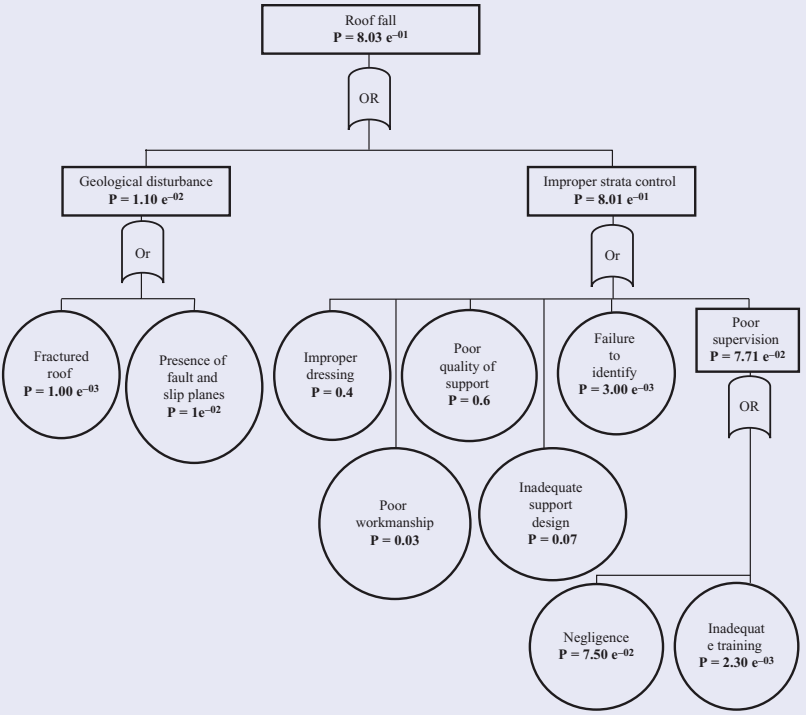


FIGURE 6.19 Fault tree for roof fall.

Initiating Event	Control measure 1	Control measure 2	Control measure 3	Fault sequence number	Description	Frequency
Roof dressing	Proper training	Identification of geological disturbance	Proper support design			
Frequency = 0.6	Prob True = 0.998	Prob True = 0.989	Prob True = 0.801			
				ES_a	Limited/ No damage	1.18 e^{-01}
				ES_b	Limited damage	4.74 e^{-01}
True				ES_c	Extensive injury	6.59 e^{-03}
False						
				ES_d	Death/Extensive injury	1.20 e^{-03}

FIGURE 6.20 Event tree for roof dressing.

7 Safety Audit and Standardization

7.1 INTRODUCTION

An audit is defined as a systematic inspection or examination of a system or unit carried out to ensure compliance to requirements. An audit can be applied to an entire organization or to a specific operation. An audit applicable to safety systems in an organization is called a safety audit. A safety audit can be defined as verifying the existence and implementation of elements of the occupational safety and health system and for verifying the system's ability to achieve defined safety objectives (IS 14489, 1998). It is a management tool that uses a systematic, periodic, and objective evaluation in order to (Champaty, 2017)

- identify how well the safety organization, management, and equipment are performing
- identify operating procedures that could lead to an accident
- identify new equipment or process changes that could have introduced new hazards
- identify inadequacy in safety inspections
- verify occupational safety and health (OSH) system compliance with established legal standards, written policies, objectives, and progress

A successful safety audit will provide a chance to identify the areas for improvement within the organization. There are two types of audits, as shown in Figure 7.1. A third party conducts the external audit while the personnel from other units or the same unit conduct the internal audit. In India, the majority of industries carry out safety audits in accordance with IS 14489 (1998) on "Code of Practice on Occupational Safety & Health Audit."

The audit can be conducted by a single auditor or by two or more auditors. Every organization that conducts an audit must appoint an audit manager, who should be skilled in planning and managing such an audit. The responsibilities of the audit manager are shown in Figure 7.2. There are four types of approaches for conducting safety audit. They are as follows (Chew, 2015):

- **the comparison approach**: analyzes subjective characteristics that have no standards and can be used universally
- **the statistic approach**: uses numerical data and statistics, such as accident frequency, injury rate, and death rate

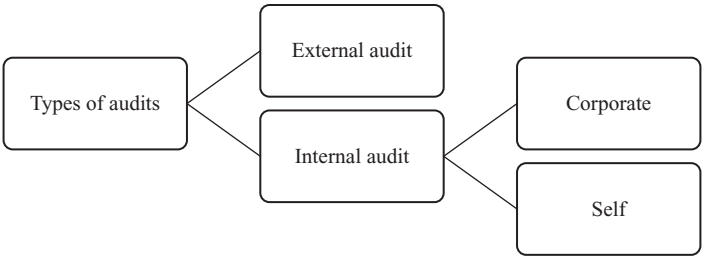


FIGURE 7.1 Types of audits.

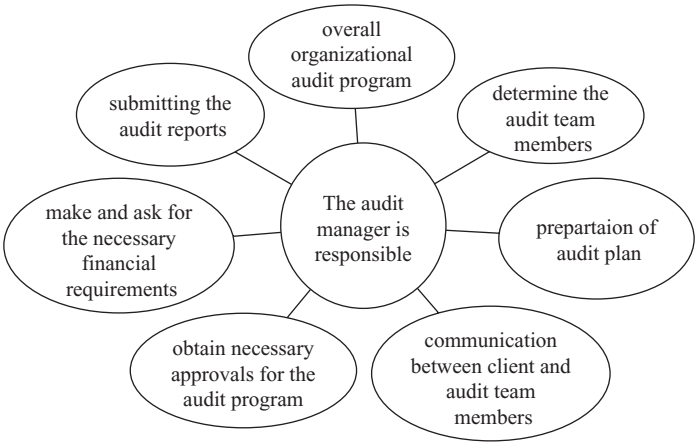


FIGURE 7.2 Responsibilities of audit manager.

- **the compliance approach**: verifies the compliance with the requirements of an act, standard rules, and safety work procedures
- **the objective approach**: analyzes the audit based on the company objectives

The following are the advantages of regularly performing a safety audit in an organization (Roux, 2014):

- determines the
  - effectiveness of the occupational health and safety programs
  - compliance of processes with the company policies and regulations
  - accuracy of the documentation of safety and health programs
- assesses the
  - safety of the workplace
  - safety of the equipment
  - effectiveness of the existing control measures employed
  - adequacy of supervisors' safety training and performance

  - adequacy of employees' safety training and performance
  - workers and management commitment to safety programs
- increases
  - the company credentials
  - the employee's awareness of safety and health regulations
- identifies and highlights potential hazards

7.2 THE AUDIT PROCESS

The auditing methodology consists of three major activities. They are

- preparing for audit or pre-audit activities
- on-site audit activities
- post-audit activities

The safety audit process is shown in Figure 7.3 (Verde, 2014).

7.2.1 Preparing for Audit or Pre-Audit Activities

The major steps involved in the preparation of an audit are (IS 14489, 1998)

- audit plan
- audit team assignments
- working documents of the audit team
- questionnaire of preliminary information

7.2.1.1 The Audit Plan

The first step in the process of developing an audit system is to determine the audit plan. To create the audit plan, the issues that need to be considered are shown in Figure 7.4 (Chew, 2015).

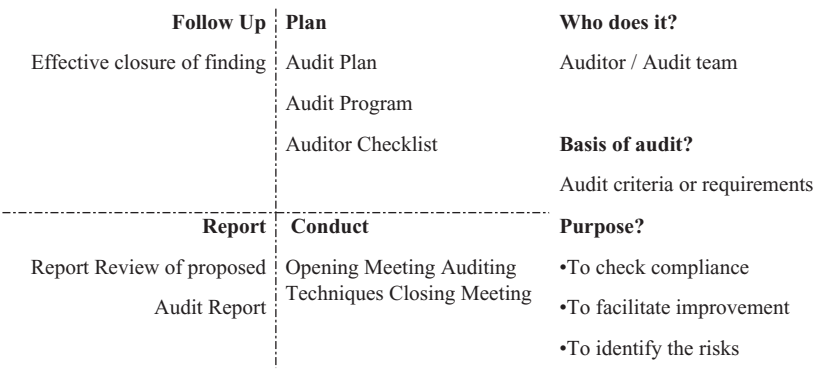


FIGURE 7.3 Safety audit process.

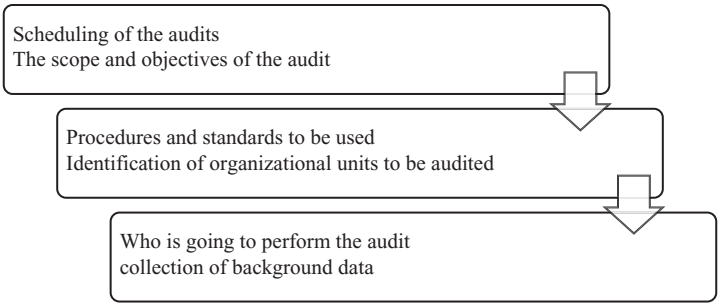


FIGURE 7.4 Steps in preparing for an audit plan.

- **Scheduling of the audits**: To ensure smoothness of the process, both audit manager and client must agree to organize and set a schedule, which should include total audit time duration, start and end time of audit, and a schedule for interviews, site visits, meetings, examination, and evidence report presentation.
- **The scope and objectives of the audit**: These should be framed based on the client's specifications. The scope should involve the amount of time and the range of documents to be included in the audit examination. Objectives need to verify whether the organization complies with the relevant legislative requirements or not.
- **Procedures and standards to be used**: These should be selected based on the client's requirements. Different organizations carry out audits according to the available occupational safety and health standards such as IS 14489, 1998; OISD-GDN-145; OHSAS 18000, 2007; ISO 45001, 2018.
- **Identification of organizational units to be audited**: Whether the audit is to be conducted for the entire organization, or specific units, or specific risk areas will be specified by the client.
- **Who is going to perform the audit**: The audit manager should select competent auditors to perform the audit. A competent auditor should meet the following requirements:
  - completed health and safety management system auditor training
  - have health and safety work experience
  - have special technical skills in the case of auditing technical systems or processes
  - should have suitable experience with and knowledge of the work environment being audited
- **Collection of background data**: The audit team should obtain documents for the work site to be audited and collect the following background data:
  - organization structural chart
  - organization policy
  - description of the operation process with block diagrams
  - work site area and site plan
  - number of employees including contractor employees

- training records on first aid
- previous history of fire, inundation, explosion, toxic gas
- accident and incident investigation reports
- accident statistics – types of accidents and analysis
- internal inspection reports
- safe operating procedures
- emergency plans
- previous audits

7.2.1.2 Audit Team Assignments

The audit manager, after consulting the team members, should assign each member with specific system elements or functional departments to audit (IS 14489, 1998).

7.2.1.3 Working Documents of the Audit Team

The checklist should be the main document designed to help the auditor's investigation, document, and report the results. Forms should be used to record the evidence for the audit's conclusions.

7.2.1.4 Questionnaire of Preliminary Information

The audit team should send the client a questionnaire seeking to obtain information about various elements of the organization's occupational safety and health system, as shown in Table 7.1 (IS 14489, 1998, 1998). This should be completed by the client and returned for study by the audit team before the field visit.

TABLE 7.1
Elements of Occupational Safety and Health System

Occupational safety and health policy	Machine and general area guarding
Occupational safety and health organizational set up	Material handling equipment
Education and training	Electrical and personal safeguarding
Employees' participation in occupational safety and health management	Ventilation, illumination, and noise
Motivational and promotional measures for occupational safety and health	Work environment monitoring system
Safety manual and rules	Prevention of occupational diseases including periodic medical examination
Compliance with statutory requirements	Safe operating procedures
New equipment review and inspection	Work permit systems
Accident reporting, analysis investigation, and implementation and recommendations	Fire prevention, fire protection and firefighting systems
Risk assessment including hazard identification	Emergency preparedness plans
Safety inspections	Process plant modification procedure
Health and safety improvement plan/targets	Transportation of hazardous substances
First aid facilities – occupational health center	Hazardous waste treatment and disposal
Personal protective equipment	Safety in storage and warehousing
Good housekeeping	Contractor safety systems
	Safety for customers

7.2.2 On-Site Audit Activities

The audit team members should visit the work site to be audited to cover the following activities:

- opening meeting with the client
- collection of evidence
- evaluating audit evidence
- closing meeting with the client

7.2.2.1 Opening Meeting with the Client

In the meeting with the client, the audit team should

- review the scope and objectives of the audit
- fix the standards to be used, organizational units to be audited, and schedule the site visits

Before starting the examination, it is the audit team needs to understand the set of formal and normal actions taken by the client's organization for internal safety management. This can be accomplished from discussions with workers, supervisors, and management personnel, and from site visits. This step usually includes developing an understanding of (Champaty, 2017)

- operation procedures
- internal controls
- organization and responsibilities
- occupational safety and health compliance requirements
- previous history of accidents

7.2.2.2 Collection of Evidence

The collection of evidence is an important activity in the audit process, as it forms the basis for the team to determine compliance with standards, company policy, and laws and regulations. The different methods for collecting evidence are site observations, questionnaires, interviews with workers, checklists, and the review of records. The review of records should be carried out to verify the accuracy, completeness, and maintenance of the records. Workers at an appropriate level should be interviewed in order to collect information. The evidence collected through interviews should be verified from other sources, such as interviewing other persons from the same or different levels, site visits, and a review of records. The auditor should visit the site for observations made during normal working hours. All the observations made should be recorded.

7.2.2.3 Evaluating Audit Evidence

After collecting all the evidence from various methods, the audit team should evaluate all their observations and findings to determine the weakness, strength, and failures in the management system, as shown in Figure 7.5. All the findings should be

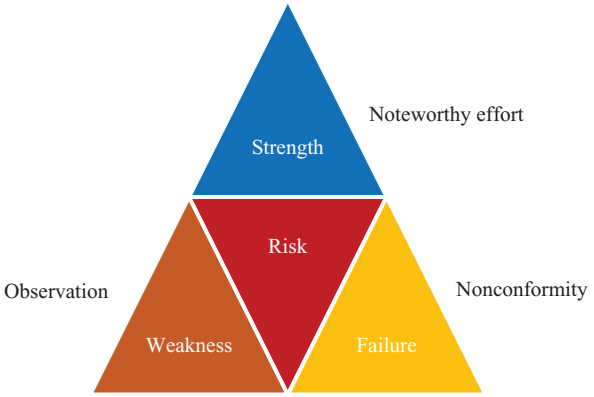


FIGURE 7.5 Audit outcome.

recorded clearly and concisely, with proper supporting evidence. The audit manager should review all the findings and communicate these to the client.

7.2.2.4 Closing Meeting with the Client

At the closing meeting, the audit manager should present the findings and recommendations to the client. The audit manager should also present the audit team's conclusions regarding the occupational safety and health system's effectiveness in ensuring that objectives will be met (IS 14489, 1998) or other audit standards/criteria. The audit manager's recommendations should aim to improve the system's specified requirements and to achieve more effective implementation of the specified requirements of the system.

7.2.3 Post-Audit Activities

The main activity after conducting an audit is to prepare documentation and reports.

7.2.3.1 Audit Documentation and Reports

As the audit manager is responsible for the accuracy and completeness of documentation and reports, a draft report should be prepared and submitted to the audit manager for comment. Once all the comments have been incorporated, a final report should be prepared under audit manager direction. The final report should contain the following items:

- introduction
- objectives
- methodology
- overview of site
- management's occupational safety and health system
- scope and objectives of the audit
- details of standards and other documents followed for conducting the audit

- details of team members
- observation of non-conformities as well as weaknesses and strengths
- the audit team's judgment of the extent of the organization's compliance with the applicable occupational safety and health system standards
- recommendations for improvement

The final reports should be signed by the audit manager and submitted to the client. The audit manager should contribute toward the formulation of an action plan for continual performance improvement against the audit findings. The life cycle of audit findings is presented in Figure 7.6.

7.3 SAFETY AUDIT IN MINES

A compliance audit is commonly practiced in the Indian mining industry. The following standards are used in this industry: the Coal Mines Regulations (CMR), 1957; The Metalliferous Mines Regulations, 1961; the Oil Mines Regulations, 1984; the Explosive Rules, 2008 (DGMS, 2018a). Generally in the mining industry a safety audit is performed as a reactive measure after an accident has occurred. For example, a safety audit was ordered in New Zealand for underground coal mines after a series of catastrophic explosions occurred at the Pike River coal mine, killing 29 men (Hartevelt, 2011). The Union Coal and Power Minister of India ordered safety audits in all coal mines after an accident occurred at Lalmatia opencast mine under Eastern Coalfields Limited that killed 18 men (Constructionweekonline, 2012).

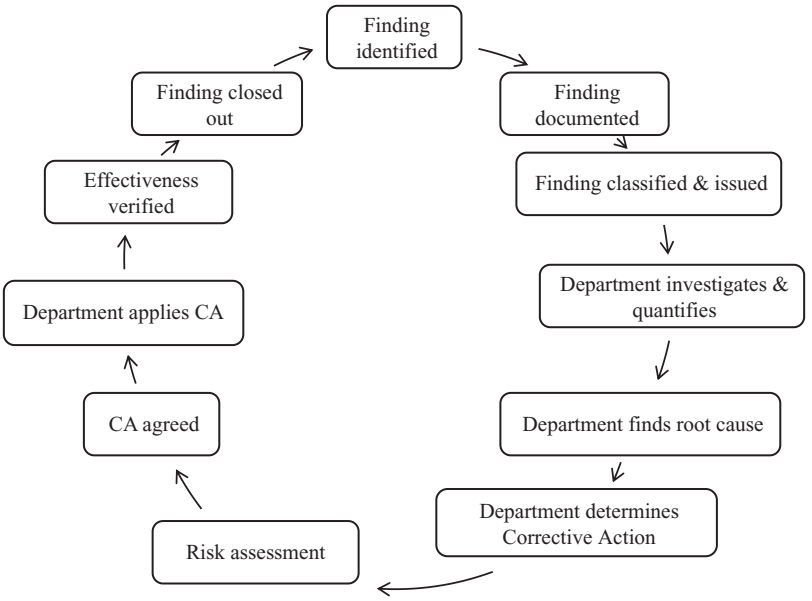


FIGURE 7.6 Life cycle of an audit finding.

Coal India Limited has made safety audits of its mines mandatory at regular intervals (usually every two years) to make coal mining safer and reduce the level of accidents.

The types of records to be examined during the mine safety audit are (Champaty, 2017)

- occupational safety and health policy
- safety organizations chart
- training records on first aid
- internal inspection reports
- accident investigations reports
- accident statistics – types of accidents and analysis
- record of work permits
- record of tests and examinations of equipment and structures as per status
- safe operating procedures for various operations
- record of monitoring of flammable and explosive substances at work place
- maintenance and testing records of fire detections and firefighting equipment
- equipment maintenance records
- equipment calibration records
- records of various surveys like noise, illumination, ventilation, explosive gases and airborne dust and toxic substances
- emergency escape plans
- previous audits

In underground coal mines, the following areas are audited according to the Coal Mines Regulations of 1957 (CMR, 1957):

Lamp room	Lighting	Strata control
Colliery workshop	Face machines	Conveyors
Electrical installations	• LHD/SDL	Haulage
Underground power supply	• Drill machine	Mine fire
Underground transport	Underground support system	Subsidence
• Rope haulage	Ventilation	Gas
• Conveyor system	Track transport	Inundation
	Coal dust	
	Explosives handling	

A sample safety audit checklist for underground coal mine ventilation is shown in Table 7.2.

7.4 SAFETY AUDIT STANDARDS

An Occupational Health and Safety Management System (OHSMS) is a structure that allows an organization to continuously identify and control its health and safety

TABLE 7.2

Safety Audit Checklist for Underground Coal Mine Ventilation

CMR Clause (Sub Regulations)	Provisions in CMR, 1957	State of Compliance	Remarks
	Adequacy of ventilation		
130 (2)	Quantity of air passing along the immediate outbye ventilation connection of at least three working faces in a development district, or outbye in the first and the last working faces in a depillaring district		
	Standards of ventilation		
Cir 5, 1966	Notice to be sent when percentage of inflammable gas exceeds 0.75% in the return air		
	Main mechanical ventilator (MMV)		
131 (1)	Siting and adequacy of MMV (10 m away from the incline mouth on the surface)		
131 (2)	Separate power supply for MMV		
131 (3)	Provision of pressure recording instrument		
131 (4)	Provision of reversal arrangement		
131 (5)	Provision of airlock in winding shaft		
	Restriction on use of booster fan		
132 (2)	Statutory provisions regarding installation of booster fan		
	Installation and maintenance of auxiliary/booster fan		
133 (1)	Provisions regarding type and siting of auxiliary/booster fan		
133 (2)	Provision of competent person for the installation of auxiliary/booster fan record keeping		
133 (3)	Weekly examination of auxiliary/booster fan by competent person		
133 (4)	Statutory air quantity measurement		
133 (5)	Authorization of person to be in charge of mechanical ventilator		
Cir 46, 1963	Calibration of instruments		
	Standing orders		
134 (1)	Framing of standing order		
134 (2)	Approval by the Regional Inspector of the standing order		
134 (3)	Display of the copy of the standing order		
Cir. 53, 1973	No stoppage of MMV, without the permission of the manager		
	Splits and airways		
135 (1)	Formation of districts/splits		
135 (2)	Position of intake airway vis-à-vis stagnant water		
135 (3)	Provision of 2 main intake airways for every district		
135 (4)	Provision/operation of doors between intake and return airway		

(*Continued*)

TABLE 7.2 (CONTINUED)

Safety Audit Checklist for Underground Coal Mine Ventilation

CMR Clause (Sub Regulations)	Provisions in CMR, 1957	State of Compliance	Remarks
	Brattices, doors, stoppings and air-crossings		
136 (1)	Provision of ventilation appliances to ensure statutory ventilation standards		
136 (2, 3 & 4)	Compliance with the standards of construction of the ventilation appliances		
136(5)	Maintenance of ventilation appliances		
136 (6)	Inspection and maintenance of records		
Cir. 17/1964	Minimum thickness of ventilation stoppings to be 38 cm		
	Velocity of air current		
	Compliance with the statutory standards		
	Auxiliary fans		
137 (1)	Installation and siting of auxiliary fans		
137 (2)	Authorization for operation of mechanical ventilator		
137 (3)	Prohibition of employment at places ventilated by auxiliary ventilation		
137 (4)	Permission for installation of 2 auxiliary fans in a ventilating district/split		
	Precaution against fire in ventilation appliances		
138 (1)	The fan housing on the surface should be fireproof		
138 (2)	Standard of site for the installation of booster fan		
138 (3)	Fireproofing of the materials connected with the construction of ventilation appliances		
	Ventilation plans to be brought up-to-date		
	Obstructions, interruptions and alterations		
140 (1)	Obstruction-free ventilation airways		
140 (2)	Fencing of poorly ventilated places		
140 (3)	Clearing of obstructions		
140 (4)	Withdrawal of persons in the event of stoppage of mechanical ventilator		
140 (5)	No interference with the ventilation system without authority		
	Precautions against gas during dewatering and reopening		
141 (1)	Supervision during dewatering		
141 (2)	The first inspection of the reopened area by competent person		
	Precautions against inflammable gas and noxious gases		
142 (1 to 6)	Compliance of statutory provisions in this regard		

(*Continued*)

TABLE 7.2 (CONTINUED)
Safety Audit Checklist for Underground Coal Mine Ventilation

CMR Clause (Sub Regulations)	Provisions in CMR, 1957	State of Compliance	Remarks
	Inspection of unused workings for gas		
	Inspection of unused workings for accumulation of gases. Applicable to fiery seams, Degree II and III mines and otherwise required by the Regional Inspector		
	Safety lamps to be used in mines		
	No lamp other than those permitted under Indian Electricity Rules, 1956, should be used unless exempted by the chief inspector		
	Determination of percentage of inflammable gas and of environmental condition		
	All statutory provisions should be complied with		
	General precautions in gassy mines		
146 (1)	No extension of the gallery beyond 4.5 m of the nearest ventilation connection unless suitable coursing is carried out		
146 (2)	No drivage of narrow gallery beyond 3 m of the widened gallery		
146 (3)	Air crossings should be explosion-proof. The stoppings between main intake and return airway must be substantially built		
146 (4)	Air current ventilating goaved out area and the unused areas should not ventilate the working faces unless permitted by the Regional Inspector		
146 (5)	No major alteration of the ventilation system without the permission of the Regional Inspector		
	Contraband		
	Contraband should not be allowed		
	Deployment of body searcher		

risks, reduce the potential for incidents, help achieve compliance with health and safety legislation, and continually improve its performance (ColdenCorporation, 2018). The OHSMS structure consists a set of plans, procedures, and actions that assists an organization to systematically manage health and safety risks associated with their working operations (WorksafeBC, 2018). Over the years, many countries have framed OHSMS standards according to their requirements and a safety audit is one of the requisite components of all the OHSMS standards framed so far. The standards relating to OHSMS are shown in Table 7.3.

The guidelines for conducting a safety audit in an organization framed by ISO and India are shown in Table 7.4.

TABLE 7.3

Various Occupational Health and Safety Management System Standards

ISO-9001: 1987	Quality systems – model for quality assurance in design/development, production, installation, and servicing
ISO-9001: 1994	Quality systems – model for quality assurance in design, development, production, installation and servicing
ISO-14001: 1996	Environmental management systems – specification with guidance for use
BS-8800: 1996	Guide to occupational health and safety management systems
OHSAS-18001:1999	Occupational health and safety management systems. specification
ISO-9001: 2000	Quality management systems – requirements
ILO-OSH: 2001	Guidelines on occupational safety and health management systems
ISO-14001: 2004	Environmental management systems – requirements with guidance for use
BS-8800: 2004	Occupational health and safety management systems: guide
ANSI-Z10: 2005	Occupational health and safety management systems
BS-OHSAS 18001: 2007	Occupational health and safety management systems: requirements
IS-18001: 2007	Occupational health and safety management systems – requirements with guidance for use
BS-18004: 2008	Guide to achieving effective occupational health and safety performance
ISO-9001: 2009	Quality management systems – requirements
ISO 31000: 2009	Risk management – principles and guidelines
ANSI-Z10: 2012	Occupational health and safety management systems
ISO-22301: 2012	Societal security – business continuity management systems – requirements
CAN/CSA-Z1000-14: 2014	Occupational health and safety management
ISO-9001: 2015	Quality management systems – requirements
ISO-14001: 2015	Environmental management systems – requirements with guidance for use
BS-45002-0: 2018	Occupational health and safety management systems: general guidelines for the application of ISO 45001
ISO-31000: 2018	Risk management – guidelines
BS-ISO 45001: 2018	Occupational health and safety management systems. requirements with guidance for use

TABLE 7.4

Audit Standards

ISO	India
• ISO-19011: 2002 – Guidelines for quality and/or environmental management systems auditing • ISO-19011: 2011 – Guidelines for auditing management systems • ISO-19011: 2018 – Guidelines for auditing management systems	• IS-14489: 1998 – On Code of Practice on Occupational Safety & Health Audit • OISD-145 – Guidelines on Internal Safety Audits (OISD, 1995)

In India, it is a statutory requirement for hazardous industries (Verde, 2014) that a safety audit is carried out every year.

Management approach	Risk orientation	Hazard Risk Control Residual risk Acceptable risk	• Prioritization • Focus on level of control
	Improvement	Management system plan Check action	• Finding • Corrective action plan • Corrective action plan closure
Operational approach	All safety elements	Levels of • Planning • Implementation • Monitoring effectiveness	
	Legal compliance	• Applicability • Implementation • Monitoring • Approach	

A safety audit at the workplace according to the ISO-14001 approach is shown in Figure 7.7. An organization that wishes to put its employees' safety and welfare at the top of its agenda, will perform a safety audit and certification program according to any one of the OHSMS standards. Over the last decade, the OHSAS-18001, 2007, Occupational Health and Safety Audit & Certification, has been the standard most commonly employed. Achieving Occupational Health and Safety Management

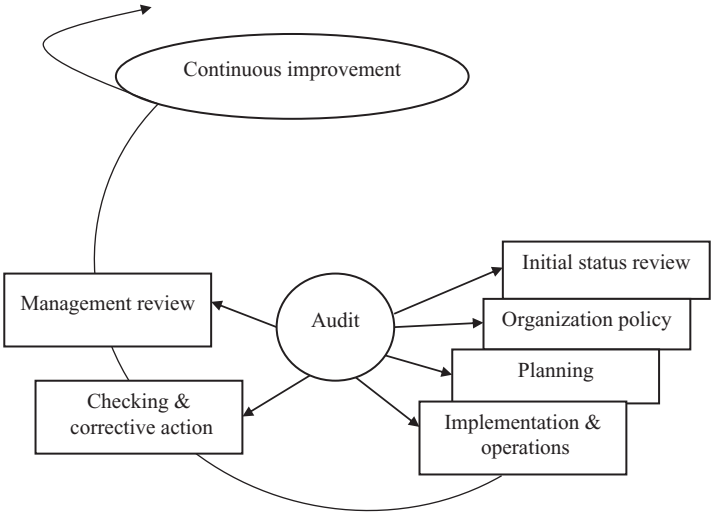


FIGURE 7.7 Safety audit at workplace.

Systems certification to OHSAS-18001 is a strong sign of an organization's commitment to its employees' health and safety. OHSAS-18001 certification enables organizations to manage operational health and safety risks and improve performance (SGS, 2018).

OHSAS 18001: 2007 (OHSAS, 2007) focuses on the following areas:

- objectives and occupational health and safety programs
- resources, roles, responsibility, accountability, and authority
- competence, training, and awareness
- operational control
- hazard identification, risk assessment, and determining controls
- communication, participation, and consultation
- legal and other requirements
- emergency preparedness and response
- performance measuring, monitoring, and improvement

ISO has recently developed a standard, ISO 45001, Occupational Health and Safety Management Systems – Requirements with Guidance for Use, to help organizations all over the world, to reduce safety and health risk, create safer work conditions, and improve workers' safety (ISO, 2018). OHSAS 18001 will be withdrawn in March 2021. So the organizations implementing OHSAS 18001 will need to be moved across to ISO 45001.

As ISO 45001 has been developed on the basis of OHSAS 18001, most of ISO 450001 will translate from OHSAS 18001, but with different codes. The major difference in ISO 45001 is in the following areas:

- management commitment
- worker involvement
- risk evaluation instead of hazard
- structure

Similar to Clause 4.5.5 in OHSAS 18001, ISO 45001 also includes an internal audit process, but in Clause 9.2.2. The main update in the audit process is that a new requirement to address non-conformities found during the audit process has been added (ISO, 2018).

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8 Occupational Health and Safety in Mines

8.1 INTRODUCTION

Occupational health and safety (OHS) issues have long been a concern in the mining industry, predominantly in underground mines. Over the years, safety and health organizations, mining companies, research institutes, and academicians have been carrying out a significant amount of work to address these issues. Notable progress has been evident in improving health and safety by utilizing advanced technology and reliable equipment and by improving regulations and training. However, a statistical analysis of accident rates in the mining industry has revealed that major accidents are still occurring in mines. Other than safety, occupational health is also a critical issue in underground coal mines. The National Institute of Occupational Health (NIOH) (India), in collaboration with the International Development Research Centre, Canada, conducted a study to discover the rates of pneumoconiosis and other respiratory morbidities among coal miners in India. This study revealed that rate of pneumoconiosis in underground coal miners was 2.84% and the rate of obstructive functional abnormalities of lungs among underground coal miners was 28.9% (NIOH, 2017). The common health hazards faced by mine workers are noise, gases, and dust pollution, etc. Therefore, there is room for the further improvement of OHS in the mining industry across the world.

8.2 OCCUPATIONAL HEALTH HAZARDS IN MINES

The life span of mining consists of mineral exploration, underground or opencast mine development, mine operation, mine closure, and land rehabilitation. Many OHS hazards are associated with the life span of mining. Compared with opencast mine workers, underground mine workers are exposed to a greater number of hazards at the workplace that adversely affect their health. The most common health hazards in mines are represented in Figure 8.1. Table 8.1 presents the diseases that have been notified as those connected with mining operations (Sishodiya and Guha, 2013).

8.2.1 Dust

A common health hazard in coal and metal mines is mainly due to dust. Almost every operation in a mine, such as blasting, drilling, excavating, loading, tipping, transporting, crushing, conveying and screening, stockpiling, and cleaning and

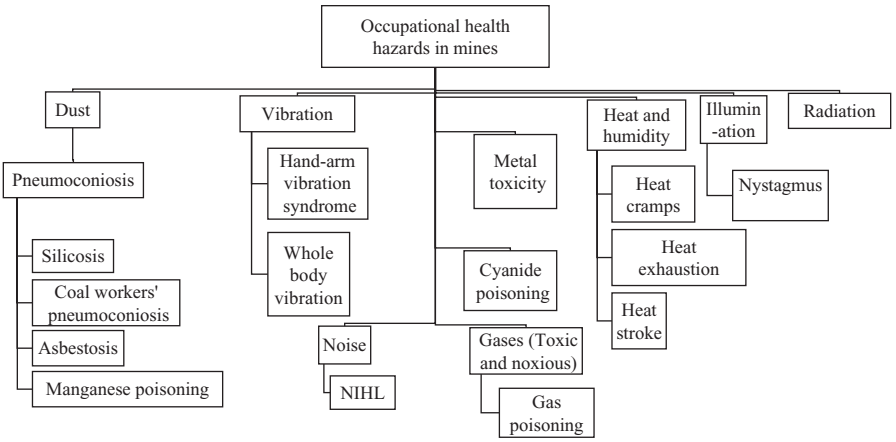

FIGURE 8.1 Health hazards in mines.

TABLE 8.1
Notified Diseases

Pneumoconiosis	Poisoning	Cancers	Others
• Silicosis • Coal workers' pneumoconiosis • Asbestosis	• Manganese poisoning • Gas poisoning	• Cancer of lung, stomach, and pleura • Peritoneum (due to asbestos dust exposure)	• Noise-induced hearing loss (NIHL) • Contact dermatitis caused by direct contact with chemicals • Pathological manifestations due to radium or radioactive substances

maintaining fixed and mobile plants, produces dust. Mine workers can be exposed to dust particles that differ in chemical composition, such as:

- dust containing crystalline silica
- coal dust
- dust containing metals such as lead, cadmium, and arsenic
- asbestos

Dust is termed as particulate matter (PM) and are of two types, respirable ($\leq PM_{10}$) and non-respirable ($>PM_{10}$). During face mechanization and the transportation of coal, a lot of fine dust will be generated and become airborne, if it is not adequately suppressed. The sources of PM emission in mines include mineral handling plant operations, blasting and drilling operations, use of LHD or SDL, crushing, conveying, and handling of overburden by draglines, vehicular emission from unpaved roads, and loading and transport of overburden and minerals by shovel-dumper

combination (Zhang et al., 2013). Health hazards associated with respirable dust are diseases such as pneumoconiosis, silicosis, and asbestosis.

The development of pneumoconiosis in a worker mainly depends on the concentration of dust in the breathing zone, the shape, size, and buoyancy of the particles, and physio-chemical reactivity. The amount of dust retained in the lungs is determined by the dust concentration in the surrounding air, the duration of exposure, and the effectiveness of clearance mechanisms of the body. The particulate matter sizes in the range of 1 to 5 μm in diameter are more dangerous as they may reach the terminal small airways and air sacs and settle in their linings. Smaller particles tend to cause acute lung injury. Larger particles resist dissolution and so may persist within the lung parenchyma for years.

Pulmonary occupational diseases are the result of the inhalation of dust and they may take years to become noticeable. Silicosis and coal worker's pneumoconiosis are most familiar to coal mine workers. The long-term exposure to coal dust leads to coal miners' pneumoconiosis, while the inhalation of crystalline silica dust leads to silicosis. The long-term breathing of asbestos fibers and retaining them leads to asbestosis.

8.2.1.1 Silicosis

Silicosis is categorized into three types: acute silicosis, chronic silicosis, and accelerated silicosis. The cumulative dose of silica is likely to be the most important factor for the development of silicosis. Generally, chronic silicosis develops between 15 to 45 years after first exposure. In some instances, even a single heavy dose or exposure to a very high concentration of silica for a short span of time may cause silicosis to develop.

8.2.1.2 Coal Workers' Pneumoconiosis

Coal workers' pneumoconiosis (CWP) is caused by long-term exposure to coal dust. It is common in coal miners and others who work with coal. It is also known as black lung disease or black lung. Small (<1 cm) rounded opacities form in the upper lung zone in milder cases of classic coal worker's pneumoconiosis. Progressive massive fibrosis (PMF) is characterized by the coalescence of small opacities into large (>1 cm) opacities. Rheumatoid pneumoconiosis (Caplan syndrome) may also affect coal miners with rheumatoid arthritis. Rapidly progressive pneumoconiosis with progressive massive fibrosis (complicated coal workers' pneumoconiosis) is being found in US coal miners (Cohen et al., 2016).

8.2.1.3 Asbestosis

Asbestosis is caused by exposure to high levels of asbestos dust over a long period of time. Some of the airborne fibers can become lodged within the alveoli – the tiny sacs inside the lungs where oxygen is exchanged for carbon dioxide in the blood. The asbestos fibers irritate and scar lung tissue, causing the lungs to become stiff. This makes it difficult to breathe. The occurrence of asbestosis varies with the cumulative dose of inhaled fibers: the greater the cumulative dose, the higher the occurrence of asbestosis. The effects of long-term exposure to asbestos typically do not show up for 10 to 40 years after initial exposure (MayoClinic, 2018).

8.2.1.4 Manganese Poisoning

Manganese is an important trace element that is found in many types of rocks and soil and it is necessary for maintaining good health. Humans can be exposed to manganese through food, air, water, or occupation. High exposure to manganese can lead to manganese poisoning, which is more common due to occupational exposure. Poisoning due to exposure to manganese during mining and processing ore is a health hazard. The symptoms of manganese poisoning are shown in Figure 8.2.

The health effects of manganese poisoning are as follows:

- birth defects
- blood clotting
- changes of hair color
- fatness
- glucose intolerance
- lowered cholesterol levels
- neurological symptoms
- skeleton disorders
- skin problems

8.2.1.5 Control Methods

NIOSH (2002) has recommended the respirable coal mine dust exposure limit as 1 mg/m^3, and respirable crystalline silica level as 0.05 mg/m^3 (time-weighted average (TWA) –10 hours, time-weighted average concentrations/day and 40-hour work week). The dust level in the work environment should be reduced to meet the prescribed limit. It is also important to frequently monitor worker exposure to dust by personal dust sampler (PDS) in the mine. The personal dust monitoring allows the measurement of the concentration of respirable dust in a person's breathing zone, and the feedback can be used for taking control measures if the concentration exceeds the legally permissible limits. The risk of pulmonary disease increases with the increase in the exposure time and years of work. NIOSH has recommended a reduction in the

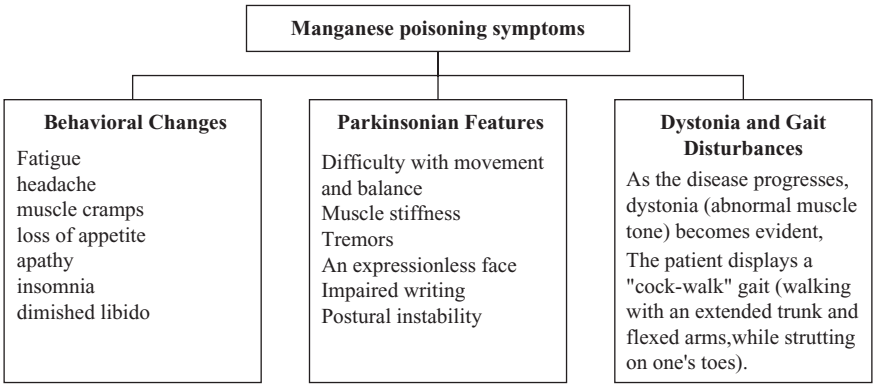

FIGURE 8.2 Symptoms of manganese poisoning.

exposure limit for coal mine dust and crystalline silica dust. It also recommended an increase in the frequency of medical examinations for both underground and surface mineworkers. The common engineering dust control methods are as follows:

- Simply wetting the dust with water before processing a pile or entering a potentially dusty environment can easily control settled dust. Water is far more effective in preventing the formation of dust than in removing airborne dust. A moisture content of 1% by weight produces a significant reduction in dust production. In underground mines, it might be more practical to aim for 5%.
- Water sprays are appropriate for use in minimizing dust. Enclosure of the spray at transfer points improves the effect. Only water sprays with a high-pressure pump can be used to control partially dangerous sized dust (<2.5 micron). Pressures should be at least 1.4 megapascal (200 psi) in order to control more of the hazardous dust. Pressure and flow instruments are recommended to monitor system performance and estimate the amount of moisture added. Rotameter-type instruments are satisfactory and inexpensive.
- The correct amount of water to spray is between 2.5 to 4 liters per minute at 0.7 MPa. If the nozzle diameter is less than 0.5 mm, the amount of additional water used at higher pressures is small.
- Water sprays of varying types are used. Some of these different types are described below
  - Full cone sprays are used to wet materials on conveyor belts and to clean the underside of belts.
  - Hollow cone sprays are used at transfer points and in crushers to knock down dust that has become airborne.
  - Atomizing sprays are useful for the reduction of airborne dust.
- All underground drilling operations require the use of water wherever possible. Rock should actually be broken under a film of water. However, no single method has been found to be efficient during the initial collaring period. Any dry drilling method requires the dust to be collected or dispersed into unoccupied areas.
- All surface mining operations should use a means of limiting dust exposure, such as an air-conditioned cabin or a drill stem shroud with the dust collected and filtered. The dust should be expelled into an unoccupied area.
- Filtration is a moderately expensive option. The sample preparation must have a bag housing for dust filtration and collection. Mobile filtration is now available for percussive drilling rigs and should be used.
- Dust from conveyors, crushers, and similar equipment can be controlled by enclosing the dust and controlling the air within the conveyors. Water sprays are more effective when used inside an enclosure.
- Drills should be provided with dust extractors to control dust at source.
- Black topping should be provided on approach and service roads to reduce dust generation.
- Water sprinklers of both fixed and mobile types should be installed for dust suppression on haul roads.

- Automatic sprinklers that start up by use of sensors should be installed at receiving pits.
- Fixed sprinklers should be provided and operated through valve control systems at coal bunkers, transfer points, and loading points.
- Dust cyclones should be provided at the bottom of the receiving pits of the crusher house.
- Full enclosure should be provided around coal handling plants (CHPs) to reduce coal dust emission.
- Materials should be wetted after loading in trucks.
- Maintenance of heavy earth moving machinery (HEMM) should be carried out regularly to minimize dust emission.
- All the HEMMs should be provided with dust-proof cabins.
- Dust masks should be provided to all the employees who are exposed to dust.

8.2.2 Noise

Noise is defined as "a sound without agreeable musical quality or as an unwanted sound." It is generated from almost all the opencast and underground mining operations from different fixed, mobile, and impulsive sources; thereby becoming an integral part of the mining environment. With increased mechanization and the use of large and high-capacity equipment, the problem of noise has become accentuated in mines. Exposure to high levels of noise over a long time causes harmful physiological effects. The detrimental effects of noise depend not only on its sound pressure level (SPL) and frequency (loudness), but also on the total duration of exposure and the age, general health, and susceptibility of the individual. The harmful effects of noise can be broadly classified into auditory effects, non-auditory effects, and threshold shift.

The mechanism of the ear is shown in Figure 8.3. Sound waves from the air around are collected by the pinna, travel down the meatus, and are conducted to the cochlea via the three auditory ossicles (i.e. the malleus, the incus, and the stapes), which act as an impedance device, matching the sound wave impedance in the air to that in the basilar fluid, and the oval window. The vibrations conducted in the basilar fluid causes groups of hair cells along the basilar membrane to move; this motion induces piezoelectric action and the mechanical energy is converted to an electrical pulse, which travels along the auditory nerve to the brain.

The inner ear is highly susceptible to injury and disease. Damage to the inner ear may result in temporary or permanent hearing loss. The auditory nerve attached to the cochlea is most susceptible to damage from noise.

8.2.2.1 Noise-Induced Hearing Loss

Hearing loss (HL) can be defined as "the decibel difference between a patient's thresholds of audibility and that for a person having normal hearing at a given frequency" (Seto, 1971). Mathematically, it is expressed as $HL = 10 \log I/I_0$ dB, where I is the threshold sound intensity for the patient's ear and I_0 is the threshold sound intensity for the normal ear. Hearing loss is can be classified as one of three types (i)

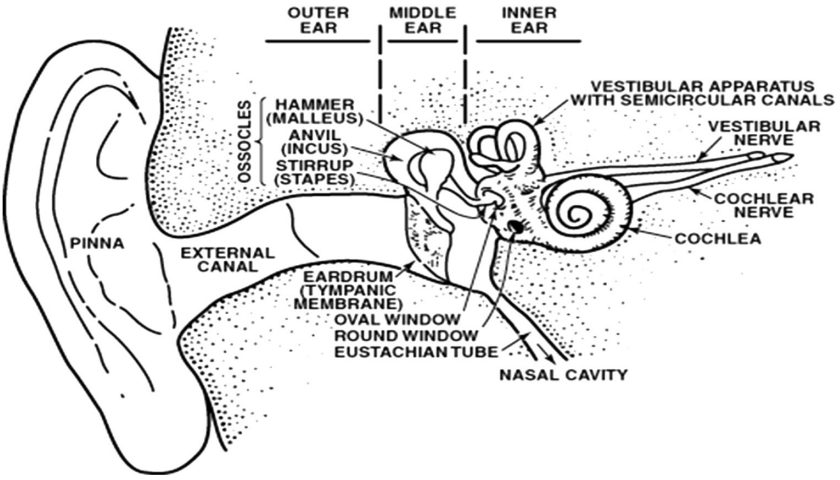

FIGURE 8.3 Mechanism of human ear.

conductive hearing loss, (ii) sensorineural (SN) hearing loss, and (iii) mixed hearing loss. Hearing loss follows chronic exposure to less intense sound than seen in acoustic trauma and is mainly a hazard of noisy occupations.

(a) Temporary threshold shift (TTS): In TTS, the hearing is impaired immediately after exposure to noise but recovers after an interval of a few minutes to a few hours.
(b) Permanent threshold shift (PTS): In PTS, the hearing impairment is permanent and does not recover at all.

The ambient air quality standards in respect of noise as given in The Noise Pollution (Regulation and Control) Rules, 2000, in India are presented in Table 8.2.

8.2.2.2 Noise Control Measures

Noise surveys help to determine the effective engineering and administrative noise control measures to be implemented in mines. They help to identify the noise pollution sources and quantify the risk exposure of workers. Effective anti-noise measures can accordingly be formulated and implemented (Tripathy, 1999). Noise can be controlled in three ways, viz. at the source, in the path, and at the receiver, as shown in Figure 8.4. Some of the approaches for controlling noise are discussed below.

8.2.2.2.1 Noise Control at Source

8.2.2.2.1.1 Enclosures Generally, two types of enclosures are used, i.e. full enclosures and partial enclosures. Various types of full enclosures are used for the control of noise, i.e. free standing, equipment mounted, close fitting, and sealed.

TABLE 8.2
Ambient Air Quality Standards in Respect of Noise

Area Code	Category of Area/Zone	Limits in dB(A) Leq* Daytime	Limits in dB(A) Leq* Nighttime
(A)	Industrial area	75	70
(B)	Commercial area	65	55
(C)	Residential area	55	45
(D)	Silence zone	50	40

Notes:
Daytime shall mean from 6.00 a.m. to 10.00 p.m.
Nighttime shall mean from 10.00 pm to 6.00 am.
The silence zone is an area comprising not less than 100 meters around hospitals, educational institutions, courts, religious places, or any other area that is declared as such by a competent authority.
Mixed categories of areas may be declared as one of the four above-mentioned categories by the competent authority.
* Leq = an energy mean of the noise level over a specified period.

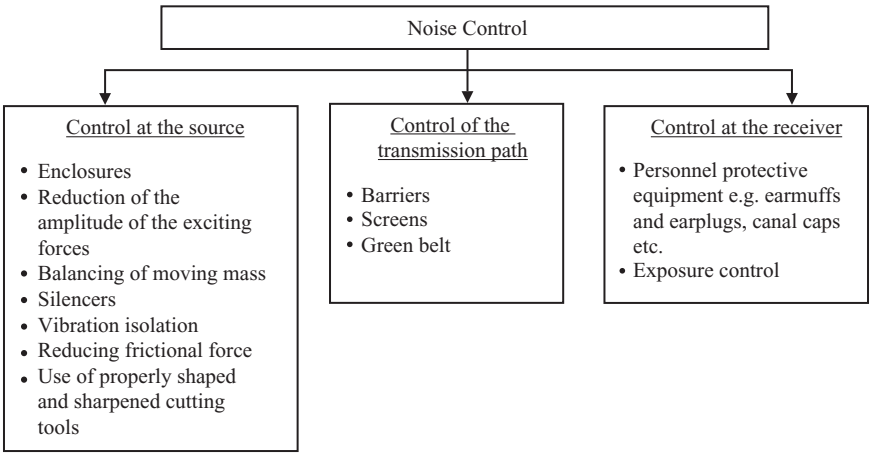

FIGURE 8.4 General methodologies of noise control.

8.2.2.2.1.2 Mufflers/Silencers Silencers or mufflers are either dissipative or reactive type. Dissipative silencers also known as absorption or absorptive silencers work on the principle of absorbing noise. Dissipative silencers are based on the use of flow-resistive materials, which are a form of porous acoustic lining. Reactive silencers work on the principle of reflecting and are tuned to provide maximum attenuation at specific frequencies; thus they work as narrow-band silencers.

8.2.2.2.1.3 Vibration Isolation Vibration isolation is applicable on the basis that structure-borne vibration travels from a source to a structure, which then radiates noise.

8.2.2.2.1.4 Damping Damping is a means of controlling the resonant response to vibration. The process involved is that of dissipating energy by converting it into heat, and thus controlling the amplitude of the response to excitation at resonance. Three types of damping applicable to mechanical systems are

- viscous damping
- dry friction damping (coulomb damping)
- hysteresis damping

8.2.2.2.2 Noise Control in Transmission Paths

8.2.2.2.2.1 Barriers Barriers are placed between a noise source and receiver as a means of reducing the direct sound received. They reduce the sound that enters a community or workplace from heavy earth moving machineries by absorbing, transmitting, or reflecting it back across the machinery or forcing it to take a longer path). Typical barriers are made of lightweight concrete blocks, asbestos board, cement board, sheet metal, fiberglass panels, and high-density plastic sheeting.

8.2.2.2.2.2 Screens The use of screens is very effective in controlling noise along a transmission path. Sound waves traveling over the screen are diffracted, creating a quiet zone on the side opposite the noise source.

8.2.2.2.2.3 Green Belts Green belts are able to reduce noise from industries as they interrupt the sound propagation and shock waves. A green belt of more than 30 meters width was found to be effective for noise attenuation of the order of 5 to 10 dB(A).

8.2.2.2.3 Noise Control at Receiver

Commercially two types of device for ear protection are used, i.e. acoustical muffs/ear muffs and earplugs. Generally, earplugs are of two types, i.e. formable and preformed ear plugs. Exposure control of workers comes under the administrative noise control. According to the Directorate General of Mines Safety (DGMS) Circular (Tech.)/18, 1975, the permissible noise limit for a worker for 8 hours' continuous exposure is 90 dB(A) in Indian mines.

8.2.3 Mine Gases and Physiological Effects

The atmosphere that has a remarkably constant composition over the whole surface of the Earth is principally comprised of oxygen and nitrogen, with small traces of carbon dioxide, moisture, and rare gases such as argon, neon, helium, krypton, and xenon. Pure dry atmospheric air has the composition as given in Table 8.3. For most

TABLE 8.3
Composition of Pure and Dry Air

Gas	Percentage by Volume	Percentage by Weight
Oxygen	20.93	23.02
Nitrogen	78.10	75.50
Carbon dioxide	0.03	0.04
Argon and other inert gases	0.94	1.44
Total	100.00	100.00

practical purposes, nitrogen, argon and other rare gases can be treated as being identical in properties, thus making the total concentration 79.04%. Hence, the composition of dry atmospheric air can be simplified to be oxygen 20.93%, nitrogen 79.04%, and carbon dioxide 0.03%. If the air contains water vapor (0.1–3%), then the percentages of the above gases reduce proportionately.

In addition to the above constituents of atmospheric air, mine air contains some impurities, which can be classified as follows:

- non-toxic and explosive gases, such as methane, acetylene, hydrogen, and other hydrocarbons
- toxic gases, such as carbon dioxide, radon, and its daughter products
- poisonous gases, such as CO, nitrous fumes, sulphur dioxide, and hydrogen sulphide
- water vapors, acid vapors and metals
- dust, smoke, etc.

8.2.3.1 Types of Damps in Mines

In the early days, the miners referred to the various mixtures of noxious and inflammable gases met with mines using certain characteristic names that indicated the most pronounced properties of the gas mixtures, which are called "damps." The term "damp" originated from the German word *dampf* meaning fume, fog, or vapor. The different damps encountered in mines are as follows:

- **Firedamp**: It is used either as (i) synonymous with methane, or (ii) referring to the mechanical mixture of gases, chiefly inflammable, given off naturally from coal and consisting for the most part of methane.
- **Blackdamp**: It is a mechanical mixture of the two extinctive gases met with in mines, i.e. carbon dioxide and nitrogen, in excess of the percentage of these gases present in ordinary air. The usual percentage of carbon dioxide varies between 5% and 20% depending upon the source of formation, the rest being nitrogen. It is also known as chokedamp or stythe.
- **Afterdamp**: This is a mechanical mixture of gases found in a mine after an explosion (firedamp or coal dust). The bulk of the mixture is nitrogen but

it also invariably contains CO, CO_2, water vapor, methane, hydrogen, and varying quantities of oxygen.
- **Whitedamp**: It is a mixture of CO and air.
- **Stinkdamp**: It is a mixture of H_2S and air.

8.2.3.2 Physiological Effects of Subsurface Gases

Table 8.4 lists the properties and health effects of gases that are most commonly encountered in underground mines.

- **Threshold Limit Values** (TLV): Threshold limit values of airborne substances refer to those concentrations within which personnel may be exposed without incurring known adverse effects to their health or safety.
- **Threshold limit value/time-weighted average** (TLV-TWA): This refers to the average concentration to which a worker is exposed over the course of a workweek. It is calculated on the basis of a zero-hour workweek and is expressed as ppm or mg/m^3.
- **Threshold limit value/short-term exposure limit** (TLV-STEL): These are maximum concentrations to which a worker can be exposed for up to 15 minutes at any time without suffering from health hazards.
- **Threshold limit value/ceiling limit** (TLV-C): These are maximum allowable concentrations that should not be exceeded even instantaneously.
- **Immediately Dangerous to Life or Health**: These are the concentrations that likely to cause death or immediate or delayed permanent adverse health effects.

8.2.4 Whole-Body and Hand-Arm Vibration

The operation of crushing plant, heavy earth moving machinery, drilling, and blasting operations in both opencast and underground mines is the major source of vibration disturbance in and around the mining complexes. When a machine oscillates due to internal and external forces, vibration is transmitted to worker's body through the vibrating surface via different means. If the vibration is transmitted through the seat or feet of the worker, then it is known as whole-body vibration (HSE, 2018d). Whole-body vibration is more commonly observed in HEMM, mobile machine, or other work vehicle operators. If the vibration is transmitted through the hands, then it is known as hand-arm vibration (HSE, 2018e). Hand-arm vibration is also known as Raynaud's phenomenon. Hand-arm vibration is more commonly observed in workers who use handheld power tools like drills.

The effects of vibration on human health progress slowly based on the duration of exposure, general health, the age of the operator, and the susceptibility of the individual. Continuous exposure to vibrations may cause vascular and neural disorders. The clinical symptoms of vibration are summarized as tingling, numbness, the appearance of a single white fingertip in the presence of cold (Palmear, 1998; Mandal and Srivastava, 2006). There are many adverse impacts relating to whole-body vibration and hand-arm vibration and some of the effects are shown in Table 8.5 (CCOHS, 2017).

In the mining industry, the use of heavy machinery or other equipment known to cause hazards cannot be eliminated. Therefore, proper control measures should

TABLE 8.4
Sources and Physiological Effects of Mine Gases

CO

- **Sources**: Fires, explosions, blasting, internal combustion engines, spontaneous or incomplete combustion of carbon compounds
- **Physiological effects**:
  - 200 ppm: Slight headache, tiredness, dizziness, nausea after 2 to 3 hours
  - 400 ppm: Frontal headache within 1 to 2 hours, life-threatening after 3 hours
  - 800 ppm: Dizziness, nausea, convulsions within 45 minutes Unconsciousness within 2 hours. Death in 2 to 3 hours
  - 1,600 ppm: Headache, dizziness, nausea within 20 minutes. Death within 1 hour
  - 3,200 ppm: Headache, dizziness, nausea within 5 to 10 minutes. Death within 30 minutes
  - 6,400 ppm: Headache, dizziness, nausea within 1 to 2 minutes. Death within 10 to 15 minutes
- **TLV-TWA**: 50 ppm
- **TLV-STEL**: 400 ppm
- **IDLH**: 1,500 ppm

CO_2

- **Sources**: Fires, explosions, blasting, internal combustion engines, oxidation of carbon, respiration
- **Physiological effects**:
  - At 5%, stimulated respiration
  - At 7% to 10%, unconsciousness after few minutes of exposure
- **TLV-TWA**: 5,000 ppm
- **TLV-STEL**: 30,000 ppm
- **IDLH**: 50,000 ppm

H_2S

- **Source**: Strata
- **Physiological effects**:
  - 10 ppm: Obvious and unpleasant odor (rotten eggs)
  - 50 ppm: Mild conjunctivitis, respiratory tract irritation in 30 to 60 minutes
  - 100 ppm: Kills sense of smell in 3 to 5 minutes, may sting eyes and throat
  - 200 ppm: Stings eyes and throat
  - 250 ppm: Exposure for 1 hour is the hazardous limit concentration, which may cause death
  - 300 ppm: Immediately dangerous to life
  - 500 ppm: Dizziness, coughing, breathing ceases within minutes, artificial respiration required
  - 600 ppm: May cause death within 2 minutes
  - 700 ppm: Unconscious quickly, death if not rescued immediately
  - 1,000 ppm: Unconscious instantly, breathing ceased, death within a few breaths. Death may occur even if rescued immediately.
- **TLV-TWA**: 10 ppm
- **TLV-STEL**: 15 ppm
- **IDLH**: 300 ppm

NO_2

- **Sources**: Air, strata
- **Physiological effects**:
  - 1 to 13 ppm: Irritation of nose and throat
  - 10 to 20 ppm: Mild irritation of eyes, nose, and upper respiratory tract

(*Continued*)

TABLE 8.4 (CONTINUED)
Sources and Physiological Effects of Mine Gases

- 80 ppm: Tightness in chest after 3 to 5 minutes
- 90 ppm: Pulmonary edema after 30 minutes

- **TLV-TWA**: 1 ppm
- **TLV-STEL**: 3 ppm
- **IDLH**: 50 ppm

SO_2

- **Sources**: Oxidation of sulphides, acid water on sulphide ores, internal combustion engines
- **Physiological effects**:
  - 0.3 to 1 ppm: Detectable by taste rather than odor
  - 3 to 5 ppm: Detectable odor
  - 10 ppm: Maximum concentration allowable for prolonged exposure
  - 20 ppm: Least amount causing coughing and irritation of eyes
  - 50 ppm: Irritation to eyes, lungs, throat
  - 50 to 100 ppm: Maximum concentration for short exposure (30 to 60 minutes)
  - 150 ppm: May be endured for several minutes. Extremely disagreeable
  - 400 to 500 ppm: Life-threatening
- **TLV-TWA**: 5 ppm
- **TLV-STEL**: 10 ppm
- **IDLH**: 100 ppm

O_2

- **Source**: Air
- **Physiological effects**:
  - 21%: Breathing easiest
  - 19.5%: Minimum required by law
  - 17%: Breathing faster and deeper, possible impaired judgment
  - 16%: First signs of anoxia or hypoxia occur
  - 15%: Dizziness, buzzing in ears, headache, blurred vision, rapid breathing
  - 12% to 16%: Rapid breathing and pulse, impaired muscular coordination
  - 10% to 12%: Emotional upset and abnormal fatigue on exertion
  - 6% to 10%: Nausea and vomiting, inability to move, unconsciousness
  - < 6%: Convulsive movements, gasping respiration, breathing ceases, cardiac arrest occurs

CH_4

- **Source**: Strata
- **Physiological effects**:
  - Asphyxiation in high concentrations due to displacement of oxygen
  - Dizziness, headache, and nausea in high concentrations
- **Explosive limit**:
  - 5% to 15% with a minimum of 12.5% O_2

H_2

- **Physiological effects**:
  - Asphyxiant at high concentrations
- **Explosive limit**:
  - 4.1% to 74%
  - Violent explosions when concentrations over 7% to 8%

TABLE 8.5
Effects of Vibration on Human Health

Vibration Type	Health Effects
Whole-body vibration	• Low back pain • Damage to circulatory, digestive and nervous system • Musculoskeletal disorder • Headache • Loss of balance • Shakiness
Hand-arm vibration	• Vibration-induced white finger • Bone cysts in fingers and wrists • Loss of light touch • Loss of grip strength • Loss of sensation in the fingers • Tingling in the fingers

be adopted to reduce the effect of vibration on workers. The control measures are as follows:

- **Use of anti-vibration gloves**: When the vibration hazards are hard to eliminate, Personal Protective Equipment (PPE) such as anti-vibration gloves should be used.
- **Anti-vibration tools**: Equipment with less intense vibration effects should be used.
- **Increasing awareness**: An awareness of the health effects of whole-body vibrations and hand-arm vibrations should be increased among workers. Proper training should be provided in the use and maintenance of machinery to avoid vibration.
- **Safe working practices**:
  - ***For whole body vibration***
    - isolate the vibrating source to reduce exposure
    - regularly maintain the equipment to avoid excess vibration
    - vibration damping seats should be used in machinery
    - reduce the number of hours of working on the vibrating machine
  - ***For hand arm vibration***
    - wear proper PPE, such as gloves or proper clothing
    - take periodical breaks to avoid continuous exposure
    - regularly maintain the tools to avoid excess vibration
    - replace the tools that are worn, blunt, or out of alignment
    - do not use broken tools
    - use the minimum strength handgrip that still allows the safe operation of the tool or process

Due to improper awareness about the health effects, there were no rules framed for minimizing the effects of vibration in Indian mining workplaces. However,

there are many international standards, such as BS 6841 (1987), AS 2670-1 (1990), ISO 2631-1 (1997), AS 2670-1 (2001), available for use in the mining industry. The International Organization for Standardization (ISO) has released ISO 2631-5: 2018 "Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 5: Method for evaluation of vibration containing multiple shocks," which provides the whole-body vibration limits for 8-hours working conditions. The guidelines on hand-arm vibrations are provided in ISO 13753: 1998 "Mechanical vibration and shock – Hand-arm vibration – Method for measuring the vibration transmissibility of resilient materials when loaded by the hand-arm system." The whole-body vibration limits for eight-hour working conditions are shown in Table 8.6 (ISO, 1997).

8.2.5 Heat and Humidity

Hot and humid conditions in the workplace have adverse effects on the workers' health and efficiency. The sources of heat in opencast and underground mines are terrestrial heat, machinery, and man. In opencast mines, environmental heat is high in the summer season. In underground mines, heat and humidity issues increase with the increase in the depth of the mine. In deep underground mines, heat and humidity are the most common issues, as the virgin rock temperatures and air temperatures increase with depth because of the geothermal gradient and auto-compression of the air column (Donoghue et al., 2000). Heat is also produced by machinery and by the human body when a physical activity is involved. The heat effects on mine workers depend on the following factors:

- velocity of air current
- psychrometric properties of the mine air
- wet-bulb and dry-bulb temperatures
- duration of exposure
- relative humidity

When a worker is exposed to excess heat and humidity, the thermal balance of the body fails, the body temperature increases, and the worker becomes vulnerable to heatstroke. With the increase in temperature, the physiological effects on a mine-worker vary, as shown in Table 8.7.

TABLE 8.6
Whole Body Vibration Limits for Eight-Hour Working Conditions

Parameter	Exposure Action Value (EAV)	Exposure Limit Value (ELV)	Units
RMS	0.45	0.90	m/s^2
VDV	8.5	17	$m/s^{1.75}$

TABLE 8.7
Physiological Effects on a Mineworker with Increase in Dry Bulb Temperature

Dry Bulb Temperature (°C)	Body Temperature (°C)	Physiological Effects
≤ 25	—	Normal blood circulation, no observable effect, heat removal from body mainly through convection and radiation
25–29	—	Heat removal rate increases, slight rise in central core body temperature, vasomotor control of body increases blood circulation
29–37.5	—	Body starts sweating and heat removal mainly through evaporation
≥ 36.9	36.9	Body temperature equals dry bulb temperature, heat transfer through convection and radiation reverses the direction, heat removal from body through evaporation only
—	39	Heart beat rises above 140 beats/min, fatal
—	41	Unconsciousness, coma, may lead to death
—	≥ 43.3	Sudden death

Heat cramps, heat exhaustion, and heatstroke are the most significant hazards in deep underground mines in increasing order of severity. The causes and preventive measures are shown below.

- **Heat cramps**: occur when an individual is exposed for a long period to a temperature higher than the normal environmental temperature.
- Heavy perspiration from the body leads to salt loss and hence to muscle cramps.
- **Prevention**
  - the person should be taken to cool place
  - salted water should be given to the patient
  - massage should be carried out to give some relief from the cramps
  - moist towels/ice packs should be applied to the forehead
  - **Heat exhaustion**: occurs because of exposure to excessive heat while an individual is at work. It is similar to a form of shock, and is triggered by the loss of fluid and salt from the body. When severe, it may develop into heatstroke.
- **Prevention**
  - the person should be moved to a cool place and allowed to rest
  - the patient's clothes should be removed
  - fan the patient's skin to reduce the temperature
  - salted water should be given to the patient
  - if necessary, oxygen should be supplied
  - Hea**t stroke**: occurs when the body is unable to remove heat because of the failure of the individual's temperature-regulating mechanisms such as, sweat glands, vasomotor control, etc. It is mainly caused by exposure to high temperature and humidity, especially when the body temperature exceeds 41°C. Heatstroke is fatal in nature and the immediate cooling of the body should be carried out, and a doctor should be called.

- **Prevention**
  - the individual should be immediately cooled by any possible means
  - the patient's clothes should be removed; and the patient should be kept in dark room
  - treatment for shock should be carried out by administering oxygen
  - ice packs, if available, should be applied near pressure points
  - the patient should be taken to a doctor immediately

The control measures for reducing heat and humidity conditions in underground mines are

- Double-door connections should be provided between intake and return airways
- Old workings should be sectionalized
- A sufficient number of forcing fans with flexible ducts should be provided; materials for the coursing of air should be in sufficient quantity
- Auxiliary fans should be installed for the ventilation of blind headings

8.2.6 Miners' Nystagmus

Good illumination is required for safe and efficient working in mines. Opencast mines are illuminated by natural lighting in the daytime and by artificial illumination in the nighttime. In the case of underground mines, artificial illumination is required from when the mine first opens until its closure. Poorly illuminated mine-working conditions can cause the health conditions of mine workers to deteriorate.

Miners' nystagmus is one of the first occupational illnesses to be identified arising from a hazardous working environment. It is common in mine workers who work in poor lighting conditions for long periods. Miners' nystagmus is the involuntary movement of eyeballs due to a disturbance of the stability of the eyes. There are 47 types of nystagmus. The direction, frequency, and amplitude of the eye movements varies from one type to another. Prior knowledge on the causes of nystagmus is essential for providing correct treatment to the victim. The causes of nystagmus can be classified as follows (Poh, 2013):

- **Physiological or Pathological**
  - Physiological causes of nystagmus include optokinetic nystagmus, vestibular stimulation, and nystagmus that occurs at extreme gaze.
  - Physiological causes are not easily missed, they are often temporary and seldomly a complaint.
- **Monocular or Biocular**
  - Most nystagmuses are biocular unless in a medial pontine stroke, where the unilateral medial longitudinal fasciculus is affected. The patient will present with contralateral internuclear ophthalmoplegia (INO). If the right medial longitudinal fasciculus is damaged, and patient is instructed to look to the right, the left eye will not look to the right while the right eye has horizontal nystagmus. This is because the medial longitudinal fasciculus function is for concurrent contraction of the medial rectus muscle and lateral rectus muscle on adduction gaze. Any lesion that damages the unilateral medial longitudinal fasciculus can produce INO.

- **Central or Peripheral**
  - Central causes of nystagmus are often pendular, do not have a fast-slow phase, and are vertical in direction; even though horizontal and jerk nystagmus can occur with central lesions. The peripheral origin of nystagmus typically presents as a horizontal and jerk nystagmus. In a peripheral lesion, jerk nystagmus has its fast phase beating away from the side of the lesion while the central lesion has its fast phase beating toward the side of lesion.
  - It is difficult to use this factor to differentiate between central and peripheral vestibular lesions because one does not know which side the lesion is in the first place. A better way to do this is by fixing the gaze and see if nystagmus is reduced or relieved. In peripheral nystagmus, it is often relieved by gaze-fixation while in central nystagmus it is not. Another important differentiating clue is the associative signs and symptoms; including cerebellar signs such as ataxia, dysdiadokinesia, intention tremors, and scanning speech; and brainstem signs such as bulbar palsy, hemiplegia, or unilateral sensory loss.
- **Acquired or Congenital**
  - It is not difficult to differentiate congenital nystagmus from acquired nystagmus; mainly by considering age. Congenital nystagmus is usually the horizontal, pendular type, and becomes worse with fixation. It is sometimes associated with albinism and blindness. However, similar presentations can occur with acquired nystagmus too, thus age is the better differentiating factor.
- **Waveform**
  - Perhaps the most important step is the recognition of the waveform. It is important to understand some postulated theories and hypotheses on these waveforms, as this could result in being able to remember the link between the waveform and the site of lesion more easily.

Providing proper lighting facilities in opencast and underground mines can prevent miners' nystagmus from occurring. The DGMS has issued guidelines for providing average illumination levels in underground mines as shown in Table 8.8 and in opencast mines as shown in Table 8.9.

TABLE 8.8
Recommended General Lighting in Underground Mines

Place	Minimum Average Illumination Level (lux or lumens/m^2)
Pit bottom	10
Main junction	15
Roadways	4.5
Haulage engine room	
Floor	10
Drum	25
Controller	20

TABLE 8.9
Recommended General Lighting in Opencast Coal and Metal Mines

Place/Area to be Illuminated	Minimum Standard Illumination to be Provided (in lux)
Work place of heavy machinery	15 Horizontal, 25 Vertical (so as to cover depth and height through which the machine operates.)
Area where drilling rig works	25 Vertical (So as to illuminate the full height of the rig)
Area where drill holes exist	15 Horizontal
Places where manual work is done	15 Horizontal, 25 Vertical
Places where loading, unloading or transfer, loading of dumpers, trucks or train are carried on	15 Horizontal, 15 Vertical
Operator cabins of machines or mechanisms	50 horizontal at all places of operation
Haul roads for trucks and dumpers	10 horizontal
Rail haulage track in the pit	10 horizontal
Roadways and footpaths from bench to bench	10 horizontal
Permanent paths for use of persons employed, etc.	10 horizontal
In-pit crusher/feeder breaker	40 horizontal
Hand picking points	50 horizontal
Conveyor transfer points and drive/tail-end area	40 horizontal
Along conveyor	20 horizontal
Mineral handling plant – places of crushing, screening, segregation, and loading/unloading	40 horizontal
Mineral handling plant – operation points	50 horizontal
Mineral handling plant – other places (in general)	20 horizontal
Pumping station	40 horizontal
Electrical substation	100 horizontal, 50 vertical
Other places of operation of electrical apparatus	20 horizontal, 20 vertical
First aid station	50 horizontal
Rest shelter	30 horizontal
Workshop	100 horizontal, 50 vertical
Parking yard	50 horizontal
General working areas as determined by the manager in writing	10 horizontal at the level of surface to be illuminated

8.2.7 Radiation

Radiation occurs when energy is emitted by a source and then travels through a medium, such as air, until it is absorbed by matter. Radiation at certain wavelengths, called ionizing radiation, has enough energy to damage DNA and cause cancer. Other health effects of radioactivity include kidney failure, shortening of life, diminished bone growth, and infertility. Health risks from ionizing radiation depend on the following factors:

- the magnitude of the absorbed dose
- the penetrating power of the radiation

- the possibility of a threshold below which there is no discernible damage
- the proportion of the target organ or organism exposed
- the rate at which the dose is delivered
- the sensitivity of the receiving cells and organs
- the type of ionizing radiation

High levels of radiation exposure can have harmful biological effects on the human body. These effects are categorized into three groups as shown in Figure 8.5.

Uranium is the used as a fuel for generating nuclear power. Uranium and its decay products emit alpha radiation and lower levels of beta and gamma radiation. The presence of a radioactive gas, called radon, in underground mines is a major concern. Many mine workers in the uranium mining industry have died due to excessive exposure to radon and its radioactive products. Along with uranium mines, radon exposure is observed in gold mines, particularly in South Africa, and coal mines in China. As uranium possesses both radioactivity and chemical toxicity, the mining and processing of uranium has well-known effects on humans and the environment. Due to exposure to radiation, lung cancer occurs commonly in uranium mine workers. A study of Czech and French uranium miners concluded that a substantial excess of lung cancer, reduced pulmonary function, and emphysema has been reported. The excess has been attributed primarily to irradiation of the tracheobronchial epithelium by alpha particles emitted during the radioactive decay of radon and its daughter products (Tomasek et al., 2008). One of the worst mining disasters occurred in Canadian uranium mines due to radiation exposure, in which around 400 uranium mine workers suffered lung cancer deaths due to excess radon exposure (Nolan, 2009).

The following active steps are required to reduce the radiation dosage in uranium mine workers:

- the amount of time of exposure of mine workers to radiation should be reduced
- the mine workers should maintain distance from radiation when working
- mine workers should use proper personal protective equipment to shield them from radiation

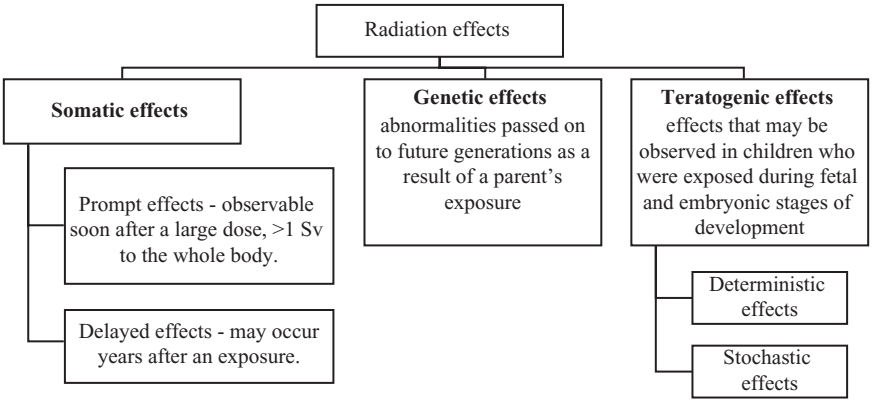

FIGURE 8.5 Classification of radiation effects.

- it is the duty of the employer to ensure the radiation doses are as low as reasonably possible
- radiation doses must be kept as far below the legal limits as is reasonable for the workplace
- dust-controlling measures should be adopted in opencast mines to minimize inhalation of gamma- or alpha-emitting minerals
- the radiation exposure of workers in the mine, plant, and tailings areas should be limited
- in underground mines, proper ventilation system should be provided to keep the radon daughter exposure low
- strict hygiene standards should be imposed on workers handling uranium oxide concentrate**

8.2.7.1 Radiation Standards

In 1959, the International Commission on Radiological Protection (ICRP) issued its recommendations for limiting human exposure to internal sources of radiation and the dose limits per year were

- 5 roentgen equivalent man (rem) to the whole body, gonads, or active bone marrow
- 30 rem to bone, skin, or thyroid
- 75 rem to hands, arms, feet, or legs
- 15 rem to all other body parts

The recommended dose limits by ICRP, the National Council on Radiation Protection and Measurements (NCRP), and the Atomic Energy Regulatory Board (AERB) for radiation workers and the public are shown in Table 8.10.

8.2.8 Cyanide Poisoning

Cyanide salts are used in the extraction of gold and silver from ores by a heap leaching process. Cyanides are highly toxic substances and their leakage into surface and

TABLE 8.10
Recommended Dose Limits for Radiation Workers and Public

	Occupational Workers		Public	
	Limit	Annual Equivalents	Limit	Annual Equivalents
ICRP	20 mSv/year over 5 years	20 mSv	1 mSv/year over 5 years	1 mSv
NCRP	Cumulative dose = Age in years * 10 mSv	50 mSv	5 mSv for 5-year period	1 mSv
AERB	100 mSv for 5-year period	30 mSv	1 mSv for 5 years	1 mSv

subsurface water can affect the surrounding environment adversely. Cyanide spills have been associated with disasters in number of countries, such as the United States, Romania, Australia, Spain, etc., and hence considerable attention is given worldwide to ban this toxic substance from use. Health hazards from cyanide poisoning are as follows:

- abdominal pain
- anxiety
- bitter almond smell on breath/vomit
- coma
- confusion
- death
- dizziness
- enlargement of the thyroid gland
- fainting
- headache
- nausea
- seizure
- shock
- skin irritation and sores
- vomiting

The physiological effects of cyanide are shown in Table 8.11 (Babut et al., 2010).

8.2.8.1 Standards for Cyanide in Water

The drinking water quality standards for cyanide are 0.2 mg/L in the United States and Canada, 0.05 mg/L in Sweden, 0.05 mg/L in India, and 0.07 mg/L according to the World Health Organization (WHO).

The permissible limit for cyanide in effluent is 0.2 mg/L in India according to IS 2490, 1983.

8.2.8.2 Best Practices for Cyanide Management

Best cyanide management should include the following:

- the mine's environmental management should include a cyanide management plan
- proper initial and refresher training should be provided on cyanide management for all stakeholders, including contractors
- the responsibilities of all stakeholders should be defined clearly
- safe operating procedures for the handling, transportation, storage, containment, use, and disposal of cyanide in the workplace should be developed and provided to all workers
- the mine's cyanide management and water management plans should be integrated
- internal and/or external cyanide audits should be conducted regularly
- the recommendations suggested in the audit reports should be implemented
- emergency procedures should be established

TABLE 8.11
Health Effects of Cyanide on People

Concentrations (ppm)	Human Response
18–36	Slight symptoms after several hours
45–55	Tolerated for 30 to 60 minutes without immediate or subsequent effects
110–135	Fatal after 30 to 60 minutes or longer
135	Fatal after 30 minutes
181	Fatal after 10 minutes
270	Immediately fatal

8.2.9 Metal Toxicity

Metal toxicity is the toxic effect of specific metals in certain forms and doses. Generally, all the heavy metals are toxic in nature, but not all are particularly toxic. Some trace metals in high doses can also be toxic. Heavy metals are metals with a relatively high density (>5 g/cm^3), atomic number, or atomic weight. Trace metals are metals that naturally occur at low levels (<1,000 ppm) in the environment. The trace elements are chromium, cobalt, copper, iron, magnesium, selenium, and zinc. They are required for maintaining good health in people and are used for various purposes in daily life. Depending on the general characteristics of heavy metals, their usage varies. Generally, they are categorized into six groups based on their usage, as shown in Figure 8.6.

As the metals are used in numerous ways in modern life, it is necessary to know about the health effects that are caused due to metal toxicity. Small amounts of heavy and trace metals are present in the environment and people's diets and are considered harmless and frequently beneficial. However, exposure to high levels of these same metals can cause toxicity (poisoning). The toxicity can be acute or chronic depending on the exposure time and properties of the metal. Metal mining can release these metals into surrounding environment. The heavy metals that are produced mainly by mining are shown in Table 8.12. The health effects due to occupation exposure to the most common toxic metals are presented in Table 8.13 (Martin and Griswold, 2009; ATSDR, 2014).

8.3 SAFETY, HEALTH AND WELFARE LEGISLATION FOR MINES

Occupational health and safety is an integrated area concerned with the safety, health, and welfare of people at work. Workers in mines are exposed to a number of

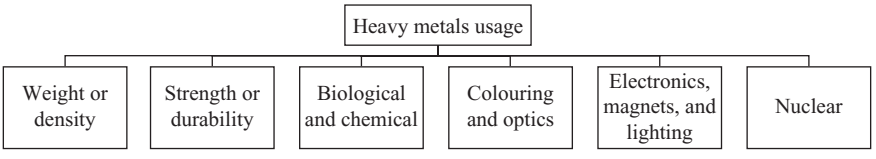

FIGURE 8.6 Categories of heavy metals based on usage.

TABLE 8.12
Heavy Metals Produced by Mining

Antimony	Arsenic	Bismuth	Cadmium	Cerium	Chromium
Cobalt	Copper	Dysprosium	Erbium	Europium	Gadolinium
Gallium	Germanium	Gold	Hafnium	Holmium	Indium
Iridium	Iron	Lanthanum	Lead	Lutetium	Manganese
Mercury	Molybdenum	Neodymium	Nickel	Niobium	Osmium
Palladium	Platinum	Praseodymium	Protactinium	Rhenium	Rhodium
Ruthenium	Samarium	Selenium	Silver	Tantalum	Tellurium
Terbium	Thallium	Thorium	Thulium	Tin	Tungsten
Uranium	Vanadium	Ytterbium	Zinc	Zirconium	

hazards, such as electricity, fire, toxic substances, noise, etc. To protect workers from the various hazards and create a safe working environment, and to reduce the occurrence of injuries and injury-related costs, organizations should have an OHS policy in place. OHS in organizations is also vital for following reasons:

- Legally, every organization should ensure that their workers are free from any harm while working in the organization.
- Economically, every organization should aim to reduce stress on workers, which can demotivate them and may lead to accidents, to prevent accidents, which can delay normal working operations and increase operational costs, to reduce the level of compensation costs borne by the organization, to reduce ill health and disease, which can result in absence from work.
- Morally, it is right to protect workers from any kind of harm.

A good OHS policy in an organization will help to improve the morale, health, production, and reputation of the organization, and decrease the absenteeism, staff turnover, and health care cost to the organization (WHO, 2018).

The aim of OHS is to embrace the safety, health, and welfare of people engaged in employment. It furthermore protects employers, family members, co-workers, and others who might be affected by the workplace environment. Workers employed in the mining industry have high occurrence rates of exposure to potentially harmful occupational hazards. Many of the mine workers work long hours and non-standard shifts, and have a high risk of exposure to OHS hazards.

8.3.1 Occupational Health and Safety Management System

An Occupational Health and Safety Management System (OHSMS) is a methodical approach to manage health and safety risks in organizations. An OHSMS can help an organization to minimize possible accidents in the workplace and improve safety performance, to increase production by reducing direct and indirect costs, to verify its OHS performance, and to improve the organization's reputation. With industrial

TABLE 8.13
Physiological Effects of Heavy Metals

Metal	Physiological Effects	Limits in Workplace Air Averaged Over 8-Hour Work-Shift (OSHA)
Arsenic	**Acute effects**: Vomiting, diarrhea, abdominal pain **Chronic effects**: Pulmonary disease, skin cancer, lung cancer, bladder cancer, cardiovascular disease, diabetes, poisoning, bronchitis, dermatitis	10 μg/m^3
Barium	**Acute effects**: Hypokalemia, gastrointestinal effects such as diarrhea, nausea, gastric pain and vomiting, change in heart rhythm, change in blood pressure, muscle weakness **Chronic effects**: Damage to the nervous system, heart, blood vessels, swelling of brain	0.5 mg/m^3
Cadmium	**Acute effects**: Lung damage, muscle pain, fever, chills **Chronic effects**: Hypertension, bone, lung and kidney disease, bronchitis	5 μg/m^3
Chromium	Acute renal failure, acute tubular necrosis, asthma, chronic bronchitis, chronic irritation, chronic pharyngitis, chronic rhinitis, congestion and hyperemia, cough, irritation of the lining of the nose, lung cancer, nasal cancer, polyps of the upper respiratory tract, runny nose, shortness of breath, sinus cancer, tracheobronchitis, ulceration of the nasal mucosa with possible septal perforation, wheezing	0.0005 to 1 mg/m^3
Cobalt	**Acute effects**: Trouble breathing, skin rashes, congestion, edema, hemorrhage of the lung **Chronic effects**: asthma, pneumonia, wheezing, fibrosis, congestion of liver, kidneys and conjunctiva, enlargement of heart, cardiogenic shock	0.1 mg/m^3
Copper	Diarrhea, dizziness, eyes irritation, headaches, kidney damage, liver damage, mouth irritation, nausea, nose irritation, stomach cramps, vomiting	0.1 mg/m^3 (fumes) 1.0 mg/m^3 (dusts/mists)
Iron	**Acute effects**: Vomiting, cardiac depression, metabolic acidosis **Chronic effects**: Hepatic cirrhosis	10 mg/m^3 (iron oxide fumes)
Lead	**Acute effects**: Vomiting, constipation, abdominal pain, reversible kidney damage, anemia, hypertension, acute encephalopathy **Chronic effects**: Neurophysiological and neuropsychological changes, neurobehavioral changes, anemia, change in kidney function, decreased fertility in men	50 μg/m^3
Mercury	**Acute effects**: Metallic taste, dysphagia, respiratory problems, nausea, vomiting, diarrhea, abdominal pain, hypertension, proteinuria, oliguric renal failure nephrotic syndrome, temporary tubular dysfunction and acute tubular necrosis, tachycardia, visual disturbance	0.1 mg/m^3

(*Continued*)

TABLE 8.13 (CONTINUED)
Physiological Effects of Heavy Metals

Metal	Physiological Effects	Limits in Workplace Air Averaged Over 8-Hour Work-Shift (OSHA)
	Chronic effects: Renal impairment, permanent damage to the nervous system and kidneys, oropharyngeal inflammation anxiety, forgetfulness, motor dysfunction, tremor, emotional lability, insomnia, cognitive dysfunction, fatigue, anorexia, erythrism	
Selenium	**Acute effects**: Diarrhea, dizziness, fatigue, nausea, vomiting, irritation of mucous membranes **Chronic effects**: Bronchial spasms, coughing, respiratory irritation, collection of fluid in the lungs, deformed nails, brittle hair	0.2 mg/m^3
Silver	Discoloration of the skin (argyria), breathing problems, mucous membranes, stomach pains, lung irritation, throat irritation	0.01 mg/m^3
Thallium	**Acute effects**: Diarrhea, coma, autonomic instability, painful neuropathy, residual neurologic symptoms, vomiting, **Chronic effects**: Alopecia, neuropathy, numbness of fingers and toes	0.1 mg/m^3
Zinc	**Acute effects**: Nausea, vomiting, stomach pain, diarrhea, metal fume fever, chills, cough, headache, fatigue, hypogeusia, iron deficiency anemia, sideroblastic anemia, neutropenia **Chronic effects**: Damage to the mucous membranes, dyspnea, cough, pleuritic chest pain, bilateral diffuse infiltrations, pneumothorax, and acute pneumonitis, decreases in high-density lipoprotein	5 mg/m^3 (zinc oxide fumes)

development taking place around the world, concerns about occupational health and safety have greatly increased. International agencies, such as the International Labour Organization (ILO) and WHO, have pushed to develop an appropriate global framework. In 2001, ILO published "Guidelines on Occupational Safety and Health Management Systems – ILO-OSH 2001" to help organizations with OHSMSs (ILO-OSH, 2001). These guidelines help to improve the health and safety of employees at the workplace, achieved through a process of policy, organization, planning and implementation, measurement of performance, and improvement of performance, all supported by constant auditing. A good OHSMS contains the components shown in Figure 8.7. Figure 8.8 shows the elements of the Indian National Framework for OHSMS (ILO-OSH, 2001).

A group of international standards and certification bodies and specialist consultants, with the purpose of removing irregularities in certification activity by different certification bodies, developed a standard for certification of OHS.

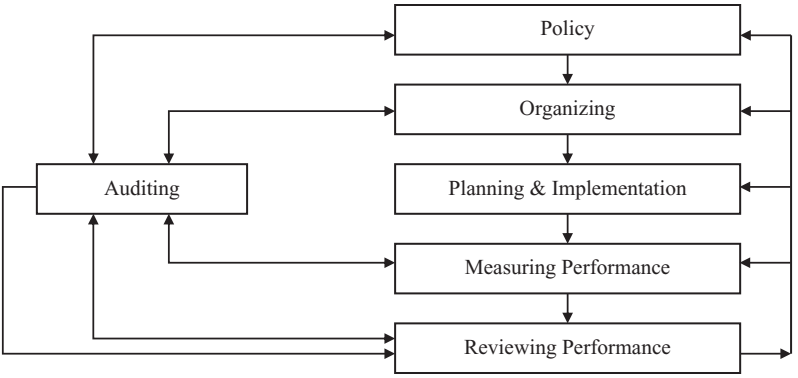

FIGURE 8.7 Components of occupational health and safety management system.

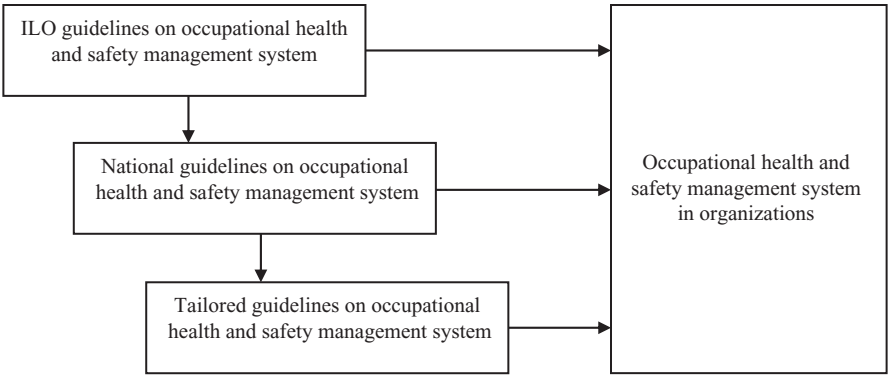

FIGURE 8.8 Elements of the Indian national framework for OHSMS.

8.3.1.1 OHSAS 18001

OHSAS 18001 (Occupational Health and Safety Assessment Series) is the British Standard for OHSMS. OHSAS 18001 was released in 1999. This standard is divided in to two parts: OHSAS 18001 and 18002. OHSAS 18001 is compatible with ISO 19001, Quality Management System, and ISO 14001, Environmental Management System, to help the incorporation of quality, environment, and OHS in the organization. OHSAS 18002 gives the guideline for implementing OHSAS 18001. The OHSAS 18001 requirements are as follows:

- OHS policy
- planning
- implementation and operation
- checking and corrective action
- management review
- continual improvement

OHSAS standards methodology is based on "Plan-Do-Check-Act."

- **Plan**: Establish the objectives and processes necessary to deliver results in accordance with the organization's OHS policy
- **Do**: Implement the processes
- **Check**: Monitor and measure processes against OHS policy, objectives, legal and other requirements, and report the results
- **Act**: Take action to continually improve OHS performance

8.3.1.2 ISO 45001, 2018

In April 2017, ISO 45001.2: 2017, the first global OHSMS standard, was published. It was based on OHSAS 18001, the conventions and guidelines of the ILO, including ILO-OSH, 2001, and national standards (ISO, 2018). The aim of the OHSMS is to provide a framework for managing OHS risks in the workplace. ISO 45001, 2018 methodology is also based on Plan-Do-Check-Act. ISO 45001, 2018 requirements are as shown in Figure 8.9.

8.3.2 OHS Legislation in India and Abroad

The beginning of the OHS concept can be traced back to the industrial revolution of the 18th century. Despite the fact that the industrial revolution increased production and helped in economic development, it also increased the harmful impacts on the health and safety of the people working in the different industries. To reduce or eliminate the harmful effects on workers, various legislation, acts, and policies were created. Every country has their own legislation, acts and policies. The legislation and public organizations of various countries are presented in Table 8.14 (DGFASLI, 2016; HSW, 1974; OHSA, 1993; OSHA, 1970).

8.3.2.1 India

The basic legislative requirements of OHS have been entrenched in the Constitution of India, and it is mandatory that they are followed by everyone. To maintain the standards of occupational health and safety, the Union Ministry of Labour and Employment has also spelled out various legislative acts, rules, and regulations. India, being a member of ILO, has ratified and signed several covenants to encourage occupational health and safety.

8.3.2.1.1 Constitutional Provisions

The notable points on OHS from the Constitution of India are as follows (DGFASLI, 2016):

- Article 24 – Children below 14 years of age shall not be employed or engaged to work.
- Article 39e – All states should give guidelines to safeguard the health and strength of workers, and citizens from entering jobs inappropriate to their age or strength because of poverty.

Context of the organization

- Understanding the organization and its context
- Understanding the needs and expectations of workers and other interested parties
- Determining the scope of the OHS management system
- OHS management system

Leadership and worker participation

- Leadership and commitment
- OHS policy
- Organizational roles, responsibilities and authorities
- Consultation and participation of workers

Planning

- Actions to address risks and opportunities
  - Hazard identification and assessment of risks and opportunities
  - Determination of legal requirements and other requirements
  - Planning action
- OHS objectives and planning to achieve them

Support!

- Resources
- Competence
- Awareness
- Communication
- Documented information

Operation

- Operational planning and control
- Emergency preparedness and response

Performance evaluation

- Monitoring, measurement, analysis and performance evaluation
- Internal audit
- Management review

Improvement

- Incident, nonconformity and corrective action
- Continual improvement

FIGURE 8.9 ISO 45001: 2018 requirements.

- Article 39f – All states should give guidelines to make sure that the children grow in a healthy manner with freedom and a dignified environment, and the childhood and youth are protected from exploitation.
- Article 42 – All states should make a facility for obtaining civilized work and maternity relief.

TABLE 8.14
Legislation and Public Organizations for Various Countries

Country	Legislation	Public Organization
USA	Occupational Safety and Health Act, 1970	Occupational Safety and Health Administration
	Miner Act, 2006	Mine Safety and Health Administration
UK	Health and Safety at Work etc. Act, 1974	Health and Safety Executive
China	Work Safety Act of People's Republic of China, 2002 Occupational Disease Control act of People's Republic of China, 2002	State Administration of Work Safety, Ministry of Health
South Africa	Occupational Health and Safety Act, No. 85 of 1993 Occupational Health and Safety Amendment Act, No. 181 of 1993	Department of Labour, Department of Mineral Resources for Mining and Energy production
Australia	Workplace Health and Safety Act, 2011	Safe Work Australia
India	National Policy on Occupational Health and Safety, 2009	Union Minister of Labour and Employment

8.3.2.1.2 ILO Conventions

The ILO is a specialized agency associated with the United Nations. It aims to improve labor conditions, promote employment, promote internationally recognized human and labor rights, and to raise living standards. The list of ILO conventions in the area of OHS in mines is presented in Table 8.15 (ILO, 2016).

8.3.2.1.3 National Policy

Framing the national policy is key to the successful execution of measures for the improvement of working conditions and working environment at a national level. In India, the Union Ministry of Labour and Employment framed the national policy on OHS at the workplace on February 20, 2009 (MLE, 2016a), with the help of the Directorate General of Factory Advice Service & Labour Institutes (DGFASLI). DGFASLI provides technical support in framing rules and conducting surveys and training programs on OHS for factories, docks, and construction sectors, while DGMS provides technical support in formulating rules and conducting surveys and training programs on OHS for mines in both organized and unorganized sectors. The central-level and state-level department responsible for OHS is shown in Figure 8.10.

To date, the central government has passed 44 labor-related statutes dealing with occupational health and safety, minimum wages, conditions of employment, accidental benefits, etc. (MLE, 2016b). However, OHS statutes are present only in factories, ports, mines, and construction sectors. A number of the current OHS statutes passed have only limited scope for problems of health and safety, as the objectives are specific.

TABLE 8.15
ILO Conventions Relating to OHS

No.	Conventions
C14	Weekly Rest (Industry) Convention, 1921
C77	Medical Examination of Young Persons (Industry) Convention, 1946
C121	Employment Injury Benefits Convention, 1964
C124	Medical Examination of Young Persons (Underground Work) Convention, 1965
C124	Medical Examination of Young Persons (Underground Work) Convention, 1965
C131	Minimum Wage Fixing Convention, 1970
C135	Workers' Representatives Convention, 1971
C138	Minimum Age Convention, 1973
C139	Occupational Cancer Convention, 1974
C144	Tripartite Consultation (International Labour Standards) Convention, 1976
C155	Occupational Safety and Health Convention, 1981
C159	Vocational Rehabilitation and Employment (Disabled Persons) Convention, 1983
C161	Occupational Health Services Convention, 1985
C162	Asbestos Convention, 1986
C176	Safety and Health in Mines Convention, 1995
C187	Promotional Framework for Occupational Safety and Health Convention, 2006
P155	Protocol of 2002 to the Occupational Safety and Health Convention, 1981

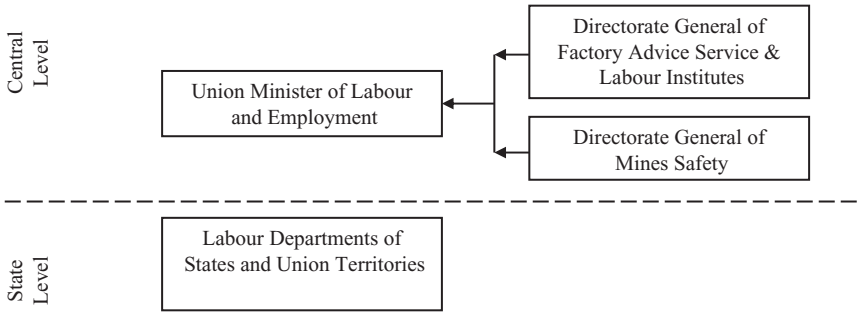

FIGURE 8.10 Central and state level departments responsible for OHS in India.

8.3.2.1.4 Statutes Applicable to Indian Mines

The initial study of mining conditions in India was studied by one HM Inspector of Mines in 1894, after the issues related to mining conditions were bought up at the International Labour Conference in 1890. In the same year, the government of India appointed a committee to frame legislation to protect those working in mines. The Indian Mines Act was first enacted in 1901 and came in to force from 1923. The Mines Act, 1952, superseded earlier legislation.

In 1902, the Bureau of Mines Inspection (later known as DGMS) was formed in Calcutta. The DGMS is the field organization under the Union Ministry of Labour

and Employment that looks after the area of OHS in mines and oil fields. The DGMS continually strives to advance health and safety standards, practices, and performance in the mining industry. It implements OHS provisions through inspectors appointed under the Mines Act, 1952, and it also conducts inquiries and inspections, issues competency tests, and organizes seminars/conferences on various aspects of the safety of workers.

In India, it is mandatory for organizations to comply with the Coal Mines Safety Legislation for safeguarding OHS in mines. The OHS legislation related to the mining industry is shown in Table 8.16 (DGMS, 2018a). Along with the legislative measures, the DGMS also endorses safety developments through promotional initiatives, such as conferences on safety in mines, vocational training, national safety awards, observance of safety week, holding rescue competitions, promoting self-regulation by management, promoting participation of workers in safety management and awareness, and information distribution.

At the individual mine level, the mine manager is responsible for maintaining the desired standards of OHS. Assistant managers, welfare officers, safety officers, ventilation officers, overmen, sirdars, shot-firers, and surveyors assist the mine manager by ensuring proper supervision and control in all activities of mining. Agents coordinate the activities at the mine level with activities at the corporate level. On safety issues in mines, the internal safety organization (ISO) acts as a link between the mine level and the corporate level. The agencies involved in safety monitoring in mines are presented in Table 8.17 (CIL, 2017).

TABLE 8.16
OHS Legislation Applicable to Indian Mines

Statutes
The Mines Act, 1952
The Mines Rules, 1955
The Coal Mines Regulation, 2017 (notified on 27.11.2017)
The Mines Rescue Rules, 1985
The Electricity Act, 2003
The Central Electricity Authority (measures related to safety and supply) Regulations, 2010
The Mines Vocational Training Rules, 1966
The Mines Crèche Rules, 1966
The Indian Explosive Act, 1884
The Explosive Rules, 2008
The Indian Boiler Act, 1923
The Mines Maternity Benefit Act & Rules, 1963
The Workmen Compensation Act, 2010
The Factories Act – 1948, Chapters III and IV
The Metalliferous Mines Regulations, 1961
The Oil Mines Regulations, 2017
The Oil Mines Regulations,1984

TABLE 8.17
Safety Monitoring in CIL

Level	Monitored by
Mine level	• Workman inspectors: according to Mines Rules, 1955 • Pit safety committee: constituted according to Mines Rules, 1955
Area level	• Tripartite committee meeting • Safety officers coordination meeting
Subsidiary HQ level	• Tripartite committee meeting • Area safety officers coordination meeting • Inspection by ISO officials
Corporate level	• CIL safety board
Ministerial level	• Standing committee on safety in coal mines • National conference in safety in mines • Various parliamentary standing committees

8.3.2.2 The United States

The OHS legislation for mines in the United States are covered under the Mine Improvement and New Emergency Response (MINER) Act, 2006. The history of US mine safety and health legislation is shown in Table 8.18 (MSHA, 2018b).

The setting out of goals in the Mine Safety and Health Act, 1977, was superseded by the current MINER Act, with the aim of improving workers' safety in mines. The key improvements made in the MINER Act, 2006 are as follows (MSHA, 2006):

- Each mine should use the latest available technology.
- Each mine should develop an emergency response plan. The emergency response plan should be reviewed, updated, and certified by the Mine Safety and Health Administration (MSHA) every six months.
- Each mine should make available two experienced rescue teams capable of a one-hour response time.
- An increase in the civil penalties for mine managements who fail to notify incidents/accidents that pose a reasonable risk of death within 15 minutes.
- The direction to employ two-way wireless communications, electronic tracking systems, and facilities for those on the surface to locate persons trapped underground.
- An increase in criminal penalties.
- The power to shut down a mine in cases where it has refused to pay a final order MSHA penalty was given to the MSHA.

8.3.2.3 Australia

Australian legislation is considered to be the most progressive legislation, as it was the first to push the move away from compliance to self-management, with greater emphasis being placed in the legislation on the duty of care, risk management principles, and workforce representation (Cliff, 2012). Unlike The United States, each state

TABLE 8.18
History of US Mine Safety and Health Legislation

OHS Legislation
1891 – First federal mine safety statute passed
1910 – Bureau of Mines created
1941 – Right of entry granted to federal inspectors
1947 – Safety standards for bituminous coal and lignite mines created
1952 – Federal Coal Mine Safety Act passed
1961 – Study authorized to examine injuries and hazards in metal/non-metal mines
1966 – Federal Coal Mine Safety Act extended to include all underground coal mines
1966 – Federal Metal and Nonmetallic Mine Safety Act passed
1969 – Federal Coal Mine Health and Safety Act passed (Coal Act)
1973 – Mining Enforcement and Safety Administration (MESA) created
1977 – Mine Safety and Health Act (Mine Act)
1977 – Mine Safety and Health Administration (MSHA) created
2006 – Mine Improvement and New Emergency Response Act (MINER Act) passed

and territory in Australia has their own legislation applicable to their workplaces. The main mining states, such as Queensland, New South Wales, and Western Australia, have specific mining OHS legislation. In addition to the harmonization of general OHS legislation, the Ministerial Council on Mineral and Petroleum Resources has developed the National Mine Safety Framework (NMSF), which aims to achieve a national consistency of occupational health and safety regimes for the Australian mining industry. In 2011, Safe Work Australia developed a single set of Workplace Health and Safety (WHS) laws known as "model laws," to be implemented across Australia (SWA, 2018a). In New South Wales, the mining OHS legislation will be applied in addition to the general OHS legislation, whereas in Queensland and Western Australia the mining OHS legislation will replace the general OHS legislation. The summary of legislative requirements in the Australian mining industry is shown in Table 8.19 (SWA, 2018b).

8.4 THE OHS STRUCTURE IN THE MINING INDUSTRY

Though the aim of the OHS organizations around the world is to provide a healthy and safe working environment and safe systems for working, the organizations involved in framing, promoting, enforcing, and updating OHS varies from one country to another.

At present, there are no government organizations that deal exclusively with OHS problems. In India, many levels of ministry and organizations are linked in the occupational health service system, as shown in Figure 8.11 (AMRC, 2014). DGMS handles the health and safety issues of workers of the mining industry. Certified agencies, such as the Central Labour Institute, the National Safety Council of India, the Indian Institute of Toxicology Research, the National Institute of Occupational Health, and the Indian Association of Occupational Health, are working to reduce OHS hazards by organizing periodic training courses for safety professionals, industrial managers, and industrial doctors and physicians.

TABLE 8.19
OHS Legislation for Australian Mines

States and Territory	Mining Legislative Framework
New South Wales	Work Health and Safety (Mines and Petroleum Sites) Act, 2013
	Health and Safety (Mines and Petroleum Sites) Regulation, 2014
Victoria	Chapter 5 of the Occupational Health and Safety Regulations, 2007
Queensland	Mining and Quarrying Safety and Health Act, 1999
	Mining and Quarrying Safety and Health Regulation, 2017
	Coal Mining Safety and Health Act, 1999
	Coal Mining Safety and Health Regulation, 2017
Western Australia	Mines Safety and Inspection Act, 1994
	Mines Safety and Inspection Regulations, 1995
South Australia	Chapter 10 of the Work Health and Safety Regulations, 2012
Tasmania	Mines Work Health and Safety (Supplementary Requirements) Act, 2012
	Mines Work Health and Safety (Supplementary Requirements) Regulations, 2012
Australian Capital Territory	Work Health and Safety Act, 2011
	Work Health and Safety Regulation, 2011
Northern Territory	Work Health and Safety (National Uniform Legislation) Act, 2011
	Chapter 10 of the Mines Work Health and Safety (National Uniform Legislation) Regulations, 2012

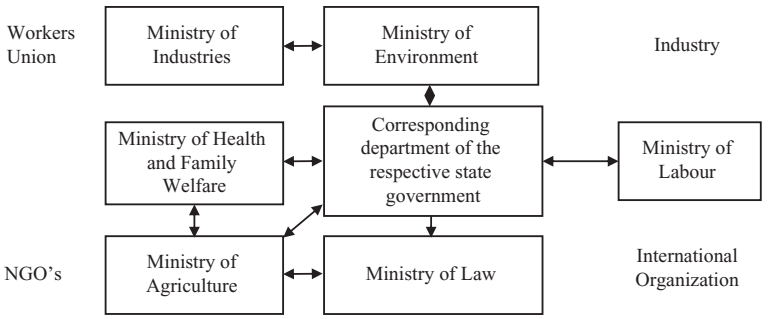

FIGURE 8.11 Organizations involved in OHS in India. (Courtesy of AMRC, 2014. OSH status report – India. Asia Monitor Resource Centre, Hong Kong. Retrieved from www.amrc.org.hk/sites/default/files/Occupational%20status%20report%20-%20India.pdf.)

8.4.1 National Institute of Miners' Health

The National Institute of Miners' Health (NIMH) is one of the main autonomous institutes dedicated to the improvement of occupational health for workers employed in the mining industry. The chief objectives of the NIMH include the following (NIMH, 2016):

- the promotion of occupational health
- the prevention of occupational diseases among workers employed in the mining industry

- research and developmental activities relating to occupational health, workplace monitoring, etc., in the mining industry
- to provide technical support services to the mining industry
- to assess health hazards in mines and direct the necessary remedial measures

The NIMH is well-known for the expert services that it provides and for the facilities it has available. Some of these expert services are epidemiological studies, respirable dust surveys, health surveillance studies, vibration studies, noise mapping model development, etc. The facilities available at the institute are

- risk assessment of work location and personal exposure assessment for noise, vibration, and dust
- health risk assessment due to vibration
- audiometry test
- determination of levels of heavy metals, free silica, etc.
- development of manpower
- research facilities relating to biomarkers in occupational diseases

8.4.2 National Institute of Occupational Health

The NIOH is the best institute established, with the support of Indian Council of Medical Research, for the promotion of the mental and physical health of employees of all occupations. The chief objectives of the NIOH are (NIOH, 2016)

- to promote research to evaluate environmental stresses/factors at the workplace
- to encourage occupational health through fundamental and applied research
- to develop control technologies and health programs through basic and fundamental research

The NIOH has published more than 500 research papers in national and international journals. Some of the major projects completed are

- the generation of databases for occupational diseases such as silicosis, asbestosis, noise pollution, pneumoconiosis, etc.
- the generation of databases on environmental health problems such as exposure to heavy metals
- the detection of links between occupational environmental exposures and health effects.
- carcinogenicity studies
- the testing of hearing protection devices
- dust control techniques for prevention of pneumoconiosis

8.4.3 Central Labour Institute

The Central Labour Institute, functioning under the Ministry of Labour and Employment, carries out training and research related to occupational health and safety. Its aim is to improve the safety, health, and productivity of workers by

improving working conditions. The institute also develops and tests personal protective equipment. To date, the Central Labour Institute has trained more than 600 doctors (CLI, 2017).

8.4.4 Coal India Limited

The safety organization structure of Coal India Limited (CIL) is shown in Figure 8.12.

8.4.5 Singareni Collieries Company Limited

The safety organization structure of Singareni Collieries Company Limited (SCCL) is shown in Figure 8.13.

8.4.6 Mine Safety and Health Administration, The United States

The US Department of Labor's Mine Safety and Health Administration works to promote safe and healthy workplaces for US miners. The organization structure of the MSHA is shown in Figure 8.14.

8.4.7 Mine Health and Safety Council, South Africa

The Mine Health and Safety Council (MHSC) is a national public body established under the Mine Health and Safety Act, No. 29, of 1996, as amended. The body comprises a tripartite board represented by state, employer, and labor members, under the chairmanship of the Chief Inspector of Mines. The OHS structure of MHSC is represented in Figure 8.15. The structure of the State Mining Corporation (STAMICO) is shown in Figure 8.16.

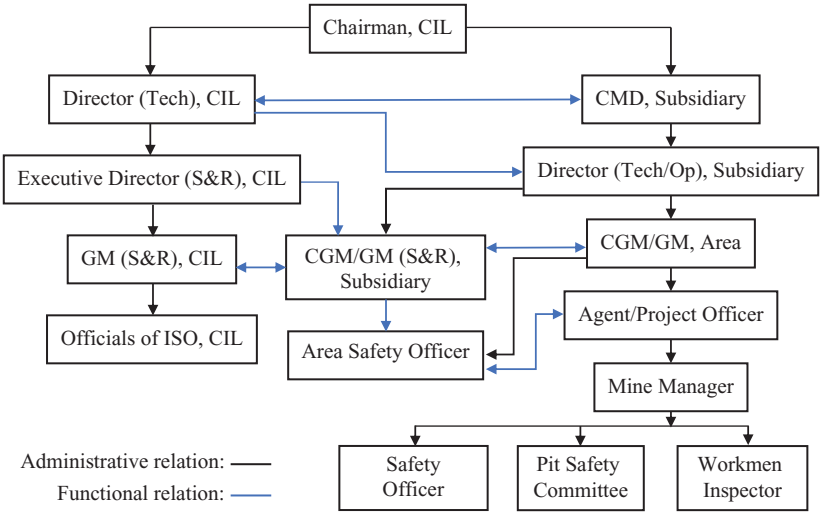

FIGURE 8.12 Safety organization in CIL.

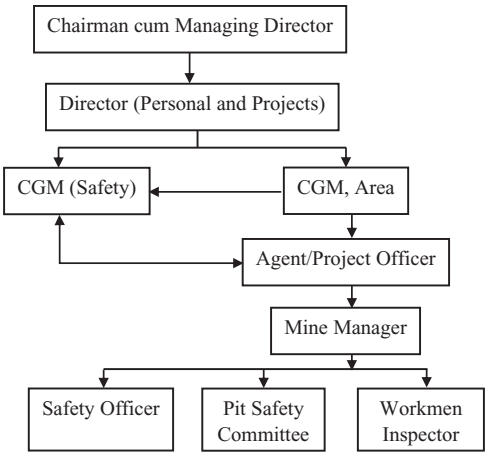

FIGURE 8.13 Safety organization in SCCL.

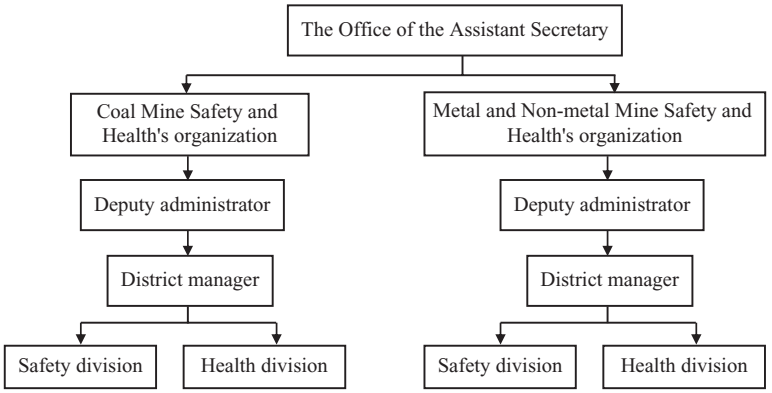

FIGURE 8.14 Organization structure of MSHA.

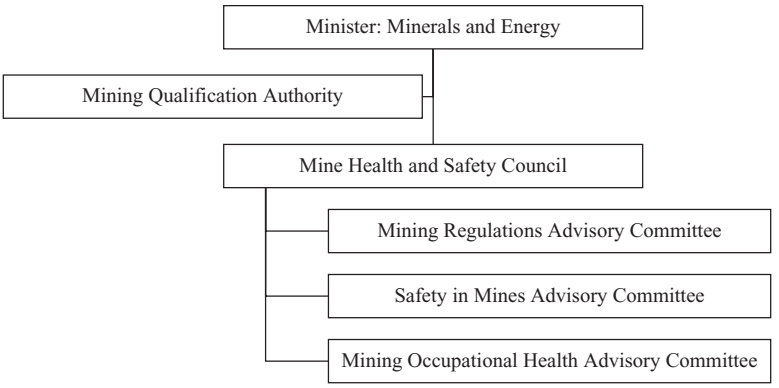

FIGURE 8.15 Organization structure of MHSC.

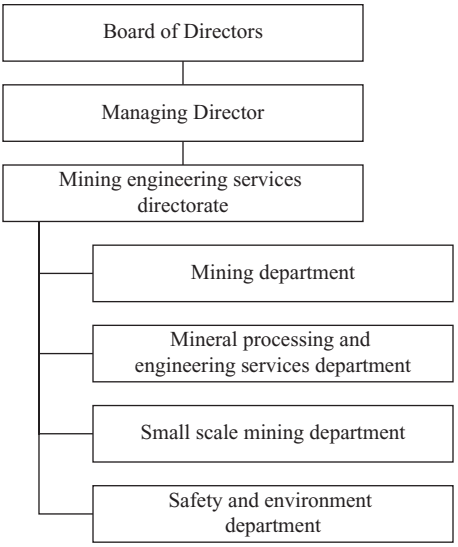

FIGURE 8.16 Organization structure of STAMICO.

8.5 MANAGING OHS ISSUES IN THE WORKFORCE

The majority of the current OHS legislation focuses on identifying all the possible hazards in the workplace, in order to eliminate or control the risks associated with these hazards. Managing OHS risks involves a four-step process: identify hazards, perform risk assessments, control risks, and review risk assessments and control measures.

However, many developing countries such as India have a good number of challenging issues for successfully managing OHS issues in the workplace. They are as follows:

- inadequate implementation of existing legislation
- lack of legislation in unorganized sectors
- shortage of OSH professionals
- lack of reliable OSH data
- lack of interest of stakeholders
- lack of awareness, education, and training about OHS among stakeholders
- infrastructure problems
- lack of corporate commitment

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9 Safety Education and Training

9.1 WHAT IS SAFETY EDUCATION AND TRAINING?

In order to reduce occupational accidents and illness and to improve safety in the mining industry, mining experts have long recognized that providing safety education and training to employees is an important element of an effective safety and health program. The general basis for providing education and training to employees is to improve awareness about the presence of safety- and health-related hazards, to develop knowledge about the causes of occupational injuries, and to promote the implementation of effective preventive measures. Safety education and training involves teaching specific skills, knowledge, specific training, and any other methods required to keep employees safe while working in the mines. Safety education and training programs vary from one country to another and from one organization to another. Every organization has their own custom-made safety education and training program for their company (Bianca, 2018).

An effective occupational safety and health program includes identification of hazards, reporting of hazards, and management of the hazardous situations. Safety training helps employees to learn about the ways to identify hazards, how to (and to whom) report hazards, and how to manage hazards. Training is not just about formal "classroom" courses and obtaining certificates to work (HSE, 2018c). Developing safety education and training programs in the organization is the most cost-effective way to protect its workers. The steps for developing an effective workplace safety training program is shown in Figure 9.1 (Katz, 2017).

In mines, employees will be trained in the following:

- safety and health training for all new mine workers
- refresher training for already employed workers
- emergency preparedness and response training
- special training for particular jobs

Education to employees will be provided in the following:

- identification and avoidance of health hazards causing illness and safety hazards causing death or disability
- using hazardous materials or working around hazardous materials
- working with heavy equipment
- working with automated machines

Providing safety education and training to employees is a continual process and it may be provided through multiple ways as shown in Figure 9.2.

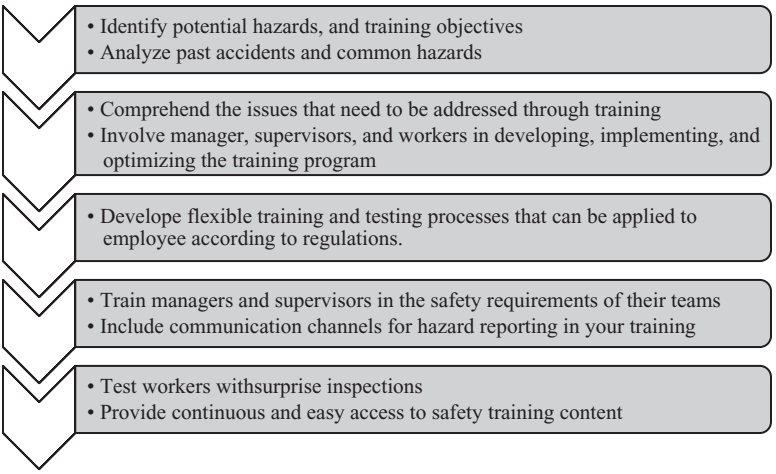

FIGURE 9.1 Steps for developing effective safety training.

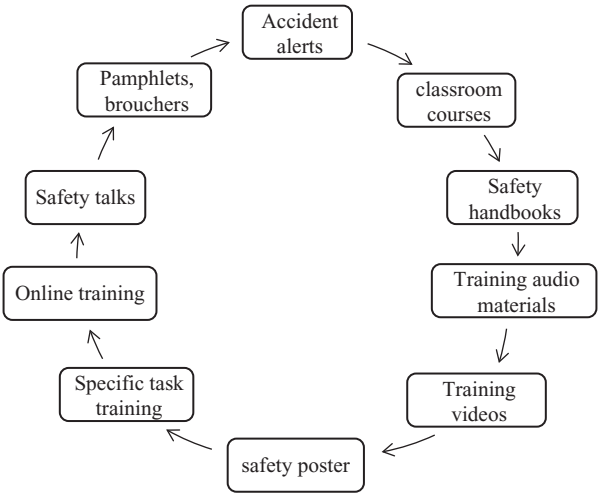

FIGURE 9.2 Types of safety education and training materials.

9.2 WHY SAFETY EDUCATION AND TRAINING IS IMPORTANT?

The mining industry is one of the most dangerous industries. Over 100 workers are killed each year in accidents at Indian mines and over 1,000 workers are injured. Therefore, preventing accidents, injuries, and health illness caused by work should be a main concern for every employee at work. As a mining operation mainly depends on its workers, the workers are the mine's most valuable assets. Therefore, educating workers on safety and health issues present in mines and training them in how to deal with the dangers present in the workplace helps the workers to be safe

FIGURE 9.3 Advantages of educating workers in health and safety information.

while working. Educating workers in health and safety information has the merits shown in Figure 9.3 (Kullabs, 2018).

Providing effective training to workers has the merits shown in Figure 9.4 (HSE, 2018c).

9.2.1 Principles of Safety Training

A training program in any organization will yield positive results only if the program is framed on clearly defined, specific requirements of the workplace. If the training program is not based on an analysis of such training requirements, the following results may occur:

- waste of resources such as money and materials
- waste of time
- false confidence regarding safety given
- high chance of accidents

To define the specific requirements of the workplace, a training needs assessment should be conducted. The training needs assessment can be defined as the process of identifying the problems indicated by a lack of compliance with standards that can be resolved partly or wholly by training. The first step in designing a training

FIGURE 9.4 Advantages of training workers on health and safety information.

program is to identify the problems in the workplace that need attention. The problems in a mine can be found in inspection reports, violation reports, accident statistics, and incident reports. The steps in training needs analysis are as follows:

- problem identification
- problem analysis
- identification of training needs
- ranking the order of the needs identified
- setting training goals and objectives

9.3 TYPICAL TYPES OF TRAINING MATERIALS IN THE MINING INDUSTRY

The aim of the training materials provided to workers, supervisors, managers, and employers, is to offer (OSHA, 2018)

- the knowledge and skills required to
  - carry out work safely
  - avoid creating hazards that could cause risk to others or selves

- increased awareness and understanding of workplace hazards
- methods to identify, report, and control workplace hazards.
- specific training when the work involves unique hazards.

Depending on the nature of the job, additional training may be required for workers, managers, and supervisors. For example, managers and supervisors may need specific training to ensure that they can fulfill their roles in providing leadership, direction, and resources for the safety and health program. Workers assigned to specific roles in the program may need training to ensure their full participation in those functions. Along with formal classroom training, informal training, such as on-the-job training, on-site explanation, or peer-to-peer training, can provide effective education and training. Informal training methods are also effective in ensuring the identification of hazards and their control and communicating safety concepts. A series of training steps to be provided for employees is presented in Figure 9.5.

Step 1: Provide program awareness training

- Initially, the program's plan, process, procedure, and structure should be understood by all the employees. Ensuring that workers, supervisors, and managers have sufficient awareness and prior knowledge of these will help obtain full participation in the program, as well as its effective development, implementation, and improvement. To achieve this aim training should be provided as follows:
  - provide training to all workers, including temporary workers, contractors, and subcontractors on
    - the safety and health program and its functions, objectives, policies, procedures

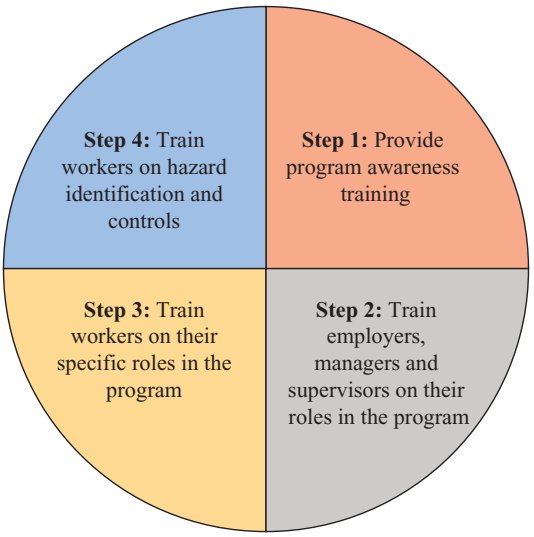

FIGURE 9.5 Series of training steps to be provided for employees.

  - the responsibilities of the employer and the rights of workers
  - how to report accidents, injuries, near-miss incidents, illness and hazards
  - how to react in an emergency
- provide information on the types of hazards present in the workplace, including both health and safety hazards
- provide information on the current preventive or control techniques being followed for the identified hazards
- ensure all workers understand the above training, and, if required, provide training material in the local language
- point out that all workers have the right to report hazards, minor incidents, injuries and near miss incidents

Step 2: Train employers, managers, and supervisors in their roles in the program

- Depending on the roles of employees, their responsibilities will vary. Therefore, training of employees is based on their roles. Supervisors and managers require specific training to fulfill their leadership roles and the workers require specific training based on their working areas
  - Point out the roles, responsibilities, and duties of employers, managers, supervisors, and workers under the legislative act
  - Train employers, managers, and supervisors
    - on the basic concepts of recognizing and evaluating hazards and the hierarchy of controls
    - on investigating techniques and identifying root causes of the accidents
    - the ways to respond to workers' reports of accidents, injuries, near-miss incidents, illness, and hazards

Step 3: Train workers on their specific roles in the program

- Additional training should be provided to workers in order to carry out their jobs safely
  - Provide instructions on
    - how to report accidents, injuries, near-miss incidents, illness, hazards, and any other concerns
    - hazard identification and control
    - program evaluation and improvement
    - participation in accident investigations

- In order to mitigate the dangers to workers as a result of mechanization/adverse geo-mining conditions, new mining technology, advance mining methods, etc., modules on various topics should be provided by management. A few of the on-the-job training modules provided in the Indian mining industry are as follows (DGMS, 1999):
  - For underground workers
    - material transportation
    - coal transportation

  - ventilation
  - roof support
  - drilling and blasting
  - cleaning and dusting
  - loading coal
  - maintenance of equipment and machines

- For surface workers
  - lamp cabin
  - compressor house, substation
  - pit top, coal handling plant, crusher house, wagon, loading
  - workshop and stores

- For opencast workers
  - electrical repairing
  - mechanical fitting
  - dumper operating
  - shovel operating
  - heavy blasting
  - blast hole drilling

Step 4: Train workers on hazard identification and controls

- For ensuring the safety of workers in the workplace, the workers should be trained to identify hazards and control measures. To achieve this, training should be provided in the following areas:
  - informal and formal methods for identifying hazards
  - the workers' job-related and general work-related hazards, and any other hazards if assigned a new task
  - hierarchy of controls measures
  - safe operating procedures
  - personal protective equipment
  - administrative controls

9.4 EDUCATION AND TRAINING PROVIDED IN VARIOUS COUNTRIES

9.4.1 ILO

Different countries have developed different education and training policies according to their requirements. Hecker (2001) stated that national education and training policies and practices will vary according to the cultural, political, economic, social, and technological background of the country. The industrially developed nations have framed state-of-the-art education and training programs and have more specialized safety and health experts than the developing nations.

In 1981, the Joint International Labour Organization/World Health Organization (ILO/WHO) Committee on Occupational Health identified the three levels of

education required in occupational health, safety, and ergonomics as (1) awareness, (2) training for specific needs, and (3) specialization (Hecker, 2001). The committee also identified the main target groups that require awareness in the safety and health area. The target group includes government legislators, company policymakers, managers, and workers. Within the target area a few government legislators, company policymakers, managers, or workers may require special training for doing specific jobs. With the ever-changing and rapidly developing work environment, specialists are required in the workplace. Such specialists require very intense education and training, much like the postgraduate and undergraduate programs of study. The basis of specific training depends on the target audience, such as upper- and middle-level managers, supervisors, and employees, as shown in Figure 9.6.

Upper- and medium-level managers and supervisors must be aware of

- different types of hazards, such as physical, psychological, chemical, and biological hazards present in the workplace
- social, organizational, and industrial relations factors that affect the present hazards

Employees need to understand and apply

- safety operating procedures
- proper tools to be used

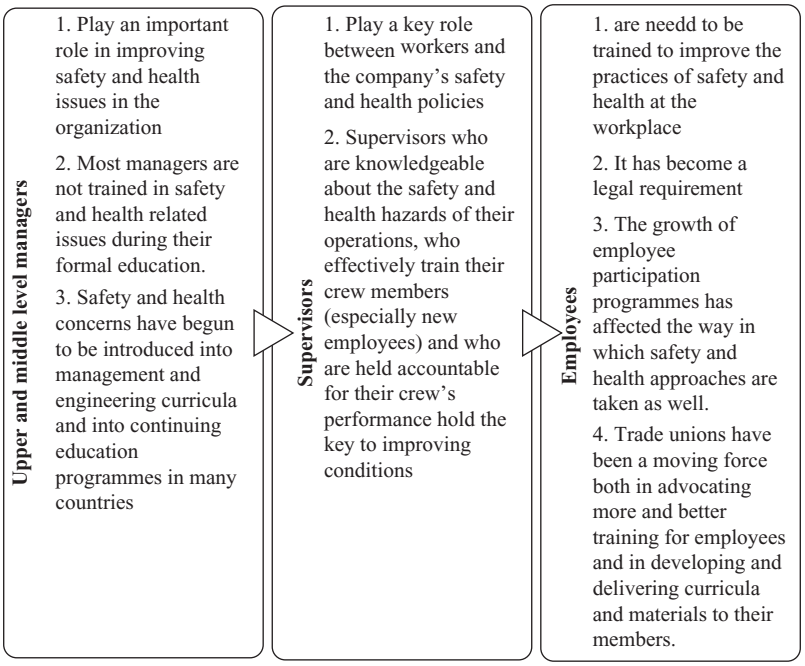

FIGURE 9.6 Types of target audience groups.

- personal protective equipment
- how to rectify identified hazards
- internal company procedures

9.4.1.1 On-the-Job Training

On-the-job training at the workplace is suitable for employees and supervisors facing specific hazards at the site. It is strongly recommended to provide the training in a classroom only if the training is of significant length.

9.4.1.2 Academic and Professional Training

There is an increasing demand for more trained safety and health experts in the developing nations. Alternatives to the university-based degree programs include on-the-job training, self-training, continuing education, and distance education, these all help for professional training development.

9.4.2 The United States

In the United States, the training requirements are pointed out in the sections of the federal code – 30 CFR Part 48 and Part 46 (MSHA, 2018d) (Tables 9.1 and 9.2). Part 48 covers all underground mining and surface mining of coal and some metals, such as gold. Part 46 covers the aggregate industry, including granite, sand, gravel, lime, and cement operations. The key difference between Part 48 and Part 36 is that Part 48 trainers must be approved by the Mine Safety and Health Administration (MSHA) while the Part 46 trainers do need this approval.

TABLE 9.1

30 CFR Part 48

Sub Part A	Training and retraining of underground miners
48.5 – Training of new miners; minimum courses of instruction; hours of instruction	
48.6 – Experienced miner training	
48.7 – Training of miners assigned to a task in which they have had no previous experience; minimum courses of instruction	
48.8 – Annual refresher training of miners; minimum courses of instruction; hours of instruction	
48.11 – Hazard training.	
Sub Part B	Training and Retraining of Miners Working at Surface Mines and Surface Areas of Underground Mines
48.25 – Training of new miners; minimum courses of instruction; hours of instruction	
48.26 – Experienced miner training	
48.27 – Training of miners assigned to a task in which they have had no previous experience; minimum courses of instruction	
48.28 – Annual refresher training of miners; minimum courses of instruction; hours of instruction	
48.31 – Hazard training	

TABLE 9.2

30 CFR Part 46

Part 46	Training and retraining of miners engaged in shell dredging or employed at sand, gravel, surface stone, surface clay, colloidal phosphate, or surface limestone mines
46.5 – New miner training	
46.6 – Newly hired experienced miner training	
46.7 – New task training	
46.8 – Annual refresher training	
46.11 – Site-specific hazard awareness training	

In-person courses are held regularly at the National Mine Health and Safety Academy in Beaver, West Virginia (MSHA, 2018d). MSHA offers wide variety of mine safety and training programs that are in-person and also online.

9.4.2.1 Training Courses Developed by MSHA

These courses of study address the training needs of miners, mine safety and health inspectors, government and industry personnel, and others concerned with the health and safety of our nation's miners. The courses covered are shown in Figure 9.7 (MSHA, 2018e).

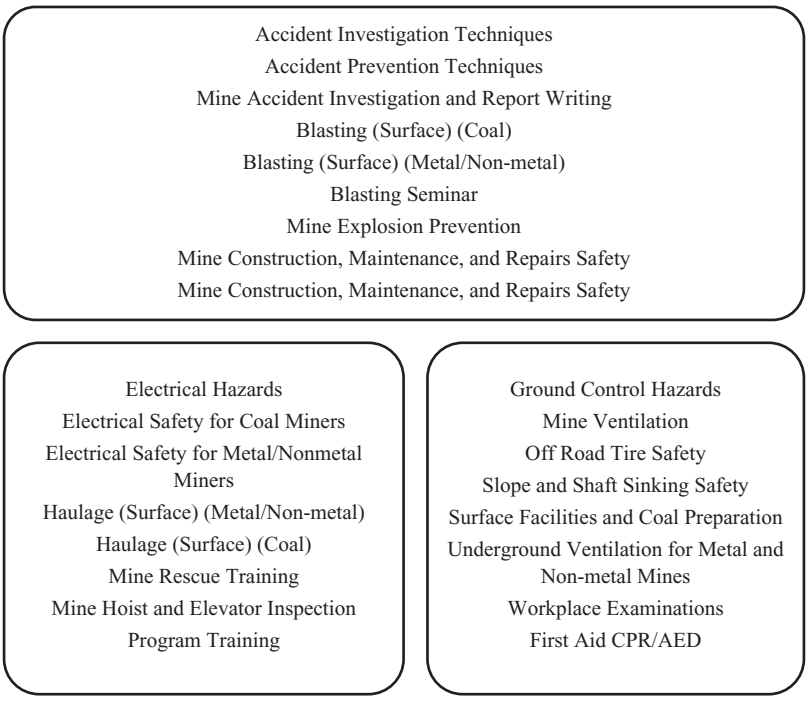

FIGURE 9.7 Types of training courses developed by MSHA.

9.4.3 The United Kingdom

In the United Kingdom, the Management of Health and Safety at Work Regulations 1999 (UK Legislation, 1999), covers the training requirements in the UK mining industry.

Rule 13 (2) Every employer shall ensure that his employees are provided with adequate health and safety training –

(a) on their being recruited into the employer's undertaking; and

(b) on their being exposed to new or increased risks because of –

their being transferred or given a change of responsibilities within the employer's undertaking,

the introduction of new work equipment into or a change respecting work equipment already in use within the employer's undertaking,

the introduction of new technology into the employer's undertaking, or

the introduction of a new system of work into or a change respecting a system of work already in use within the employer's undertaking.

Rule 13 (3) The training referred to in paragraph 13 (2) shall –

(a) be repeated periodically where appropriate;

(b) be adapted to take account of any new or changed risks to the health and safety of the employees concerned; and

(c) take place during working hours.

9.4.4 Australia

The Australian minerals industry uses a formalized approach for analyzing mine operating needs for training intended to improve performance. It should incorporate safety and health training with both skills and task training (Department of Mines, Industry Regulation and Safety, 2002). The main responsibility of the mine operators is to implement a training scheme in mines. The steps in the training schemes are shown in Figure 9.8.

9.4.4.1 Training Program Requirements

- The training scheme should
  - provide initial induction training for newly employed workers
  - give additional training for workers transferred to new workplace
  - give refresher training for all the workers
  - train and employ workers on the surface of the mines before they proceed to work underground
  - train under personal guidance when undertaking new tasks
  - give skills maintenance training
  - keep records of the training.
- Training should focus on
  - job and task performances
  - identifying potential failures

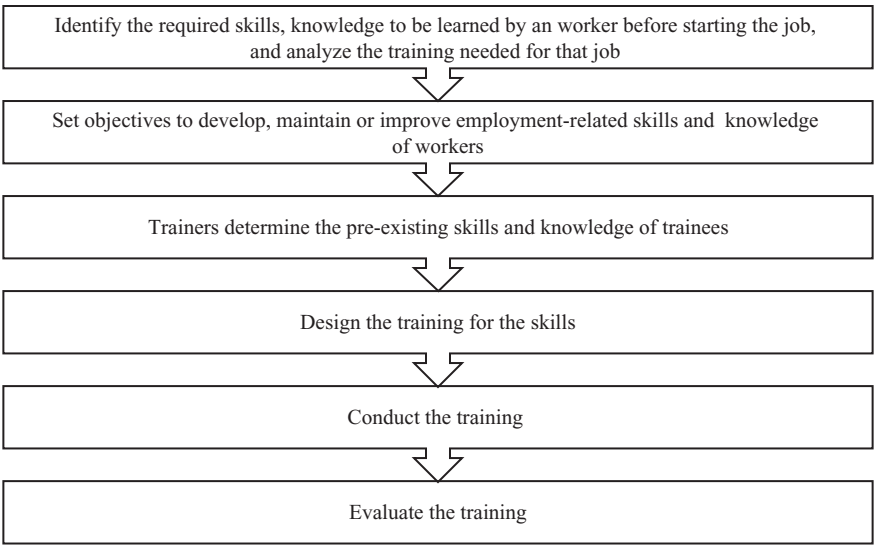

FIGURE 9.8 Steps in training scheme.

  - hazardous conditions
  - unsafe work situations
- Refresher training should include describing techniques for updating all workers on changes in the working environment, changes in working procedures and practices, and new equipment operating procedures
- Review mine training schemes regularly

9.4.4.2 Training Needs Analysis

Before providing different types of training to employees, it is necessary to analyze the training needs in the organization to assess the types of training required by the workers. Analyzing training needs includes the analyzing the work environment, skills, and knowledge of all the workers as well as analyzing the actual tasks that people carry out. The stages of training needs analysis are as follows:

- study the place of work
- analyze jobs
- forecast job changes
- evaluate the current approach employed toward health and safety at work
- assess management training needs
- assess supervisors' training needs

A joint approach to training, where managers, supervisors, and health and safety representatives attend training together, can produce good results.

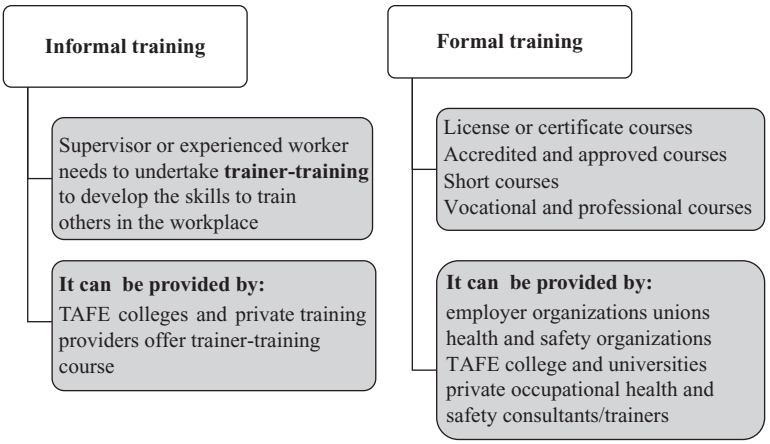

FIGURE 9.9 Methods of training.

9.4.4.3 Types of Training

The type of training to be provided for each employee will be depends on the following:

- role and responsibility of the worker
- workers' occupations
- types of injuries and diseases recorded at the workplace
- hazards present at the workplace
- hazards identified during the inspection

Informal training and formal training are the two ways of providing training to employees, as shown in Figure 9.9.

9.4.4.4 Specific Training Requirements

Along with formal and informal training as part of the safety and health program, specific training is required for all the employees in the organization. The types of specific training are

- induction training
- follow-up on induction training
- on-the-job training
- first aid training

9.4.4.5 Induction Training

Induction training should be provided to all new or transferred employees. Induction training for new and transferred employees could include the following:

- a description of the safety and health committees present in the organization
- an introduction to safety and health representatives

- a visit to the workplace
- a description of the facilities present at the workplace
- a description of the hazards present at the workplace and the current measures employed to control risks
- a visit to the location of firefighting equipment
- an explanation of how to use the firefighting equipment
- a review of the location of emergency exits
- the distribution of personal protective equipment and clothing, such as safety jacket, hard hat, safety boots, etc.

Induction training enables the employees to

- familiarize themselves with the roles and duties of the safety and health representatives and committees
- familiarize themselves with the safety and health procedures present in the workplace
- familiarize themselves with the role and responsibilities of the employees
- recognize the hazards of the workplace
- understand ways to report recognized hazards to the supervisors
- familiarize themselves with general safety rules, such as
  - emergency response plans
  - emergency escape routes and assembly points
  - equipment safety
  - hazard communication
  - safe operating procedures
  - proper ergonomic techniques
  - accident, near-miss, and violations reporting

9.4.4.6 Follow-Up on Induction

The supervisors, to make sure that new or transferred workers understand the description of the job and to ensure that safe operating procedures are being followed, should carry out regular follow-ups after induction. Depending on the kind of the job and the workplace environment, follow-ups should be carried out daily until the supervisor is satisfied, and then on a weekly basis for a minimum of three months.

9.4.4.7 On-the-Job Training

On-the-job training varies from one job to another, as different jobs have different roles and locations. To ensure that any particular job is carried out successfully, training should be provided in the following areas:

- check previous work experience of the worker
- explain the job to be carried out in detail
- explain the main role of the job
- give an demonstration of
  - safe operating procedures

  - potential hazards in the workplace
  - risk control or mitigation measures
- ask the worker to identify the possible hazards in the workplace
- observe the worker while performing the job and suggest corrections if any are required
- observe the worker until the person in charge is fully satisfied with the worker's understanding of the job.

9.4.4.8 First Aid Training

Induction on first aid training, facilities available, and practices at the mine should be given to all newly recruited employees in the mines. It helps in providing first aid in an emergency. The workers employed as part of the first aid facility should have completed first aid training, which includes artificial resuscitation techniques. The first aid certificate-holders should be re-examined at least every three years.

9.4.5 South Africa

According to the Mine Health and Safety Act, 1996 (MHSA, 1996), the Mining Qualifications Authority (MQA) must establish the education and training standards for the South African mining industry. The MQA is the sector education and training authority (SETA) for the mining and minerals sector. MHSA contains three main approaches related to health and safety training and education provisions

- workers should be trained to execute specific operations in ways that combine self-protection with the avoidance of risks to fellow workers and others who may be affected, including the general public
- induction and refresher training should be designed for all mine officials focusing on the problems that represent the greatest risk to health and safety
- Adult Basic Education and Training (ABET) is a primary intervention for health and safety in the mining industry

As far as reasonably possible, managers of mines should provide health and safety training to all their employees in order to assist them to perform their work safely and without risk to health.

9.4.5.1 Task- and Operator-Focused Training

- One aspect of health and safety training is to provide workers with training to execute specific operations in ways that enable them to work without risk to their own health and safety, or that of others.
- The MQA has facilitated the production of extensive qualifications and 140 skills programs, and has assisted in the development of associated national unit standards relating to the mining activities of many workers, such as explosives handlers, blasters, drillers, winch operators, drivers, and shaft sinkers.

9.4.5.2 Induction and In-Service Training

- The training of mine workers such as machinery operators, drivers, and laborers is the main responsibility of the employer. Since the literacy rate is very low and many workers do not have adequate formal schooling, they are usually trained for the particular job after securing employment.
- The MQA has provided guidelines for employers regarding safety and health training for the induction of new recruits to mining, or any other underground workers.
- Employers, using their own training sections or third party training providers, usually provide induction training and refresher training of their choice. The mine management or mine manager will determine the quality, number of days, and types of training to be provided.

9.4.5.3 Education and Health and Safety

All mining companies move forward the national initiative in adult education with a view to improving communication in mines, which will, in turn, result in improved health and safety. Adult basic education and training are the most relevant training interventions for health and safety. The MQA was specifically tasked with the improvement of the occupational health and safety (OHS) skills capacity in the industry, by reducing the rate of illiteracy and increasing the supply of human resources in areas where skills that are critical to OHS are scarce.

9.4.6 India

In India, the Mines Vocational Training Rules, 1966 were framed with the aim of educating mine workers about the challenges of mining. These rules provide initial, refresher, and specialized training for mine workers. The training for workers should be provided at the mines' vocational training centers, approved by the Directorate General of Mines Safety (DGMS).

9.4.6.1 Vocational Training Centers

These centers are located and maintained by the various mine managements at convenient points accessible to all workers, both employed and to be newly employed. The DGMS may permit a common training center for any group of two or more mines (under the same management or even different managements), if they are so situated as to be convenient for such instruction. Every such center should be placed under the charge of a whole- or part-time training officer, duly qualified and assisted by competent instructors and other staff. Necessary equipment, including audiovisual aids and other facilities for the various courses of instruction should be provided at the training centers. The types of vocational training centers are shown in Table 9.3.

The schedule of training provided for mine workers in Indian mines is shown in Table 9.4.

TABLE 9.3
Types of Vocational Training Centers

A.	Vestibule Training Centre (large, management-wise)	To serve a group of coal mines belonging to the same management with a total employment of 10,000 workers or above
B.	Group Training Centre (medium, area-wise)	To serve a group of coal mines belonging to the management or different managements with a total employment of at least 2,500 workers
C.	Unit Training Centre (small, unit-wise)	To serve a unit (individual) coal mine employing over 800 workers

TABLE 9.4
Schedule of Courses Provided

First	Rule 6(1): Course of theoretical and gallery training for surface and opencast workers
Second	Rule 6(2) (a): Course of theoretical and gallery training for workers below ground
Third	Rule 6(2)(b): Course of special additional training for entrants to gassy mine
Fourth	Rules 8 and 10: Course for refresher training
Fifth	Rule 12: Course of training for timber mistry (Foreman)
Sixth	Rule 13: Course of training in the handling and use of explosives
Seventh	Rule 14: Course of training on shot-firing
Eighth	Rule 17: Course of training in gas testing

9.4.6.2 Basic/Initial Training Courses

Apart from a six-day course of lectures and demonstrations at the above centers for all new entrants, a scheme of practical (on-the-job) training, under the close personal supervision of competent trainers, should be imparted at the place of work in the mines. These "trainers" are to be carefully selected from skilled workers, who are themselves given a course of six safety lectures specially designed for the purpose, before new entrants are placed under their charge. In the case of underground workers, this "on-the-job" training should extend over a period of 12 days. Also an additional course of training for six days should be given at these centers to those workers who are to be employed in gassy mines.

9.4.6.3 Refresher Courses and Special Training Courses

A course of off-time refresher training should be given for (a) all categories of present workers, such as those engaged in shot-firing blasting operations and gas-testing personnel. Also newly employed timber mistries in mines should be given a special course of whole-time instruction for a week. At least one-fifth of the persons employed at each mine are to be trained in the above refresher course every year.

TABLE 9.5
Summary of the Training Scheme

Sl. No.	Category of workers	Ref. to rules and schedule	*No. of days of lectures at vocational training	Remarks
A. Initial/Basic Course				
I.	All new entrants for employment in work	Rule 6		For underground workers an additional course of "on-the-job"
	(a) above ground/opencast workings;	Sch. I	6 days (whole-time)	Training for 12 days under direct personal supervision of "trainers"
	(b) below ground in gassy non-mines; and	Sch. II	6 days (whole-time)	Also workers to undergo relevant courses for change in place of employment
	(c) below ground in mines	Sch. II & III	12 days (whole-time)	
B. Refresher Course				
1	Re-employed workers after Rule 8 break of service of one year or more;			
	(a) on surface and opencast workers	Sch. IV (1)	3 lectures	Training within one month for re-employment
	(b) for underground workers in gassy mines	Sch. IV(1)+IV(2) + IV(3)	3+3+6=12 lectures	
	(c) for underground workers in non-gassy mines	Sch. IV(1)+IV(2)	3+6 = 9 lectures	
2	Already employed workers in gassy mines i.e. category (b) above	Rule 10 Sch. IV(3)	6 lectures	All persons to be trained during the first year
3	Already employed workers, categories (a) and (c) as above	Rule 9 Sch. IV(1) & IV(2)	3 + 6 = 9 lectures	At least one-fifth of the total number of persons in each category be trained each year
C. Development Course				
1	All workers employed in handling explosives and also those with a break of service of 6 months or more	Rules 13 & 16 Sch. VI	6 lectures	All persons to be trained during the first year. For opencast metalliferous mine workers, a course of four lectures only.
2	All potential shot-firers before appearing for competency examination as newly appointed shot-firers who have not undergone this course of training or with a break of service exceeding 6 months	Rule 14 Sch. VII	12 lectures	Training to be completed within one month of emp1oyment/ re-employment
3	Timber mistries (a) to be newly employed from categories of timbermen (b) to be re-employed after a break of service exceeding 6 months	Rule 12 Sch. V	6 days (whole-time)	Training to be completed before appointment as timber mistry

Source: The Mines Vocational Training Rules, 1966.

TABLE 9.6
Specific Categories of Underground Workers

Category	Initial training days	Refresher training days
Track layers	24	12
Coal-cutting/drilling machine crew	36	18
Attendants of haulage/conveyors.	24	12
Ventilation (bratticing gang)	18	9
Attendants of fan (including auxiliary and booster fans)	18	9
Stowing gang	24	12
Pick miners	24	12
Persons employed on installation repair and maintenance of machines	24	12
Trammers	24	12
Tyndals	25	18
Loaders	24	12
General mazdoors	18	9
Crane operators (including mobile crane operators)	24	12
Cleaning/wetting/stone-dust barriers/watering-gangs, stone-dusting	24	12
Drill operators.	36	12
Loco drivers	36	18

TABLE 9.7
Specific Categories of Opencast Workers

Category	Initial training days	Refresher training days
Dozer and loader operators	36	24
Dumper operators	36	24
Shovel operators	36	24
Welders and gas cutters	36	24
Fitter helpers	36	18
Fitters, electricians, etc.	70	36
Persons employed in management of materials (stores)	24	12

A working group containing officials from coal, metal, and oil mines was formed in 2015 for the preparation of draft Mines Vocational Training Rules, in order to address the changes in present and future technological developments in mining industry and to include contractor workers' safety (DGMS, 2018b).

9.4.6.4 Mines Rescue Rules, 1985 (DGMS, 1985)

The course of instruction and practices shall be as follows:

Part I: Initial course
A. Instructions: Instructions in the following subjects:

- the general methods of dealing with fires below ground and the recovery of mines after fires and explosions
- the construction, use, repair, maintenance, and testing of the type or types of breathing apparatus provided, and the smoke helmets or other apparatus serving the same purpose
- the use of methods and apparatus for reviving persons
- the properties and the methods of detection of noxious and inflammable gases that may be found in mines
- the taking of gas samples in an irrespirable atmosphere
- the reading of mine plans

B. Practices: Not less than twelve practices with breathing apparatus and not less than two practices with smoke helmets or other apparatus serving the same purpose. The practices in each case shall be carried out under conditions devised to resemble those likely to be encountered in operations below ground and requiring the use of such apparatus and shall be carried out as follows:

- Not more than eight and not less than five men shall take part in any practice.
- The practices with breathing apparatus shall commence in ordinary air, and shall progress gradually until practices can be carried out in a hot and irrespirable atmosphere.
- The practices with breathing apparatus shall comprise the following operations:
  - repeatedly raising and lowering of a weight of 25 kilograms to and from a height of 1.8 meters by means of a rope and pulley
  - walking continuously at a fair pace for half an hour
  - building and removing temporary stoppings of stone, brick, sandbags, brattice cloth or other materials, and carrying the materials required for such operations over a distance of at least ten meters
  - removing debris in a confined space, as representing the clearing of a fall of roof
  - setting timber or other roof supports
  - carrying, pulling. or pushing on a stretcher a live person or dummy body weighing 70 kilograms along the length of the gallery
  - the rapid establishment of communication

Part II: Practices and instructions after becoming competent
A. Instructions: Revision of all subjects included in Part I.

B. Practices: At least eight practices with breathing apparatus in every calendar year of which at least four months shall take place in mines, and the remainder in hot and irrespirable atmosphere in the training gallery at a rescue station. As far as practicable these practices shall be evenly distributed,

so that the gap between two consecutive practices shall not exceed four months: provided that, if a rescue-trained person fails to undergo a refresher practice over a period exceeding four months, the Chairman, Board of Mining Examinations may, on being satisfied that the discontinuance was on valid reasons, permit him subject to the provisions confirmed in rule 21, to undergo a special course of refresher practices and instructions, extending over five consecutive days, whereupon he shall again become active.

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10 Innovations in Mine Safety Engineering

10.1 VIRTUAL REALITY

10.1.1 Introduction

Virtual reality (VR) can best be described as "a way for humans to visualize and interact with the artificial 3D environments created using computer graphics" (Aukstakalnis and Blatner, 1992). VR refers to a high-end user interface that involves real-time simulation and interactions through multiple sensorial channels. It is an illusion of a three-dimensional (3D), interactive, computer-generated reality where sight, sound, and sometimes even touch are simulated to create pictures, sounds, and objects that actually seem real. VR, with its increasing dynamic, interactive, and experiential characteristics, becomes able to simulate real environments with various degrees of realism. VR-based training tools can, by contrast, provide simulated exposure to real-world working conditions without the associated risks. The concept of VR has been around for nearly half a century, however the recent advances in hardware and software have brought this technology to within the budgetary reach of industrial mining usage.

10.1.2 Types of Virtual Reality Systems

- immersive VR
- desktop VR/Windows on World (WoW)
- telepresence
- mixed reality (augmented reality)
- distributed VR

The different types of VR systems are shown in Figure 10.1. A schematic diagram of typical VR architecture is shown in Figure 10.2.

10.1.3 Technology VR

- **Hardware**
  - **Head-mounted display (HMD)**
  - HMD is a device like a face mask or a helmet that fits over the head. A typical HMD uses liquid crystal display or cathode ray tube methods to provide images and may have headphones for audio.
  - **Binocular omni-orientation monitor (BOOM)**
  - BOOM is one of the oldest head-coupled stereoscopic display devices. The display is suspended from a weighted boom that can rotate freely.

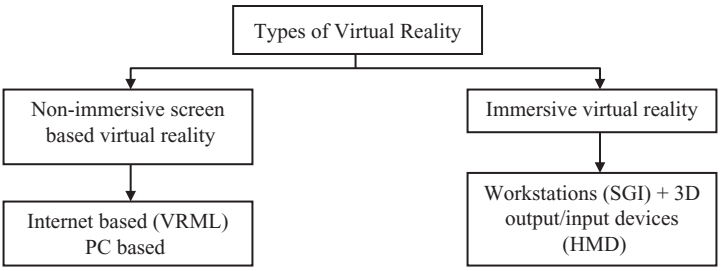

FIGURE 10.1 Types of VR systems.

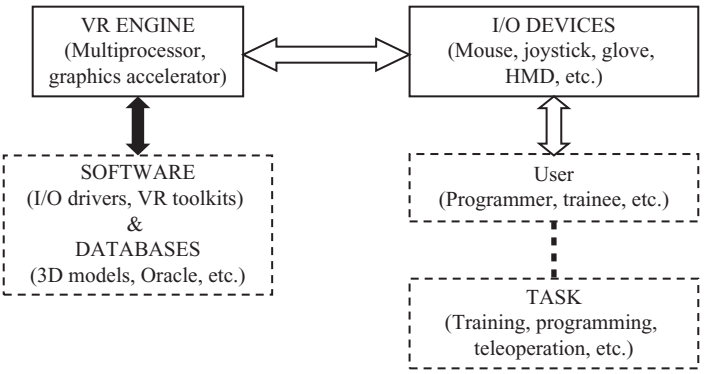

FIGURE 10.2 The architecture of basic VR system.

It uses a cathode ray tube to provide high-resolution display, and it is very easy to use.

- **Cave automatic virtual environment (CAVE)**
- CAVE is an immersive VR environment where the walls and floor of a room-sized cube are used for projecting images. The walls are made up of rear-projection screens. A head-tracking system continuously adjusts the stereo projection to the current position of the viewer.
- **Data glove**
- A data glove looks like a glove worn on the hand, but it is equipped with sensors for tactile sensing and fine motion control. Data gloves enable the natural interaction with virtual objects by hand gesture recognition.
- **Control devices**
- Control devices control the virtual objects in a three-dimensional environment.

- **Software**
  - **Virtual Reality Modeling Language (VRML)**
  - VRML is a standard file format for interactive simulation within the World Wide Web. VRML is a phenomenon that is universally accessible, can be hyperlinked, and is becoming commonplace on the World Wide Web. It is a file format for describing interactive, three-dimensional

virtual environments. It is capable of representing static and animated objects and it can have hyperlinks to other media such as sound, movies, and images (VRML, 1998). VRML has been largely superseded by X3D.

- **X3D**
- X3D is an ISO-ratified, royalty-free, open standard file format and run-time architecture to represent and communicate 3D scenes and objects. X3D is considerably more mature and refined ISO X3D standard. It provides a system for the storage, retrieval, and playback of real-time, 3D scenes in multiple applications, all within an open architecture, and supports a wide range of domains and user scenarios (Web3D, 2018).

- **Architecture**: The architecture of VR has the following components:
  - input processor
  - simulation processor
  - rendering processor
  - world database

10.1.4 Benefits of Using VR

The Research Triangle Institute noted that the elements that make it hard to train and practice skills in hazardous industries are as follows:

- hazardous working conditions
- unavailability of equipment for training
- high costs involved in training

VR training simulators can be useful in the following conditions:

- when the necessary environment cannot be experienced in the real world
- to make training situations really "real"
- when training mistakes would be costly
- to build interfaces that are sensible and can be manipulated

The advantages for the mining industry of using VR training systems are as follows:

- the cost required for providing real-world training is reduced drastically
- systems can be designed in different languages
- VR has a flexible configuration, can be customized, and is interactive
- they protect the trainee from being exposed to real-world hazardous conditions
- they improve safety, reduce accidents or injuries, and fatality numbers
- they reduce learning time for instructors and trainees
- they provide unlimited access to costly/non-available machines
- they enable practice without training in hazardous/dangerous conditions

10.1.5 Applications of VR in the Mining Industry

VR is a more immersive way of interacting with computers for certain applications. The requirements will vary for different industries or sectors. In the mining industry, the application of VR is mainly focused on training, hazard identification and controlling, and equipment simulation. The different countries/agencies involved in VR applications in mining and their areas of research are summarized in Table 10.1 (Stothard and Swadling, 2010; Mitra and Saydam, 2011).

10.1.5.1 CSIRO – VR in Mine Automation

Australian Commonwealth Scientific and Industrial Research Organization in short CSIRO has developed a technique for simulating rock mass behavior, and integrating complex, geospatial datasets into web-accessible 3D models. This allows the mine management to provide training on complex data in a normal environment.

10.1.5.2 University of New South Wales – Developing and Deploying Simulations

The University of New South Wales (UNSW) faculties of engineering, in collaboration with the College of Fine Arts, has developed a 360° surround, VR, stereo-projection theater system known as Advanced Visualization and Interactive Environment (AVIE). It has developed and deployed immersive, interactive simulations widely within the Australian mining industry and 18 different mine safety training and mining engineering education modules have been run in the AVIE environment.

Three large-screen projection units are used to create an underground coal mine in the AVIE environment. The training program is scenario-based, and the trainees are required to answer various safety-related questions. Trainers will interact with the trainees to clarify points, lead discussions, answer questions, and check on progress.

The School of Mining Engineering at UNSW initially developed eight modules aimed at training coal mine workers for the New South Wales Mines Rescue Stations. These eight modules included

- hazard awareness
- rib and roof stability
- self-escape
- truck inspection
- isolation procedures
- spontaneous combustion
- deputies inspection
- outburst management.

10.1.5.2.1 Hazard Awareness Module

The hazard awareness module contains a 3D representation of a coal mine room and pillar development in which 24 hazards are present and includes – coal accumulation under conveyor belt, missing drive head guards, unsupervised equipment, water

TABLE 10.1
Countries Involved in VR Applications in Mining

Country	Organization	Areas
Australia	University of Queensland	• Mineworker and student training • Data visualization • Accident investigation
	University of New South Wales	• Mineworker and student training • Data visualization
	CSIRO	• Mineworker and student training • Data visualization • Equipment simulation
	Western Australia Department of Industry and Resources	• Data visualization • Accident investigation
Canada	Mining Innovation Rehabilitation and Applied Research Corporation (MIRARCO)	• Geology • Geochemistry • Equipment simulation
Germany	Deutsche Montan Technologie GmbH	• Mineworker and student training • Data visualization • Equipment simulation
	Deutsche Steinkohle	• Mineworker and student training • Data visualization • Equipment simulation
South Africa	SIMRAC and CSIR Miningtek	• Hazard awareness training
	Kumba's VR Mine Design Centre, University of Pretoria	• Testing evacuation procedures • Accident reconstruction • Mineworker and student training • Risk analysis • Responding to potential hazards
	STS3D	• Blasting simulation
	Tshwane University of Technology	• Hazard identification and control
Spain	AITEMIN (Association for Research and Industrial Development of Natural Resources)	• Mineworker and student training • Equipment simulation • Data visualization
United Kingdom	AIMS, University of Nottingham	• Mineworker and student training • Data visualization • Equipment simulation • Accident investigation
United States	National Institute for Occupational Safety and Health (NIOSH)	• Mineworker and student training • Data visualization • Accident investigation
	Pennsylvania State University	• Mineworker and student training • Accident investigation
	Virginia Polytechnic Institute	• Mineworker and student training • Data visualization • Accident investigation
	University of Missouri-Rolla	• Mineworker and student training • Equipment simulation

accumulation, sagging roof, equipment in unsafe locations, shuttle car operation and traversal of shuttle car wheeling roads, auxiliary fan operation, etc. Similar to the roof and rib stability module, the trainees can navigate through the mine and select areas that are deemed to be hazardous.

10.1.5.2.2 Isolation Module

This module contains a 3D representation of a coal mine room and pillar development. The module is split up into six sub-modules, each of which allows trainees to follow a mining procedure involving some form of hazard, and examine the issues involved in the correct isolation and restoration of energy. These include the following:

- Conveyor belt fines accumulation: a section of the belt must be cleaned
- Feeder breaker: a large rock has jammed the feeder breaker
- Continuous miner vent: the continuous miner must be isolated in order to install vent tubes
- LHD: the steering hose on the LHD needs to be replaced
- Box and fan move: the auxiliary fan and load center are to be advanced to the next pillar
- Belt and fire line move: the conveyor belt, feeder, and fire line are to be advanced to the next pillar

10.1.5.2.3 Outburst Module

The outburst module was developed to make people aware of what a gas outburst is, as well as learn the consequences, in order to prevent such events in future. The module presents a virtual reproduction of a catastrophic outburst event. Trainees are then presented with information about outburst management procedures and ten common outburst indicators.

10.1.5.2.4 Mining Education VR Modules

There are eight educational modules aimed at both undergraduate and postgraduate mining engineering students in order to improve effectiveness in the teaching and learning experience. These include

- ViMINE
- truck and shovel
- laboratory rock testing
- mining in a global environment
- seismic data monitoring for a block caving mining system
- longwall top coal caving
- block caving
- coal geology (under development)

10.1.5.2.5 ViMINE

ViMINE allows mining engineering students to experience various aspects of a mining operation, working together and integrating several types of simulation into one

environment. The students can access information from different simulations and make decisions throughout the life of the simulated mine, from initial exploration to final site rehabilitation, and evaluate their effectiveness for building systems-thinking skills. ViMINE allows students to carry out a number of mine design projects where they can link separate mine planning and design simulation software packages as part of one simulation exercise and to design various aspects of a mining operation and assess the feasibility of different design options. The ViMINE mining method selection module is a simple module used for mining method selection. Fourteen different terrains are available to simulate the various possible surface environments, which might exist in proximity to a mineral deposit. The students then decide on the mining method using their knowledge and taking into consideration environment and possible community constraints.

10.1.5.2.6 Truck and Shovel Module

This module contains a library of resources pertaining to truck and shovel operations. The first part acts as a virtual tour of several truck and shovel operations and contains 23 photographic 360° panoramas, 2 aerial photographs, 6 interviews with personnel, 3 full resolution 360° panoramic videos, 15 assorted videos, and almost 400 still photographs. Students can also navigate, in 3D, a full digital terrain map of an open-cut mining operation at the Hunter Valley, NSW, Australia.

10.1.5.3 Western Australia Department of Industry and Resources

In 2017, the Department of Mines, Industry Regulation and Safety superseded the Western Australia Department of Industry and Resources. This department creates tools for incident and accident investigations and mine workers training by using digital photographs and 3D interactive virtual environments. It also supports mining applications such as the monitoring of mine environments and the analysis of rock mass structure.

10.1.5.4 University of Queensland – VR Research at MISHC (Minerals Industry Safety and Health Centre)

The Institute of Sustainable Minerals Industry, Advanced Computer Graphics and the Virtual Reality Research Group (SMI-VR) at the University of Queensland, in conjunction with various research organizations, have developed VR applications to address a number of mining industry issues, such as accident reconstruction, mining engineering education, mine planning, safety training, environmental hazard assessment, and data visualization. The VR applications developed are shown in Table 10.2 (Kizil, 2003; Kerridge et al., 2003).

Along with the above applications, a number of accident reconstruction projects have been developed and six teaching modules for virtual mining methods have also been developed. The teaching modules are as follows:

TABLE 10.2
VR Applications in Mining

Area	System	Purpose
Drill rig training simulation	BigTED virtual drill rig system	• Equipment inspection • Operator training
Open-pit simulation	Hybrid system that combines VR, GPS, and the internet	• Data visualization
Underground hazard identification and barring down training simulation	Safe VR	• Equipment and site inspections • Basic workplace health and safety issues identification
Ventilation survey and real-time monitoring simulations	University of Queensland Experimental Mine (UQEM)	• Data visualization • Training and education • Ventilation survey • Real-time monitoring system
Instron rock testing simulation	Instron VR	• Rock testing machine simulation • Uniaxial compressive strength testing simulation

- strip mining
- cut-and-fill mining
- longwall mining
- block caving
- sublevel stoping
- open-pit mining

Training students in the VR environment will help them to gain knowledge on how

- a truck-shovel combination works
- to carry out a laboratory test, e.g. uniaxial compressive strength
- to operate a machine
- to carry out dangerous operations, such as blast tie-in and blasting exercise

10.1.5.5 Deutsche Montan Technologies GmbH (DMT) and Deutsche Steinkohle – Knowledge-Based Maintenance and Training Systems for the Mining Industry

Researchers at DMT and Deutsche Steinkohle have developed VR longwall shield supports, a tailgate drive, and a plough guide for training purposes. They have also created a program for a handheld device to store information miners can use on the job (Kizil, 2003).

10.1.5.6 AITEMIN – VR as a Training Tool for Mine Machine Operators

AITEMIN (in Spain) in collaboration with CERCHAR and LAAS (in France) has developed a VR simulator of a road header. The simulator consists of a motion platform that simulates the incline and feel of the machine along with realistic visual, sounds, and physical sensations (Fuentes-Cantillana et al., 1991).

10.1.5.7 University of Missouri-Rolla – VR Training of Jack-Leg Roof Bolters

Researchers at the University of Missouri have developed a Miner Simulator System (MinerSim) for training underground mining roof bolters. MinerSim is an augmented VR system with integrated hypermedia. Along with the VR roof bolting mine environment, web tutorials including text materials, videos, 3D images, and animations are also provided (Nutakor, 2008).

10.1.5.8 Virginia Polytechnic Institute – Immersive Virtual Environments for Mining and Engineering Applications

The Virginia Polytechnic Institute (VPI) has focused on developing various virtual environments (VEs) for data visualization using adaptive and real-time geologic mapping, analysis, and design of underground space (AMADEUS); hazard identification for powered haulage equipment in metal and non-metal mines; and training on haul trucks and conveyor belts.

10.1.5.9 NIOSH Pittsburgh and Spokane Research Laboratories – Creating Games for Serious Safety and Health Training

Researchers at the National Institute for Occupational Safety and Health (NIOSH) have used a game engine to develop a portion of an underground coal mine for training mine workers. The first aim in the game is to train the workers in reading mine maps. The trainee can walk through the mine freely in 6 entries and approximately 35 crosscuts of the virtual mine environment.

They have also developed fire evacuation training software for training purposes. The fire escape training software allows four trainees to work together in a virtual world via a computer network to locate the proper evacuation routes.

10.1.5.10 VR Systems in South Africa

The application of VR systems in the mining industry is more popular in South Africa than in the United States and Australia. The development of VR systems is more focused on hazard awareness training, causes of ground falls, accident reconstructions, and mine workers' and students' training (Van Wyk, 2006). SIMRAC and CSIR Miningtek developed a PC-based VR for providing hazard awareness training to mine workers.

Kumba's VR Mine Design Centre has developed many modules for educating and training students and mine workers in the VR environment. Animated accident reconstruction simulations have been developed indicating scenes of the causes of an accident as well as procedures for corrective measures to avoid the same. Another module aids trainees to identify the risks and dangers involved with underground moving machinery.

VR simulations are now successfully being used in the mining industry for risk analysis, simulation applications, hazard awareness and training, equipment simulation, working methods simulations, data visualization, and accident reconstructions. It is strongly believed that the application of VR training systems can enhance the mining industry's safety record and save lives by increasing the quality and effectiveness of safety training.

10.2 ELECTRICAL SAFETY

10.2.1 Introduction

Electricity is an essential part of the modern mining industry. In opencast and underground mines electricity is used for various purposes, such as lighting, operating transportation machinery for men and materials, mineral cutting machinery, drilling, etc. Irrespective of the advantages of using electricity, all electrically powered equipment has significant hazards that can harm workers if not maintained or handled properly. There are two types of electricity, i.e. static and dynamic. Dynamic electricity is commonly used in mines. The types of hazards and risks associated with the use of electricity are shown in Figure 10.3.

The major types of injuries associated with the electricity are as follows (NOAA, 2018):

- **Death**: Occurs when electricity flows through a worker's body
- **Serious injury**: Occurs low values electricity flows through the worker's body
- **Burns**: Occur when a worker comes into contact with improperly maintained electrical wiring or equipment; they can also occur due to thermal energy released from the arc
- **Falls**: Occur when a worker working at heights experiences electric shock

10.2.2 Electrical Hazards

10.2.2.1 Electric Shock

Electric shock is a physiological reaction caused when an electric current passes through the human body. The common cause of electric shock is contact with electrical wiring. It occurs when a worker either directly or indirectly is exposed to live

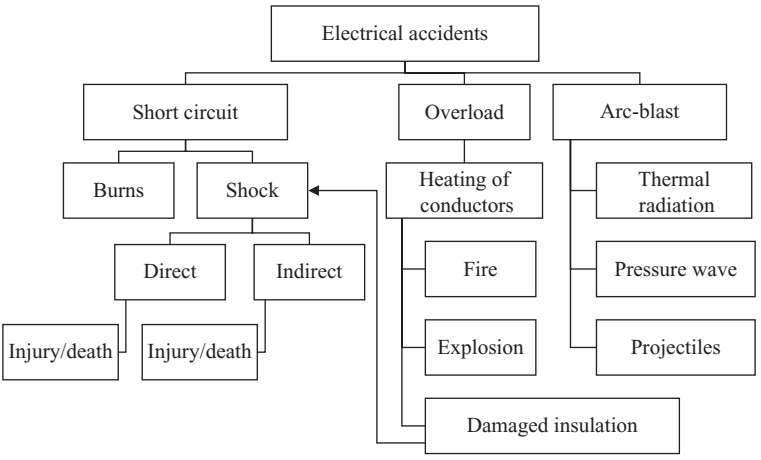

FIGURE 10.3 Accidents due to electricity.

electric wiring. A less common, but still probable, cause of electric shock is exposure to high voltages. A high voltage can be sufficient to jump an air gap between the victim and the electric device. Depending on the magnitude of current, length of exposure time, and dry or wet skin condition, the severity and consequences of an electric shock may vary from minor shock to fatal electrocution. The relationship between the amount of current for a 60-cycle hand-to-foot path of one second's duration of shock and the degree of injury is presented in Table 10.3.

10.2.2.2 Fire and Explosion

Electrical sparks, overheated equipment, or conductors are common sources of ignition for an explosive mixture in the atmosphere of a mine. Improperly connected or spliced wires are a common source of ignition for fire in mines.

10.2.2.3 Arc Flash

Arc flash occurs when high amperage currents arc though the air, irrespective of voltage. Arc flash can occur at the following places:

- transformers
- fused disconnects
- switchboards
- motor control centers
- panel boards
- metal-clad switchgear

When an arc flash occurs, the following hazards may occur:

- the temperature may reach as high as 35,000°F
- a high amount of radiated thermal energy will be exploded from the electrical equipment
- pressure waves with the capacity to damage hearing, eyesight, and memory may be produced
- nearby large objects may be propelled, depending on the pressure waves generated

TABLE 10.3
Relationship Between Electrical Current and Injury

Current	Reaction
1 mA	Perception level
5 mA	Slight shock felt; not painful but disturbing
6–30 mA	Painful shock, "let-go" range
50–150 mA	Extreme pain, respiratory arrest, severe muscular contraction
1,000–4,300 mA	Ventricular fibrillation
10,000+mA	Cardiac arrest, severe burns, probable death

10.2.3 Electrical Safety-Related Work Practices and Protective Methods

Following the safety-related work practices and employing protective methods can prevent harm from electrical hazards when work is performed near or on energized electrical equipment or circuit. The specific safety-related work practices must be consistent with the nature and extent of the associated electrical hazards.

10.2.3.1 Overhead Lines

Unauthorized workers working near overhead lines should not be allowed to handle the conductive objects or come closer. The minimum distances to be maintained are shown in Table 10.4 (OSHA, 1995). Before commencing any work near overhead lines, all overhead lines should be de-energized and grounded.

10.2.3.2 Use of Protective Equipment

Protective equipment must be provided to all the electrical workers to protect themselves from electrical injuries. Electrical protective equipment should be

- in safe, reliable, and good working condition
- inspected and tested periodically

The type of electrical protective equipment and tools to be provided are as follows (EHS, 2018):

- protective shields, protective barriers, or insulating material must be used to protect employees from shock, burns, or other electrical-related injuries.
- protective equipment such as safety glasses for the eyes must be worn
- non-conductive head protection must be worn wherever there is danger of head injury from electrical shock or burns.
- insulated tools and handling equipment must be used by employees working near exposed energized conductors or circuit parts

10.2.3.3 Alerting Techniques

Alerting other workers can help in reducing or preventing electrical accidents. The type of alerting techniques to be used are as follows:

- warn workers by displaying safety signs, safety symbols, or accident prevention tags

TABLE 10.4
Distance to be Maintained from a Worker Working Near Overhead Lines

Voltage to Ground	Distance
50 kV or below	10 feet
Over 50 kV	10 feet (plus 4 inch for each 10 kV over 50 kV)

- barricades such as fences should be provided as well as warning signs.
- if warning signs or barricades are not available, an attendant should be stationed to warn and protect workers.

10.2.3.4 Arc Flash Personal Protective Equipment

Due to the high magnitude of consequences associated with arc flash, appropriate Personal Protective Equipment (PPE) should be used, depending on the energy level as shown in Table 10.5. This PPE provides protection after an arc flash incident has occurred. Workers must ensure that they have reviewed all appropriate safety requirements before starting the work. Face shields or safety glasses, leather-over-rubber hand gloves, and leather boots for energy levels above 4 cal/cm² should be used for arc flash protection.

10.2.4 Safety Instructions for Working with or Near Electrical Appliances in Mines

- Ensure that all electrical equipment is properly
  - grounded
  - connected
  - insulated
  - in good working order
- Do not repair or maintain electrical equipment
  - without turning off the electricity
  - when the working condition are wet
  - when the workers' hands are wet
- A pre-start inspection of all the electrical machinery should be carried out to ensure all the power cables, bars, fittings, and cord-and-plug connected equipment are free from damage. If any damaged equipment is found, repair or replace the damaged equipment before using the machinery.
- When the electrical machinery is under maintenance or repair
  - shut down or disconnect the machinery power supply
  - use lock-out tags to avoid the accidental starting of machinery
  - hang a caution board saying "shutdown taken" on the switch under shutdown

TABLE 10.5
Personal Protective Equipment Requirements for Arc Flash Protection

Category	Energy Level	PPE Requirements
0	≤2 cal/cm²	Non-melting or untreated natural fiber
1	4 cal/cm²	Fire-resistant shirt and pants
2	8 cal/cm²	Fire-resistant shirt and pants, cotton underwear
3	25 cal/cm²	Two layers fire-resistant clothing, cotton underwear
4	40 cal/cm²	Fire-resistant shirt and pants, multilayer flash suit, cotton underwear

  - use low-voltage (LV) or high-voltage (HV) hand gloves
  - use an LV or HV arc flash suit
  - use a face shield
  - the electrician should not wear any metal ornaments or jewelry (such as a metal watch strap, finger rings, or bangles)
- All electrical apparatus associated with the machines should be reasonably free from dust, dirt, and moisture and should be clear of obstruction.
- The electricity should always be cut off from all conductors and apparatus not in use.
- Unauthorized workers should not be allowed to enter a substation or transformer room or enter the working of any apparatus.
- The tripping mechanism circuits of all the electrical appliances should be tested daily.
- Only approved electrical cables should be used.
- All the repaired joints should be properly vulcanized.
- A danger board stating the voltage grade should be provided near all the apparatus.
- A chart for the procedure for shock treatment should be provided at all suitable locations underground.
- The earthing of the flameproof enclosures of all the apparatus should be checked daily.
- The seal, charge and discharge of all cap lamps should be checked before starting the shift.
- The fuses of all cap lamps should be checked regularly – always use right size of fuse.
- The interlocking of surface main mine ventilation with switchgears controlling power to the underground should be done in order to cut off the power supply automatically at the time of breakdown of the main mine ventilation.
- Guard wires should be provided at every road and other line crossing.
- Clearly label all the fuse boxes and circuit breakers.
- Do not touch a worker or electrical equipment in the case of an electrical accident.

10.2.5 Electric Shock Treatment

Step 1: Turn power off from mains. Separate the victim away from the power source using non-conductive items.
Step 2: Check the response of the victim and any visible injuries and call for ambulance.
Step 3: Remove mouth obstructions. The airway may be opened by tilting the victim's head back and lifting this chin.
Step 4: Examine the indications of breathing for five seconds.
Step 5: Check the pulse. If present, put the victim in the recovery position. If breathing is not there, begin rescue breathing. If breathing and pulse are absent administer cardiopulmonary resuscitation (CPR) (alternate 30 chest compressions with two rescue breaths and repeat as needed).

10.3 INTRINSIC SAFETY AND FLAMEPROOF APPARATUS

10.3.1 Introduction

The majority of accidents in the world's mining industry are due to explosions in underground mines. The main source of ignition of these explosion accidents have been traced back to sparks generated by electrical circuits, which are present in electrically operated machinery, signaling, lighting equipment, etc. When a fault develops in an electrical circuit located in a hazardous area, where there is, for example, gas or coal dust present, the fault could cause sparks or heat sufficient to ignite the gas and cause a disaster. Many types of electrical protection have been developed over the years to prevent explosions. According to IEC 60079 (IECEx, 2018), the most common electrical protection types are presented in Table 10.6.

The two most common protection types are

1. intrinsic safety
2. flameproof or explosion-proof equipment

10.3.2 Intrinsic Safety

Intrinsic safety is a non-physical type of protection technique for the safe operation of electrical equipment in hazardous areas. Hazardous areas are those locations in a mine or any other plant that have the presence of explosive mixtures of coal dust, toxic gases, or other combustible materials for long period of time. Intrinsic safety in electrical equipment is provided by limiting the thermal and electrical energy required for ignition and by ensuring only low currents and voltages can enter the hazardous areas. The common method to limit electric current is by using a series of resistors, and the method to limit voltage is by using multiple Zener diodes. Intrinsically safe devices are designed in such a way that they will not be able to produce spark or heat sufficiently to ignite an explosive mixture in the hazardous area. The typical circuit for intrinsically safe apparatus is given in Figure 10.4.

TABLE 10.6
Common Type of Electrical Protection Techniques

Code	Description
d	Flameproof equipment
e	Increased safety
i	Intrinsic safety
m	Molded encapsulation
n	Non-incendiary
op	Optical radiation
p	Pressurization
q	Quartz encapsulation
t	Protection by enclosure

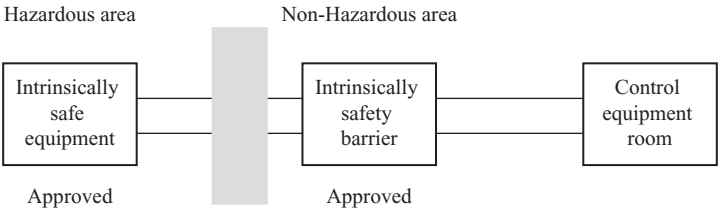

FIGURE 10.4 Typical intrinsic safety circuit.

In intrinsic safety barriers, dangerous incoming potentials are grounded with galvanic isolation barriers. That there is no direct connection between the safe and hazardous area circuits is ensured by interposing a layer of insulation between the two. Both the equipment mounted on the hazardous area and the safe barrier, i.e. galvanic/Zener barrier mounted on the non-hazardous area, must be intrinsically safe. The intrinsic safety protection technique is the only technique that offers maintenance without shutting down the working operation and does not need a gas clearance certificate.

Only circuits that can operate with low voltages and currents can use intrinsic safety methods for protection. The following equipment is designed with intrinsic safety barriers and is available for use in hazardous areas:

- solenoid valves
- current-to-pressure (I/P) converters
- potentiometers
- infrared temperature sensors
- resistance temperature detectors (RTDs)
- strain gauges
- thermocouples
- proximity switches
- pressure, flow, and level switches
- 4–20 mA dc two-wire transmitters
- magnetic pickup flowmeters
- LED indicator lights

Various countries have developed standards for intrinsic safety, as presented in Table 10.7.

The presence of all three elements – oxygen, source of ignition (spark or heat), and gas/dust – is required for an explosion to occur. Intrinsic safety works on the principle of removing the source of ignition by using a Zener barrier or galvanic isolator. Functionally, Zener barriers and galvanic isolators have the same objective, to limit the voltage, current, or stored electrical energy.

10.3.2.1 Zener Barrier

A Zener barrier is a passive device that limits the high voltage and current from reaching the hazardous areas. A Zener diode limits the voltage, while an output

TABLE 10.7
Countries that Developed Standards for Intrinsic Safety

Country	Organization Name
International	IEC (International Electrotechnical Commission)
Italy	CESI (Centro Elettrotecnico Sperimentale Italiano)
UK	BASEEFA (British Approval Service for Electrical Equipment in Flammable Atmospheres)
Germany	PTB (Physikalisch-Technische Bundesanstalt)
North America	Factory Mutual Research Corporation
Canada	Canadian Standards Association

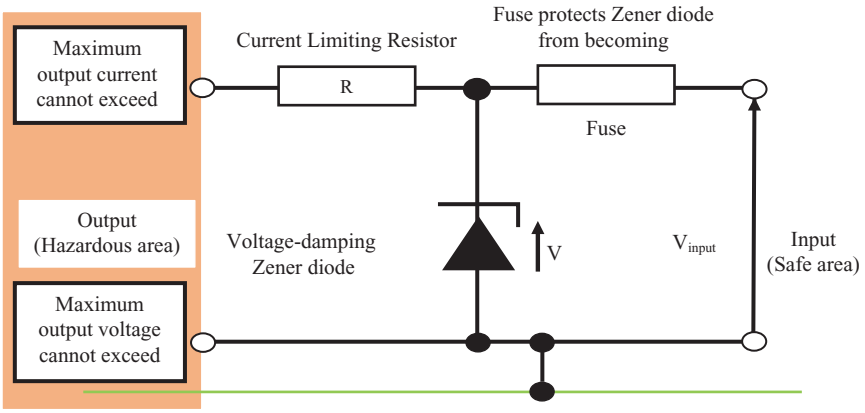

FIGURE 10.5 Zener diode in an intrinsically safe circuit.

resistor limits the current. An intrinsically safe circuit with a Zener diode is shown in Figure 10.5.

The components of the circuit are fuse, current limiting resistor, Zener diode, and intrinsically safe earth. As the safety depends on these components, they are called as safety components. The purpose of the fuse is to protect the Zener diode. The Zener barrier needs to be replaced if the fuse blows due to high voltage above the Zener diode's voltage. The main key to safety is the intrinsically safe earth. The Zener barrier can be used in zone 1, zone 2, and zone 3. The classification of hazard zones (0, 1, and 2) and their suitable intrinsically safe group (Ex i) is presented in Figure 10.6. The "faults" are those in components upon which the safety of the installation depends.

10.3.2.2 Galvanic Isolator

A galvanic isolator is an active device that blocks the low-level direct current (DC) from traveling down the alternating current (AC) safety ground. It works on the principle of isolating functional sections of electrical systems in order to prevent current

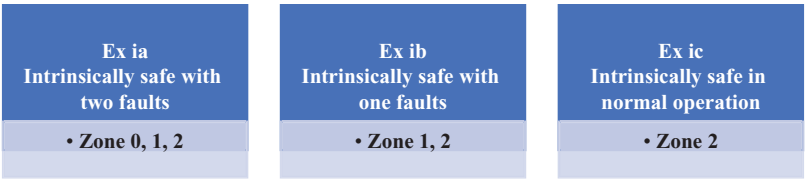

FIGURE 10.6 Classification of hazardous zones and use of intrinsic safety circuits.

TABLE 10.8
Differences between Zener Barrier and Galvanic Isolator

Zener Barrier	Galvanic Isolator
Passive device	Active device
Cost effective solution	Superior, long-term solution
	Better noise immunity
	No intrinsic safety ground maintenance required
	Fewer impedance concerns
	Signal conversion options
	Logic control features

flows. In galvanic isolators, there will be no direct conduction path. The energy can still be transmitted between the functional section by other means such as optical, induction, electromagnetic waves, capacitance, mechanical, or acoustic.

Despite the fact that the objectives of the both Zener barrier and galvanic isolator are to limit energy in hazardous locations, there are differences in principle, operation, etc. The main differences between Zener barrier and galvanic isolator are shown in Table 10.8 (Barbour, 2012).

Irrespective of the barrier used, the intrinsically safe wiring must be separated from non-intrinsically safe wiring by a partition, a conduit, or an air space and should be labeled to distinguish intrinsically safe and non-intrinsically safe wires. Conduits and raceways inside hazardous areas must be sealed or vented so they do not transfer the hazardous atmosphere to the safe area (Esi, 2018). The advantages and disadvantages of intrinsic safety are presented in Table 10.9.

10.4 FLAMEPROOF OR EXPLOSION-PROOF EQUIPMENT

If a system or component is explosion-proof, an explosion is possible, but a specifically designed enclosure keeps the flames, sparks, or hot gases from exiting the enclosure. They typically have extended treaded flanges that provide a long flame path designed to cool and contain the explosion; therefore, any ignition is both contained and controlled (WIKA, 2018).

The equipment is simply contained in a heavy protective enclosure, usually made of die cast steel, occasionally plastic. If heat or sparks from faulty equipment within

TABLE 10.9
Advantages and Disadvantages of Intrinsic Safety

Advantages	Disadvantages
• The most notable advantage of intrinsic safety is that it is the only technique that is allowed to be used under Zone 0 of the IEC Classification system for hazardous areas	• Not suitable for high-power devices
• It prevents explosion risks and provides a safe work environment	• As the intrinsic safety circuits are powered by 24 V DC power, they are only suitable for low-power devices such as small capacity solenoid valves, pressure transmitters, and control valve positioners
• It is easier to install than other protection methods • It is low cost • No need to use bulk explosion-proof enclosures • Maintenance and diagnostic work can be performed without shutting down the production and ventilation in the work area • Ideal for low-power devices • Accepted throughout the world	• Great care is required in installation and maintenance of intrinsically safe field wiring

the enclosure ignite flammable gas present within it, the resulting explosion is contained within the enclosure (LGM, 2018).

Advantages: simple to design the system, suitable for high-power equipment.

Disadvantages: equipment becomes extremely heavy and expensive; opening the enclosure while powered is not permitted

The terms "explosion-proof" and "flameproof" are largely interchangeable. Although there are some subtle differences, engineers and the market in general usually use both terms to mean the same thing, i.e. a piece of electrical equipment designed for use in a hazardous area by means of heavy duty enclosure.

10.4.1 Flameproof Equipment in Mines

Flameproof, the only method generally applicable to lighting and power installations, depends upon mechanical design to prevent any explosion inside the case of the apparatus or machine from igniting the external atmosphere.

10.4.1.1 Definitions of Flameproof Apparatus

According to British Standard 229/4689 (Sinha and Singh, 1966),

> "A flameproof enclosure for electrical apparatus is one that will withstand, without injury, any explosion of the prescribed flammable gas that may occur within it under practical conditions of operation within the rating of the apparatus and will prevent the transmission of flame such as will ignite the prescribed flammable gas that may be present in the surrounding atmosphere."

According to the Directorate General of Mines Safety (DGMS), India, as mentioned in the Coal Mines Regulations (CMR) (2017),

> "flameproof apparatus means an apparatus that can withstand without injury any explosion of the inflammable gas that may occur within it and can prevent the transmission of flame such as will ignite the inflammable gas which may be present in the surrounding atmosphere."

When designing a flameproof enclosure it is to be kept in mind that

- any sparking caused by the electrical equipment cannot and should not ignite firedamp (methane gas) outside the enclosure
- if a flammable mixture of firedamp enters the enclosure and is ignited by electrical sparking the resulting explosion cannot ignite firedamp outside the enclosure.

In view of this, the enclosure must be completed with no holes or gaps through which flames caused by an explosion can pass out. All joints between parts of the enclosure must be a close fit.

10.4.1.2 Types of Flameproof Enclosures

- A totally enclosed (TE) motor is a motor so constructed that the enclosed air has no connection with the external air, but it is not necessarily airtight.
- A totally enclosed, fan-cooled (TEFC) motor is a totally enclosed motor with augmented cooling by means of a fan, driven by the motor itself, blowing external air over the cooling surfaces and/or through the cooling passages, if any, incorporated in the motor.
- A totally enclosed separately air-cooled (TESAC) motor is a totally enclosed motor with augmented cooling by means of a separately driven fan blowing external air over the cooling surfaces and/or through the cooling passages, if any, incorporated in the motor.
- A totally enclosed water-cooled (TEWC) (or other liquid-cooled) motor is a totally enclosed motor with augmented cooling by means of water- or other liquid-cooled surfaces embodied in the motor itself.

10.4.2 Construction of a Flameproof Enclosure

For all flameproof equipment intended for use underground in a mine where flammable gases may be present, the following features of construction are standard.

10.4.2.1 Casing or Housing: It Should Be of Stout Metal Construction

10.4.2.1.1 Joints

If the flame path is long enough and the joint is a close enough fit, flames and hot gases produced by an internal explosion will not be able to ignite any firedamp in the surrounding atmosphere outside. The flame path should never be less than 12 mm (as per BS 229) and less than 6 mm (as per BS 4689). It may vary between 18 and 30 mm for applications in mines.

FIGURE 10.7 Flange joint.

The flames and hot gases pass out through the joints. The shortest route that flames could take through the joint is known as the flame path, as shown in Figure 10.7.

The standard design followed by manufacturers is 0.75 inch to 1.25 inch (18 mm to 30 mm) for applications in mines. However, the joints of most mining equipment have minimum flame path of 1.0 inch with maximum clearance of 0.020 inch as BS 229, or 25 mm. (approx. 1 inch) with maximum clearance of 0.5 mm (approx. 0.020 inch) as BS 4683.

In order to ensure that the heat and flame produced by such an explosion cannot ignite firedamp in the general body of the atmosphere, more closely and tighter fitting joints are required. The maximum joint clearance for oil-filled equipment is 0.006 inch.

- **Joint Surfaces**: All flameproof joints consist either of two metal surfaces, or of one non-metal surface and one metal surface. No paint or soft packing material is permitted.
- **Fixing Bolts**: Fixing bolts have a tensile strength adequate to resist the heaviest pressure likely to be placed upon them.
- **Holes for Fixing Bolts**: Holes for fixing bolts do not pass into the enclosure. These are either blind (or bottomed) or they are situated in external flanges, as shown in Figure 10.8.
- **Shrouding**: The heads of bolts should be fixed properly so that they can be removed only with a box spanner or key (see Figure 10.9).
- **Cable Entries**: Cable entries are always sealed off both from the main enclosure and the external atmosphere as shown in Figure 10.10. Flameproof cable couplers are secured to connecting tubes by grub screws or soldered or crimped connections. The 300 amp FLP (flameproof) adaptor is attached to the FLP terminal chamber through a flameproof flange. The FLP cable coupler is then connected to the 300 amp FLP adapter using standard 300 amp connecting pins.
- **Plugs and Sockets**: When a socket or adapter forms the cable connection to apparatus within a flameproof enclosure, the body of the socket or adapter makes a flameproof joint with the main part of the enclosure.

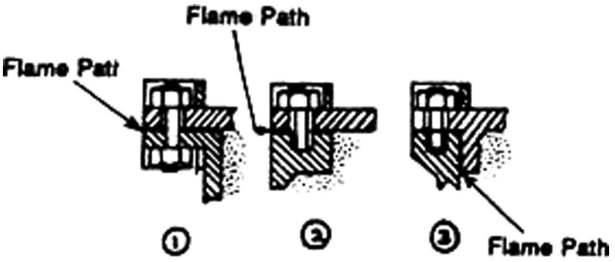

FIGURE 10.8 Holes for fixing bolts. 1. Bolt in exterior flame. 2. Internal log. 3. External log.

FIGURE 10.9 Shrouding.

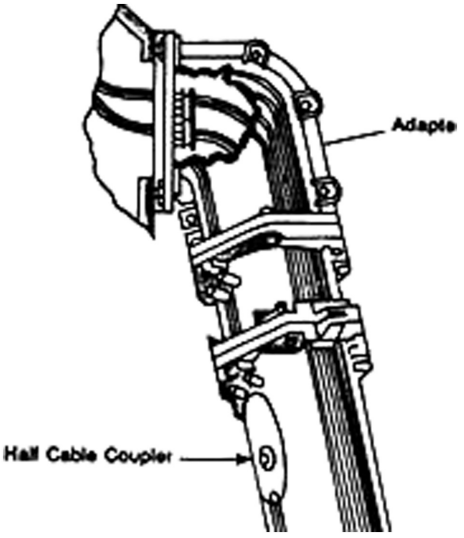

FIGURE 10.10 Cable entries.

- **Shafts**: The shafts and other rotating equipment, which must protrude from the housing, are equipped with flameproof glands. The minimum flame path along the shaft is normally 1.0 inch and in accordance with BS 229, the diametric clearance must not exceed 0.020 inch as in Figure 10.11.

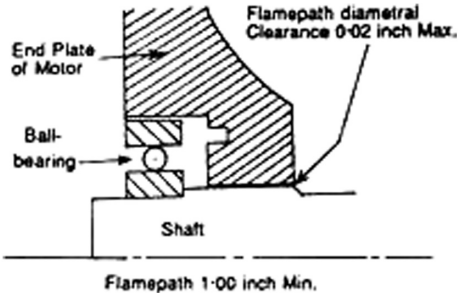

FIGURE 10.11 Flameproof gland.

- **Rods and Spindles**: Rods and spindles are provided with bushed holes that are not less than 1 inch long and, to conform to BS 229, have diametric clearance not exceeding 0.020 inch.
- **Glass Window**: Windows are flat plates of toughened or annealed glass not less than 1/4 inch thick.
- **Glass for Light Fitting**: The glass is cemented into a retaining ring and is secured by a bearing ring. The metal rings form a flameproof joint with the body of the light fitting.

10.4.2.1.2 Statutory Guidelines According to IS: 9559–1980

- The transformers shall be in flameproof construction where statutorily required and shall be of an approved type.
- Rope Haulage Equipment: The smaller haulages may be driven by flameproof Squirrel cage induction motor with flameproof direction-line starter or star-delta starters.
- Handheld coal drills shall be of flameproof construction and rated between 0.93 and 1.1 kW at 125 V.
- Coal-cutting machines: The machines consist of a flameproof motor and controller and are connected to the control gear by a screened flexible cable with plug and socket assembly.

10.4.2.1.3 IS 3682 (1966)

Indian Standard Specification for Flameproof Alternating Current Motors for Use in Mines

- the requirements for flameproof enclosures of electrical machinery and apparatus for use in mines and such other places where flammable gases or vapors may exist or may originate inside the enclosure are covered by IS: 2148: 1962
- this standard covers flameproof AC motors designed for use in mines and having insulated windings with class A, E and B insulation

10.4.3 Preventive Maintenance of Flameproof Equipment

For perfect functioning of flameproof equipment it is most important that regular periodical inspections should be carried out without fail.

1. (a) carefully examine the cast metal casing for any fractures or cracks
   (b) check the welded joints of fabricated housings
   (c) any enclosure that is damaged in any way should not be allowed to remain in service
2. Check the clearance at all points in every joint with feeler gauges.
   The maximum clearance anywhere in a joint permitted by BS 229 and BS 4683 is as follows:
   BS 229
   (a) 1″ flame path, 0.020″ gap between flanges
   (b) 1/2″ flame path, 0.016″ gap between flanges
   (c) oil-filled enclosure, 0.006″ gap between flanges

   BS 4683
   (a) 6.0 mm (approx. 1/4″) flame path, 0.3 mm (approx. 0.012″) gap in between flanges
   (b) 12.5 mm (approx. 1/2″) flame path, 0.4 mm (approx. 0.016″) gap in between flanges
   (c) 25.0 mm (approx. 1″) flame path, 0.5 mm (approx. 0.020″) gap in between flanges

   Oil-filled equipment is not specified for group gases in BS 4683.
   [**Note**: The maximum joint gaps laid down in BS 229 are principally for the guidance of manufacturers. When working on flameproof apparatus at a pit, the gap dimensions laid down by the mining electrical engineer must be adhered to if different from those specified above.]
3. Check that the shrouds, which guard bolt heads and nuts, are free from dirt and any other fused metals or cements and are undamaged. Shrouds should in no case be removed.
4. Carefully inspect armor and cable glands to ensure that the armoring or cable sheath is firmly gripped.
5. Examine cable connectors and couplers to ensure that all the components are in place and that the parts are tightly screwed together.
6. Check glass windows and well glasses for damage. Replace immediately any glass that is cracked or broken with fresh glass. Complete with retaining and backing rings. Glass, which is cemented in, must be returned for repair to either the manufacturer or a workshop authorized or fit to carry out repairs of FLP equipment.
7. When replacing any cover plates, doors, or plugs, which have been removed from a piece of flameproof equipment, the following procedures should be adopted:
   (a) make sure that all the mating surfaces are thoroughly wiped clean.

(b) inspect every blind hole before replacing the bolt to ensure that it is clean and will allow the bolt to seat properly.
(c) tighten all nuts and bolts securely, but do not use more force than is necessary to ensure that the gaps between mating surfaces are within the prescribed limits and that the bolts will not work loose through vibration

The access to joints on some equipment, such as power loader switch compartment doors, is sometimes difficult and, in some cases, impossible. In these cases, a dowel is provided in the body of the machine, lining up with a hole in the front cover. When the joint is tight, the face of the cover will be flush with the top of the dowel.

[**Note**: If a broken bolt has to be removed from a blind hole, care is necessary to avoid damaging the tapings, otherwise the new bolt may not secure the joint adequately. If the broken stud cannot be removed, the equipment must be returned to the manufacturer or an approved workshop for repair. Drilling out the broken stud should not be undertaken on-site owing to the fact that the distance between the bottom of the hole and the inside of the enclosure can unknowingly be reduced and so invalidate the flameproof properties. The hole may even penetrate through into the interior of the enclosure and consequently destroy the whole piece of the equipment. Broken or missing bolts or set screws must be replaced by others of the correct diameter, thread, length type of head, and quality of steel.]

(d) When all the securing bolts have been tightened, check the clearances of all joints as described under maintenance (Section 10.4.3, point 2).

8. Whenever equipment has been dismantled check the clearances of all shaft and spindle glands, whether of the plain or labyrinth type. The correct method is to make micrometer measurements of the diameter of the shaft at various points along the length of the gland surfaces and then to subtract these measurements from corresponding micrometer measurements of the gland bore diameter.

The diametric clearance should not exceed 0.5 mm. (0.020 inch) at any point along the length of the gland.

10.4.3.1 Caution

Do not alter the design of a flameproof enclosure in any way. It is not permissible, for instance, to drill any new hole in the housing or to replace any part with a new part that is not in accordance with the approved flameproof specification and certificate.

The usage differences between intrinsic safety and flameproof equipment in mines are presented in Table 10.10 (LGM, 2018)

10.5 PERSONAL PROTECTIVE EQUIPMENT

The main principle of any safety effort is to eliminate or manage possible hazards that workers might be exposed to by using engineering or administration methods

TABLE 10.10
Differences between Intrinsic Safety and Flameproof Equipment in Mines

Intrinsic Safety Equipment	Flameproof Equipment
All telephone and signal systems in mines should be intrinsically safe	More suitable for industrial applications where working conditions are good, with informed and responsible supervision, and inspection and maintenance are meticulous
Certified for use with gases in groups I, II, III, and IV	Certified for use with gases in groups I, II, III
Not suitable for high-voltage motors	Flameproof or explosion-proof is the only protection mechanism available for motors operating at high voltages

rather than by providing and using Personal Protective Equipment. PPE falls last in the hierarchy of control measures to be adopted for managing hazards. However, in cases where it is not possible to eliminate or control hazards by engineering approaches, the workers should use suitable types of PPE. PPE is equipment that is designed to protect the wearer's body, i.e. head, eyes, hands, legs, face, and legs from safety and health risks such as physical, chemical, electrical, and gravitational hazards present at the workplace. PPE includes equipment such as hard hats or safety helmets, boots, belts, hand gloves, goggles, earplugs, and respiratory protective equipment. Experienced miners know what gear they need to prevent or at least minimize injuries on the job.

In all the safety programs, use of PPE is considered to be necessary and important. It is the responsibility of the management to provide the appropriate types of PPE. The management should also ensure that the workers are provided with proper training, instructions, and procedures to use, wear, store, and maintain the PPE. The provisions for use of suitable types of PPE are directed by various legislation.

10.5.1 Selecting and Using Proper PPE

The correct and adequate use of PPE is a key control for managing hazards on nearly every job. The selection of appropriate PPE depends on the types of hazards present at the workplace, the workplace rules and regulations, and the procedures adopted at the workplace. Therefore, before selecting appropriate PPE, the following should be determined:

- What hazards are present at workplace?
- Who are exposed to hazards?
- How long are the workers exposed to hazards?
- How much are the workers exposed to hazards?

The workers should be trained in the following areas to use PPE:

- when to use PPE
- what types are suitable and what types are necessary
- how to wear, adjust, and take off the PPE

- what is the life period of PPE
- how to maintain the PPE
- how to dispose of the PPE

It is the responsibility of the management to check that the PPE provided is

- a quality and certified product
- of the proper size and fitting

If PPE is to be used, a PPE program should be implemented. This program should address the hazards present; the selection, maintenance, and use of PPE; the training of employees; and the monitoring of the program to ensure its ongoing effectiveness (HSE, 2018a).

10.5.2 Types of Personal Protective Equipment

PPE is required to protect different parts of the body from different hazards. Currently, a wide range of PPE is available for each area of the body, as shown in Figure 10.12.

FIGURE 10.12 Types of personal protective equipment.

The requirements of PPE for any particular job will depend on the following (Table 10.11):

- the types of hazards present while executing a job or task
- the hazards identified in pre-job risk assessment
- the rules at the workplace
- the accepted practices and culture

TABLE 10.11

The basic types of PPE presented below should be made available at every workplace

Head Protection

- PPE for head protection includes hard hats and headgear and should be required for tasks that can cause any force or object falling onto the head
- When performing head protection safety checks, ensure that there are no dents or deformities on the shell and connections are tightened inside
- Do not store in direct sunlight and always replace a hard hat if it was used for any kind of impact, even if damage is unnoticeable

Hearing Protection

- PPE for hearing protection includes ear muffs and earplugs and should be used for tasks that generate a high level of noise (>85 dBA for 8 hours of work daily) that can cause hearing problems and loss of hearing
- The equipment must fit the ear canal perfectly
- Recommended types include formable earplugs to fit on different sizes of ear canals

Face and Eye Protection

- PPE for face and eye protection includes safety goggles and face shields and should be used for tasks that can cause loss of vision or of an eye, burns, splashes, sprays of toxic liquids, etc.
- Ensure no cracks or deformities on the lenses
- Ensure the strap is in good working order and is firmly sealed to the cheek and forehead

Foot Protection

- PPE for foot protection includes knee pads and safety boots
- These are used where foot and leg injuries from falling or rolling objects, hot substances, electrical hazards, and slippery surfaces are likely
- Use boots with slip-resistant soles

Hands Protection

- PPE for hands protection includes safety gloves and should be used for tasks that can cause hand and skin burns, absorption of harmful substances, cuts, fractures, or amputations
- They should fit perfectly with no spaces and should be free from cuts, burns and chemical residue, and contamination
- Some examples of gloves commonly used as PPE include rubber gloves, cut-resistant gloves, chainsaw gloves, and heat-resistant gloves

Body Protection

- PPE for body protection includes safety vests and suits and should be used for tasks that can cause body injuries from extreme temperatures, flames and sparks, toxic chemicals, insect bites, and radiation
- The body protection should be clean and free from cuts and burns and well fitting

Fall Protection

- PPE for fall protection includes safety harnesses and lanyards and should be strictly used for tasks that risk causing injury by falling from a height
- The straps must be free from tears, deformities, and burn marks, and the buckles should be connected securely and tightly

Respiratory Protection

- PPE for respiratory protection includes respirators and should be used to prevent harmful materials or gases entering the body by inhalation
- There are two main types of respirators
- One type of respirator functions by filtering out chemicals and gases, or airborne particles, from the air breathed by the user
- A second type of respirator protects users by providing clean, respirable air from another source. This type includes airline respirators and self-contained breathing apparatus (SCBA) The equipment must be tested for fit and the employee must understand its proper use.

10.5.3 Legislative Provisions for PPE

All the mineral-producing countries follow various standards framed for the provision and use of PPE at work. The International Organization for Standardization (ISO) Technical Committee ISO/TC 94 governs the standards for use of PPE for personal safety (ISO/TC 94, 2018). This committee has published over 150 standards relating to

- head protection (ISO/TC 94/SC 1)
- protective clothing (ISO/TC 94/SC 13)
- firefighters' personal equipment (ISO/TC 94/SC 14)
- respiratory protective devices (ISO/TC 94/SC 15)
- foot protection (ISO/TC 94/SC 3)
- personal equipment for protection against falls (ISO/TC 94/SC 4)
- eye and face protection (ISO/TC 94/SC 6)

CoreSafety (2013) has published PPE and rules compliance to protect workers from potential safety and health hazards at the workplace. All PPE should meet the standards developed by the American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI), or other local or international standards. The regulations for the personal protection of workers working in US surface

Personal protection	57.15001 First aid materials 57.15002 Hard hats. 57.15003 Protective footwear. 57.15004 Eye protection. 57.15005 Safety belts and lines. 57.15006 Protective equipment and clothing for hazards and irritants. 57.15007 Protective equipment or clothing for welding, cutting, or working with molten metal. 57.15014 Eye protection when operating grinding wheels.
Surface only	57.15020 Life jackets and belts.
Underground only	57.15030 Provision and maintenance of self-rescue devices. 57.15031 Location of self-rescue devices.

FIGURE 10.13 Regulations for personal protection in surface and underground mines.

and underground mines are specified in subpart N (MSHA, 2018c). An outline of the regulations is presented in Figure 10.13.

The legislative requirements for providing and using PPE for workers and other persons working in Australian industries are set out in regulations 44 and 45 of Work Health and Safety Regulations, 2011 (WHS, 2011). Regulation 45 states that the owner of the business should provide PPE to workers at the workplace. The owner should also provide information, instructions, and training on how to use, wear, store, and maintain PPE. Regulation 46 states that the owner of the business should provide PPE to other persons who visit the workplace.

From April 2018, Regulation (EU) 2016/425 governs the provision and use of PPE at the European level. Regulation (EU) 2016/425 replaced the previous European Community Directive 89/686/EEC on PPE. Based on the Directive 89/686/EEC, the UK HSE (2015) has framed regulations for personal protective equipment at work under the Health and Safety at Work Act, 1974. These regulations are application to all industries, including the mining industry, in the United Kingdom. The Canadian standards on PPE are shown in Table 10.12 (IHSA, 2018).

TABLE 10.12
Canadian Standards for PPE

CSA Standard Z94.4-02	Selection, care and use of respirators
CSA Standard Z94.3-07	Eye and face protectors
CSA Standard Z94.1	Protective headwear
CSA Standard Z195-09	Protective footwear
CSA Standard Z94.2.02	Hearing protection devices (performance selection, care and use)

The mining industry in India follows the rules and regulations outlined in CMR, 2017; The Metalliferous Mines Regulations (MMR), 1961; The Oil Mines Regulations (OMR), 1984; the Mines Rescue Rules (MRR), 1985. In the Coal Mines Regulations, 2017, the regulations 240–244 give the provisions for PPE. They are as follows:

- **240 Use, supply and maintenance of protective footwear**
  - No person shall go into, or work, or be allowed to go into, or work in a mine, unless he wears protective footwear of such type as may be approved by the Chief Inspector by a general or special order in writing.
  - The protective footwear shall be supplied free of charge, at intervals not exceeding six months, by the owner, agent, or manager of a mine, who shall at all times maintain a sufficient stock of protective footwear in order to ensure immediate supply as and when need for the same arises.
  - Where footwear is provided otherwise than as specified in this regulation, the supply shall be made on payment of full cost.
  - The owner, agent, or manager of a mine shall provide at suitable places in the mine dubbing and revolving brushes or make other suitable alternative arrangements for the cleaning of protective footwear by the persons using them.
- **241 Use and supply of helmet**
  - No person shall go into, or work, or be allowed to go into, or work in a mine, other than the precincts of a mine occupied by an office building, canteen, crèche, rest shelter, first aid room, or any other building of a similar type, unless he wears a helmet of such type as may be approved by the Chief Inspector by a general or special order in writing.
  - The helmet shall be supplied free of charge, at intervals not exceeding three years or such other intervals as the Chief Inspector may specify by a general or special order in writing to the owner, agent, or manager of a mine, who shall at all times maintain a sufficient stock thereof in order to ensure immediate supply as and when need for the same arises: Provided that when a helmet is accidentally damaged during legitimate use, the owner, agent, or manager shall immediately replace the damaged helmet free of cost.
  - Where a helmet is provided otherwise than as specified in this regulation, the supply shall be made on payment of full cost.
- **242 Supply of other personal protective equipment**
  - Where it appears to the Regional Inspector or the Chief Inspector that any person or class of persons employed in a mine is exposed to undue hazards by reason of the nature of his employment, he may, by a general or special order in writing, require the owner, agent, or manager of the mine to supply to such person or class of persons, free of charge, gloves, goggles, shin guards, respirators or such other protective equipment as may be specified in the order.
  - The protective equipment provided shall be replaced free of charge by the owner, agent, or manager whenever it is rendered unserviceable by legitimate use: Provided that in any other event, the replacement shall be made on payment of full cost.

    - If any dispute arises as to the life of any protective equipment, it shall be referred to the Chief Inspector for decision.
- **243 Use, supply and maintenance of self-rescuer**
    - No person shall go into, work or be permitted to go into or work below ground in any mine unless he is provided with and carries with him a self-rescuer of such type as may be approved by the Chief Inspector by a general or special order in writing.
    - If such a self-rescuer is accidentally damaged during use or goes out of order or becomes unserviceable or having exceeded its specified life, or has been used, the owner, agent, or manager shall immediately replace such self-rescuer.
    - The owner, agent, or manager of every mine where self-rescuers are to be used, shall: (a) at all times keep sufficient stock of self-rescuers so that they are readily available whenever needed; (b) provide, at the mine, adequate arrangements for cleaning, maintenance and inspection of self-rescuers.
    - Ensure that every person who may be required to use a self-rescuer undergoes a course of training in the use of a self-rescuer, as may be specified by the Chief Inspector by a general or special order in writing.
- **244 Obligation of persons provided with personal protective equipment**
    - Whenever the owner, agent, or manager of a mine supplies any person with any personal protective equipment, he shall use the same while doing the work for which he is supplied with such protective equipment.

A summary of Indian mining laws governing use of PPE in coal and metal mines has been given in Table 10.13.

In general, the hazards present, workplace rules and regulations, and procedures adopted at the workplace will affect the PPE requirements on the job. Although PPE is required to carry out any job safely, it is only the last control as there are a lot better controls that can be used to prevent an accident from happening, prevent workers from getting hurt, or to isolate the hazards all together. PPE really only comes into play when something has already gone wrong, so our first line of attack should be to stop things from going wrong.

10.6 IT APPLICATIONS AND INNOVATIONS IN MINE SAFETY

10.6.1 Introduction

The mining industry is considered as a low-tech industry when compared to other highly hazardous industries. Over the years, due to the rapid development and advancement of computer technology, its application in mining industry has also increased sharply. The popular applications of information technology (IT) in mining are related to mine planning areas. More recently, the development of new innovative systems and the research on IT applications concerning improvements in mine safety have also been increasing. The application of the Internet of Things (IoT) is becoming common in mining operations. Be it a fully automated smart mine, miner tracking, or the application of drones in disaster recovery, the mining industry is catching

TABLE 10.13
Summary of Indian Mining Laws Relating to PPE

Equipment	Provision of Regulation				Standard Followed	BIS Licensing
	CMR, 2017	MMR, 1961	OMR, 2017	Mine Rescue Rules, 1985		
Protective footwear	240	182	121		• IS: 3976 – 1995	yes
• Safety rubber canvas boots					• IS: 9885 (Part I) –1981	
• Protective boots for oilfield workmen					• IS: 11226 – 1993	
• Leather safety footwear having direct molded soles					• IS:1989 (part I) – 1986 • IS: 3738 – 1975	
• Miners' safety boots with leather soles					• IS: 11225 – 1985	
• Rubber knee boots						
• Leather safety shoes for women workers in mines and steel plants						
• Helmet	241	182A	122		• IS: 2925 – 1984	yes
• Safety belt			37 & 126		• IS: 3521 – 1983	yes
• Breathing apparatus				11(5)	• IS: 10245 (Part I & II) (1st rev.)	
• Smoke helmets and apparatus serving same purpose				11(5)	• IS: 10245 (Part III) – 1982	
• Reviving apparatus				11(5)	• IS 13366 – 1992	
• Self-rescuers	243			11(5)	• IS 9563 – 1980	yes
• Lifeline			37 & 126			

TABLE 10.14
Different Technologies and their Utilization in the Mining Industry

Mine Company	Country	Technology	Application
V. M. Salgaocar & Bro.	India	Near field communication solution	Vehicle tracking
Byrnecut Mining	Western Australia	Active RFID system	Collision avoidance
Beltana Coal Mine	New South Wales, Australia	Wi-Fi-based active RFID	Miner tracking
Goldfields, Harmony Gold Mining Co., AngloGold Ashanti	South Africa	RFID-based tracking system	Vehicle tracking
Stobie Mines, North Mines	Canada	Wi-Fi access points in underground	Voice-over-internet protocol (VOIP) communication system, automation applications, asset-tracking
Steel & Mines Department	Odisha, India	RFID-based tracking system	Mineral tracking
Singareni Collieries Company Limited	India	GPS-based vehicle tracking system	Vehicle tracking

up with the technology. The innovations in mining will help in improving safety, production efficiency, and reduce operational and maintenance costs, and environmental impacts. A few practical applications of IT and innovations were observed in the following areas:

- miner tracking
- vehicle tracking and collision prevention
- environment monitoring
- software for improving mine safety
- disaster recovery
- virtual reality.

Some mining companies that are using information technology for improving safety are shown in Table 10.14 (Roberti, 2013).

10.6.2 Innovations in Mine Safety

10.6.2.1 Miner Tracking

Mine workers often get trapped in underground mines when accidents like a roof fall, explosion, inundation, fire, etc. occur. In such cases, the response time for starting the rescue operation makes a lot of difference in saving the trapped mine workers. To initiate the rescue operations the rescue teams require to know the locations of the trapped workers and the toxic gas concentration levels. The availability of

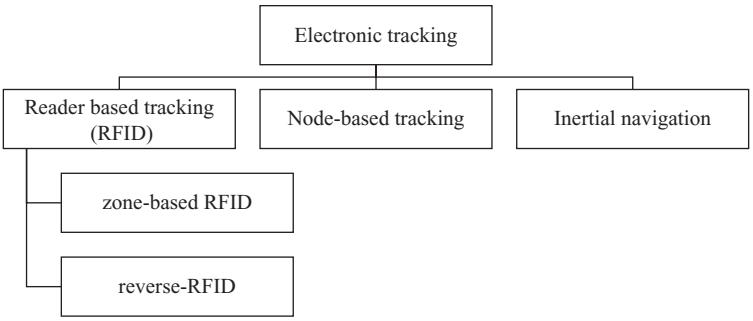

FIGURE 10.14 Common electronic tracking technologies.

a communication system in the underground mine also helps the rescue teams in quickly withdrawing the workers.

Currently, all the Indian underground mines and many mines around the world are using manual tracking to know which mine workers are working underground and their general locations. The disadvantages of manual tracking are that it is hard to pinpoint the exact locations of the mine workers; it is hard to search for the mine workers in a quite large working sections; and it is hard to rescue workers without knowing their locations. In some cases, many rescue workers have lost their lives while tracking trapped mine workers, for example, three rescue workers died while tracking six trapped workers in Crandall Canyon mine collapse, Utah (USMD, 2018). Following the disaster at Sago mine in West Virginia, it was made mandatory to implement electronic tracking and communication systems in the US underground mines (MSHA, 2006). The limitations of manual tracking can be overcome by using electronic tracking techniques. Electronic tracking systems help the mine officials at the surface to know which mine workers are working underground and their exact locations.

The common electronic tracking technologies available are represented in Figure 10.14 (NIOSH, 2013).

10.6.2.1.1 Reader-Based Tracking

Radio frequency identification (RFID) is an identification technology and it is the commonly employed approach for tracking mine workers in the mining industry. An RFID system consists of an RFID tag, an RFID reader, and an antenna. The RFID tag contains an antenna and an integrated circuit to transfer data from tag to reader. The RFID reader, via radio waves captures, the data encoded in the RFID tags and converts the radio waves to a usable form of data. The data are then transferred to a database through a communication interface. The advantage of an RFID system is that the RFID tag data can be read outside the line of sight. Depending on the placement of RFID tags and readers, the RFID technique can be categorized into zone-base RFID and reverse-RFID.

- **Zone-Based RFID**: In zone-based RFID, the readers are installed at specific locations within the mine and all the mine workers are provided with an RFID tag with a unique identification. Whenever a mineworker with

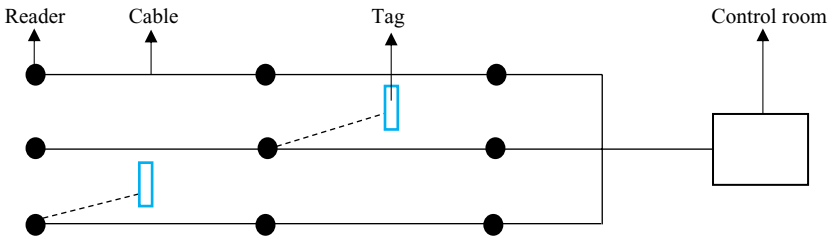

FIGURE 10.15 Sample block diagram of zone-based RFID approach.

a tag passes within the range of a reader, the reader communicates with the respective tag by sending a radio frequency signal to which the tag responds. Upon receiving a response from the tag, the reader sends the location information to the control room located at the surface. As the location information received in the control room is determined to be within the radio frequency range of the reader, this approach is called a zone-based RFID. A sample block diagram of a zone-based RFID is presented in Figure 10.15.

- **Reverse-RFID**: In reverse-RFID, the tags are installed at specific locations within the mine and all the mine workers are provided with a reader. The tags are programmed to send the identification information periodically. The reader placed on the mineworker receives the signal and sends the information to the control room. As the reader is not installed at a specific location, the transmitting medium should be wireless. Generally, a radio transmitter is used to send the information to an ultra-high-frequency leaky feeder system. The ultra-high-frequency leaky feeder system sends the information to the control room located at the surface. The advantage of using reverse-RFID is that the cost of tags is less. So, a greater number of tags can be installed to cover more areas and increase accuracy in identifying locations. The sample block diagram of reverse-based RFID is presented in Figure 10.16.

The following factors affect the performance of the RFID system:

- the presence of metal objects
- the distance between the tag and the reader

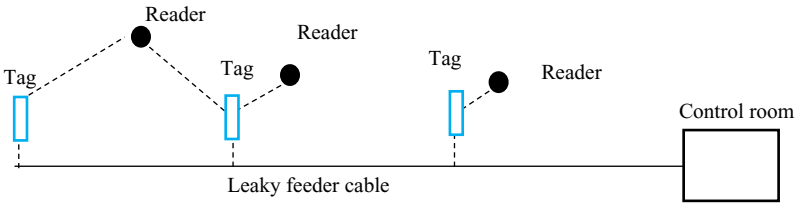

FIGURE 10.16 Sample block diagram of reverse-RFID approach.

- the presence of multi-tags or readers close to each other
- the frequency of transmission of data by the reader.

10.6.2.1.2 Node-Based Tracking

In a node-based tracking system, the tracking is integrated with the communication system. The mine workers' radio acts as a tracking device. Each radio has a unique identification number. When a mineworker passes through the radio frequency range of a node, a link will be established between radio and node. Each node has a unique identifier and specified location associated with it. This information will be sent to the control room via a communications backhaul link.

The main limitations of node-based tracking are that a mineworker's location should be within 600 meters from the nodes and that closely located nodes will have frequency overlap.

10.6.2.1.3 Inertial Navigation

Unlike reader-based or node-based tracking, inertial navigation does not use radio frequency signals or tags to determine location. In inertial navigation, sensors are used to identify various types of motion, such as changes in the Earth's magnetic field, rotations, or accelerations. More recently, Global Positioning System (GPS) has replace inertial navigation, however, as GPS signals do not penetrate the earth, they cannot be used in underground mines.

10.6.2.2 Vehicle Tracking and Collision Prevention

Many types of machinery/vehicles are used in opencast and underground mines in the mineral excavation process. Accidents due to machinery, mainly dumpers, in opencast mines is still a great concern for mine management around the world. The machinery in mines moves back and forth all the time making the working areas somewhat chaotic, compounded by the fact that heavy vehicles do not have the line of sight of small vehicles and mine personnel around it. To reduce the level of accidents and effectively manage vehicle traffic in mines, installing a vehicle tracking system is a practicable solution. The benefits of vehicle tracking are as follows:

- improve safety by understanding traffic information
- know the precise location of the vehicles
- identify the operators who drive a vehicle dangerously
- reduce vehicle idle time and fuel wastage by knowing the shortest routes available
- improve production
- alert operators on speed, idle, and location violations

Vehicle tracking systems use GPS for locating the vehicles combined with software that collects fleet data for a comprehensive picture of vehicle locations, as shown in Figure 10.17. The vehicle locations can be accessed on a digital map or on specialized software.

GPS-based vehicle tracking can be active or passive. In active tracking, the GPS location, vehicle speed, vehicle direction, etc. are transmitted in real time via satellite or cellular networks to a computer or control room. While in passive tracking, the

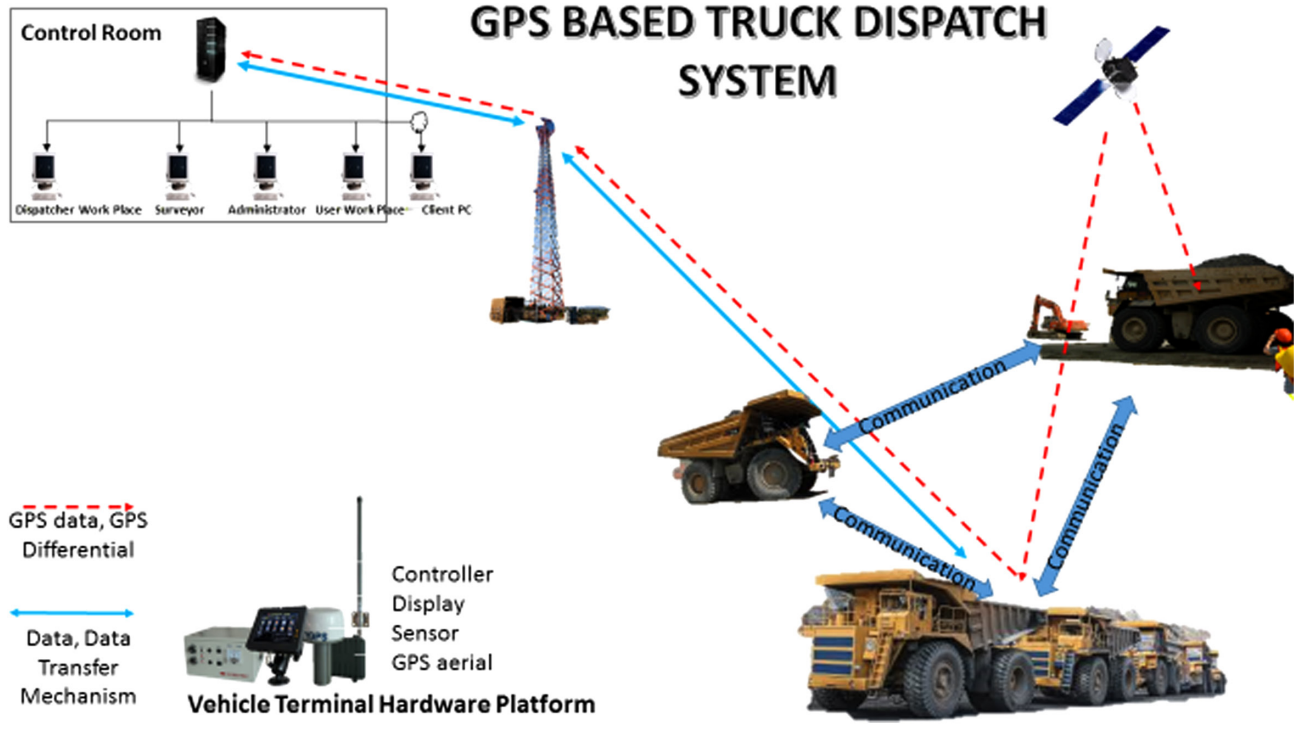

FIGURE 10.17 GPS-based vehicle tracking system.

same data are stored in a device located in the vehicle. When the vehicle is returned to a scheduled point, the data are transmitted to the computer. Passive tracking is suitable where there are no network coverage areas.

Along with the vehicle tracking system, the other application of GPS trackers in mining operations are as follows:

- blast hole drilling guidance
- control of vehicles such as dozers, bucket wheels, and explosive trucks
- asset tracking
- GPS surveying
- fleet management and vehicle dispatch system

To improve safety further, the latest technology, such as seat belt interlock systems, which prevent a vehicle from starting if the belt is unbuckled and collision avoidance systems, which use electromagnetic energy to sense the presence of vehicles and people and alert the operator before accidents occur, should be incorporated in the vehicles (Zatezalo, 2018). In 2015, in the US, Mine Safety and Health Administration (MSHA) (2015) ordered all mining companies to equip proximity detection systems in continuous mining machines. A proximity detection system uses electronic sensors to detect nearby machines and mine workers, gives audible and visual warnings, and stops the machines before coming into contact with another machine or a mineworker. A shovel equipped with proximity sensors is shown in Figure 10.18.

10.6.2.3 Disaster Recovery

When a disaster occurs in a mine, it is difficult to initiate a rescue operation due to unsafe conditions, such as extreme toxic gas concentrations or fire. The lack of knowledge regarding the geological integrity and environmental conditions of the mine also delay the rescue and recovery efforts. Therefore, it is feasible to employ robotic technology to view real-time information, including video, to detect the

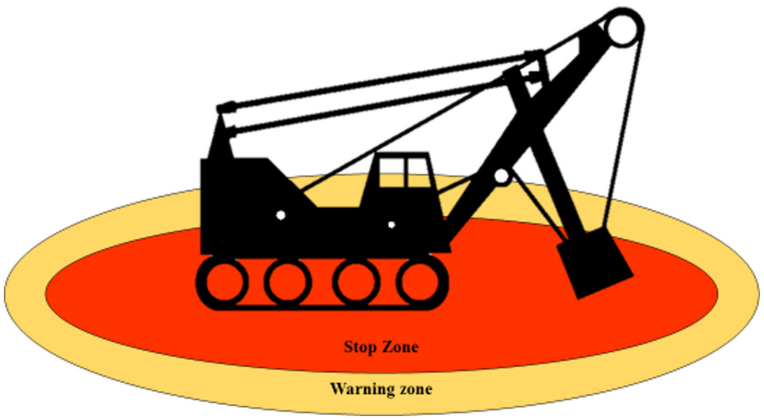

FIGURE 10.18 Shovel equipped with proximity detection system.

locations of trapped mine workers, to provide supplies to trapped mine workers, or to know the gas concentrations. This helps the rescue team to avoid exposure to hazardous environmental conditions as well as in planning the rescue operation. According to Murphy (2001), rescue robots can be classified into four major types, as follows:

- **Unmanned Ground Vehicles** work on the ground surface and can assist rescuers find and interact with trapped mine workers in areas where it is dangerous or difficult for rescue personnel to enter.
- **Unmanned Surface Vehicles** float on the surface of water and can help rescuers to locate and bring the right equipment to the mine workers.
- **Unmanned Underwater Vehicles** have the ability to search through water and identify fatalities and hazardous subjects or material.
- **Unmanned Aerial Vehicles** (drones) work without any contact with the ground surface and can help in transporting medical aid to victims as well as presenting a rough scenario of the accident site to the rescue team.

Unmanned aerial vehicles are suitable for opencast mines, while a combination of all the above four types is required for underground mines (Reddy et al., 2015). In 2001, MSHA (2001) acquired a military robot, nicknamed V2, for rescue operations, as shown in Figure 10.19.

The V2 rescue robot is equipped with three cameras and gas sensors for environment sampling. It can be operated from a safe place by 5,000 feet fiber optic cable. NIOSH (2017), also in the US, has funded two rescue robots: Gemini-Scout mine rescue vehicle and Sarcos Snake robot. The two robots are equipped with gas sensors, multiple cameras, and two-way voice communication. The Gemini-Scout mine rescue vehicle is track-mounted, while the Sarcos Snake robot is tandem track-mounted.

10.6.2.4 Misfire Detection

The blasting of ore or rock is a very common practice for the extraction of minerals in mines. Sometimes all the drill holes filled with explosives may not blast. These failed blasts are called misfires. If any misfires occur in mines, it is necessary to

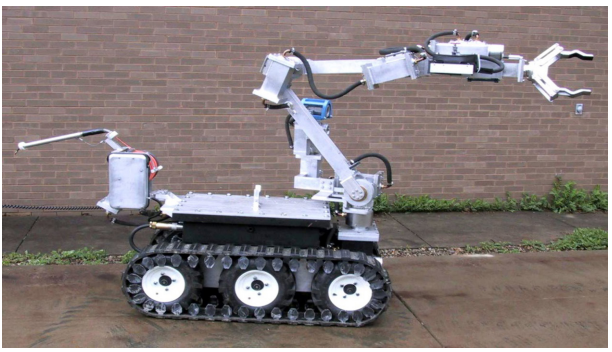

FIGURE 10.19 Mine rescue robot. (Courtesy of MSHA, 2001. Mine rescue robot. Retrieved from https://arlweb.msha.gov/SagoMine/robotdetails.asp.)

identify the locations in order to prevent any risk in the future, as the misfired explosives can be initiated due to sudden shock impact, for example by a boulder.

Dual-frequency RFID solutions based on a combination of low-frequency (LF) and high-frequency (HF) technologies can read through rocks and in the proximity of metals. They can be used for real-time tracking and monitoring of explosives and for the detection of misfired detonators (Morhard et al., 2007). Before blasting, RFID tags are attached to the detonators that are placed inside drilled boreholes. The failed blast detonator will constantly emit the signal after blasting, making it easy to identify the misfired explosives.

RuBee technology can also be used for identifying for misfired explosive detonators. RuBee technology uses LF for communication and employs long-wave magnetic signaling so that it can read through rocks and close to metal items. The data can also be stored in tags. In fact, RuBee produces less power and lower field strength than other detectors. This technology may have a great potential for detecting, tracking, and monitoring explosives or boosters before and after blast in cases of misfires (Mishra et al., 2012).

RuBee technology can also be used for identifying buried objects and trapped mine workers. Similar to the RFID tags, RuBee tags are installed on the mine workers' cap lamps and on machinery. In cases of the trapping of machinery or mine workers, the RuBee tag and base station communicate using magnetic waves.

10.6.2.5 Underground Telecommunications

Wired communication systems are commonly used in underground mines. In the case of an emergency, wired communications may sometimes get damaged, making it impossible to communicate with the control room located at the surface. To improve communication systems in underground mines, wireless networks have been developed. The currently available wireless network technologies can be installed thousands of feet underground and used to communicate with each other and with the control room above ground.

10.6.3 Other Innovations for Improving Mine Safety

10.6.3.1 Ground Monitoring

Strata failure is the most frequent cause of accidents in underground and opencast mines. To improve safety conditions many innovative systems have been developed for monitoring strata behavior. The techniques used in mines are presented below.

10.6.3.1.1 In Underground Mines

There is a wide variety of instruments, such as electrical, mechanical, hydraulic and pneumatic, and optical, available for monitoring ground movement in mines. However, electrical instruments are most commonly employed in mines. The main components of electronic ground movement instruments are a transducer, a data acquisition system, and a linkage between these two components. The transducer converts the physical change into an electrical output signal, and the data acquisition system measures the electrical output signals with a computer. Strata monitoring instruments are most commonly used to measure the following (Sankar, 2011):

- roof-to-floor convergence recorders
  - telescopic convergence rod
  - remote convergence indicator
- load cells
  - rock-bolt load cell
  - vibrating-wire load cell
  - mechanical load cell
  - hydraulic load cell
  - strain-gauge load cell
- change of stress over pillar: stress cell, earth pressure cell, or borehole pressure cell
- load profile of rock bolt: rock-bolt strain gauge
- deformation of pillar: pillar strain meter or crack meter
- bed separation and caving behavior in goaf: multipoint borehole extensometer
- convergence and bed separation in the immediate roof: tell-tale extensometer
  - spring
  - multi-wire
  - dual height
  - triple height
  - cable bolting
  - single rotary
  - auto warning

10.6.3.1.2 In Opencast Mines

The types of instruments available for slope monitoring in opencast mines are as follows:

- time domain reflectometry
- extensometers
- crack meters
- piezometers
- inclinometers

10.6.3.2 Fatigue Management

One of the main cause of dumper accidents in opencast mines is due to dumper operator inattentiveness and tiredness. Sensors equipped in the helmet or wristwatch of the mine workers can continuously monitor the signs of fatigue and measure alertness in order to reduce distraction-related accidents. Smartcap is a safety cap developed for coal miners, vehicle operators, truck operators, and equipment operators. It is rigged with an electroencephalogram (EEG) system that continuously analyzes the wearer's brain waves and warns the operator about signs and symptoms of fatigue in real time (Olewitz, 2015).

10.6.3.3 Stone Dusting

The effective application of stone dust in underground mines can prevent a coal dust explosion from occurring. However, it hard to spray stone dust regularly and evenly throughout the mine. Vale's Carborough Downs coal mine, in Australia,

has developed an innovative tool, a stone-dust spray bar, which can be utilized in underground mines to effectively apply stone dust (Tara, 2016). The spray bar hangs from the roof and the stone-dust bags are loaded into a pressurized pod duster. The pressurized pod duster is connected to the stone-dust spray bar for a consistent and effective application of stone dust. This innovative tool reduces the manpower, cost, and time required.

10.6.3.4 Intelligent Illuminated Signage

Effective traffic management could prevent the majority of vehicle accidents in opencast mines. Safestop is an intelligent illuminated signage developed by Nick Dyer and John Phillips, with the aim of preventing vehicle collision (Tara, 2016). Safestop uses radar technology to detect oncoming vehicles at junctions. Radar is used due to its ability to identify objects through vision-blocking matter, such as smoke, fog, or dust. The radar systems are configured so that either vehicles with right of way or vehicles stopping or approaching signage are detected. Where vehicles with right of way are detected, the direction of approach is indicated by the flashing of either the left or right side LED lights. Sign approach configurations, used to prevent signage run-through events, will flash all sign lights to gain the driver's attention.

10.6.3.5 Infrared Thermal Camera on Underground Mobile Equipment

Accidents involving mobile equipment such as LHD or SDL occur due to poor visibility in the underground mine workplace. The installation of infrared thermal cameras on mine machinery aids the machinery operator to identify persons near the machinery, as the infrared thermal camera detects heat instead of light. The camera can detect the heat signature of persons, cables, machines, and any other warm objects and gives a warning to the operator.

10.6.3.6 Ground Penetrating Radar

Ground penetrating radar can be used for measuring the thickness of barrier pillars in order to provide protection against the inundation of underground mines.

10.6.3.7 Automatic Fire Detection and Suppression System

Fire due to overheating, oil leaks, the presence of combustible materials, or faulty electrics in machinery are common in underground and opencast mines. For the early detection of fire in machinery, an automatic fire detection and suppression system can be installed, especially in equipment such as dozers, dumpers, shovels, draglines, etc. The components of the automatic fire detection and suppression system are (Automation controls, 2009)

- control panel
- alarm and speaker
- linear heat-sensing cable
- pressurized main cylinders of dry chemical powder
- CO_2/N_2 as expellant gas
- distribution system/hose assembly
- nozzles
- power supply

In the case of fire, the linear heat-sensing cable detects the fire and sends a signal to the control panel. The control panel starts an audiovisual alarm to alert the driver and opens the electromechanical actuator located between the expellant cartridge and the main cylinder. From the expellant gas cartridge, pressurized gas, CO_2/N_2, enters into the main cylinder, which is filled with a fire extinguishing agent. The expellant gas fluidizes the fire extinguishing agent, which flows through a distribution system to fixed nozzles and so to the fire area, where the fire can then be suppressed. In the case where the driver observes fire, the driver can also manually open the electromechanical actuator.

10.6.4 IT Applications in Mining Industry

In the last few years, many mining companies have been using the Internet of Things to make the workplace safer, optimize production scheduling and equipment maintenance, and reduce costs. IoT is the concept of connecting objects such as embedded devices, sensors, and computer-based machines to the internet and so enable communication with other connected objects (Som, 2017). The IoT helps to integrate all the mining equipment into a single IoT ecosystem, which can be managed from a central control room, as shown in Figure 10.20.

The main components of the IoT are objects such as vehicles, equipment, a network, and the systems or users with web-enabled devices (Short, 2018). The commonly found items of equipment in mining are shovels, dumpers, bucket wheel excavators, draglines, scrappers, etc. In IoT systems, the vehicles are connected with a wireless sensor network (WSN) or any other dedicated sensors for monitoring and recording the physical conditions of the environment and transmitting the collected data through a network, such as a geographic information system (GIS), to a central location. The combination of WSN with GIS has also been widely utilized in underground mines to enhance safety and health (Chehri et al., 2009). Moridi et al. (2015)

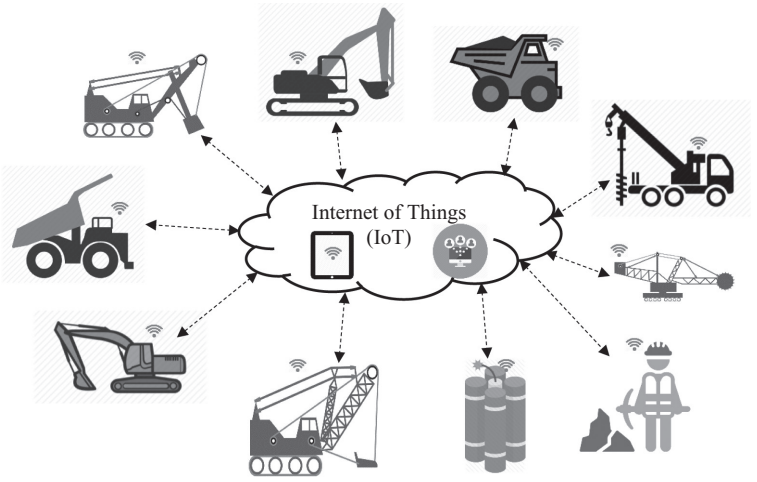

FIGURE 10.20 IoT system.

reported that the ZigBee (based on IEEE 802.15.4) protocol is a new wireless sensor technology that has greater benefits than other WSNs for underground monitoring and communication systems. In an underground mine environment, the combination of a ZigBee network and GIS can be successfully used for environment monitoring, such as gas concentrations, temperature, humidity, etc., sending and receiving text messages in the case of an emergency or if physical damage of communication cables occurs, and the optimization of ventilation fans power consumption. In opencast mines, it can be used for area monitoring, slope failure detection, air pollution detection, and machine health detection.

The advantages of using IoT in the mining industry are as follows (Som, 2017):

- to ensure the safety of people and equipment
- to automate the maintenance and operations of machines
- to move from preventive to predictive maintenance
- to improve traceability and visibility
- to get real-time data and analytics

A few case studies of IoT applications in mining industry are presented below (IoTONE, 2018).

Company name	Network	Software	Purpose
Goldcorp	Wifi, IPv6	Cisco-connected mining solution with RFID	Real-time location system, ventilation control, real-time visibility, tracking of mine workers and assets
Dundee Precious Metal	Cisco Aironet wireless access points	Cisco unified wireless network	Mineworker location, equipment location, bucket usage, vehicle status, engine and oil temperature
Joy Mining		Connext DDS	Continuous miner system's cutter pressure, cutter rate, critical machine parameters, floor and ceiling levels
ArgonST	Boeing's mesh network topology	Web 2.0 browser-based application developed by combining Sine-Wave's platform and Boeing's mesh network topology	Communication, monitoring and support underground mining operations

10.6.4.1 Mine Environment Monitoring

Toxic gases in underground mines are produced during various mine operations, such as blasting or the excavation of minerals, due to the machinery used. There are complex working conditions and confined spaces in underground mines, which mean that the gases accumulate in different areas. Therefore, environment monitoring should be carried out along with providing proper ventilation. Generally, manual gas monitoring will be carried out only periodically. However, continuous monitoring should be used, as the mining operations will be continuous. Knowledge of gas

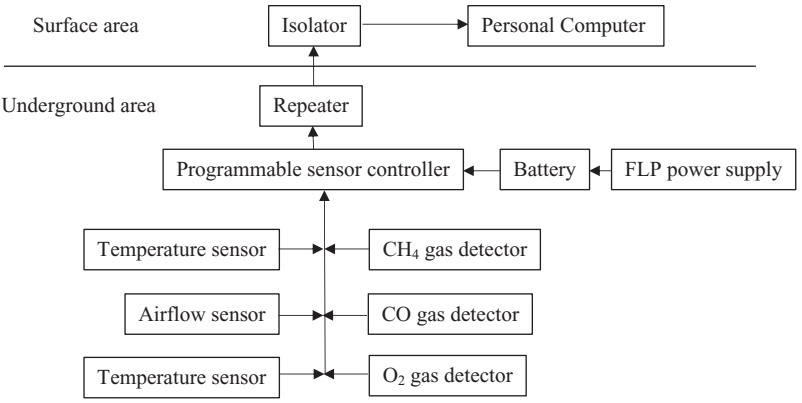

FIGURE 10.21 Telemonitoring system.

concentrations in underground mines also helps rescue teams in carrying out rescue operations quickly and effectively.

A few mines in India have installed telemonitoring systems for the continuous monitoring of underground mine environment. A schematic diagram of a telemonitoring system is shown in Figure 10.21 (Vishwagroup, 2018). A telemonitoring system is an online telemetry system. A telemetry system is an automated communication process by which measurements and other data are collected at remote or inaccessible points and transmitted to receiving equipment for monitoring. The major components of a telemonitoring system are

- personal computer at surface location
- isolator
- underground remote station
- sensors and their associated units

A personal computer is connected to a printer and an interface unit with isolator. The isolator provides optical isolation and acts as an interface between the hazardous underground areas and the computer. The underground remote station consists of a programmable sensor controller, pilot circuit interlocking, and control. The programmable sensor controller is the telemetry unit that is designed to use both analogue and digital. The programmable sensor controller sends the collected signal to the computer through repeater and isolator. The sensors, which are installed at predefined locations in the underground mine, sense the particular parameters and convert them into proportionate analogue voltage signals. These signals are sent to the programmable sensor controller, which, in turn, converts them into digital form and then sends to the personal computer for data logging and display on the monitor.

10.6.4.2 Virtual Reality

The majority of accidents in both underground and opencast mines are due to human error. Human error is mainly caused by improper training and a poor understanding

of the working conditions. Virtual reality has the potential to provide real-life training scenarios for mine workers. Virtual reality training also reduces the cost, time, and labor required. Many organizations have developed virtual reality centers for providing training in the following areas:

- mine workers' training
- accident investigation and reconstruction
- equipment simulation
- hazard identification simulation
- opencast and underground operations simulation
- underground ventilation simulation

10.6.4.3 Software for Improving Mine Safety

In 2018, many risk management tools are commercially available for evaluating the risks in hazardous industries. RiskSpectrum and Logan are two types of commercially available risk assessment software that are suitable for the mining industry. Both these tools are popular for fault tree analysis (FTA) and event tree analysis (ETA) (Lloyd, 2017; Logan, 2018). SCRAM is an open source probabilistic risk analysis tool that supports FTA, ETA, static FTA, probability analysis, and uncertainty analysis (SCRAM, 2018). A few other popular software tools are also presented in Table 10.15.

RISKGATE is an interactive, online, risk management system developed at the University of Queensland, Australia. This tool focuses on methods to control occupational health and safety hazards of opencast and underground coal mines. Input data for this tool were collected from mining industry experts who participated in

TABLE 10.15
Software Tools for Risk Assessment

Provider	Software	Type
Isograph	RELIABILITY WORKBENCH INCORPORATING FAULTTREE+	Quantitative risk assessment
	HAZOP+	Quantitative risk assessment
DNV	SAFETI	Quantitative risk assessment
	PHAST	Consequence modeling
Shell Global Solution	FRED	Consequence modeling
	SHEPHERD	Hazard evaluation and quantitative risk assessment
TNO	EFFECTS	Consequence analysis
	RISKCURVES	Quantitative risk assessment
RELCON	RISKSPECTRUM	Quantitative risk assessment
QUEST	CANARY	Consequence analysis
Windchill Quality Solutions (Relex)	WINDCHILL FMEA	Risk assessment
	WINDCHILL FTA	Risk assessment

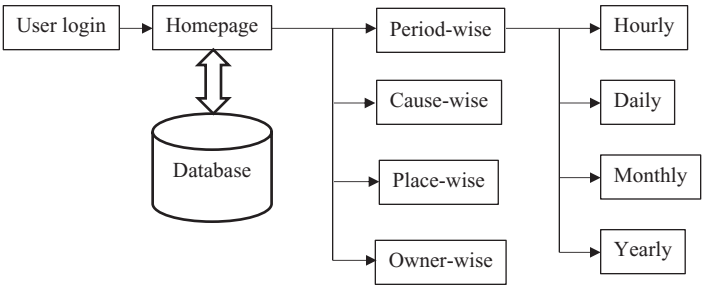

FIGURE 10.22 Flow diagram of SafeStat.

research workshops (Kirsch et al., 2014). The Bowtie approach was used for this tool to enable an understanding of causes and their associated consequences.

Yerpude and Kher (2015) conceptualized a web-based safety information and decision support system for underground coal mines using a standardized database management platform integrated with coal mine information and a decision support model as a modern tool for the safety of mine personnel.

Tripathy and Reddy (2016) developed web-based software, SafeStat, for accident analysis in Indian mines. The flow diagram of SafeStat is presented in Figure 10.22. Using SafeStat, it is easy to generate accident analysis data on an hourly, daily, monthly, and yearly basis, depending on the requirements of the user. Analysis owner-wise, cause-wise, and place-wise can also be carried out using SafeStat. The input for this application was collected from DGMS accident data and can be dynamically updated with the latest available data. SafeStat can be useful as management tool for assessing how accident prone a mine is.

10.6.5 Initiatives and Safety Practices Followed in Indian Mines

10.6.5.1 Coal India Limited (CIL)

- **Online Safety Monitoring System**: The CIL Safety Information System (CSIS) has been developed and uploaded to the CIL website. Relevant safety-related information from each mine is being uploaded in the same system on continual basis for better safety management.
- **Imparting Special Training by SIMTARS**, Australia accredited trainers: Executives have undergone specialized training on risk assessment through SIMTARS, Australia. The SIMTARS-trained executives are training the mine-level executives as well as members of safety committees of the individual mines on identifying the hazards and evaluating the associated risks in the mines, and how to prepare risk assessment-based Safety Management Plans (SMPs), Principal Hazards Management Plans (PHMPs), and Standard Operating Procedures (SOPs).
- **Establishment of Geo-Technical Cells** in all subsidiaries: Geo-technical cells have been established in all subsidiary headquarters and are headed

by senior-level mining discipline officers, assisted by an adequate number of multidisciplinary technical experts, including a geologist.

- **Safety Management Plans**: Site-specific risk assessment-based SMPs have been prepared for each CIL mine by involving mine officials and workmen; and these are being updated on continual basis. The process of risk assessment in mines is continuous and ongoing for improving the safety standards of mines on a real-time basis. All SMPs are being monitored through the internal safety organization (ISO) of each subsidiary.
- **Principal Hazards Management Plans**: PHMPs are also being formulated as a part of an SMP to avert any mine disaster or major mine accident. Recommended control measures, in the form of a Trigger Action Response Plan (TARP), are being implemented to deal safely with any emergencies.
- **Emphasis on Adoption of the State-of-the-Art Technology in Suitable Geo-Mining Locales**: A greater number of surface miners needs to be deployed to eliminate blasting operations in open cast projects (OCPs).
- **Standard Operating Procedures**: Site-specific, risk assessment-based SOPs for all mining and allied operations are framed and implemented. The same are being updated on continual basis to cater to changing mine dynamics.

10.6.5.1.1 Adoption of the State-of-the-Art Mechanisms for Strata Management (Ministry of Coal, 2018)

- strata support systems are based on scientifically determined rock mass ratings (RMRs)
- strata control cells are provided to monitor the strata support systems
- mechanized drilling machines are deployed for roof bolting
- resin capsules are used in place of cement capsules
- the latest strata monitoring instruments are used to monitor roof conditions
- quality training is provided for all levels of workers, such as roof support crew, blasting crew, officials, and grassroots-level workers

10.6.5.1.2 Mechanisms for Monitoring the Mine Environment

- detection of mine gases by using CO-detectors, multi-gas detectors, or methanometers
- environmental telemonitoring systems (ETMSs) and local methane detectors (LMDs) are used to monitor the mine environment continuously

10.6.5.1.3 Mine Safety Inspections

- round-the-clock supervision of all mining operations by an adequate number of competent and statutory supervisors and mine officials
- surprise back shift mine inspections by mine-level and area-level officials
- periodic mine inspections by headquarter-level and area-level senior officials
- regular mine inspections by officials of the internal safety organizations of the respective subsidiary and of CIL
- regular inspections by workmen inspectors appointed in each mine

10.6.5.1.4 Steps for Prevention Accidents in OCPs

- mine-specific traffic rules are framed and implemented for effective maintenance of traffic
- safe operating procedures and codes of practice are developed and circulated among heavy earth moving machinery (HEMM) operators, maintenance staff, and others.
- HEMM operators are provided with ergonomically designed seats and air-conditioned cabins
- automatic fire detection and suppression systems are installed in HEMM machinery
- dumper operators are trained using simulators
- rearview mirrors, proximity warning devices, and audiovisual alarms are installed in the dumpers
- GPS-based operator-independent truck dispatch systems (OITDSs) are used in opencast mines for tracking HEMM movements inside the mine
- specialized training is provided for contractor workers based on the nature of their jobs
- lighting arrangements using high mast towers for the enhancement of illumination according to the stipulated guidelines.
- eco-friendly surface miners are used to eliminate blasting operations
- shock tubes and electronic detonators are used for controlling ground vibrations and fly rocks

10.6.5.1.5 New Initiatives Taken Up by CIL in the Year 2017

- a memorandum of understanding (MoU) is in the process of finalization between CIL and SIMTARS, Australia for the following:
- enhancing the skill level of the employees of CIL by imparting advanced-level training
- establishing a Mine Virtual Reality Training Centre at the Indian Institute of Technology (formerly known as the Indian School of Mines) (IIT-ISM), Dhanbad, with the state-of-the-art technology
- technical solutions for the underground sector in challenging geo-mining locales
- the detection and mitigation of fire and associated hazards in Jharia and Raniganj Coalfields
- the development of suitable training modules based on the concept of risk management for all mining and allied operations, and the revamping of the existing "The Mines Vocational Training Rules," 1966, in association with DGMS to cater for the present needs
- the adoption of "Take Responsibility for Accident Prevention" (TRAP) for tangible reductions in operation-related incidents
- the formulation and implementation of disaster prevention Strategies to avert the occurrence of disasters in the future

10.6.5.2 Neyveli Lignite Corporation Ltd (NLC)

- **CCTV Surveillance for Specialized Mining Equipment (SME)**: SMEs are equipped with CCTV surveillance systems to monitor and avert the inadvertent entry of any of the workforce into accident-prone areas.
- **Slope Stability Monitoring Radar Equipment**: The procurement of slope stability monitoring radar equipment for prewarning that slope or rock mass movement is in progress.
- **Simulator**: The procurement of a simulator for imparting training on a real-time basis to SME operators and CME (conventional machine equipments) operators is in progress.
- **Emergency Response System**: Emergency preparedness and response systems for fire, inundation have been prepared for all mines and mock rehearsals are conducted at regular intervals.

10.6.5.3 Singareni Collieries Company Ltd (SCCL)

- **Rearview cameras**: All dumpers are equipped with rearview cameras in opencast mines.
- **Automatic Fire Detection and Suppression Systems (AFD & SS)**: AFD & SSs are installed in all the heavy earth moving machinery.
- **Hazard identification**: The identification of hazards in all mining operations and associated risks is being carried out.
- **Roof Support Systems**: Adoption of roof support systems based on geotechnical studies.
- **Roof Bolters**: Introduction of roof bolters for resin capsule bolting.
- **Proximity-Warning Devices**: All dumpers are equipped with proximity warning devices in opencast mines.
- **Telemonitoring System**: Telemonitoring systems are used for real-time monitoring of CH_4 and CO gases in underground mines.
- **Strata Monitoring Cells**: To monitor strata control activities in the mine environment, each region is provided with strata monitoring cells. The services of scientific institutions such as the Central Institute of Mining and Fuel Research (CIMFR) Dhanbad, the National Institute of Rock Mechanics (NIRM), Kolar Gold Fields, India, are being utilized for designing panels for effective strata management and environmental issues.
- **Slope Stability Monitoring**: SCCL is planning to monitor slope stability by using radar technology at two opencast mines. Based on the assessment of the usefulness of this new technology, this monitoring mechanism will be extended to other opencast mines in the future.

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11 Disaster Management

11.1 INTRODUCTION

Disaster is defined as any sudden occurrence that causes damage, loss of human life, ecological disruption, or deterioration of health and health services on a scale sufficient to warrant an extraordinary response from outside the affected community area. Mining is one of the most disaster prone sectors in India. The history of mining has been tainted by many disasters, killing and mutilating a large number of workers. From 1901 to 2016, 59 mining disasters occurred in India, leading to the death of 2,247 mine workers. One of the extreme mining disasters in the Indian mining industry occurred on December 27, 1975, due to the inundation from an old abandoned incline working to new deep shaft mine workings in the same seam of Chasnala colliery, leading to the death of 375 miners. Accordingly, the Directorate General of Mines Safety (DGMS) has strengthened the laws relating to the safety of employees more than the laws relating to production. Over the years, mining, according to the provision of the statute (from The Mines Act, 1952 to The Oil Mines Regulations, 2017), has minimized accidents but failed to eliminate them entirely, either due to human error or a result of equipment failure. The most recent disaster has occurred at Eastern Coalfields Ltd's Lalmatia mines in Jharkhand, on December 30, 2016, in which 23 mine workers were buried due to overburden dump failure. Though the occurrence of disasters in mines are becoming less frequent, they have serious consequences. Therefore, disasters should be properly managed using disaster management plans to mitigate the consequences.

A disaster is a man-made or natural event that leads to the sudden disruption of normal life, as shown in Figure 11.1. In India, disasters are often classified into two broad categories

1. **Natural disasters**: These include earthquakes, floods, droughts, landslides, tsunamis, heat waves, cold waves and fog, and cyclones.
2. **Man-made disasters**: These include industrial and chemical, mine, transportation, stampede, and epidemic disasters. The probable disasters in mines include both natural and man-made. So far, no natural disasters, such as floods, earthquakes, etc., have caused damage to mine workings.

In Indian coal and non-coal mines, disaster management is a continual process involving DGMS, disaster management organization at the mines, rescue responders, mine officials, and the mine workers. Over the years, different statutes for coal and non-coal mines have focused on post-disaster management. Successful disaster management requires a greater understanding of hazards and their potential disastrous consequences, reducing the risk of the identified hazards, preparing resources, and responding to and recovering from the occurrence of a disaster.

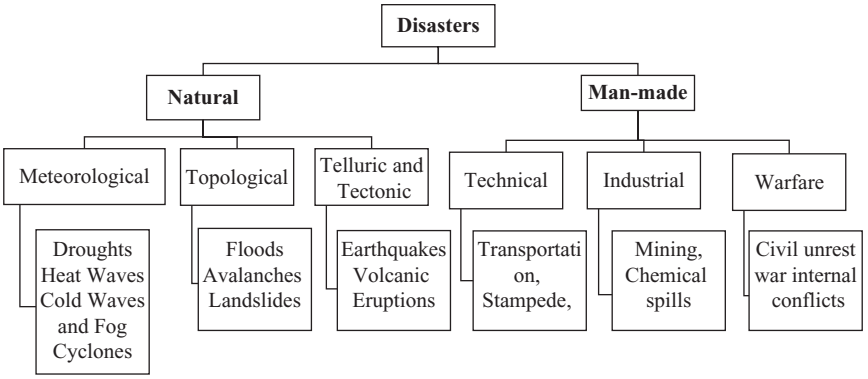

FIGURE 11.1 Types of disasters.

11.2 PHASES OF DISASTER MANAGEMENT

According to the Disaster Management Act, 2005 (NDMA, 2005), "disaster management" means a continuous and integrated process of planning, organizing, coordinating, and implementing measures that are necessary for

- prevention
- mitigation
- preparedness
- response
- evacuation, and rescue and recovery
- rehabilitation and reconstruction

Effective disaster management depends on a thorough amalgamation of disaster plans at all levels of the organization, and an understanding that the lowest levels of the organization are responsible for managing the emergency and getting additional resources and assistance from the upper levels (Tripathy, 2011). There has been a paradigm shift in disaster management. Traditional disaster management includes post-disaster assistance. Modern disaster management includes proactive prevention, mitigation and preparedness activities, organizational planning, training, and information management. The new model encompasses total disaster risk management and takes a comprehensive approach to risk reduction. There are three different phases of activity in disaster management as shown in Figure 11.2. They are as follows:

- **Pre-Disaster Phase**: The components of the pre-disaster phase are mitigation and preparedness.
  - **Mitigation**: Covers the structural and non-structural measures undertaken to lessen or eliminate the likelihood or consequence of hazards. Effective mitigation requires an efficient mechanism for identification, assessment, and monitoring of disaster risks. The identification of

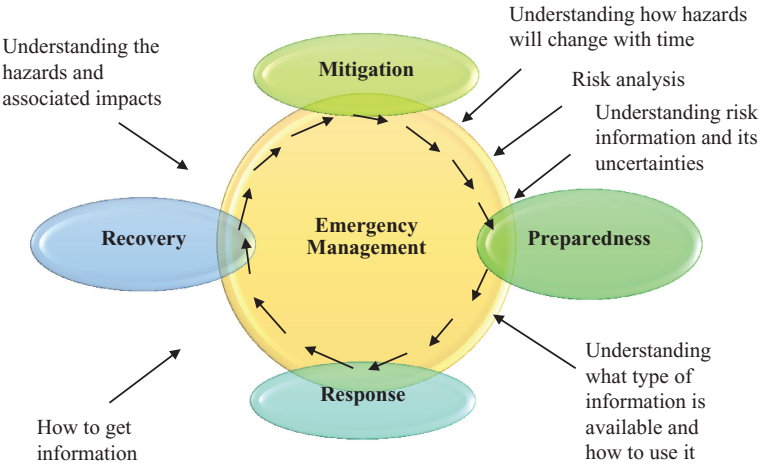

FIGURE 11.2 Emergency management cycle.

risks is a precursor to mitigation. Risk assessment includes identifying hazards, determining their probability of occurrence, estimating their impact, and determining measures to reduce the risk.

- **Preparedness:** Covers the advance steps taken to ensure adequate response to the impact of hazards. In the preparedness phase, emergency organization members develop preparedness measures, such as the formulation of evacuation plans and communication plans, the development of warning systems, the proper maintenance of rescue equipment, and the training of personnel for firefighting, rescue of men and machinery, fighting inundation, and carrying out first aid.

- Disaster Phase
  - **Response:** Includes the deployment of rescue operators to the disaster area in order to save lives, reduce health impacts, and ensure safety. A response can be of an immediate, short-term, or prolonged duration. Efficient rescue operations depend on the training of rescue personnel and the plans developed in preparedness phase. The response activities undertaken during or immediately after a disaster include immediate relief, rescue, damage assessment, and debris clearance.
- Post-Disaster Phase
  - **Recovery:** Objectives include to restore or improve the disaster-affected area to its pre-disaster state, and the rehabilitation and reconstruction of the damaged critical infrastructure. An active recovery effort incorporates disaster risk reduction measures.

11.2.1 Mine Emergency Response Plan Guidelines for the Mining Industry

To prevent or control the consequences of accidents in the mining industry, the preparation of a mine emergency preparedness and response plan has become a prerequisite. A mine emergency response plan should be prepared in advance and provide the

necessary procedures for dealing with emergency situations. The mine emergency response plan helps to determine the following:

- the measures to be taken to prevent an emergency situation
- in the event of an emergency, the precautions to be taken to minimize the consequences
- the immediate actions to be taken by the mine workers to restrict the effects of the emergency situation
- the training required by workers to carry out the procedures defined within the mine emergency response plan
- the responsibilities of mine officials until the emergency is brought under control
- the resources that should be available, such as rescue and firefighting equipment in order to carry out rescue actions

11.3 MINE DISASTERS AND CLASSIFICATION

The definition of "disaster" was not defined in the Mines Act, 1952, the Mines Rules, 1955, or the Coal Mines Regulations, 2017, or, in fact, any other statute relating to mining operations in India. The United Nations Office for Disaster Risk Reduction (2015) has described disaster as a combination of the exposure to a hazard, the conditions of vulnerability that are present, and insufficient capacity or measures to reduce or cope with the potential consequences. The top ten mining disasters around the world are presented in Table 11.1 (SafetyConsortium, 2018). The disasters involving ten or more fatalities in Indian coal and non-coal mines during 1901–2016 are presented in Table 11.2. Tables 11.1 and 11.2 reveal the fact that disasters continue to occur in coal and non-coal mines, in spite of precautionary measures and the availability of preventive tools and systems.

TABLE 11.1
Top Ten Mining Disasters around the World

Date of Accident	Name of Mine	Killed	Cause
4-26-1942	Benxihu colliery, China	1,549	Coal dust explosion
3-10-1906	Courrieres, France	1,099	Coal dust explosion
12-15-1914	Hojo coal mine, Kyushu, Japan	687	Gas explosion
10-14-1913	Senghenydd colliery, Wales	439	Gas explosion
01-21-1960	Coalbrook, South Africa	437	Pillar failure
6-6-1972	Wankie No. 2 colliery, Rhodesia	426	Coal dust explosion
5-28-1965	Dhori colliery, Dhanbad, India	268	Coal dust explosion
12-27-1975	Chasnala colliery, India	372	Inundation
12-12-1866	Oaks colliery, Barnsley, England	361	Explosion
12-6-1907	Fairmont coal company's No. 6 and No. 8 mines, Monongah, West Virginia, the United States	361	Explosion

TABLE 11.2

Details of Disasters in Indian Coal and Non-Coal Mines during 1901–2016

Coal Mines			
Date of Accident	**Name of Mine**	**Killed**	**Cause**
6-16-1908	Nadir Khas	20	Explosion
2-07-1910	Dishergarh	11	Explosion
10-15-1910	Sitalpur	12	Roof fall
11-26-1910	Namdang	14	Explosion
11-09-1911	Kendwadih	14	Explosion
7-11-1912	Phularitand	21	Inundation
6-28-1913	Jotejanake	13	Inundation
10-22-1913	Chowrasi	27	Explosion
8-31-1915	Chanda	10	Collapse of pillars
2-04-1916	Bhowra	24	Collapse of pillars
7-20-1916	Dishergarh	14	Explosion
11-18-1918	Dishergarh	10	Explosion
11-24-1919	Kustore South	14	In-shaft (rope/chains breaking)
2-28-1921	Amlabad	11	Explosion
3-09-1922	Khost	13	Explosion
1-04-1923	Parbelia	74	Explosion
4-14-1923	Rawanwara	16	Collapse of pillars
2-17-1931	Ningah	13	Explosives
1-16-1935	Loyabad	11	Inundation
6-29-1935	Bagdigi	19	Explosion
7-24-1935	Kurhurbaree	62	Explosion
1-30-1936	Loyabad	35	Fire
12-18-1936	Poidih	209	Explosion
7-06-1942	Makerwal	14	Inundation
2-22-1943	Sodepur 9, 10 & 11 pits	13	Roof fall
10-08-1943	Jhamuria 7 & 8 pits	12	Air blast
3-19-1946	Begunia	13	Explosion
7-12-1952	Dhemo main	12	Roof fall
8-05-1953	Majri	11	Inundation
3-14-1954	Damra	10	Explosion
12-10-1954	Newton Chikli	63	Inundation
2-05-1955	Amlabad	52	Explosion
9-26-1956	Burradhemo	28	Inundation
2-19-1958	Chinakuri 1 & 2 pits	176	Explosion
2-20-1958	Central Bhowrah	23	Inundation
1-05-1960	Damua	16	Inundation
5-28-1965	Dhori	268	Explosion
4-11-1968	West Chirimiri	14	Collapse of pillars

(*Continued*)

TABLE 11.2 (CONTINUED)
Details of Disasters in Indian Coal and Non-Coal Mines during 1901–2016

Coal Mines

Date of Accident	Name of Mine	Killed	Cause
3-18-1973	Noonodih Jitpur	48	Explosion
8-08-1975	Kessurgarh	11	Roof fall
11-18-1975	Silewara	10	Inundation
12-27-1975	Chasnala	375	Inundation
9-16-1976	Central Saunda	10	Inundation
10-04-1976	Sudamdih Shaft	43	Explosion
1-22-1979	Baragolai	16	Explosion
6-24-1981	Jagannath	10	Fire
7-16-1982	Topa	16	Roof fall
9-14-1983	Hurriladih	19	Inundation
1-25-1994	New Kenda	55	Fire
9-27-1995	Gaslitand	64	Inundation
3-03-1997	New Moghla	10	Explosion
6-24-2000	Kawadi Mine	10	Side fall
2-02-2001	Bagdigi	29	Inundation
6-16-2003	Godavarikhani No. 7 LEP	17	Inundation
10-17-2003	Godavarikhani No. 8 A	10	Roof fall
6-15-2005	Central Sounda	14	Inundation
9-06-2006	Bhatdee	50	Explosion
5-06-2010	Anjan Hill	14	Explosion
12-30-2016	Lalmatia mine	23	Overburden dump failure

Non-Coal Mines

Date of Accident	Name of Mine	Killed	Cause
12-06-1910	Shivrajpur Manganese	12	Fall of sides
09-18-1920	Badwin Lead-Silver	11	In-shaft ascending/descending
05-16-1929	Bawdwin Silver-Lead-Zinc	10	Fall of roof
04-16-1932	Lady Rangi Mica	19	Suffocation by gases
04-19-1952	Champion Reef Gold	20	Rock burst
6-30-1952	Champion Reef Gold	10	Rock burst
5-27-1955	Champion Reef Gold	10	Rock burst
9-29-1957	Rajupalem Barytes	11	Fall of sides
8-28-1994	Rajpura Dariba Galena & Sphal	13	Irruption of water
2-25-2010	Hamsa Mineral Granite mine	14	Fall of sides

Based on the accidents causing death to ten or more persons in the past, the main causes of coal mine disasters can be classified as follows:

- explosion
- inundation
- ground movement
- fire
- in-shaft (ropes/chains breaking)
- explosives

The main causes of non-coal mine disasters can be classified as follows:

- rock burst
- inundation
- fire
- winding shaft

It can be observed from Table 11.2 that during 1901–2016, in coal mines, about 53% of disasters were caused by explosion and 33% by inundation, killing 1,198 and 738 miners respectively. Ground movement issues such as roof fall, side fall, overburden failure, air blast, or premature collapse of pillars have caused disasters for 8% of the total and led to 183 deaths. Fire has caused disasters for 4% of the total and led to 100 deaths. Other causes, such as in-shaft breaking of chains/ropes and explosives have caused disasters for 1% of the total each and led to 14 and 13 deaths of miners respectively.

In non-coal mines, ground movement issues such as roof fall, side fall, and rock burst have caused disasters for 67% of the disasters and led to 87 deaths. Suffocation by gases has caused disasters for 15% of the total and led to 19 deaths. About 10% and 8% of the disasters were caused by inundation and in-shaft ascending/descending and killed 13 and 11 miners respectively.

11.4 EMERGENCY PREPAREDNESS AND DISASTER MANAGEMENT PLAN

11.4.1 Legislative Requirements

With the increasing concern for improving safety in mines, various countries have suggested the application of effective risk assessment and management in mines. One of the requirements of an effective risk assessment and management is preparing a plan for emergency preparedness that includes the means of detecting the onset of an emergency early and responding to it effectively and promptly. The approaches for emergency preparedness and disaster management by various countries are as follows:

11.4.1.1 BS-OHSAS 18001: 2007

In the United Kingdom, section 4.4.7 of OHSAS 18001: 2007 (BSI, 2007) has recommended that companies prepare an emergency preparedness and response plan. The plan should contain procedures to

- identify potential emergency situations in the company
- respond to such emergency situations to prevent or mitigate the safety, health, and environment consequences,

The companies should periodically test response procedures to emergencies and revise if necessary both after periodical testing and following the actual occurrence of emergencies.

11.4.1.2 India

The emergency preparedness regulations for Indian coal and metal mines are presented in the Coal Mines Regulations, 2017 (CMR, 2017) and the Metalliferous Mines Regulations, 1961 (DGMS, 1961).

11.4.1.2.1 The Coal Mines Regulations, 2017

Regulation 199A of the Coal Mines Regulations (CMR) has focused on preparing an emergency plan for using at the time of the emergency (DGMS, 1957). The plan outlines response activities, such as the duties and responsibilities of the mine officials and workers, the provision of training, including mock rehearsals at regular intervals, and information management, including how to give instructions in order to avoid incongruous orders being given at the time of emergency.

Over the years, the paradigm of disaster management has shifted from post-disaster to pre-disaster. Regulation 252 of the Coal Mines Regulations (DGMS, 2017a) emphasizes emergency prevention, preparedness, response procedures, and periodic emergency drills. DGMS (2017a) has also focused on hazard identification and risk assessment for accident prevention and control activity in mines.

An emergency response and evacuation plan should include the following:

- procedures for response to emergency situations that require immediate first aid treatment, medical treatment, and transportation
- procedures for evacuation of injured persons
- procedures to make arrangements for the rescue of persons incapacitated or trapped in coal mines
- duties of mine officials for governing actions identified to implement an emergency response
- procedures to establish emergency communication systems
- providing notification systems like alarms
- procedures to be followed by workers who remain to perform critical operations before they evacuate
- providing rescue apparatus such as self-contained self-breathing devices, etc. to workers at risk
- training on emergency escape routes and procedures to all personnel
- mock exercises to be performed at regular intervals
- an emergency response team that is trained, equipped, and immediately available to respond to fires or other hazards that create mine emergencies

11.4.1.2.2 The Metalliferous Mines Regulations, 1961

Similarly to Regulation 199A of CMR (2017), the regulations for preparation of an emergency plan for metal mines are described in 190A of MMR, 1961 (DGMS, 1961).

The plan outlines response activities, such as the duties and responsibilities of the mine officials and workers, the provision of training, including mock rehearsals at regular intervals, and information management, including how to give instructions in order to avoid incongruous orders at the time of emergency.

11.4.1.3 Western Australia

11.4.1.3.1 Emergency management planning

The development of emergency development plans to manage any given emergency is best completed under three different categories (DMRIS, 2018)

- emergency plan
- crisis management plan
- emergency response plans

11.4.1.3.1.1 Emergency Plan Regulation 4.30 of the Mines Safety and Inspection Regulations 1995 (GWA, 1995) highlights the preparation of an emergency plan for dealing with emergencies in mines. The preparation of an emergency plan includes the following:

1. the identification of hazards that might cause an emergency at the mine
2. the assessment of risk of such an emergency occurring
3. preventive or controlling measures to deal with such emergency situations, including
   a. provisions for appropriate facilities and equipment
   b. provisions for providing and testing effective alarm systems
   c. procedures to deal with emergency situations
   d. training of employees in emergency procedures, firefighting, mine rescue, and other relevant emergency response functions
   e. periodical review of facilities, equipment, and procedures

In the case of a fire, an accidental explosion (including a sulphide dust or coal dust explosion), a failure of the primary ventilation system, flooding, an inrush of mud or tailings, an inrush or outburst of gas, or the extensive collapse of workings, specific emergency precautions are required to be taken for underground mines. In the case of an emergency, the principal employer at, and the manager of, an underground mine must ensure that, so far as is practicable, the following things have been done to ensure the safety of persons working underground in the mine:

1. an alarm system has been installed and a procedure has been established for activating the system
2. a procedure has been established for the prompt notification of rescue and firefighting teams
3. a procedure has been established for evacuating persons working underground
4. fire refuge chambers and fresh air bases (FABs) are provided for persons working underground

5. provision has been made for the safety of drivers of winding engines at underground shafts
6. all employees are adequately trained and retrained in emergency procedures and the use of emergency equipment and facilities
7. emergency drills have been conducted on a regular basis

11.4.1.3.1.2 Crisis Management Plan The crisis management plan provides a system for the overall management of an emergency, and contains identified responsibilities for key personnel to protect the company's employees, operations, business continuity, and reputation.

The crisis management plan should include

- procedures and protocols for dealing with external authorities and stakeholders at a corporate level
- arranging external services such as counseling, notification of next of kin, and transport, accommodation, and food for any extended activities at the mine site
- advising the board, shareholders, and other stakeholders of potential implications arising from the event, such as loss of reputation or prolonged shutdown of the site
- advising external parties of disrupted production at the site, which could involve suppliers engaged in deliveries to the site, or customers expecting delivery of product from the site
- establishing defined and well-understood links with the site's emergency plan

11.4.1.3.1.3 Emergency Response Plans In emergency response plans, the responsibilities and procedures to follow in case an emergency arises are listed. Emergency response plans should be developed for probable situations (surface or underground) identified from the risk assessment, such as:

- vehicle accident
- fixed or mobile plant catastrophic failure
- fire
- ground failure
- loss of ventilation
- explosives incident
- falls from height or to depth
- chemical or fuel release
- lost person(s)
- electrical incident
- gas release or explosion
- engulfment
- failure of tailing storage facility
- confined space incident

The emergency response plans should include the following information:

- procedures for how to respond to specific scenarios
- duties of various site personnel or agency during an emergency
- communication systems
- equipment and facilities identified in the risk assessment as being necessary to deal with an emergency
- assignment of emergency response duties
- contact details for personnel trained in first aid, communications systems, and other specialist fields like firefighting, rope rescue, etc.

11.4.1.4 The United States

The regulations relating to emergency preparedness in US underground coal mines are covered under CFR Title 30, regulations 49, 50, and 75, while surface coal mines and surface areas of underground coal mines are governed by regulations in CFR Title 30, regulations 50 and 77.

11.4.1.4.1 Underground mines

All underground mines should have a mine rescue notification plan outlining the procedures to follow in notifying the mine rescue teams when there is an emergency that requires their services (eCFR, 2018a).

11.4.1.4.1.1 Mine Emergency Evacuation Plan The mine emergency evacuation and firefighting plan should include the following (eCFR, 2018b):

- procedures for evacuating the mine in emergencies such as fire, gas, explosion, or inundation
- procedures for withdrawing all mine workers not required for a mine emergency response
- procedures for the speedy assembly of mine rescuers, transportation of trained rescue and firefighting miners, rescue apparatus, and fire suppression equipment to the location of the mine emergency
- the location of firefighting and suppression equipment available in the mine
- the use, care, and maintenance of self-rescue devices, including hands-on training in the complete donning and transferring of all types of self-rescue devices used at the mine
- the locations of the escape ways, routes of travel to the surface, exits
- an evaluation of the escape way system; mine map; emergency evacuation plan and firefighting plan in effect at the mine
- locations of abandoned areas
- locations of refuge alternatives
- details of annual training that includes practical training in self-contained self-rescuers (SCSR) in smoke
- procedures relating to the deployment of refuge alternatives

11.4.1.4.1.2 Emergency Response Plan The emergency response plan should include the following for each refuge alternative and component:

- the types of refuge alternatives used in the mine, i.e. a prefabricated self-contained unit or a unit consisting of 15 psi stoppings constructed prior to an event and held in a secure space and an isolated atmosphere
- procedures or methods for maintaining approved refuge alternatives and components
- the rated capacity of each refuge alternative, the number of persons expected to use each refuge alternative, and the duration of breathable air provided per person by the approved breathable air component of each refuge alternative
- the methods for providing breathable air; ready backup oxygen controls and regulators; airlock; breathable air in the airlock; sanitation facilities; harmful gas removal; monitoring gas concentrations; lighting
- the maximum air temperature at refuge alternatives should be included
- the locations for the refuge alternatives should not be in direct line of sight of the working face; they should not be closer than 500 feet from belt drives, explosive magazines, abandoned areas, entrances, air compressors, or fuel, oil, or other flammable materials storage

For a refuge alternative consisting of 15 psi stoppings constructed prior to an event in a secure space and an isolated atmosphere, the emergency response plan shall specify that

- the breathable air components shall be approved by the Mine Safety and Health Administration (MSHA)
- the refuge alternative can withstand exposure to a flash fire of 300°F for 3 seconds and a pressure wave of 15 psi overpressure for 0.2 seconds

If the refuge alternative sustains persons for only 48 hours, the emergency response plan should detail the advance arrangements that have been made to assure that persons who cannot be rescued within 48 hours will receive additional supplies to sustain them until rescue. Advance arrangements should include the following:

- pre-surveyed areas for refuge alternatives with closure errors of less than 20,000:1
- an analysis to demonstrate that the surface terrain, the strata, the capabilities of the drill rig, and all other factors that could affect drilling are such that a hole sufficient to provide required supplies and materials reliably can be promptly drilled within 48 hours of an accident at a mine
- permissions to cross properties, build roads, and construct drill sites
- arrangements with a drilling contractor or other supplier of drilling services to provide a suitable drilling rig, personnel, and support so that a hole can be completed to the refuge alternative within 48 hours

- capability to promptly transport a drill rig to a pre-surveyed location such that a drilled hole would be completed and located near a refuge alternative structure within 48 hours of an accident at a mine
- the specifications of pipes, air lines, and approved fans or approved compressors that will be used
- a method for assuring that, within 48 hours, breathable air shall be provided
- a method for assuring the immediate availability of a backup source for supplying breathable air and a backup power source for surface installations

The emergency response plan should specify that the refuge alternative be stocked with the following:

- a minimum of 2,000 calories of food and 2.25 quarts of potable water per person per day in approved containers sufficient to sustain the maximum number of persons reasonably expected to use the refuge alternative for at least 96 hours
- a manual that contains sufficient detail for each refuge alternative or component addressing in-mine transportation, operation, and maintenance of the unit
- sufficient quantities of materials and tools to repair components
- first aid supplies

11.4.1.4.1.3 Opencast Mines All opencast mines should establish and maintain a communication system from the mine to the nearest medical facility in the case of an emergency (eCFR, 2018c). Provisions for emergency medical assistance, transportation for injured persons, reporting requirements, and posting requirements are to be prepared well before an emergency occurs. The responsibilities of mine operators are as follows:

- make arrangements with the ambulance service for providing 24-hour emergency transportation of injured workers
- make arrangements with the medical services, such as hospital, clinic, and pharmacy, for providing 24-hour medical assistance to injured workers
- report the emergency situation to the Coal Mine Health and Safety District Manager for the district in which the mine is located
- report changes made in the arrangements to the Coal Mine Health and Safety District Manager within ten days

11.5 THE EMERGENCY PLANNING PROCESS

The emergency plan should be relevant, practical, and up-to-date. The process for developing an emergency plan should use the correct information and procedures, as shown in Figure 11.3 (HSWA, 2016).

- **Assess Potential Emergencies**: The first step is to assess the situation. For example, what emergency situation could happen at the task that could

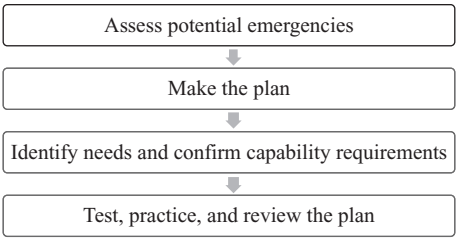

FIGURE 11.3 Emergency planning process.

require an immediate response, and how can the operation respond to each identified emergency situation.

- **Make the Plan**: Consider what to plan to deal with the emergencies identified, whom to consult while developing plans, how to make the plans accessible to workers, and how to communicate the developed plans to workers.
- **Identify Needs and Confirm Capability Requirements**: Consider the types of resources needed to deal with the various emergency situations, the types of training to be provided to workers, and the types of designated officials required.
- **Test, Practice, and Review the Plan**: Determine how to test the developed plan, what type of mock exercises should be done and how often, how to identify the improvement areas in the plan, and who will review and audit the plan and how often.

11.5.1 Emergency Preparedness and Disaster Management Plan for Mines

11.5.1.1 Underground Mines

As there will be no time to prepare or plan the steps and approaches to deal with a disaster once it has occurred, generally the plans are prepared in the pre-disaster phase. The pre-disaster phase involves evaluating the risks, preparing for emergencies such as mine fires, explosions, inundation, etc., and preparing the disaster management plan.

The contents of the disaster management plan should be as follows:

1. Rooms for different purposes
2. Geology, coal seams and their status
3. Details of outlets
4. Dangers
5. Standing consultative committee
6. Action committee
7. Emergency response supervisors
8. Rescue-trained persons
9. Firefighting persons

10. Duties of persons in an emergency
11. Mock rehearsals
12. Copies of plan to be displayed
13. Enforcement of plans
14. Special instructions

11.5.1.1.1 Rooms for different purposes

When the manager declares an emergency, the following rooms should be kept ready:

- operation control room (emergency control room)
- room for rescue personnel and rescue equipment.
- room for public address
- room for treatment to injured
- room for security personnel
- room for visitors and press
- canteen
- laboratory

11.5.1.1.2 Geology, coal seams and their status

The number of seams, their minimum and maximum depths, working status, directions and average dips of the seam, and any remarks should be described here.

11.5.1.1.3 Details of outlets

The details of the locations, depths, dimensions, and purposes of the shafts and inclines should be described here.

11.5.1.1.4 Dangers

The previous history of fire, inundation, and explosion, if any, occurred should be described here.

11.5.1.1.5 Standing consultative committee

This committee will meet in the case of a severe emergency only and advise and help the manager of the mine, or the principal official to deal with the situation.

11.5.1.1.6 Action committee

This committee, working under the guidance and control of the project officer, will share the working of emergency responses.

11.5.1.1.7 Emergency response supervisors

Emergency response supervisors will be responsible for notifications of the emergency and for taking immediate steps to control the situation until the actions committee or other senior officers take over.

11.5.1.1.8 Rescue-trained persons

Details such as name, telephone number, and quarter number for each of the rescue-trained personnel should be attached.

11.5.1.1.9 Firefighting persons

Details such as name, telephone number, and quarter number of each of the firefighting-trained personnel should be attached.

11.5.1.1.10 Duties of persons in an emergency

11.5.1.1.10.1 Duties of workers

If any worker notices any signs indicative of emergency such as fire, inundation, explosion, or roof fall in an underground mine, the worker shall immediately inform the nearest official, i.e. the mining sirdar/overman/under-manager. In case any official is not available nearby, the worker shall contact the communications dispatch system (CDS) operator, who will locate the nearest mining official and send him to deal with the rescue.

11.5.1.1.10.2 Duties of the underground officials

The underground official, on being informed of the occurrence of emergency underground, should immediately

i. verify the correctness of the information
ii. withdraw all persons under his charge to a safe place
iii. send the information to the overmen of other districts by telephone or special messenger for the safe withdrawal of workers
iv. send the information to the telephone exchange and the manager

11.5.1.1.10.3 Duty of the mine timekeeper

i. On receiving information about the disaster, the timekeeper should send a telephone message about the emergency to all telephone points in the underground areas, working districts, fan operators, and substation attendants on duty.
ii. The timekeeper should then inform the manager or acting manager and, in their absence, proceed to call principal personnel. The timekeeper must give this telephonic message clearly and concisely and should not spend any time discussing the circumstances.
iii. He should ensure that there is a supervisor(s) at the surface and underground during the emergency time.
iv. After obtaining authorization from the manager, a state of emergency should be declared by sounding a siren of 12 blasts at the mine.

11.5.1.1.10.4 Duties of the officer in charge of control room

i. He should check the number of missing men from the register and lamp room record.
ii. He should also obtain the casualty list from the medical officer.
iii. He should provide adequate supervision and control at all times at the surface and underground ensuring continuity of official in charge.
iv. He should call additional rescue team personnel from neighboring collieries, consulting with the rescue station superintendent.

v. An authorization system should be put into operation for persons to obtain a lamp and proceed underground.
vi. A running record should be kept of all the important events chronologically.
vii. He should check material and equipment immediately available underground, at the rescue room, and the colliery store.
viii. The names, addresses and occupations of the workers available to assist in recovery work should be recorded in a register kept for the purpose.
ix. He should contact the medical superintendent of the dispensary.

11.5.1.1.10.5 Duties of the lamp room official

i. Issue lamp only with the authorization of the operation control room.
ii. Prepare a list recording the names of persons who are issued with lamps, giving the cap lamp numbers, and send a copy thereof to the operation control room/manager's office. The official should keep the list updated and inform the control room of changes at every hour.
iii. Keep all the lamps brought up from below ground separately until further orders.

11.5.1.1.10.6 Duties of the CDS operator

i. Try to establish contact with those underground and collect the details.
ii. Send information to manager/principal official present on the surface.
iii. Send information by telephone to the following in order of priority:
    a. all members of standing consultative committee of the mine
    b. all members of the action committee
    c. the managers of any adjacent mines
    d. keep a record of all outgoing and incoming messages in telephone log book.

11.5.1.1.10.7 Duties of the storekeeper

i. Check the stock of materials according to the emergency materials list.
ii. Send a list of emergency materials available at the store to the operation control room.
iii. Make arrangements for additional materials from the regional store and from adjacent mines.
iv. In consultation with the surface control room, arrange for the transport of materials to underground as needed.

11.5.1.1.10.8 Duties of the standing consultative committee

The standing consultative committee shall immediately hurry to the operation control room/manager's office, formulate a line of action, and start authorizing different officials

i. for surface and underground control in different shifts, allocating roster duty
ii. as officer in charge of the control room
iii. take necessary decisions for sealing off fire, dewatering water, organizing rescue and recovery operations as the situation warrants

11.5.1.1.10.9 Duties of the colliery engineer

i. Immediately report to the operation control room.
ii. Contact the storekeeper.
iii. Send a messenger to call such workers and mechanics as will be required for dealing the emergency.
iv. Check the ventilation fans.
v. If a messenger from underground states that the air shaft should not be used, take the necessary steps to prevent access to the shaft mouth and fan drift.
vi. Establish a transport system from the stores and stockyards to the mine.
vii. Have loaded readily available stores materials, such as dry sand, sand bags, brattice cloths, timbers, girders, auxiliary fans, air tubes, water pipes, fire-fighting hose, extinguisher refills, and such other materials likely to be required.
viii. Issue authorization to the surface emergency workers.

11.5.1.1.10.10 Duties of the surveyor

i. Arrange for extra rescue plans to be made available.
ii. Arrange for staff to go underground as soon possible and place a tag with a numerical value on the victims' bodies before removal.
iii. Record dates on plans regarding the positions of bodies and other evidence.

11.5.1.1.10.11 Duties of the welfare officer

The welfare officer should report to the control room and assist in the preparation of the following facilities:

i. stretcher casualty station
ii. walking casualty station
iii. mortuary accommodation

The welfare officer should

1. Supervise the preparation of the following accommodation:
   a. room for rescue team to assemble in and receive instructions
   b. sleeping accommodation if rescue operations are to be prolonged.
2. Obtain a copy of the list of workers in the mine from the mine timekeeper and make a note of the men who have come out of the mine.
3. Inform and cooperate with the police for identification of the bodies.
4. Deal with enquiries from the victims' relatives, but not issue statements.
5. Prepare a list of volunteers in three shifts.

11.5.1.1.10.12 Duties of the canteen manager/official

i. The canteen manager should report to the control room and take any necessary steps for additional canteen staff and the additional supply of food.
ii. Consideration should be given to operate the canteen immediately and to issue a system of tickets for all the teams to the canteen. Arrangements

should be made to control the issue of the tickets only to authorized persons from the operation control room.

iii. Arrangements should be made to send responsible persons underground, at fixed times, with sandwiches, hot drinks, etc. for the rescue teams and other parties and to arrange hot drinks for the injured in the stretcher casualty station.

11.5.1.1.10.13 Duties of security staff

The security staff should control the roads, keeping them clear for ambulances, rescue vans, and other vehicles; and also

i. arrange for the identification of bodies
ii. supervise the mortuary arrangements

11.5.1.1.11 Mock rehearsals

Mock rehearsals should be carried out once a quarter to ensure the efficiency of the emergency plan and ensure that all those concerned are thoroughly familiar with their duties and responsibilities, so that, at the actual time of an emergency, they will be able to give a prompt and immediate response.

11.5.1.1.12 Copies of plan to be displayed

Copies of the emergency plan shall be kept at the mine office, mine timekeeper room, incline mouth, fan house and other places in a legible condition.

11.5.1.1.13 Enforcement of the plan

The manager or, in his absence, the principal officer present at the mine at the time of any emergency will put this disaster management plan into operation either in an emergency or immediately following a disaster or similar circumstances.

11.5.1.1.14 Special instructions

Some special instructions considering the condition of the mine should be prepared well in advance and should be made available in the control room for ready reference.

These instructions should include the following points.

i. Escape route and rescue party access way:
   An emergency may arise in the mine for various reasons, such as inundation, fire, explosion, roof fall, etc. In which case, persons working below ground are to be withdrawn to a safe place through their normal traveling route. In case the normal route is affected by the emergency, the withdrawal of persons from the danger/disaster at any part of the mine is to be carried out using the predetermined escape routes shown in the color yellow on the plan for the different areas.
ii. Rescue plan:
   In addition to the requirements of the rescue rules, the rescue plan should also show the site for emergency stopping and the gradient of all main roads/drifts.

iii. Firefighting plan:
This should include the following information: Fire station, pumps, hoses, fire extinguishers, sand buckets, sand dumps, stone dust dumps, hydrants, water valves, water lodges, the gradient of all main roads and drifts, distances from the air shaft along all main roads in ¼ km intervals.
iv. Ventilation instructions, electric power instructions, and any special hazards

11.5.1.2 Opencast Mines

While the contents of the plan should remain same as for underground mines, the duties of mine personnel vary. The duties of the respective personnel are as follows:

Immediately on noticing any emergency, a person should, by telephone, inform the emergency response supervisor/supervisor staff/attendance clerk as follows:

- give the location of incident
- hold on until the message is repeated back
- he shall also try to deal with the situation within his means

11.5.1.2.1 Duties of persons in an emergency

11.5.1.2.1.1 Duties of the emergency response supervisor

- The person in the control room will receive details of the emergency.
- Verify the authenticity of the report.
- Sound the emergency siren.
- Send information to the time officer in charge.
- Withdraw work persons from the area affected or likely to be affected and assume full responsibility for handling the situation and rescuing the affected workers.
- Depute a representative at the emergency control center/field office and plan the deployment of vehicles, whenever/wherever necessary.
- Initiate actions to deal with the emergency and continue with these efforts until more senior officials take over.
- Keep an ambulance available at the control center.
- Ascertain, with the help of the time officer in charge, details of missing persons, if any, and report the same to the control room.

11.5.1.2.1.2 Duties of the time officer in charge

On hearing the emergency siren/alarm/message

- Immediately switch off the main power supply.
- Hurry to the emergency point and keep the maintenance crew in readiness.
- Arrange the availability of an electrical supply in the affected area.

11.5.1.2.1.3 Duties of the attendance clerk

- Immediately inform the safety officer/agent/CISF (Central Industrial Security Force) check post to ensure that they operate the emergency siren, sounding ten blasts when directed.
- Make sure that the emergency response supervisor has been informed.

- Inform the assistant manager, engineer, personnel manager, and medical officer.
- In consultation with the supervisor, prepare a list of missing persons and send the same to the control room.

11.5.1.2.1.4 Duties of the mine manager

- Order emergency siren, if considered necessary.
- See that all members of action committee are informed.
- Arrange to inform all members of the standing consultative committee, if circumstances so warrant.
- Depending on the nature of the emergency arrange to inform the first aid/rescue station, fire station, and other mines (when outside help is required).
- Inform the general manager, head of the project, head office.
- Send information to the Director/Deputy Director of Mines Safety.
- Report to the control room.
- Ensure the availability of materials from stores.
- Arrange men and materials for the withdrawal of machines, when required.
- Prepare a report on the emergency and how it was dealt with.

11.5.1.2.1.5 Duties of the officer in charge of the control room/field office

- Ensure that all key personnel are on duty and that duty cards have been distributed.
- Keep a constant watch on the requirements of men and materials and arrange the same (including for firefighting and rescue persons).
- Arrange for the distribution of emergency badges to keep unwanted persons away.
- Record the sequence of events in the operation logbook and leave written instructions for the next officer in charge.
- Ensure that a record of all incoming and outgoing telephone calls is maintained.
- Leave the control room only when relieved by the next officer in charge, as recorded by the mine manager in the register.

11.5.1.2.1.6 Duties of the safety officer

- Report to the control room.
- Arrange rescue-trained and firefighting personnel.
- Inform the surveyor and fire officer.
- Ensure the availability of PPE, including respiratory protective devices, asbestos fireproof suits, smoke masks etc.
- Reporting and documentation
  - conduct a detailed enquiry into the causes and circumstances that led to the incident
  - document reports and evidence
  - ensure correct format for reporting to different statutory and government bodies

- arrange insurance follow-up both for men and materials
- post written instructions and notices warning about poisonous gases, liquids, or affected atmosphere, etc., thereby cautioning the public.

11.5.1.2.1.7 Duties of the workshop official and plant official

- Report to the control room.
- Ensure availability of materials from stores.
- Ensure disconnection of electric supply from the emergency area if so required.
- Arrange for the withdrawal of machines when required
- Contact the electricity substation to maintain an uninterrupted power supply to safe areas.
- Maintain a proper communication system.

11.5.1.2.1.8 Duties of the security officer

- Arrange for the identification of dead bodies.
- Supervise mortuary arrangements.
- Maintain law and order in general.
- Assist in firefighting if required.

11.5.1.2.1.9 Duties of the civil engineer

- Ensure the provision of alternate water supplies.
- Arrange for post-incident testing of the water and water stream for contamination.
- Arrange the structural inspection after fires, explosions etc.
- Arrange the provision of post-incident recovery services.
- Ensure a supply of water in all the hydrants concerned in the event of fire.

11.5.1.2.1.10 Duties of the environmental manager

- Ensure there is minimum of adverse effect on air, water, soil, and plant.
- Ensure that the pollutants created in the process of dealing with the emergency are cleared and/or safely disposed of in an environmentally friendly way.
- In the case of gas leaks, etc., ensure spill containment and clean-up for the following:
  - the plugging of leaks
  - the suppression of hazardous gas
  - the containment of spills, liquids, or solids on land or water bodies
  - the containment of spills to water bodies
  - the clean-up of spills into water bodies
  - arrange support services for field response forces
  - arrange the maintenance of apparatus and equipment
- In case of contamination of water, appropriate notification should be sent to all concerned with copies to be displayed on noticeboards.

11.5.1.2.1.11 Duties of the workmen inspector

- Report to the control room.
- Assist the safety officer in arranging the rescue team of trained fire-fighting personnel.
- Assist in providing first aid to persons.

11.6 CONDUCT OF RESCUE AFTER DISASTERS

While the disaster management plan helps the mine workers in being prepared for emergency situations, the actual rescue operation conducted in the first few hours will help in saving lives. The steps involved in conducting a rescue operation after disasters such as fire, inundation, explosion, and roof fall are presented below.

11.6.1 Fire in Underground Mines

On observing fire or smoke, the following immediate steps should be taken:

- Evacuate all persons from the districts except those necessary to deal with the fire.
- Immediately inform the CDS, in order to inform the manager or senior officers available.
- Ensure all persons use the escape route.
- Gather together the available rescue persons within the mine or district.
- Explain the position to the immediate officer in charge of the shift. Then shift officials should decide whether persons from other districts should be withdrawn or not, which will depend upon the extent of the fire and its likely effect on other districts.

Procedures for the shift official

- If the fire is small and detected in the initial stages, it can be quenched with available fire extinguishers of the district.
- If the available equipment cannot quench the fire, it will be safer to assume greater danger to other districts and steps should be taken to withdraw all persons from the other districts as well.
- Communicate the latest status of the fire to the manager through the CDS.

The manager in turn will initiate the subsequent steps as follows:

- Immediately proceed to the mine after receiving the information of fire. Analyze the available information and inform the agent, general manager, and rescue station. Proceed underground and take the necessary steps for further evacuation of survivors. Give clear guidelines as to the path of travel for the escape of trapped persons based on the situation of the fire and presence of toxic gases.
- Inspect the site to assess the respirable and irrespirable zone, with the help of safety lamp, CO-detector, and methanometer.
- Decide the most suitable place for a fresh air base to deal with the fire.

- Arrange for procurement, transportation, and stocking of materials such as brattice cloth, hollow blocks, stone, cement, sand, props, etc., up to the FAB.
- Arrange to assemble essential workers, such as rescue-trained persons, masons, support men, etc.
- Instruct the surveyor for the preparation of rescue and recovery plans. Extra copies of these plans should be prepared and be available at the FAB.
- The FAB should have basic facilities such as lighting, communication, drinking water supply, and catering arrangements. A doctor should also be positioned there with minimum support staff and medical equipment.
- The area in and around the occurrence of the fire must be treated with adequate quantities of dry stone dust. This dusting operation should however be carried out without causing the slightest hindrance to the main rescue and recovery operation. This dusting helps in preventing coal dust explosion.
- Strict security should be posted in order to not allow any person into the return airway. The persons going into the mine and coming out of the mine should be clearly recorded.
- The pros and cons of the effects of reversal of the main mechanical ventilator fan should be critically analyzed. Even if it reversed, it should be done only for a limited period to allow the withdrawal of persons in the mine.
- Temporary arrangements for an analytical lab facility should be established on the mine surface to have faster air sample analysis.
- All the rescue and recovery work by the rescue teams wearing breathing apparatus must comply with the statutory provisions of the Mines Rescue Rules, 1955.
- The status of rescue work should be assessed at half-hour intervals and communicated to the surface control room and in turn to the Disaster Management Committee.
- The team of rescue persons, with the help of oxygen self-rescuers, should rescue persons who have saved themselves by barricading themselves from the irrespirable zone. If the air contains enough oxygen, chemical filter-type rescuers can also be used for bringing these persons out.
- For persons who are affected by CO poisoning, oxygen resuscitators should be applied and the person should be carried on a stretcher.
- All persons rescued should report to the doctor at the FAB and further action should be decided on his advice.
- The top priority should be given to the recovery of those who are still alive, and those who may be trapped. The next most important priority should be given to the recovery of dead bodies.

11.6.2 Fire in Opencast Mines

When a person notices fire in the mine, the person should take immediate steps to extinguish it using whatever material or appliances are available at or near the site. If the fire is too extensive to be tackled, the person should proceed to give warning to the nearest official present.

The mining sirdar, overman, or other mining official to whom warning is given should send warning by the fastest possible means to

- other parts of the mine, especially to the attendance clerk, for sounding the siren, so that persons may be withdrawn
- the manager
- a senior official if he is in the opencast working at the time

On hearing the fire signal or on being informed through any other means, the colliery firefighting and rescue teams should immediately report to the control room. All work of dealing with or sealing off a fire or heating opencast should be conducted in accordance with Regulation 117 of the Coal Mines Regulations, 1957, and other relevant statutory provisions, and any recommendations made in this regard by the Director General of Mines Safety through circulars issued from time to time.

Fires that cannot be dealt with immediately and all spontaneous heating, shall be dealt with by firefighting and rescue teams specially detailed for the job, and in accordance with instructions issued by the manager, or, in his absence by the principal mining official present at the mine.

11.6.3 Explosion

In case of explosion, the following immediate steps should be taken:

- The official should send word inbye for the men to withdraw from their working places and join him at the *station* of the district.
- At the *station* the official should explain the situation and urge the workers to remain calm and follow the instructions.
- If the ventilation of the district is apparently normal and no smoke or afterdamp is coming in with the intake air, the official should lead the men outbye via the intake airway asking the workers to keep together.
- The official should instruct a level-headed, experienced person to bring up the rear. If the explosion was purely local in character and confined to one district, the party could then reach the surface safely.
- If the district is on the return side of the explosion, escape is possible via the return airway to the nearest ventilation door by short-circuiting the air current.
- If smoke or afterdamp is found traveling in bye with the intake air or it is concluded that explosion is in an intake airway, it would be unwise to try to escape through the afterdamp. It would be better to remain or retreat in bye and conserve the fresh air of the district.
- The official should therefore short-circuit the ventilation at the entrance of the district and erect brattice stopping to barricade the district from the rest of the mine.
- The official should leave a chalked message.
- Air contained in the workings should remain respirable for a considerable time. Illumination should be maintained as long as possible by trimming down all the safety lamps and extinguishing some electric cap lamps, in order to conserve them for later use.
- The official should arrange to assemble essential workers, such as rescue-trained persons, masons, support men, etc.

- The official should instruct the surveyor for the preparation of rescue and recovery plans.
- Strict security should be posted in order to not allow any person into the return airway. The persons going into the mine and coming out of the mine should be clearly recorded.
- Temporary arrangements for analytical lab facility should be established on the mine surface to have faster air sample analysis.
- All the rescue and recovery work by the rescue teams wearing breathing apparatus must comply with the statutory provisions of the Mines Rescue Rules, 1985.
- The status of rescue work should be assessed at half-hour intervals and communicated to surface control room and in turn to the Disaster Management Committee.
- The team of rescue persons, with the help of oxygen self-rescuers, should rescue persons who have saved themselves by barricading themselves from the irrespirable zone. If the air contains enough oxygen, chemical filter-type rescuers can also be used for bringing these persons out.
- For persons who are affected by CO poisoning, oxygen resuscitators should be applied and the person should be carried on a stretcher.

11.6.4 Inundation in Underground Mines

On observing unusual seepage, rising water levels, or the threat of inundation, the following immediate steps should be taken:

- Withdraw all the workers from the mine in the areas likely to be affected.
- The withdrawal of workers from the dip-most point of the mine is of the first priority.
- Workers themselves will try to run away from the drowning work areas toward a rise. In case the outlet from the mine is cut off from the rising water level, there is a possibility of persons taking refuge in the rise side workings (air pockets).
- The sirdar or overman of the district who has seen the rising water should simultaneously inform the shift official and the manager of the mine through the CDS.
- The shift official should immediately inspect the affected area, assess the situation, and give his firsthand information to his superiors and to the manager.
- The manager should summon the rescue persons and doctors. He should also inform the agent, the nodal officers, and the general manager.
- The rescue of such persons who took shelter in air pockets can be carried out by locating the likely air pockets from a study of the mine plans. From the surface, large diameter holes should be drilled to reach such pockets. Metal capsules are lowered with the help of temporary winches and then persons are rescued one by one from such air pockets.

- The selection of the site for the borehole to be drilled to reach the trapped persons can be decided in consultation with DGMS officials present at the site.
- The manager should immediately proceed underground and assess the situation as to the extent of the area drowned, availability of power, and ventilation for commissioning of dewatering operations.
- If the rising water level has disrupted the ventilation circuit, the same should be established by breaking the ventilation stoppings at the dip-most point, to connect the intake and return airways for the flow of air current.
- The colliery manager should assess the numbers of persons who have escaped from the mine and those who may still be taking shelter in any possible air pockets. This estimate will give the number of lives lost during inundation. To decide the number of missing persons the manager should further check with the shift official, the mine timekeeper, the lamp room official, and the co-workers who have escaped.
- The manager should assess the total quantity of water with the help of the surveyor and the requirements for pumps and other materials for dewatering the area.
- The manager should immediately send the detailed report regarding the procurement and supply of pumps, pipelines, men and other equipment required to deal with the situation.
- In the meantime, the area general manager should form a core committee, inspect the site, and confirm the assessment made by the manager, with any modifications.
- The area general manager should coordinate all the activities and oversee the smooth functioning of all the committees.
- The engineering department should start installing the additional pumps that they have with them, and should procure further pumps for the purpose of emergency preparedness to be stationed at the mine's rescue station.
- Both telephone and good lighting arrangements should be established at the site of the operation.
- What to do with the discharge from the additional pumps installed to dewater the area should be decided, depending on the situation, such as the availability of main sump capacities, the total head required to be dealt with by the pumps, the availability of old workings, and the necessity of the further recovery of survivors or casualties.
- While the dewatering operations are in progress, the engineer in charge of the operation should decide about moving the pumps and extending the pipelines if necessary.

11.6.5 Inundation in Opencast Mines

If there is heavy rain causing the water level to touch the danger mark or if there is a rapid or unusual rise in the level of water in the drain, the drain supervisor should immediately inform the timekeeper and shift official on duty.

- The shift official should instruct the face supervisor to withdraw the persons, pay loader, surface miner, drill, tippers, etc. from the coalface to a safe point.
- The face supervisor should arrange to withdraw the persons from the bottom of the quarry to top wards and machines to a safe place.
- The face supervisor should be present throughout the withdrawal of men and machines.
- The men and machines should be withdrawn in an orderly manner and without creating any panic.

11.6.6 Major Roof Fall

In case of a major roof fall, the following immediate steps should be taken:

- Workers should be withdrawn from the working places of the district and the manager should be informed through the CDS.
- The shift under-manager should immediately inspect all the working places.
- The saving of trapped persons is most important. It should be done with the help of the available manpower at the site or from other parts of the mine.
- In case of difficulty in rescuing the victims of roof falls with the resources available at the mine, the rescue station should be informed immediately and all available resources, including a search camera, and pneumatic jacks, etc. from the rescue station, shall be summoned and utilized.
- Soon after inspection by the senior officers, the rescue work of trapped persons should be placed under the charge of a senior mining officer.
- Sufficient care should be taken to avoid further casualties. The help of rescue-trained persons available within the district and within the mine should be included in the rescue and recovery operations.
- Firsthand information should be communicated to the surface after assessing the actual situation at half-hour intervals.
- If the trapped persons are unable to be rescued immediately, they should be given immediate requirements such as water, and liquid diet with the help of small diameter pipes.
- If the position of a victim in a roof fall cannot be located by physical senses, a search camera can be used.
- Information obtained by the search camera should also be useful to decide the line of progress to rescue the persons.
- If the trapped persons are beneath huge boulders, pneumatic lifting bags, hydraulic lifting cylinders, or other suitable equipment, which are available with the regional rescue stations, can be used to lift these objects.
- Maintain a constant dialogue with the trapped persons, keep them in good spirits, and keep up their morale.
- The safety of the persons engaged in the rescue work is also of paramount importance.
- A safe and secure place as near as possible to the location of the fall should be located and used as base for conducting the work of rescue and recovery

of the trapped persons. The base should be under the control of senior officer. Any person or group of persons going beyond this point should have special permission.
- A good amount of care and caution needs to be exercised in dressing, supporting, and debris clearing with the aim of reaching the location of the trapped persons.
- A secondary team should start to support all vulnerable points surrounding the major fall by using additional supports to protect the persons engaged in rescue work.
- Good lighting arrangements should be provided at the base of rescue operations and up to the point of fall.
- Telephone communication should be established from the base to the surface.
- If ventilation is sluggish at the place of fall, mobilize additional resources in order to increase the amount of air.
- A standby team should be kept ready at the base to relieve the team of persons engaged in rescue work as soon as they are tired.
- As soon as possible after rescuing the victims from underneath the fall, they should have first aid treatment while still underground and then be sent to the surface for further treatment.

11.7 CASE STUDIES

Over the years, disasters in the mining industry have occurred due to failures in procedures, methods, equipment, management, technology, etc. It is necessary to learn from previous disasters in order to prevent the recurrence of the accident/incident. Due to the presence of inherent hazards in the mining operations, it is logical to be prepared for emergency situations. A few case study analyzes are presented below to help to build the bridge between technical concepts and the reality of real-life situations.

11.7.1 Moura No. 2 Mine

Date of the Accident: August 7, 1994
Owner: BHP Mitsui Coal Pty Ltd
Number of Deaths: 11
Place: Moura, Queensland, Australia

On August 7, 1994, at approximately 11.35 p.m., an explosion occurred in Moura Mine No. 2, which led to the deaths of 11 workers. A total of six main seams (A, B, C, D, E, and F) were present in Moura mines, in which seam D was mined by Moura Mine No. 2. The average thickness of the seam varied from 4.5 m to 5 m and the depth was over 265 m. Seam D was a gassy seam containing up to 15 m^3/tonne of 98% methane gas. However, there was no history of gas outburst.

On the day of the incident, 21 mine workers were working underground, of whom 11 workers were deployed in the southern area, 9 were deployed in the northwest

area and 1 was working in the main Dips belt area. The weak methane explosion occurred in the 512 panel at 11.35 p.m. on August 7, 1994. 512 panel is located on the southern side of the mine, where 11 workers were deployed. A second and violent explosion occurred at 12.20 p.m. on August 9, 1994. The rescue operations were not possible due to the second explosion and the mine was sealed as a result.

11.7.1.1 Inquiry findings

- The first explosion occurred due to the spontaneous combustion of coal, which consequently ignited accumulated methane gas.
- The mine management failed to take preventive measures to treat the heating of coal in 512 panel.
- There was no provision for the withdrawal of victims from the Moura No. 2 mine in the case of an emergency.
- A much more violent explosion followed the first explosion on August 9, 1994.
- Large volumes of gases, dust, and smoke were spread in the working areas and were emitted to the surface
- All the surface facilities were covered with heavy dust, smoke, and carbon monoxide at a level of 400 ppm.
- The rescue operations were halted and mine was sealed after the second explosion.

The inquiry made recommendations in relation to the following (Wardens Inquiry, 1996):

- research into spontaneous combustion
- spontaneous combustion management
- panel design
- sealing – designs and procedures
- mine safety management plans
- mine surface facilities
- training and communications
- literature and other training support
- statutory certificates
- ventilation officer
- withdrawal of persons
- emergency escape facilities
- gas-monitoring system protocol
- self-rescue breathing apparatus
- inertization, inert atmospheric condition by infusion of inert gases/stone dust

11.7.2 Sago Mine Explosion

Date of the Accident: January 2, 2006
Owner: International Coal Group, Inc.

Number of Deaths: 12
Place: Tallmansville, Upshur County, West Virginia

At 6:26 a.m., on January 2, 2006, an explosion occurred at Sago Mine in which 12 workers died and one was seriously injured. Before the incident, a pre-shift inspection was carried out at 5.50 a.m. and cleared the mine for work. Two crew teams, consisting of a total of 29 mine workers, entered the mine workings to start the first shift. The first team entered the mine at 6 a.m. and the second team along with 3 other workers entered the mine shortly thereafter. The temperature was strangely warm and a storm, accompanied by heavy rain and lightning, was in the area.

An explosion occurred around 6.26 a.m., one mineworker died due to carbon monoxide poisoning; following the explosion, the second crew and other workers successfully evacuated the mine. The first crew was trapped inside the mine. The mine officials went underground to assess the situation and found that all the ventilation controls were damaged due to the explosion. Due to the presence of smoke and toxic gases, the mine officials terminated their rescue efforts and evacuated the mine.

Rescue teams, including federal and state agencies, were organized. Due to the presence of high levels of carbon monoxide and methane, the rescue operations were delayed. A plan was prepared to drill a borehole for communication and air sampling purposes. The rescue teams entered the mine after the gas levels were stabilized. On January 3, the rescue team found one miner alive and twelve mine workers dead behind a barricade. The surviving mineworker was rescued and transported to hospital. On January 4, the bodies of the dead mine workers were recovered from the mine.

11.7.2.1 Findings

- The main seals failed to withstand the explosion force.
- The mine management failed to monitor the mine gases in the sealed areas.

11.7.3 Crandall Canyon Mine Collapse

Date of the Accident: August 6, 2007, and August 16, 2007
Owner: Genwal Resources, Inc. and Murray Energy Corporation
Number of Deaths: 6 mine workers on August 6, 2007, and 3 rescue workers on August 16, 2007
Place: Huntington, Emery County, Utah

On August 6, 2007, in the early morning, a seismic or ground failure occurred in Crandall Canyon mine. Six workers were trapped underground due to the incident. On receiving the information, four rescue teams arrived at the mine site. The trapped workers did not respond to the radio calls from the rescuers. The mine management believed that the mine workers were working about four miles from the mine entrance (USMD, 2018). The timeline of rescue and recovery operations is presented in Table 11.3.

TABLE 11.3

The Timeline of Rescue and Recovery for the Crandall Canyon Mine Collapse

Date	Rescue and Recovery Operations
8.7.2007	• Repair of damaged ventilation system was carried out • The MSHA's personnel evaluated the roof conditions of mine • First borehole of 2 inch was started at crosscut 138 approximately where the miners were believed to be the evening before
8.8.2007	• A new rescue plan allowing the rescue from underground under heavy rib support was approved • Second borehole drilling was started
8.9.2007	• The first borehole broke through the mine cavity. • A microphone was lowered through the borehole to determine any underground activity • Second borehole drilling was continued
8.10.2007	• Low oxygen levels were detected from the first borehole • A two-man rescue team tried to advance in the number 1 entry, but failed
8.11.2007	• The second borehole broke through to the mine cavity • A camera was lowered into the cavity, only wire mesh of the roof was detected
8.12.2007	• Third borehole drilling was started • A second camera was lowered into the cavity • No communication was detected
8.13.2007	• A second camera was lowered into the cavity • No communication was detected • Third borehole drilling was continued
8.14.2007	• Third borehole drilling was continued • Preparations started to drill a fourth borehole
8.15.2007	• The third borehole broke through the mine cavity • A microphone was lowered through the borehole, but no communication was detected; however, seismic equipment recorded an unidentified noise • A camera was lowered into the cavity, but no activity was recorded
8.16.2007	• Drilling of fourth borehole was started in the morning • In the evening, a significant bounce had occurred, which resulted in the death of three rescuers and injured six rescuers • Rescue efforts from inside the mine were halted
8.18.2007	• The fourth borehole broke through the mine cavity • A camera was lowered into the cavity, but no activity was recorded
8.19.2007	• Drilling of fifth borehole was started
8.22.2007	• The fifth borehole broke through the mine cavity • The rescuers tried to lower a camera, but failed due to a blockage of the hole
8.23.2007	• Drilling of sixth borehole was started
8.25.2007	• The sixth borehole broke through the mine cavity • A camera was lowered into the cavity, but no activity was recorded
8.27.2007	• The rescuers tried to lower a robot through sixth borehole, but failed due to too much debris

(*Continued*)

TABLE 11.3 (CONTINUED)
The Timeline of Rescue and Recovery for the Crandall Canyon Mine Collapse

Date	Rescue and Recovery Operations
8.28.2007	• Drilling of seventh borehole was started
8.30.2007	• The seventh borehole broke through to the mine cavity • No activity was recorded • MSHA appointed a team investigate the accident

11.7.4 New Moghla Colliery

Date of the Accident: March 3, 1997
Owner: J&K Minerals Ltd.
Number of Deaths: 10
Place: Rajouri District (J&K State), India

On March 3, 1997, at approximately 1.15 p.m., a gas explosion occurred at the 12th level north workings of New Moghla mine. As a result of the explosion, four mine workers were dead due to excessive burns, and there was a roof fall, which trapped five workers. Thirteen workers, working at the 12th level, had seriously injuries, in which three were injured due to burns and ten workers were injured due to debris thrown by the explosion. The rescue team found the five trapped mine workers on March 7, 1997, but they were dead due to asphyxiation (Novamining, 2014b).

General details of the mine: The mine has two separate sets of underground workings with incline entries. The inclines 5, 6, and 7 were the entry to one set of workings, while the inclines 1, 2, and 3 were the entry to the second set of workings. The accident occurred in the second set of workings, which extended up to 14 levels, with a depth of 100 m. The gallery widths ranged from 2 m to 2.5 m, and the galleries were 2 m in height. The mine was a second degree gassy mine without a gas survey. The average number employed underground was 200.

At the time of the accident, in the workings, a 25 HP axial flow fan was fitted at the mouth of Incline No. 3, which was the main return airway. It was exhausting about 430 m^3/min of air at a pressure of 25 mm of water gauge. An auxiliary fan was installed in 12th level north, close to the 1st rise, for conducting air to the working faces through tubing made of brattice cloth. Overmen with methanometers had detected inflammable gas in the workings from time to time; the maximum concentration reported being 1.5%. At the time of the accident 123 persons were present below ground.

11.7.4.1 Findings

The following findings were identified from the detailed investigation carried out by DGMS:

- There was no rescue room at the mine site. Despite suggestions made by DGMS, the mine management had failed to establish a rescue room at the mine site.

- Self-rescuers were not provided to underground workers.
- Although the mine was declared as a second degree gassy mine, no provisions were made to conduct a gas survey in the mine.
- No preventive measures were framed to deal with the gases.
- There was a shortage of manpower for working underground and of mine officials, such as the mine engineer and surveyor
- There was a shortage of materials, such as switchgear, electrical cables, proper type of auxiliary fan, and even building materials for the construction of ventilation stoppings.
- The main ventilation fan was too small for the mine and was incapable of producing adequate ventilation in the workings.
- The auxiliary fan was improper in that its hub and blades were made of light aluminum alloy, the use of which was prohibited because of the possibility of incendiary sparks being given off when struck.
- Frictional sparks from the fan were identified as the source of ignition.
- Long blind headings were found without making interconnections.
- Irregular pillar sizes were identified.
- Excessive air was leaking through ventilation stoppings and doors.
- An adequate quantity of fresh air was not reaching the auxiliary fan with the result that it recirculated the air

11.7.4.2 Conclusion

A large volume of methane at high concentration had accumulated in the development workings due to the stoppage of the auxiliary fan. When the auxiliary fan was started the next day, the accumulated mixture was diluted until it came within the explosive range. Frictional sparks created by the auxiliary fan blades rubbing against the metallic duct ignited the gas to cause the explosion.

11.7.5 Mahabir Colliery

Date of the Accident: November 13, 1989
Owner: Eastern Coalfields Ltd.
Number of Deaths: 6
Place: Raniganj Coalfield, West Bengal, India

On November 13, 1989, at approximately 4 a.m. heavy flooding was reported. The heavy flooding was due to the puncture of Narainkuri seam into an abandoned shaft. At the time of the incident, 232 mineworkers were employed underground. Of these, 161 workers were rushed out to the surface as they were working near the shafts. However, 71 workers could not reach the shafts as the roadways leading to the shafts had flooded. In a short time, both the shafts became flooded up to a height of 12 m (Novamining, 2014c).

General details of the mine: The Narainkuri seam was accessible through two shafts, A and B, which were about 86 m deep. At the time of the accident, development was going on towards the rise-most area of the mine. The overlying Ningah seam (parting 22 m) had been worked and abandoned a long time before and was

full of water. There was a telephone connection between the underground workings. Over the telephone, mine officials learned that only 65 miners had taken shelter in the rise part of the workings and 6 miners could not be accounted for.

Rescue and recovery: It was decided by the mine management to dewater the mine by installing submersible pumps in the two shafts and, at the same time, to drill a large diameter hole in the rise-most area to establish communication with the trapped miners.

The pumping operation was started at 1.45 p.m. on November 13, 1989. As of November 18, 1989, 11 pumps with a total capacity of about 1,750 m^3/hour were worked in the two shafts. It was reported from the underground workings that heavy inflow was continuing through the shaft on 34, possibly due to recirculation from surface cracks. To stop the flow from Pit No. 34, this pit was reactivated by erecting a temporary headgear and winder and this shaft was later plugged on November 20, 1989, to stop the flow from Ningah to Narainkuri seam. After this was done, the level of water in shafts A and B started receding at a faster rate.

A borehole of diameter 255 mm was drilled for communication purpose. The drilling was started on November 13, 1989, at 9.30 p.m. and completed after six hours, at 3.30 a.m. on November 14, 1989. All the trapped workers were asked to assemble at the communication borehole. Food, torches, drinking water, and medicines were lowered through this borehole.

A second borehole of diameter 200 mm was drilled close to the first borehole on November 14, 1989, at 9.30 a.m. The borehole was enlarged to 304 mm, then 381 mm, then 457.2 mm, and finally to 546 mm. The top 11 m of the borehole was enlarged to 723.9 mm diameter and was lined with 609.6 mm diameter steel ventilation ducting, to prevent the alluvial portion of the borehole from collapsing. A steel capsule of 431.8 mm inside diameter and 2.5 m height was installed. A 12 tonne crane was used for lowering and raising the capsule. All the 65 persons were taken out from the mine by 9 a.m. on November 16, 1989.

11.7.5.1 Observations

- Improper plan: Pit No. 34, was not shown on the plan of Narainkuri seam.
- For the first time in the history of mining in India, 65 miners trapped below ground were rescued through a large diameter borehole drilled from the surface.

11.7.6 Gaslitand Colliery

Date of the Accident: September 26–27, 1995
Owner: Bharat Coking Coal Ltd.
Number of Deaths: 64
Place: Jharia Coalfield, Jharkhand, India

On September 27, 1995, at approximately 1.15 a.m., the underground mine was flooded due to heavy rainfall, which resulted in the drowning of 64 mineworkers. The Gaslitand mine is situated on the bank of Katri River. The extraction of coal

over a prolonged period had resulted in a lowering of the ground level, which in places was even lower than the bed of the river. It had also caused cracks to develop all over the surface and even in the riverbed (Novamining, 2014d).

11.7.6.1 Timeline

The timeline of events before the incident was as follows:

- On September 26, 1995, at around 4 p.m., rain started as light drizzle.
- At 6 p.m., the rain turned into a heavy downpour with strong winds.
- At 9.15 p.m., there was a complete electrical power failure and all the machinery and equipment operated by electricity, including the main mechanical ventilator, stopped functioning.
- By 10 p.m., the water level in Katri River had risen above the danger and withdrawal mark. However, there was no guard on duty in the second shift to keep a watch on the water level.
- By 10 p.m., the neighboring mines had withdrawn their underground workers.
- At around 10.15 p.m., the driver of steam winder of the 6th pit refused to operate it because of the accumulation of rainwater below the drum.
- The driver of the steam winder and the banksman left their places of duty without handing over charge to persons of the next shift.
- There were three boilers for supplying steam to the winder: two Lancashire boilers and one vertical boiler
  - one of the Lancashire boilers was under repair
  - as the boiler was not operated after 10.15 p.m., the vertical boiler turned cold in a short time
  - the Lancashire boiler was not stoked and fed with coal after 10.15 p.m. and the adverse weather reduced the steam pressure to much below the operating pressure
- As the main mechanical ventilator had stopped working, all the underground workers assembled at the 6th pit bottom at 11 p.m. and gave the signal to raise them. But their signals remained unattended.
- On being informed of the dangerous rise in the water level of Katri River by the river guard of the third shift, the manager and safety officer rushed to the mine at about 12.30 a.m.
- The manager instructed the safety officer to stay at the 7th pit and arrange to withdraw the six persons employed in that section.
- The manager proceeded to the 6th pit to supervise the withdrawal of the persons there. However, he found that the steam pressure was not adequate to operate the winder. He then went to the boiler house.
- At 1 am, the manager reached the boiler house. Efforts to generate steam as an emergency could only have started after that. However, it was already too late.
- At 1.15 a.m., the embankment broke and the river water entered the old quarry. Very soon after that the retaining walls were washed away and the

water entered the old disused quarry, which was connected to below ground workings.

- At about 1.30 a.m., a sudden gust of cool air forced its way up through the 6th pit. The current of air became stronger and soon it came out with great violence shaking the entire headgear structure. The cage at the pit-top was lifted up and this resulted in a violent overwind. The sound of water entering the pit with great force could be heard from the surface. The entire mine was completely filled with water drowning all the 64 mine workers who were underground at that time.

11.7.6.2 Observations

- A record of 210 mm rainfall was observed between 8 p.m. and 11 p.m.
- No mine official was present for the second shift.
- The management failed to take basic precautions and failed to withdraw workers around 10 p.m.
- There is clear violation of duties and absence of discipline demonstrated by the winding engineman not operating the winder in spite of receiving signals from below ground.
- The banksman and attendance clerk failed to inform their superiors.
- The fireman stopped maintaining steam pressure in the boiler without prior permission.

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12 Mine Rescue

12.1 INTRODUCTION

Mine rescue apparatus as used in mines, also called respirators or respiratory protective equipment, includes all types of apparatus that enable a wearer to enter or remain for long or short periods in irrespirable and toxic atmospheres retaining his full physical and mental capacities. They are primarily used for the respiratory protection of men employed in fighting mine fires and in rescue and recovery work after explosions. The saving of lives of men overcome by toxic gases or oxygen-deficient atmosphere forms the immediate and most urgent objective of mine rescue. Figure 12.1 gives the classification of the various types of apparatus that have been developed and are used in mines today.

The various types of apparatus fall generally into the following three main classes:

1. self-contained breathing apparatus (SCBA)
2. filter apparatus or filter respirators
3. fresh air tube breathing apparatus or supplied respirators

12.2 SELF-CONTAINED BREATHING APPARATUS

A self-contained breathing apparatus is an apparatus that supplies all the requirements for respiration by itself and is independent of the surrounding atmosphere (DEP, 2018).

There are two types of self-contained breathing apparatus

1. **Closed-circuit apparatus**: In closed-circuit apparatus, the carbon dioxide in exhaled air is absorbed by the absorbing canister, and oxygen is resupplied to the wearer through breathing bag. The resupplied air is oxygen-enriched. This apparatus supplies with compressed oxygen from the oxygen cylinder to the wearer through the cylinder valve, pressure reducer, pressure demand valve, or demand valve.
2. **Open-circuit apparatus**: In open-circuit apparatus, the exhaled air (carbon dioxide) is released to the outside atmosphere through the exhalation valve in the facepiece, and the wearer is supplied with fresh air to breathe. This apparatus supplies compressed air from the air cylinder to the wearer through the cylinder valve, pressure reducer, pressure demand valve, or demand valve.

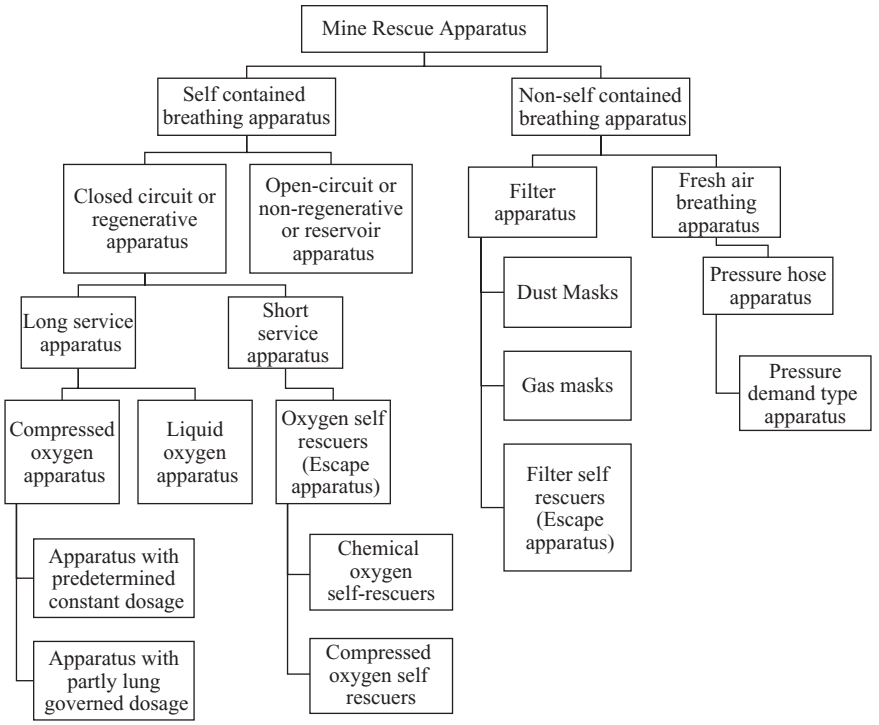


FIGURE 12.1 Classification of mine rescue apparatus.

The other type of classification, depending on the amount of oxygen that can be supplied to the rescuer's self-contained breathing apparatus (SCBA), can also be classified into

3. **Primary apparatus**: this has a minimum of 2 hours of service time.
4. **Auxiliary apparatus**: these units provide, by law, 30 to 60 minutes of service time.

12.2.1 Open-Circuit Type (Compressed Air)

12.2.1.1 Description

This type of apparatus (Figure 12.2) enables the wearer to breathe on demand from a high-pressure air cylinder via a lung-governed demand valve, and/or a pressure reducer connected to a full-face mask. The exhaled air passes from the face mask through a non-return valve to the atmosphere. Open-circuit SCBAs utilize either "negative pressure" or "positive pressure" operation.

- **Negative pressure**: SCBA may be used with a standard face mask instead of filter canisters, and air is delivered to the wearer when he breathes in, or, in other words, reduces the pressure in the mask to less than the outside

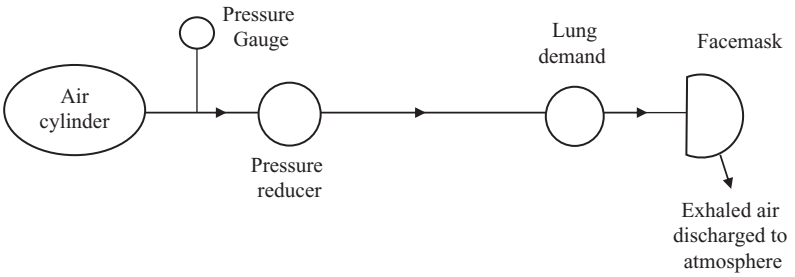


FIGURE 12.2 Schematic diagram of a two-stage open-circuit SCBA.

pressure, hence the name "negative pressure." The limitations of this are obvious, as any leaks in the device or in the interface between the mask and the face of the wearer would reduce the protection offered.

- **Positive pressure**: SCBA addresses this limitation. By careful design, the device is set to maintain a small pressure inside the face piece. Although the pressure drops when the wearer breathes in, the device always maintains a higher pressure inside the mask than outside of the mask. Thus, even if the mask leaks slightly, there is a flow of clean air out of the device, automatically preventing inward leakage under most circumstances. "Positive pressure" SCBA is preferable for most applications.

12.2.1.2 Limitations

The maximum allowed inward leakage is about 0.05%, equivalent to a normal protection factor of 2,000.

The positive pressure apparatus will provide greater protection. The working duration will be reduced in direct proportion to any increase in ambient pressure; for example, at a pressure of 2 bar the working duration is halved.

12.2.2 Closed-Circuit Type (Oxygen)

12.2.2.1 Description

In this type of apparatus (Figure 12.3), after the carbon dioxide content of the exhaled air has been effectively reduced and it has been enriched with the oxygen content of the cylinder, the wearer can rebreathe the exhaled air. It is used with a full face mask or with a mouthpiece, noseclip and goggles.

12.2.2.2 Limitations

The working duration is slightly reduced at raised ambient pressures and sets supplying pure oxygen to the wearer should not be used at pressures above 1.843 bar.

Depending on the source of oxygen supply, the apparatus may be divided into

1. compressed oxygen apparatus
2. self-generating or chemical oxygen apparatus
3. liquid oxygen apparatus

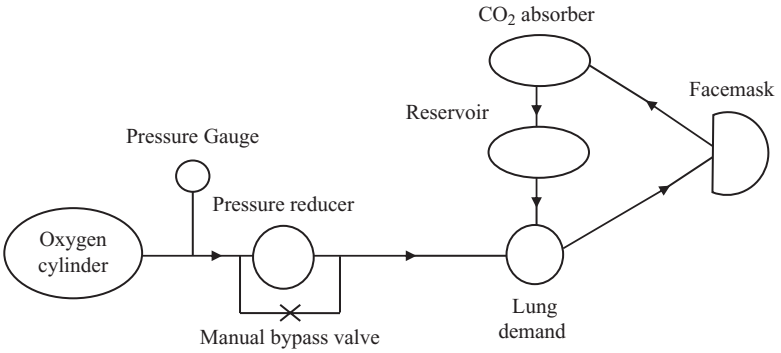


FIGURE 12.3 Schematic diagram of closed-circuit SCBA.

Compressed oxygen and liquid oxygen apparatus are the principal types of breathing apparatus used by mine rescue stations throughout the world, the compressed oxygen apparatus being most commonly used.

12.2.2.3 Self-Contained Compressed Oxygen-Type apparatus

The self-contained breathing apparatus used in Indian mines are of two well-known makes (Ramlu, 1991)

- Draeger self-contained compressed oxygen apparatus
- Proto self-contained compressed oxygen apparatus

Proto Mark IV and Mark V apparatus used to be the main types used in most rescue stations. Nowadays most rescue stations are using BG-4, Travox-120, and BG-174 SCBA, BioPak 240R, and Viking Z Seven. The technical details of modern self-contained compressed oxygen apparatus are presented in Table 12.1 (Avon, 2019; Draeger, 2019; Biomarine, 2019; Dezega, 2019).

12.2.2.3.1 Draeger BG-4

The BG-4 (Figure 12.4) is a compressed oxygen, closed-circuit apparatus with a disposable soda lime CO_2-absorbent canister. It has been NIOSH-certified four times as both a 3-hour and 4-hour apparatus and a standard- and positive-pressure apparatus. The 4-hour positive-pressure version of the BG 4 consists of a cylinder with a fill pressure of 3,135 psi at room temperature.

The 3-hr version comes with a fiberglass-wrapped cylinder. The BG-4 has a constant flow of O_2 of at least 1.5 L/min atmospheric temperature and pressure, dry (ATPD) plus a volume-activated demand valve. The relief valve is also volume-activated and purges exhaled air before it enters the CO_2-absorbent canister. The face mask is connected to the set by the breathing tubes. The user exhales into the face mask, through the exhalation check valve and breathing hose, through the CO_2-absorbent canister, and into the spring-loaded breathing bag. Upon inhalation, the user draws air from the breathing bag, through the heat-absorbent canister, the inhalation hose and check valve, and back to the face mask.

TABLE 12.1
Details of Self-Contained Compressed Oxygen Apparatus

	Viking Z Seven	BG 4	BG-174	Travox-120	BioPak 240R	P-30EX
Make	Avon	Draeger	Draeger	Draeger	Biomarine	Dezega
Duration of use (hours)	1	4	4	2	4	4
Operating temperatures	−26°C	40°C	40°C	−15°C to +40°C		
Oxidation catalyst		Soda lime	Pelletized soda lime	Oxy soda lime cartridge	Solid core CO_2 scrubber	Soda lime
Weight (kg)	5.21	15.5	12.8	10.9	15	11.8
Oxygen cylinder		400 L at 200 bar	400 L at 200 bar	200 L at 200 bar	440 L at 207 bar	400 L
Constant oxygen metering (L/min O_2)		1.5 to 1.9	1.5	0.8	1.8	1.4
Breathing bag volume (L)		5.5	6	7	6	5

FIGURE 12.4 Draeger BG-4.

12.2.2.3.2 BG-174

The BG-174 is a negative-pressure-type, closed-circuit SCBA. The outline of the BG-174 is shown in Figure 12.5. The components of BG-174 include oxygen cylinder, cylinder valve, pressure gauge, pressure gauge shutoff, oxygen distributor, manual bypass valve, pressure reducer, inhalation valve, lung demand valve, lung demand valve needle, warning signal control, medium pressure line, metering orifice, diaphragm, cotter pin, face mask, exhalation tube, exhalation valve, inhalation tube, inhalation valve, CO_2 absorption, breathing bag, and saliva trap.

12.2.2.3.2.1 Working of BG-174 The oxygen cylinder couples to the oxygen distributor, which feeds the pressure reducer, the manual bypass valve, and through the pressure gauge shutoff valve and the pressure gauge. These form the high-pressure components of the set (Burstoninnovation, 2018).

The pre-flush unit is fed from the pressure reducer and activates when it is subjected to a surge of pressure, i.e. when the cylinder valve is opened normally. It rapidly injects oxygen into the tube that connects the CO_2 absorption canister to the

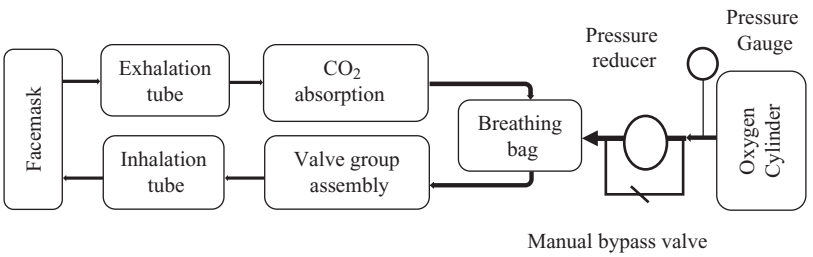


FIGURE 12.5 Outline of BG-174.

breathing bag. The breathing bag has a volume of approximately 6 L. The pressure reducer reduces the pressure of the oxygen supplied by the cylinder to maintain a pressure in the medium pressure line. The manual bypass valve bypasses the pressure reducer to supply oxygen at cylinder pressure to the pre-flush line. The medium pressure line connects the pressure reducer to the metering orifice, lung demand valve and warning signal control bellows in the valve group assembly.

The metering orifice allows oxygen to flow at into the valve group assembly. This is the constant dosage supply and is normally sufficient for up to medium workload.

The face mask is connected to the set by the breathing tubes. The saliva trap is on the inhalation tube. The valve group assembly also contains two one-way valves to maintain the correct flow direction through the set and minimize tidal rebreathing in the face mask. The inhalation valve is in the inhalation tube connection and only allows oxygen to flow from the valve group assembly into the inhalation tube.

The exhalation valve is in the short tube that connects the valve group assembly to the CO_2 absorption canister and only allows oxygen (which at this point contains CO_2) to flow from the exhalation tube to the CO_2 absorption canister.

Should the wearer empty the breathing bag and create sufficient negative pressure in the set (between −1 and −4 mbar) when inhaling, the diaphragm in the valve group assembly is drawn inward, pushing the cotter pin against the lung demand valve needle. This causes the base of the needle to temporarily lose its seal and allow oxygen to bypass the metering orifice.

The CO_2 absorption canister is filled with pelletized soda lime, which absorbs the carbon dioxide from the exhaled oxygen. The oxygen then flows into the breathing bag from where most of each breath is taken. A by-product of the absorption process is heat and for this reason, the CO_2 absorption canister is designed to give off heat.

With a fully charged cylinder, the BG-174 has a working duration of 4 hours. There are seven valves on the BG-174, three are manually operated (cylinder valve, manual bypass valve, and pressure gauge shutoff valve) and the other four operate automatically when affected by the wearer's breathing (inhalation and exhalation valves, lung demand valve, and pressure relief valve).

12.2.2.3.3 Travox 120

The Travox 120 has internal connection to the breathing bag and also a soda lime cartridge for CO_2 absorption. It weighs 10.9 kg and has a capacity of 1 liter, which can run for 2 hours. The working of Travox 120 is similar to BG 174.

12.2.2.3.4 Proto Mark IV Apparatus

Proto Mark IV is a self-contained breathing apparatus, which protects the worker from the inhalation of carbon monoxide. The Proto self-contained breathing apparatus comprises a chest-mounted, canvas-covered "breathing bag," oxygen cylinders, supply tubes, a noseclip, a mouthpiece, and a skullcap. The Proto recycles exhaled carbon monoxide into the chest-mounted breathing bag, purifies it with sodium carbonate, and, with the aid of the oxygen contained in the cylinders, permits the user to have clean air for breathing (Table 12.2).

TABLE 12.2
Specifications
Proto Mark lV

Endurance (nominal)	2 hours
Cylinder capacity, empty	3 L
Cylinder capacity at 122 bar	382 L
Breathing bag capacity, full	Excess of 5 L
Mass of apparatus, fully charged	17.27 kg
Oxygen flow rate	2 L/mine

12.2.2.3.4.1 Special features The molded rubber breathing bag with integrally molded ribs is divided into compartments by a ribbed rubber partition that extends from the top to a little over the bottom and a charge of 2 kg of carbon dioxide absorbent "protosorb" is placed at the bottom of the bag, divided equally between the front and rear compartments. It is fitted at the top right-hand corner with a manual relief valve (Figure 12.6).

- A cooler is used to reduce the temperature of the regenerated air before inhalation. The cooler is a two-compartment copper chamber containing 170 g of a chemical disodium phosphate, which melts at a temperature of 35°C. The melting of the sodium phosphate results in the absorption of heat. The chemical resolidifies on cooling and remains permanently in the cooler.
- The reducing valve is of the well-proven diaphragm design in which a spring-loaded diaphragm is balanced by the reduced pressure at which the reducer is set so that the diaphragm is continually moving backward and forward maintaining a constant flow independent of cylinder pressure.
- The apparatus is not mounted in a carrying frame but is worn on the front and back of the wearer.

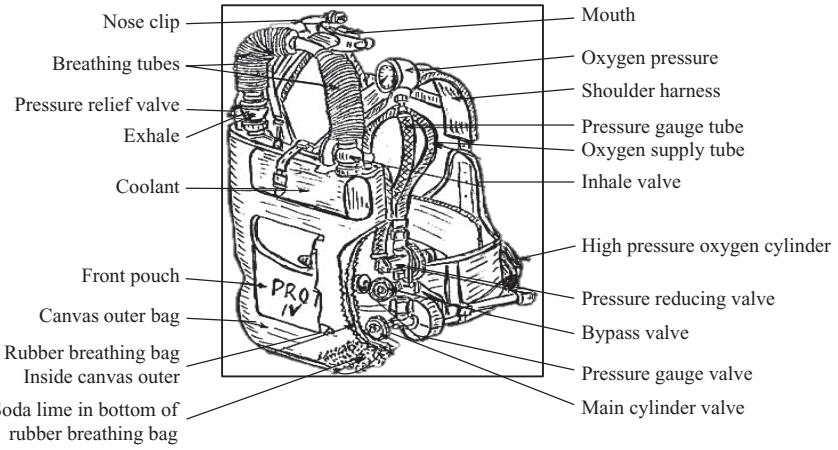


FIGURE 12.6 Proto Mark IV apparatus.

12.2.2.3.4.2 Circulatory system The exhaled air containing unused oxygen and carbon dioxide enters the breathing bag at the top of the front compartment vie the exhalation tube and exhalation valve and passes down this compartment, through the chemical absorbent lying in the bottom of the bag, and up the back compartment as purified air.

- The purified air mixes with fresh oxygen, which is being constantly delivered at the top of the back compartment from the cylinder through the reducing valve, and, on inspiration, the oxygen-air mixture passes through the cooler, inhalation valve, and inhalation tube into the wearer's lungs. When the bypass valve is opened, the breathing bag is filled directly from the oxygen cylinder. The manual relief valve prevents excessive pressure build-up.

12.2.2.3.5 Proto Mark V Apparatus

The Proto Mark V apparatus is an improvement over the Proto Mark IV. It is available as a 1-hour or 2-hour apparatus. In the 1-hour apparatus the coolant is a calcium chloride but in the 2-hour it is soda phosphate, as in the Mark IV. The weight of the 1-hour apparatus is 14.5 kg and that of 2-hour apparatus is 17.2 kg. The oxygen flow rate in the 2-hour apparatus is 12.0 L/min. and in the 1-hour apparatus, 2.5 L/min. The 2-hour Mark V apparatus is fitted with a warning signal to indicate the approach of cylinder exhaustion and it can be supplied with a wide vision face piece and a speaking diaphragm. The bypass valve is of push button type instead of the hand wheel type of Mark IV.

12.3 AEROLOX LIQUID OXYGEN BREATHING APPARATUS

This apparatus (Figure 12.7) was officially approved in 1968 for use in mine rescue work in British mines, replacing the Proto Mark IV and liquid air apparatus. Aerolox is a 2-hour, closed-circuit, liquid oxygen breathing apparatus, which provides cool, dry air even when being used in a hot environment. Breathing resistance is so low that it is hardly noticeable under heavy work conditions. The rated duration of Aerolox is two hours with a 25% safety factor at hard work rate and a 5.5 lb charge of liquid oxygen. As the work rate decreases so the duration increases. The apparatus contains a liquid oxygen container and evaporator, a regenerator, a breathing bag, a facepiece, and a relief valve. It is a long duration apparatus with 2½-hour endurance under strenuous exertion. It contains a liquid oxygen charge of 2.5 kg and a breathing bag capacity of 5 L. The oxygen flow rate can be varied between 6 to 12 L/min, and the total weight of the apparatus when fully charged is equal to 14.85 kg. The liquid oxygen container contains asbestos fibers that absorb the liquid oxygen and prevent the escape of free liquid into the breathing circuit. It is surrounded by a baffled evaporator, which is designed so that evaporation of liquid oxygen is controlled by the wearer's breathing rate.

The regenerator contains Protosorb 1.6 kg of 10 mesh. The breathing bag is located below the evaporator. The mouthpiece consists of noseclips, two breathing tubes, and a connecting piece. There is an automatic relief valve, which relieves excess evaporated oxygen in the breathing circuit. The working principle is closed-circuit SCBA by means of liquid oxygen evaporation. The safety factor 25%,

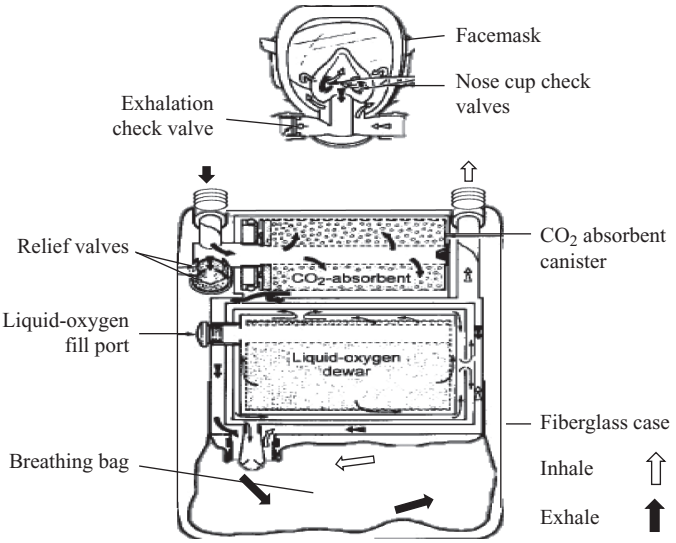


FIGURE 12.7 Siebe Gorman Aerolox schematic diagram.

30 minutes. The scrubber material Protosorb or soda lime. The mouthpiece is dual hose, with no shutoff valve. Oxygen is transported in a Dewar flask.

12.3.1 Description of the Evaporator on the Aerolox Apparatus

The Aerolox apparatus consists of a perforated, tinned brass, inner case packed with calcined asbestos wool, which is surrounded by four further tinned brass cases, the inner three of these taking the flow of evaporated oxygen from the center case, through suitably placed apertures, into the fourth section, through which regenerated air from the purifier also flows. A plug screws into a filling orifice on the outside of the evaporator and this orifice connects with the inner canister containing the calcined asbestos wool. The calcined asbestos wool serves to soak up the liquid oxygen charge, thus preventing the liquid from swilling about inside the evaporator (Table 12.3).

12.3.2 Special Features

- it provides cool, dry oxygen to the wearer at a temperature below the ambient temperature for full duration of the apparatus
- it removes heat from the wearer's body via respiratory tract
- it is light in weight

12.3.3 Circulatory System

- The exhaled, warm, saturated air containing unused oxygen and carbon dioxide passes through the exhalation valve and exhalation tube into the radial flow generator or purifier where it is freed from CO_2.
- The purified air then passes over the first section of the liquid oxygen evaporator, which cools and dries the air before it enters the breathing bag, where

it is mixed with cool, fresh gaseous oxygen. The air-oxygen mixture passes through the inhalation tube and inhalation valve into the lungs, completing the circuit.

TABLE 12.3
Specifications
Siebe Gorman Mk-1 and Mk-2 Aerolox

Endurance	3 hours
Liquid oxygen charge	2.9 kg
Mass of apparatus	
Fully charged	15.9 kg (Mk-1)
	12.7 kg (Mk-2)
Failing to	13.2 kg (Mk-1)
	12.7 kg (Mk-2)
Oxygen flow rate	12.5 L/min (Mk-1)
	12.4 L/min (Mk-2)
Absorbent charge	1.6 kg 8/12 mesh 4

12.4 FILTERED AIR RESPIRATORS

This apparatus is of the open-circuit type and provides respiratory protection for limited periods against carbon monoxide in an atmosphere containing not more than 2% carbon monoxide and not less than 16% oxygen needed to sustain life.
There are two main types of air filter masks that are used in mines

1. chemical respirators or filter masks
2. particulate respirators or mechanical filter respirators

The chemical respirators can be further divided into

1. canister-type filter masks, gas masks, or gas respirators
2. self-rescuer respirators or filter self-rescuers

12.4.1 Oxygen Self Rescuer

Oxygen self-rescuers provide protection against toxic and noxious gas in mine atmospheres and enable the wearer to escape from the danger zone to a place of safety. The exhaled air is regenerated and enriched with oxygen for rebreathing so that the wearer is independent of the surrounding atmosphere.

The oxygen self-rescuers commercially available today are bigger and two to four times heavier than the filter self-rescuers. With further design developments, they may increasingly replace the filter self-rescuers, which offer limited protection.

Depending on the oxygen source, there are two types of oxygen self-rescuers: chemical oxygen and compressed oxygen self-rescuers. The two types of oxygen

self-rescuers have many common parts, such as the mouthpiece, breathing hoses, CO_2 absorbent bed, breathing bag, and relief valve.

12.4.1.1 Chemical Oxygen Breathing Apparatus

Chemical oxygen breathing apparatus is suitable for areas where there are high hazard concentrations or where oxygen deficiency may suddenly occur. Most of the chemical oxygen apparatus uses potassium superoxide (KO_2) for both the oxygen source and the CO_2 absorbent. These are closed-circuit breathing apparatus, which generate oxygen through the reaction of the exhalation air with the chemical. The chemical reacts with the humidity and carbon dioxide of the exhalation air, releasing pure oxygen that fills the breathing bag from which oxygen-containing air is again inhaled. The carbon dioxide of the exhalation air is absorbed without additional auxiliary means.

The oxygen supply is breath-controlled. The lower the breathing rate, the less oxygen is generated and the longer the service time of the apparatus. This results in long service times if the user is at rest. Chemical oxygen breathing apparatus are stored under no pressure in airtight, closed containers. Thus, they can be stored for years without requiring maintenance. The most frequently used chemical oxygen breathing apparatus is shown in Table 12.4.

12.4.1.2 Compressed Oxygen Breathing Apparatus

The compressed oxygen breathing apparatus needs parts that include a high-pressure storage bottle, a regulator to step down the high pressure, a constant-flow valve, and, in most cases, a demand valve. The compressed oxygen apparatus uses bottled oxygen under high pressure for the oxygen source, with a separate chemical bed for CO_2 absorption. The most frequently used compressed oxygen breathing apparatus are shown in Table 12.5.

TABLE 12.4
Chemical Oxygen Breathing Apparatus (Metallurgist, 2018)

		Weight (kg)	
Apparatus	**Duration (min)**	**In Case**	**In Use**
Draeger OXY-SR 60B	60	3.80	3.40
MSA 60-min SCSR	60	4.04	3.00
SSR-90	90	4.69	3.08
AZG-40	40	2.03	1.68
Fenzy Spiral II	45	3.49	3.05
WC-7	45	2.94	2.55
MSA 10-min PBA	10	1.24	0.82
MSA 10/60	70	2.18	4.73
Lockheed PBA	60	2.11	2.00
Westinghouse PBA	60	3.85	3.44

TABLE 12.5
Compressed Oxygen Breathing Apparatus (Metallurgist, 2018)

Apparatus	Duration (min)	Weight (kg)	
		In Case	In Use
CSE AU-9A1	60	4.95	4.30
Ocenco EBA 6.5	60	3.51	3.10
USD SCEBA-60	60	3.40	3.24
Draeger OXY-SR 30	30	2.39	2.39
Draeger OXY-SR 45	45	2.39	2.39
PASS 700	60	8.60	6.60

12.4.1.3 Self-Rescuer Respirators

A self-rescuer respirator is an emergency gas respirator that provides respiration protection against carbon monoxide gas in underground mines resulting from explosion or fire. A self-rescuer respirator is small, compact, and lightweight (max. 1,000 g) and, unlike an oxygen self-rescuer, is a one-time use respirator for escape purposes only. A sectional diagram of self-rescuer respirators is shown in Figure 12.8. A filter self-rescuer consists of a sealed filter canister cartridge that is drawn over by a flannel filter bag to act as a coarse dust filter, an exhalation valve, a mouthpiece and chin rest, a noseclip, head straps, and a carrying case with carrying straps and seal. The canister contains a layer of highly efficient drying agent to protect a layer of hopcalite catalyst from moisture.

In the self-rescuer respirators, the respiration is provided by converting toxic carbon monoxide to non-toxic carbon dioxide using an oxidation catalyst, of a material such as hopcalite. To keep the oxidation catalyst functioning, the respirators are generally equipped with a dust filter and moisture trap, as either contaminant would reduce its effectiveness. To reduce the heat generated during the oxidation reaction, the respirators are equipped with an integral heat exchanger. MSA IW65 is one of the most commonly used self-rescuers in Indian mines.

12.4.1.3.1 Working

The expired air is passed through the heat exchanger and out through the spring-loaded expiratory valve to prevent moisture contamination. Excess saliva is also expelled through the expiratory valve. Protected in a stainless-steel case, the self-rescuer respirator has a positive hermetic seal. If the seal is broken, it should not be used unless it is replaced with a new factory seal. The weight of the entire assembly is approximately 1 kg and can be carried comfortably on the hip via a belt. It can be carried by every miner on his body and may be taken off only at the workplace.

12.4.1.4 Gas Masks

A gas mask is a mask that forms a sealed cover over the mouth and nose to protect the wearer from inhaling airborne toxic materials. The airborne materials can be

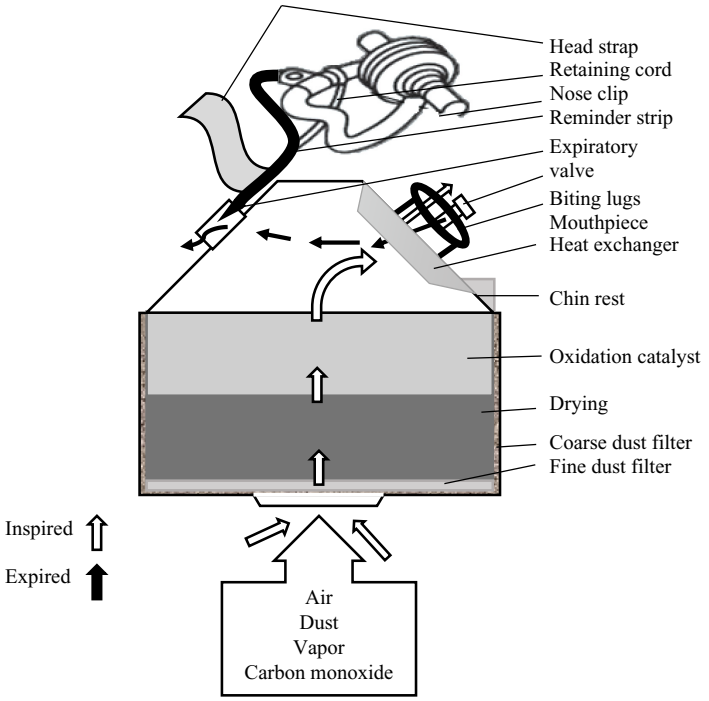


FIGURE 12.8 Sectional diagram of self-rescuer respirator.

airborne particulates or toxic gases. Many gas masks provide protection from both toxic gases and particulates. A few gas masks are also respirators. The mask can be a single-canister or double-canister type.

A few gas masks can cover the full face of the wearer in order to protect the face of the wearer. The full-face gas masks have a polycarbonate full-face window. A sectional view of a gas mask canister is shown in Figure 12.9. All Service-Type Canisters of oval cross-section, contain mechanical and chemical filters deposed one above the other to remove the toxic dusts, fumes, mists, and smoke, to absorb acid gases and organic vapors, and to convert carbon monoxide to carbon dioxide. The canister has opening at the top and at the bottom so that, when the wearer inhales, the external air surrounding the wearer enters the bottom opening, passes upward through the filters arranged in layers, and leaves the canister through the top opening. The elimination of irrespirable or toxic constituents of air is affected by the process of chemical absorption, physical absorption, catalytic oxidation, and mechanical filtration. The absorbents used for the removal of gases and vapors are in the form of granules.

The main difficulties with using a gas mask are

- the wearer may be exposed to many different types of toxic materials
- the gas masks can be used only for a limited time unless the filter device in the mask is replaced

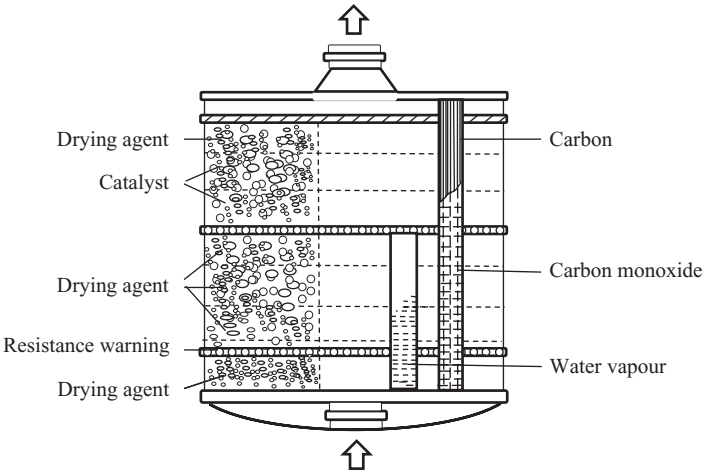


FIGURE 12.9 Gas mask canister.

Various types of filter layers are

- cellulose particulate filter for removing dusts, fumes, mists, and smoke
- impregnated activated charcoal and caustite for absorbing organic vapors
- activated charcoal and baryta-charcoal for the removal of acid gases
- silica gel or charcoal impregnated with sulphuric acid for the removal of ammonia
- anhydrous calcium chloride or calcium chloride/zinc chloride for the removal of final traces of moisture, etc.

The catalytic oxidation of carbon monoxide at ordinary temperatures to the relatively harmless carbon dioxide is affected by hopcalite, an activated granular mixture of manganese peroxide and copper oxide.

A check valve (inhalation valve) is provided either in the top opening in the canister (internal check valve) or in a special coupling (external check valve) that connects the canister with the breathing tube, to pass air through the canister in one direction only, thus preventing the exhaled air from entering the canister. It also provides sealing against the moisture.

A facepiece assembly permits the wearer to breathe through his nose or mouth. It consists of a molded rubber facepiece (full mask), which readily fits any face with minimum dead space, an exhalation valve, a corrugated breathing tube, and a head harness. The facepiece is usually of the wide vision type with one or two non-fogging, large-area lenses. The breathing tube connects the facepiece to the canister.

There is a warning device or built-in indicator to give a positive indication to the wearer when the canister is no longer effective against carbon monoxide.

A canister harness supports and holds the canister securely against the body. The canister may be worn on the front, on the side, or on the back of the wearer.

12.5 FRESH AIR HOSE OR TUBE BREATHING APPARATUS

The fresh air hose breathing apparatus (FABA) (Figure 12.10) can be used anywhere, as the air is supplied from the hazard-free atmosphere. For the same reason, there are no time restrictions on the use of FABA.

This apparatus, also called supplied-air respirators or hose masks, supplies the wearer with fresh air from a source of fresh air supply through a flexible non-collapsible air tube or air hose so that the wearer is independent of the surrounding irrespirable atmosphere. There are two types of air hose apparatus

1. suction hose apparatus
2. pressure hose apparatus

12.5.1 Suction Hose Apparatus

These are designed to work at a short distance from fresh air. The wearer sucks or draws fresh air through the hose by the inspiratory effort of his lungs. As the inspiratory resistance increases with increasing length of the hose, the use of the suction apparatus is limited to short distances within 20 m of fresh air.

A suction hose apparatus consists of a full mask (double or single lens type), half mask or a mouthpiece with a noseclip, a flexible corrugated breathing tube, a 25 mm diameter smooth bore hose of canvas and rubber with embedded spiral wire armoring, a stout leather belt with a rustless connecting socket or metal clamp to prevent the hose from dragging on the facepiece, half mask, or mouthpiece, and an air filter to prevent entry of dust and foreign matter. An expiratory valve is provided either on the facepiece or on the facepiece/mouthpiece connector, and an inspiratory valve is placed either in the connecting socket or on the facepiece/mouthpiece connector.

The apparatus is available as a lateral or back type. In the lateral type, the connecting hose socket or clamp on the belt is positioned on the left hip so that the shoulders of the wearer are free. The back-type apparatus, on the other hand, has

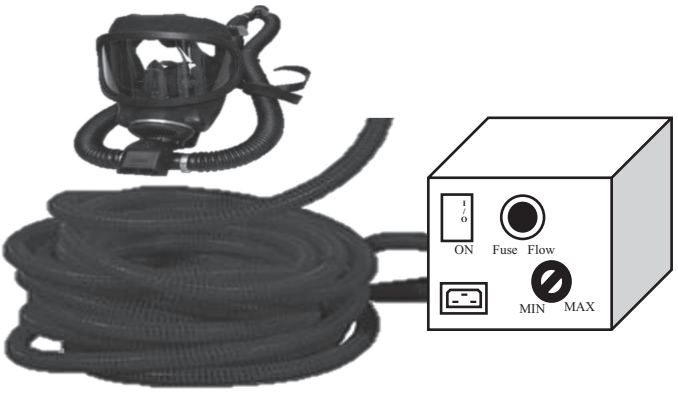


FIGURE 12.10 Fresh air hose breathing apparatus.

twin corrugated breathing tubes passing over the shoulders, connected to a swivel-type metal Y connecting socket on the wearer's back. Such apparatus is particularly suited for work in confined spaces into which the wearer enters from above. For reasons of safety, suction hose apparatus is not approved for use below ground.

12.5.2 Pressure Hose Apparatus

In this type of apparatus, fresh air is continuously forced through a hose to the wearer by means of a suitable air supply device. Such apparatus is used when the distance between the workplace and fresh air is between 20 and 200 m, depending on the means of air supply. As the air hose is constantly under a positive pressure, there is no danger to the wearer from leakage of outside irrespirable atmosphere into the apparatus.

Pressure hose apparatus is available as a lateral- or back-type apparatus. A lateral-type pressure hose apparatus consists of a gas-tight facepiece or mouthpiece with noseclip, a flexible corrugated breathing tube, a breathing bag or equalizer, a belt with a connecting socket containing an inspiratory valve, and shoulder harness. With a valveless facepiece or mouthpiece, an expiratory valve is provided on the facepiece or mouthpiece connector to which the corrugated breathing tube is attached. The breathing bag serves to maintain a continuous flow in the breathing tube during the inspiration and expiration phases and to smooth down the peak demands.

The back-type apparatus has two corrugated breathing tubes passing over the shoulders. It has one inspiratory and one expiratory valve. Fresh air is supplied to the wearer by using one of the following devices:

- manual bellows
- centrifugal blower (hand motor or hand-operated motor)
- compressed air injector (operation from compressed air storage cylinders)
- compressed air lines by compressed air systems incorporating a fine filter

The maximum lengths of air hoses that can be used with pressure hose apparatus are

- with manual bellows: up to 50 m
- with electric blowers (using a breathing bag and with one apparatus user): up to 100 m

Hand bellows are used for short working periods and where electricity is not available. For long working periods, apparatus with a blower or injector unit can be used, capable of supplying air for two men. With motor hand-operated blowers, the blowers can be hand operated when the electric current is interrupted or is not available. When using air from permanent compressed air lines, an oil filter should be used for cleaning the air and making it respirable. The compressed air supply hose is made from electrically conducting, oil-resistant synthetic rubber for use in areas with explosion hazards.

When using compressed air pressure hose apparatus, a manually operated regulator must be used so that the volume of air required can be adjusted. The excess of expired air escapes into the atmosphere through an expiratory valve. The main advantage of an air hose apparatus is the low breathing resistance. The disadvantage, however, lies in the heavy, large-diameter, unwieldy air hoses.

12.5.2.1 Precaution When Using Fresh Air Hose Apparatus

The following precautions should be observed when using a fresh air hose apparatus:

- the apparatus should be used by trained rescue men
- before commencing work, the method of signaling should be decided; if a code of signaling is laid down by regulations, it should be followed
- a person should never work without an observer, who should also be a trained rescue man, in readiness at the fresh air source or base for help
- the wearer should see that the air hose does not get pinched or jammed
- full face mask- and half mask-type apparatus should not be used except in conjunction with either a rotary blower or compressed air injector that is capable of maintaining positive pressure
- when the wearer gives the signal "I require help" the fresh air supply must be maintained

12.6 THE MINES RESCUE RULES, 1985

The government of India, under section 59 of the Mines Act, 1952, published the Mines Rescue Rules, 1985 (DGMS, 1985). The purpose of the rescue rules is to permit mine owners of underground mines to establish and maintain rescue station(s). The functions of the rescue station(s) are as follows:

a. to train the miners in rescue and recovery operations; initial training and refresher training should be provided
b. in the case of explosion or fire, an inrush of water, or influx of gases, to perform and support in rescue and recovery operations at the mine
c. if there is no rescue room at the mine, to perform the functions of rescue room in respect of such an underground mine

These rescue rules are applicable to all coal and metal mines in India. They consist of 6 chapters, 38 rules and 8 schedules. Details are as follows:

Chapters	Rules	Title
I	1–2	Preliminary
II	3–11	Rescue Stations and Rescue Rooms
III	12–16	Duties and Responsibilities of Superintendents, etc.
IV	17–23	Organization and Equipment in Mines
V	24–33	Conduct of Rescue Work
VI	34–38	Miscellaneous

The salient features of the Rescue Rules, 1985 are as follows:

- **Chapter I**: It includes the applicability of the rules, and the different definitions used in the rules. It gives the definitions of the act, below ground mine, chief inspector, owner, principal official, rescue room, rescue station, superintendent, etc.
- **Chapter-II**

Rule 3: It deals with the chief inspector to permit or require the owner of an underground mines to establish and maintain a rescue station. Every rescue station should have one superintendent, at least two instructors, and a rescue team of not less than 18 rescue-trained persons. If a superintendent is absent for more than 60 days, a new superintendent should be appointed.

Rule 5: Establishment and location of rescue room: If there is no rescue station within the radius of 35 km of an underground mine that employs more than 100 persons underground, the owner should establish a rescue room near the entrance of the mine at the surface.

Rule 6: Functions of rescue room: The functions of a rescue room are to provide facilities for the storage, assembly, testing, and adjustments of breathing apparatus and other rescue equipment and apparatus, and for their speedy transport to mines.

Rules 7–9: Concerns the qualification and experience of the superintendent, instructors, and rescue-trained personnel.

Rule 11: Rescue equipment should be made available even at the places where no rescue rooms are provided (see Table 12.6).

TABLE 12.6

Equipment to be Kept at Every Rescue Station

Breathing apparatus	Two-hour self-contained breathing apparatus – 54
	Short duration self-contained breathing apparatus – 6
	Absorbent charges – 2,000
Resuscitating apparatus	Resuscitating apparatus – 12
	Spare cylinders – 8
Tube apparatus	Pressure type with bellows – 2
	Spare helmets – 2
	Pressure type with fan – 1
Ancillary equipment	Oxygen cylinders – 12
	Oxygen pump (hand-driven) – 4
	Oxygen pump (power-driven) – 2
	Bobin meter – 3
	Flowmeter – 2
	Universal tester – 2
	Pressure gauge testing device – 2
	Oxygen testing apparatus – 1
	Apparatus testing tool kit – 8
Lamps, etc., and gas testing device	Flame safety lamps with maintenance kit – 8
	Electric safety lamps

- **Chapter III**

Rules 12–16: These deal with the duties and responsibilities of the superintendent, instructors, rescue room official, rescue-trained personnel, and rescue room attendant.

- **Chapter IV: Organization and Equipment in Mines**

Rule 17: The provision of telephonic communication.

Rule 18: The provision of rescue training.

Rule 19: It is the responsibility of the manager of an underground mine that employs more than 100 persons underground to ensure that at least 5 rescue-trained persons are readily available at the surface at any time. If more than 500 persons are employed, then 1 rescue-trained person for every 100 persons employed should be available at the surface. Accommodation should be provided for rescue-trained persons near the mine.

Rule 21: Instructions and practices, etc.: Every person selected for training in rescue work should undergo the course of instruction and practice (as shown in Table 12.7). The rescue-trained persons, upon passing the training, will be certified by the superintendent. The record of all persons receiving training, undergoing practice, and receiving instruction shall be kept at every rescue station.

- **Chapter V: Conduct of Rescue Work**

Rule 24: Duties of manager in emergency: In the case of an emergency, the mine manager shall

- inform the rescue room or the rescue stations serving the mine for necessary assistance
- summon rescue-trained persons employed in the mine
- inform the owner, agent, or manager of nearby mines to make available the services of rescue-trained persons employed therein, if so required
- inform the rescue station about the nature of the occurrence, stating whether assistance will be needed from the rescue station
- summon medical assistance
- send information of the occurrence to the Regional Inspector

Rule 25: Accommodation at the below ground mine for persons engaged in rescue work: Whenever rescue personnel are engaged in rescue and recovery operations, suitable accommodation with basic amenities for storage and charging of apparatus required for rescue work should be provided.

Rule 26: Entry into below ground mines for rescue or recovery work: In the case of an emergency, only rescue-trained persons with self-contained breathing apparatus should be permitted to enter the mine for rescue and recovery work.

Rule 27: Fresh air bases: In the case of an emergency, a fresh air base or bases should be established at the earliest opportunity. The fresh air base should be located near to the irrespirable zone or zones and in fresh air. It should have telephone connections, two medical practitioners, a spare rescue team, reviving apparatus, first aid facilities, gas sensors for CO, hygrometer, flame safety lamps, etc.

TABLE 12.7
Course of Instruction and Practice for Rescue Training

Instructions	The general methods of dealing with fires underground and the recovery of mines after fires and explosions
	The construction, use, repair, maintenance, and testing of the type or types of breathing apparatus provided, and the smoke helmets or other apparatus serving the same purpose
	The use of methods and apparatus for reviving persons
	The properties and the methods of detection of noxious and inflammable gases that may be found in mines
	The taking of gas samples in irrespirable atmosphere
	The reading of mine plans
Practices	Not less than 12 practices with breathing apparatus and not less than 2 practices with smoke helmets or other apparatus serving the same purpose
	The practices in each case should be carried out under conditions devised to resemble those likely to be encountered in operations below ground and requiring the use of such apparatus; they should be carried out as follows:
	(a) Not more than 8 and not less than 5 men shall take part in any practice
	(b) The practices with breathing apparatus should commence in ordinary air, and should progress gradually until practices can be carried out in hot and irrespirable atmospheres
	(c) The practices with breathing apparatus should comprise the following operations:
	(i) repeatedly raising and lowering of a weight of 25 kg to and from a height of 1.8 m by means of a rope and pulley
	(ii) walking continuously at a fair pace for half-an-hour
	(iii) building and removing temporary stoppings of stone, brick, sandbags, brattice cloth or other materials, and carrying the materials required for such operations over a distance of at least 10 m
	(iv) removing debris in a confined space, as representing the clearing of a fall of roof
	(v) setting timber or other roof supports
	(vi) carrying, pulling, or pushing on a stretcher a live person or dummy body weighing 70 kg along the length of the gallery
	(vii) the rapid establishment of communication

Rule 28: Leader: Every rescue team engaged in work with breathing apparatus in a mine shall be under a leader, who should be appointed by the superintendent.

Rule 30: Test of apparatus: Before entering an irrespirable atmosphere underground for the rescue operation, the leader of the rescue team should test or witness the testing of all the self-contained breathing apparatus for leakage. Any unsafe apparatus should not be used.

Rule 31: Duties of leader below ground: The duties of the rescue team leader underground are as follows:

- he should give his attention solely to directing the team and to maintaining its safety
- he should keep the team together and should not allow any member of the team to stray
- he should not engage in manual work

- he should examine the roof and supports during the journey
- if the atmosphere is clear, the leader should clearly indicate the route by means of arrow marks in chalk
- if the atmosphere is obscure, the leader should see that a lifeline is led in from the fresh air base, and should not allow any member of the team to move out of reach of that line
- he should carry a watch, and should record the pressure of the compressed oxygen at intervals of 20 minutes or so
- during traveling he should adopt the pace of slowest member; if any member of the team is in distress, he should immediately return to the fresh air base with the whole team

He should not permit any member of the team using breathing apparatus in a mine to remain at work at any time for a period longer than one-and-a-half hours or such other period as may be specified by the chief inspector in respect of the breathing apparatus being used.

Rule 32: Rescue team members and their duties: Every rescue team using breathing apparatus in an underground mine should not be less than five in number and not more than six, including the leader. The team members should obey the orders if the leader.

- **Chapter VI: Miscellaneous**

Rule 35: General management: It is the responsibility of the owner to establish, maintain, and ensure the proper functioning of the rescue room or rescue station as required under these rules, to appoint instructors, superintendent, rescue-trained persons, and rescue room official, and to provide necessary rescue equipment and apparatus as may be needed for compliance with the provisions of these rules.

Rule 36: Inspections: The chief inspector, or other inspector authorized by him on his behalf, or the Regional Inspector may enter, inspect, and examine any rescue station and rescue room and make such examination or inquiry as he thinks fit.

Rule 37: Power to relax: Where in the opinion of the Chief Inspector, the conditions pertaining to a mine or rescue station or rescue room are such as to render compliance with any provisions contained in these rules, unnecessary or impracticable, he may by an order in writing and subject to such conditions as he may specify therein grant exemption from the said provisions.

12.7 RESUSCITATION

Resuscitation is the set of procedures applied for correcting physiological disorders such as shortage of heartbeat or breathing in an unwell person. The well-known examples of resuscitation are cardiopulmonary resuscitation (CPR) and mouth-to-mouth resuscitation. In an unwell person, resuscitation needs to be performed before the arrival of the emergency ambulance to improve the chances of survival.

12.7.1 Preparatory Measures for Resuscitation

12.7.1.1 Proper Positioning of Patient

In order that the lungs are well ventilated, it is necessary to position the patient in such a posture that the chest cavity expands as much as possible during inhalation but does not remain in the contracted position during exhalation. The patient must be laid on his back on a flat surface with his shoulders raised and supported by a 15 cm thick pad of clothes or folded blanket. All tight clothes around the back, chest and waist must be loosened.

12.7.1.2 The ABCs of Resuscitation

This involves the clearing of Airway, Breathing, and Circulation.

12.7.1.2.1 A. Airway

In an unconscious person, the mouth is often closed and the tongue falls back and obstructs the air passage. In addition, the lower jaw recedes downward and backward. To ensure a free air passage, therefore, the mouth must be opened by hand or by means of a mouth opener and the pharyngeal cavity cleaned of water, chewing gum, chewing tobacco, mucus, food, blood, teeth, etc. The tongue must be pulled out either with hand or forceps and held by means of a bandage. In most cases the holding forward of the tongue is not necessary. It is sufficient if the head is tilted backward and then turned laterally.

Check if the victim is breathing by looking at the chest movement and by listening to the breathing sound. If the victim is breathing, roll the victim onto his or her side. If the victim is not breathing, provide rescue respiration.

12.7.1.2.2 B. Breathing

- the best way to provide rescue respiration is by using the mouth-to-mouth technique
- the cervical spine should be protected during resuscitation
- oxygen should be provided to the victim using a mask

12.7.1.2.3 C. Circulation

After providing rescue respiration, check for circulation by finding the victim's carotid artery pulse in the neck to see if the heart is beating. If there is no pulse found after providing rescue breathing, artificial circulation should be provided (see Section 12.7.2).

12.7.1.3 Retaining Body Heat

In an unconscious person, the formation of heat in the body often ceases. For maintenance of metabolism in the body cells, it is necessary that whatever heat is in the body is retained. The patient should, therefore, be laid on a blanket and their body, excepting the upper portion, covered with warm blankets. In every case, wet clothes must be removed. Any ventilating current must be prevented from acting on the body by hanging brattice cloth in the airway.

12.7.2 Methods of Artificial Respiration

Artificial respiration is the act of restoring or initiating respiration by using mechanical or manual methods in a person who is not breathing or not able to make respiratory effort on his or her own. Time is of the greatest importance for the success of resuscitation. Even while rescuing the patient, the rescuers should constantly think of saving time. There is enough oxygen in the blood to keep cells alive for about ten minutes but the brain cells start dying after being deprived of oxygen for only four minutes. It is not always necessary to take the patient to the fresh air base but a place in fresh air nearest the place of accident will be satisfactory.

The methods of artificial respiration can be divided into the following two groups:

(a) mechanical methods using resuscitators
(b) manual methods using hands

12.7.2.1 Mechanical Method Using Resuscitators

Although the manual method of artificial respiration has the advantage that it can be employed immediately, it suffers from an important disadvantage that the first aider can get quickly fatigued and the resuscitation of the patient may not be carried out uniformly. It is for this reason resuscitating equipment was developed, as it requires no manual assistance in operation and maintains uniform respiration.

Depending on the method of operation, the resuscitators can be divided into two groups. To the first group belongs equipment that brings about resuscitation in a manner similar to the manual method. By application of external pressure on the chest cavity, the stomach, and the diaphragm, the air in the lungs is expelled. For inspiration, the stomach and the chest or the arms are raised. In the second group is included apparatus that automatically provides controlled artificial respiration. An oxygen-air mixture is blown into the lungs during the inspiration phase and sucked out or expelled by recoil of the respiratory muscles and lungs during the expiration phase. Well-known examples are the Draeger Pulmotor and Oxylog LA.

12.7.2.1.1 Pulmotor

The pulmotor was the first artificial respiration device developed for automatically delivering gas and/or air at specific volumes. It was designed to resuscitate the victims of mine disasters, and also became popular for victims of smoke inhalation, drowning, and electric shock. A schematic diagram of a pulmotor is given in Figure 12.11. The pulmotor consists of

- a face mask
- one or two oxygen cylinder(s)
- a pressure reducing valve, three shutoff valves, and a safety valve
- a cycling or switching valve unit
- an aspirating injector
- a secretion bottle
- an oxygen economizer breathing bag
- an inhalation mask
- oral airways

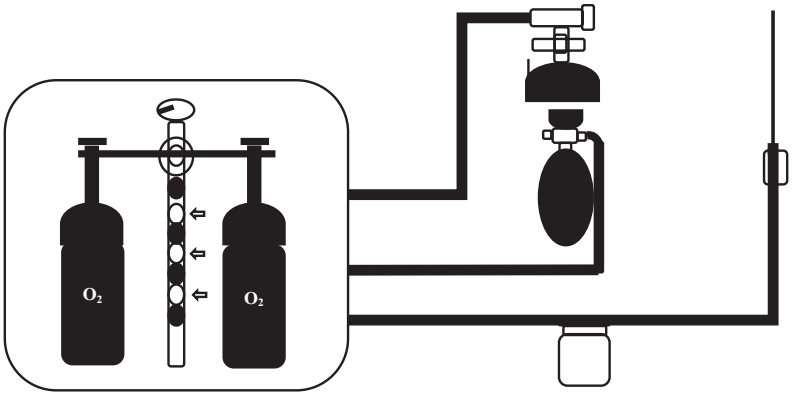


FIGURE 12.11 Schematic diagram of pulmotor.

The reducing valve reduces the high-pressure oxygen to a constant operating pressure. Of the three shutoff valves, one is connected to the aspirating injector, another to the oxygen inhalation mask, while the third unit is connected to the switching unit. The changeover valve is normally set for 50% O_2, the remaining being atmospheric air sucked by an injector. It is set for 100% O_2 in a toxic atmosphere. When a pressure of about +20 mbar is reached in the lungs, the inspiration phase is completed and the switching unit switches over automatically to the expiration phase and begins to suck air out of the lungs. As the required negative pressure of −10 mbar is reached toward the end of the expiration phase, the appliance switches over to a new inspiration phase. At 50% setting, 5–15 L/min oxygen is necessary whereas at 100%, 12–35 ml/min of oxygen is needed. At a respiratory volume of 8 L/min respiration can be carried out for 2 hours at the 50% oxygen setting. It can give protection for up to 50 minutes when used with 100% oxygen.

The procedure for performing artificial respiration using a pulmotor is as follows:

- Before resuscitation
  - Lie the victim down on his back with his head tilted backward and turned to one side.
  - Clean the pharyngeal cavity.
  - Clean the lower air passages by using the aspirating catheter of the pulmotor aspirator.
  - If the air passage is clear, insert an oral airway into the mouth to prevent the falling back of the tongue.
- During resuscitation
  - Press the face mask with the switching unit and turn on the cylinder valve and shutoff valve for resuscitation. If the face mask fits tightly, the switching unit will start functioning and automatically change over from inspiration to expiration and vice versa.

The pulmotor provides automatic cycling of breathing by blowing an oxygen-air mixture into the lungs of the victim and removing the carbon dioxide charged

exhaled air out of the lungs by suction under preset positive and negative pressures. The switching rate depends on the size of the lungs and on the oxygen flow rate. If the switching is too fast, the oxygen supply must be reduced. The negative pressure at the end of expiration assists the blood circulation but, in special cases, a special attachment is supplied for cutting it out during the expiration phase. If the change-over takes place rapidly, it will mean that the air passages are still not free and have to be cleaned again. When the switching unit operates normally, the face mask is fastened to the head band by means of straps.

It is necessary that no air enters the stomach during resuscitation, as the diaphragm that is stressed upward would hinder the expansion of the lungs and circulation of the blood. During the operation of the pulmotor, the rescuer should always observe that the respiratory rhythm remains constant. If during resuscitation the action of the heart cannot be observed any longer, heart massage must be carried out during the expiration phase. Should severe spasms occur, as happens with carbon monoxide poisoning, the tongue should be immediately loosened after lifting the face mask and, if necessary, respiration interrupted. The pulmotor should not be used except as an inhalator in cases of poisoning by nitrous fumes. It should however be emphasized that the first few minutes after breathing has ceased are the most crucial and that manual respiration must be started at once and continued until the pulmotor becomes available.

12.7.2.2 Manual Methods

Manual resuscitation operation should be continued, once it has been started, until natural breathing is restored or until such time as the doctors decide that further efforts will be of no avail.

- Schafer's method
- Sylvester's method
- Holger-Nielsen method
- Mouth-to-mouth resuscitation

12.7.2.2.1 Schafer's Method

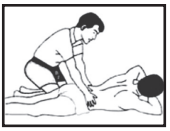
The patient is placed in prone position and a small pillow is put underneath the chest and epigastrium. The head is turned to one side. The advantage of this method is that the patient being in the prone position, mucus or saliva comes out of the mouth and cannot obstruct the airways. The procedure is shown in Figure 12.12.

These movements are repeated about twelve times a minute (roughly the normal rate of respiration).

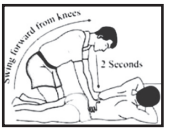
By this operation, it is possible to have a total pulmonary ventilation of 6,500 ml per minute, and this amount is sufficient for the complete aeration of the blood.

12.7.2.2.2 Sylvester's (Chest-Pressure-Arm Lift) Method

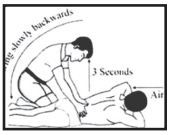
This method is to be used only when it is impossible to turn the patient on to his face. The patient is placed on his back on a flat surface, inclined if possible from the feet upward. Remove all tight clothing. Place a folded article or small cushion under the shoulders.



The operator kneels down by the side of the patient facing towards his head.

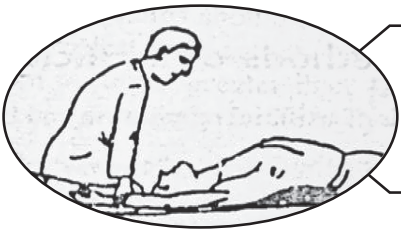


Induce expiration
Two hands are placed on the two sides of the lower part of the chest and then the operator slowly puts his body weight leaning for wards and pressing upon the loins of the subject. Intra-abdominal pressure increases, the diaphragm is pushed up and air is forced out of the lungs.



Induce inspiration
Swing the first aider's body slowly backwards to its first position thus removing the weight from the hands (which are kept inposition) and relaxing the pressure on the abdomen. The diaphragm descends and air is drawn in.

FIGURE 12.12 Schafer's method.



Induce inspiration:
Kneel at a convenient distance behind the patient's head and grasp his forearms just below the elbows, draw the arms upwards, outwards and towards the first aider, with a weeping movement, making the elbows touch the ground. The cavity of the chest is thus enlarged and air is drawn into the lungs.

Induce expiration:
Bring the patients flexed arms slowly forwards, downwards and inwards; press the arms and elbows firmly on the chest on each side of the breast-bone. By this means air expelled from the lungs.

FIGURE 12.13 Sylvester method.

Maintain a free entry of air into the windpipe. An assistant should catch hold of the patient's tongue and draw it forward as far as possible, and hold it in the position. The procedure is shown in Figure 12.13.

Repeat these movements alternately and for twelve times a minute. The rhythm is pressure for two seconds and relaxation for three seconds.

12.7.2.2.3 The Holger-Nielsen (Back-Pressure-Arm Lift) Method

- Place the victim on the ground, face to one side, with overlapping hands under the head.
- Clear the air passage, if any blockage found. Keep the victim straight in order to keep air passages completely open and free.

FIGURE 12.14 Holger-Nielsen method, (a) Keep the arms and forearms straight; lean forward to apply pressure by the weight of the upper part of the body; (b) Count one-two and then lean back, sliding hand to just above elbows of the patient, as you count three; and (c) Grasp the arms of the victim near the elbows and lift them up, keeping upper limbs straight. Count four-five and then lower patient's arms back to original position as you count six.

Kneel near the victim's head, placing one knee near his head and the opposite foot by the side of the corresponding side elbow. The knee and foot may be alternated from time to time. Place both hands over the lower parts of the victim's shoulder blades, the fingers spread and the thumbs near the midline. The procedure is shown in Figure 12.14.

- Then start all over again.

This method is not suitable if the patient has injuries of the chest wall or fractures of the arms.

12.7.2.2.4 Mouth-to-Mouth/Nose Resuscitation

- Mouth-to-mouth/nose resuscitation (Figure 12.15) is the simplest method to be used during emergency, and is very effective. In this method, the rescuer or first aider blows air forcibly into the patient's mouth or nose to inflate his lungs and stimulate the act of inspiration.
- No efforts are required for expiration of air as it occurs due to the recoil of the elastic chest walls.

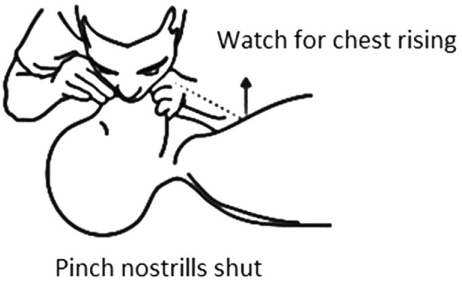


FIGURE 12.15 Mouth-to-mouth resuscitation.

- When applying the method, the first aider kneels down behind the patient's head, puts his face on the patient's face, and blows his own breath hard into the patient's mouth.
- After the blowing, the first aider moves his face aside, takes a deep breath, and again blows his breath into the mouth of the patient. This operation is continued till the patients shows signs of breathing. A rhythm of 12 to 15 operations/minute should be maintained. While using the method, considerations of hygiene have to be put to one side.
- When adopting any of the methods of artificial respiration, time is very important. Moreover, the first aider should know what treatment the patient needs first. For example, if a victim is having an arterial hemorrhage, artificial respiration should be given only after the uncontrolled arterial hemorrhage has been stopped by proper treatment.

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13 First Aid and Ambulance Work

13.1 INTRODUCTION

First aid is an assistance given to any person after an accident, not with an aim to cure the person but to prevent any further harm being done (Khatri, 2014). First aid is provided only to people with sudden injury or illness. It involves the treatment of minor injuries such as wounds, cuts, burns, bruises, fractures, etc. A medical doctor, nurse, compounder, person with a valid first aid certificate, and self-help, if assistance is not available, can provide first aid.

The aim of first aid is to make a victim comfortable and to avoid complications until the doctor oversees the victim. The general rules of first aid are as follows:

1. Carry out essential tasks first.
   a. **Save life**: The main aim of first aid is to save life. In the case of an accident or injury, the priority of the first aider is to check Airway (A), Breathing (B), Circulation (C), and Deadly bleeding (D), ABCD in short.
      i. **Airway**: Check if the airway of the victim is clear from any obstruction. An obstruction of the airway can lead to a fatality.
      ii. **Breathing**: When the airway of the victim is clear, check the victim's adequacy of breathing. If required, provide artificial respiration.
      iii. **Circulation**: If the victim is not breathing, give chest compressions and rescue breathing. Chest compressions will provide circulation. If the victim is breathing check the pulse.
      iv. **Deadly bleeding**: Check if there is any bleeding. If there is bleeding, perform DEPT (Direct pressure, Elevation, Pressure point, Tourniquet).

2. Provide additional treatment.
   a. **To prevent further harm**: Keep the patient from further harm by providing any other additional treatment if required.
3. Promote recovery by helping the victim to combat shock.
4. Allay fear; reassure the victim.
5. Do not attempt too much.
6. Do not allow crowding near the victim.
7. Do not remove clothing unnecessarily.
8. Take the victim to the nearest hospital or medical facility as quickly as possible.

The job priority of the first aider will vary from one organization to another. A few examples are

a. **3B system**: Breathing, Bleeding, and Bones
b. **4B system**: Breathing, Bleeding, Brain, and Bones
c. **DRAB**: Danger, Response, Airway, Breathing

An organization in the UK first-aiders can be trained to use to use DRAB system during their primary survey. The DRAB system is as follows:

Danger: Check if you, any bystanders, or the victim are in danger.

Airway: If the victim does not respond, open their airway. Put one hand on their forehead, two fingers on their jaw and tilt their head back whilst lifting their chin. **Response**: Check if the victim is conscious or unconscious.

Breathing: Check by look, listen, and feel for victim's breathing. If the victim is unconscious and breathing normally, put them into the recovery position, check for injuries and call for an ambulance. If the victim is not breathing, then perform chest compressions.

13.2 FIRST AID AFTER ACCIDENTS

First aid can be provided for different types of serious and minor injuries. The most common injuries are fracture, burns, bleeding, and electric shock.

13.2.1 Fracture

A crack or break in the bone is known as fracture, as shown in Figure 13.1. Fractures can be classified as simple or compound fractures.

1. **Simple fracture**: A simple fracture is also called as closed fracture. In a simple fracture, the broken bone remains within the body, without damaging the surface of the skin. A simple bone fracture is not usually life-threatening, but it does require immediate medical care.
2. **Compound fracture**: A compound fracture is also called an open fracture. In a compound fracture, the broken bone penetrates the surface of the skin and outside air reaches freely to the broken bone. A compound fracture is more dangerous than a simple fracture.

Fractures can also be classified as incomplete or complete fractures.

1. **Complete fracture**: In a complete fracture, the bone breaks into two or more pieces. The types of complete fracture are
   a. single fracture: the bone breaks in one place into two pieces
   b. comminuted fracture: the bone breaks into three or more pieces
   c. displaced fracture: the bone breaks into pieces and changes the original alignment
   d. non-displaced fracture: the bone breaks into pieces and does not change the original alignment
   e. compression fracture: the bone breaks under pressure
   f. segmental fracture: the bone breaks in two places in a way that leaves at least one segment floating and unattached

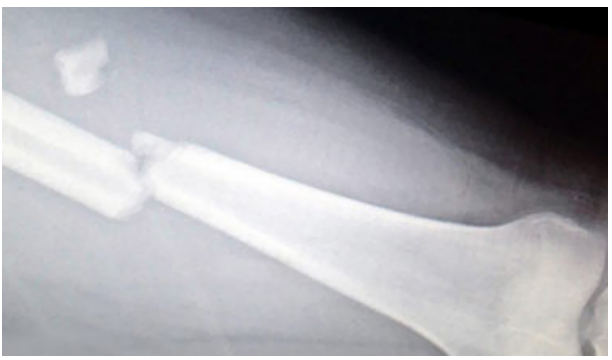

FIGURE 13.1 Fracture of bone.

- complicated fracture: the broken bone damages the surrounding tissues or vital organs

2. **Incomplete fracture**: In an incomplete fracture, the bone does not break completely. The types of incomplete fracture are
   a. greenstick fracture: the bone breaks on one side and is bent on other side
   b. hairline fracture: the bone breaks in a thin crack
   c. buckle fracture: the bone breaks on one side and a buckle develops on the other side

The symptoms of fracture are

a. bleeding, swelling, bruising, and tenderness around the injury
b. severe pain
c. deformity
d. difficulty in movement

The common causes of fracture in mines are: slip/trip, fall of person, and fall of object.

- ***Do's***
  - In the case of bleeding, lift and apply pressure to the wound using a clean cloth or bandage.
  - Immobilize the injured area with suitable splints; in the case of a broken back or neck, help the victim stay as still as possible.
  - Apply ice cubes or a cloth soaked in cold water to the injured area.
  - Apply a sterile bandage to the injured area.
  - Help the victim to combat shock.
  - Take the victim to the doctor.

Don'ts

- Do not attempt to move the patient from the site of accident. However, if there is danger due to a fall of roof or sides, or influx of noxious gases, the victim should be carefully removed to a safe place.
- Do not move the victim without immobilizing the broken bone.
- Do not attempt to straighten the broken limb.
- Do not move joints above/below the fracture.
- Do not give oral liquids/food.

13.2.2 Burns

A burn is damage to the skin or other tissues caused by contact with chemicals, radiation, friction, cold, electricity, and heat. The common causes of burns in mines are

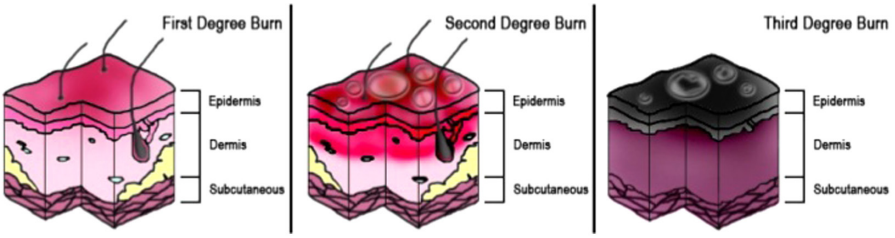

FIGURE 13.2 Types of burns.

fires, friction, electricity, and explosion. Based on the severity of the damage caused to the skin, burns are categorized in three main types, as shown in Figure 13.2.

1. **First degree burns (superficial)**: This type of burn involves only the outer layers of the skin, called the epidermis, leading to red and non-blistered skin. The burned area may swell and cause pain.
2. **Second degree burns (partial thickness)**: This type of burn involves both the epidermis and dermis, leading to red, blistered, and some thickening of the skin. The burned area swells and weeps fluid. These burns are usually painful.
3. **Third degree burns (full thickness)**: In this type of burn, the skin, along with the muscles, bones, blood vessels, and nerves are damaged. The color changes to brown or charred. The burned area appears leathery with widespread thickness appearing white.

13.2.2.1 For all burns

- ***Do's***
  - Remove smoldering material or hot or burned clothes from the victim
  - Remove jewelry and tight clothing before swelling or blisters occur.
  - For first degree burns, immerse the burned area under cool water until the pain reduces; and for second degree burns, immerse the burned area under cool water for 10 to 15 minutes.
  - Cover the area with a clean cloth or sterile, non-sticky bandage.

Don'ts

- Do not apply extreme water pressure to the burn area.
- Do not forcefully remove the cloth that is stuck to the burn area.
- Do not break blisters.
- Do not apply ice, butter, oil, or ointment that can cause infection to the burn area.

If the victim has caught fire, help the victim to smother flames by use of "Drop, Cover and Roll" and immediately cover the victim with a blanket.

13.2.2.2 Chemical burns

- ***Do's***
  - Clean the chemicals by washing the skin under cool running water.
  - Remove the clothes and jewelry that came into contact with the chemicals.
  - After cleaning, apply a cool, wet cloth on the burn.
  - Loosely cover the burn area with a dry clean cloth or sterile, non-sticky bandage.

13.2.2.3 Electrical burns

- ***Do's***
  - Call for an ambulance immediately.
  - Look to see if there is any contact with the electrical source.
  - Turn off the electrical source or try to remove it by using a non-conducting object.
  - Prevent shock by lying the victim down and raising the legs with a wooden stick.

Don'ts

Do not help a victim who has suffered from an electrical burn without checking whether the victim is still in contact with a live electrical wire.

13.2.3 Bleeding

Bleeding is defined as the loss or escape of blood from the human body. The human body has several types of blood vessels that can bleed, including arteries, veins, and capillaries. There are many different types of injury that can cause bleeding in mine accidents. Injury to any part of the body can cause a blood vessel to break and lead to either internal or external bleeding. The different types of bleeding are shown in Figure 13.3 (Michael, 2015).

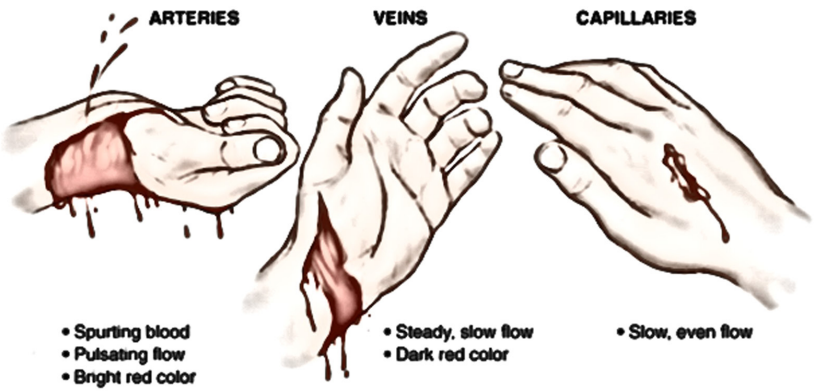

FIGURE 13.3 Types of bleeding.

- ***Do's***
  - Bleeding control can be summarized by the acronym DEPT.
    - **D (Direct pressure)**: Apply direct pressure to the wound or cut with a clean cloth or sterile pad until the bleeding stops. If the blood soaks through the cloth or sterile pad, then put another cloth or sterile pad on over it and continue to apply pressure.
    - **E (Elevation)**: If the cut or wound is on the leg or arm, raise the limb above the heart to slow the bleeding.
    - **P (Pressure point)**: If the use of direct pressure and elevation fails to control the bleeding, then apply pressure at the pressure point.
    - **T (Tourniquet)**: Apply a tourniquet above the cut or wound, and tighten it until the bleeding stops.
  - Clean the cut or wound with warm water and soap.
  - Apply antibiotic cream to reduce the chance of infection.

Don'ts
- Do not use iodine or hydrogen peroxide to clean the wound.
- Do not apply a tourniquet if there is no bleeding.

13.2.4 Electric shock

Electric shock is an injury caused when an electric current passes through the body, as shown in Figure 13.4. The danger from an electric shock is classified based on how high the voltage is, what type of current passed, how the current passed, and the person's health. An electric shock can cause burns, dehydration, clotting of blood, cardiac arrest, internal damage, and other injuries.

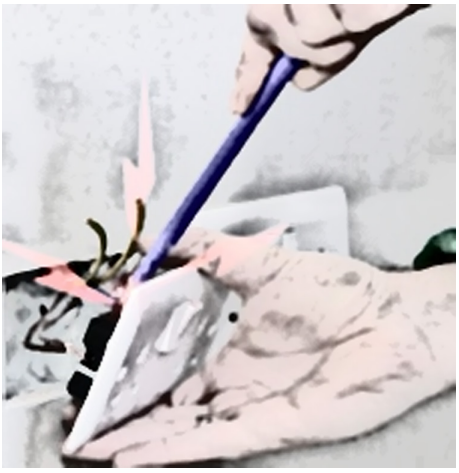

FIGURE 13.4 Electric shock.

- ***Do's***
  - Turn off the power in order to separate the victim from the power source.
  - If unable to turn off the power, stand on some non-conductive material, such as a wooden board, and separate the victim using a non-conductive object.
  - If the victim is not breathing, do cardiopulmonary resuscitation (CPR).
  - Check for other injuries due to electric shock.
  - If the person is unconscious, but is breathing and has a heartbeat, you should place him in the recovery position and monitor his breathing and heart rate until medical help arrives.

Don'ts
Do not help the victim without separating him first from the source of electricity.

13.2.5 Shock

Shock is a medical condition that develops when the body is not getting sufficient blood flow. Lack of blood flow means the cells and organs are not getting enough oxygen. Shock can happen due to heart problems, such as heart failure or heart attack, allergic reactions, low blood volume because of dehydration or bleeding, infection, damage to nervous system, or spinal injury (Medline, 2018).

The symptoms of a person suffering from shock are

- confusion
- anxiety
- chest pain
- bluish lips and fingernails
- low or no urine output
- weak pulse
- unconsciousness
- moist skin
- weak, faintness, or dizziness
- pale, cool, clammy, sweaty skin

The person suffering from shock is unstable and may collapse, become unconscious, or suffer cardiac arrest unexpectedly (Webmd, 2018).

- ***Do's***
  - If a person is conscious and does not have any injury to the head, neck, spine, or leg, lay the victim down on their back.
  - Raise the leg about 12 inches.
  - If the victim is bleeding from the mouth or vomiting, then turn the victim on their side.
  - If the victim is not breathing, perform chest compressions.
  - Treat any other injuries such as cuts or wounds.

- Loosen tight clothing.
- Cover the victim with a blanket to keep them warm.
- Reassure the victim.

Don'ts

- Do not raise the victim's head
- Do not give the victim anything to eat or drink by mouth.
- Do not move the victim with a suspected spinal injury.

13.2.6 Heart Attack

When there is no or low flow of blood with oxygen to the heart, the heart muscle begins to die and leads to a heart attack. The heart supplies blood to various parts of the body and if it stops working, then that is the end of a person's existence.

A person suffering from a heart attack will have the following symptoms:

- a sudden chest discomfort, such as pressure, pain, or squeeze on the chest; this can last for a few minutes
- pain or discomfort in the upper body including left shoulder, below the breast bone, arm, neck, jaw, or back
- shortness of breathing
- heartburn or indigestion
- weakness, lightness, or dizziness
- anxiety
- irregular heartbeats
- cold sweats

- ***Do's***
  - If a person is having the above symptoms, put them in a sitting position with their knees raised. This is because lifting the person's legs up for about 10–15 inches will let more blood flow toward the heart.
  - Loosen any tight clothing.
  - Immediately call an emergency helpline for an ambulance service.
  - Ask whether the victim is carrying any prescribed drugs, for example nitroglycerine for heart problems.
  - Ask the victim to chew 300 mg of aspirin slowly, because aspirin inhibits the growth of the blockage, but it also acts on platelets in the blood.
  - If the victim is breathing and has a pulse, cover them with a warm blanket.
  - If the victim is unconscious, immediately do CPR, i.e. give artificial respiration.

To perform CPR (Figure 13.5), place your palm on the chest region to pump – 15 pumps followed by 2 artificial respirations. Continue until the medical help or ambulance arrives.

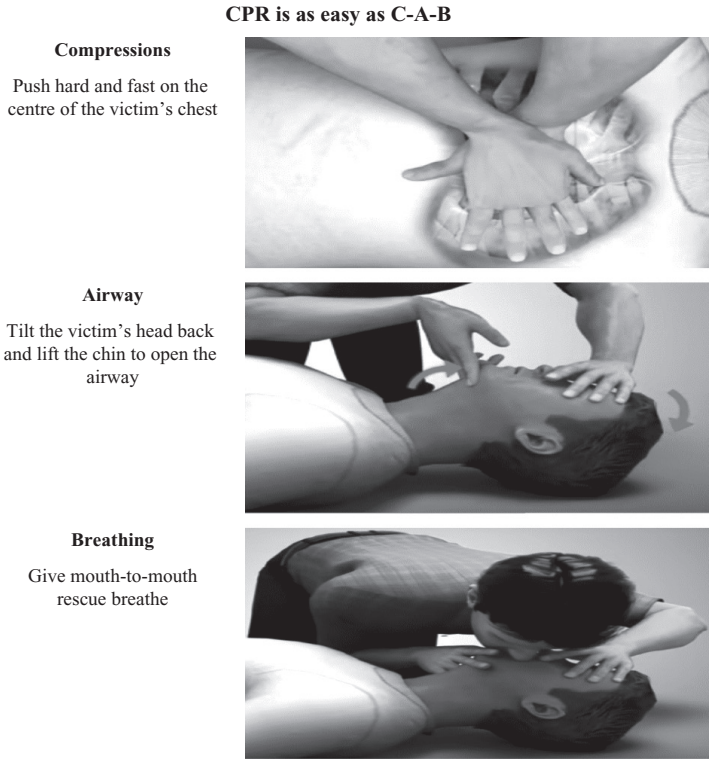

FIGURE 13.5 CPR procedure. (Adapted from Phillips, 2014. Emergency steps to be taken for first aid of heart attack. Retrieved from www.inlifehealthcare.com/2014/03/22/emergency-first-aid-hear t-attack/#.WQxlWNSGN1s.)

Don'ts

- Do not leave that person alone.
- Do not give any other medication.
- Do not wait for the symptoms to go away.

13.2.7 Choking

Choking occurs when a foreign object blocks the airway and the victim cannot breathe properly. In adults, choking most commonly occurs while eating, when the food blocks the airway. If a victim is choking, then they will have the following symptoms:

- difficulty in breathing or noisy breathing
- inability to cough forcefully
- inability to talk
- skin, lips, and nails turning blue or dusky
- loss of consciousness

- ***Do's***
  - If it is mild blockage
  - Encourage the victim to keep coughing and clear the blockage.
  - Ask the person to spit out the object if it is there in the mouth.

In the case of a severe blockage

- Bend the victim forward.
- Give up to 5 sharp blows to the back between the shoulder blades using the heel of the hand.
- Check the victim's mouth for any object blocking the airway. Ask the victim to remove the object if possible.
- If the back blows do not work, then give up to 5 abdominal thrusts, by wrapping both the arms by standing behind them and pulling the arms sharply inward and upward.
- Continue by altering back blows and abdominal thrusts and keep checking their breath.
- Call for medical assistance.
- If the victim becomes unconscious, start performing chest compressions and rescue breaths.

Don'ts
Do not try a finger sweep to remove the object, if you cannot see the object in the person's mouth.

13.2.8 Heat Exhaustion and Heat Stroke

Sweat evaporates from the skin to cool the body. If this personal cooling system does not work properly or fails to work at all, heat exhaustion or heatstroke can occur. Heat exhaustion is a warning that the body is getting too hot. With heatstroke, the body organs start to overheat. If not treated, heatstroke can result in death. The cooling mechanism of the body can fail due to excessive humidity, extreme heat, or activity in the hot sun.

For heatstroke, the symptoms are: body temperature greater than 104°F, dizziness, headache, disorientation, confusion, fatigue, moist skin; if the heatstroke is due to exertion, the symptoms are: hot dry skin, fluctuating blood pressure, rapid heartbeat, rapid shallow breathing, absence of sweating, irritability, confusion, lack of consciousness/coma, and seizures.

For heat exhaustion, the symptoms are: cool, clammy, pale skin, normal, low, or only slightly elevated body temperature, thirst, muscle cramps, dizziness, headache, sweating, dry mouth, fatigue, weakness, nausea, weak or rapid pulse, and vomiting.

- ***Do's***
  - Move the victim to a shady, cool place.
  - Lower the body temperature by
    - sponging with a wet towel
    - applying ice packs in armpits, groin, and neck
    - spraying cool water on the victim
    - Give water with electrolytes or fresh juice.

  - If the victim is vomiting, turn them on their side to keep the airway open.
  - Let the victim rest.

Don'ts

- If the victim is vomiting, do not give the victim anything to drink.

13.2.9 Fainting

Fainting occurs when the brain temporarily does not receive sufficient blood, leading to a loss of consciousness. There are many causes of fainting, including head injury, epilepsy, stroke, poisoning, diabetes, and conditions associated with a lack of oxygen.

- ***Do's***
  - Catch the victim before he/she falls.
  - Check the victim's consciousness by pinching them.
  - Lay the victim on their back.
  - Check for injuries and causes of unconsciousness
  - If there are no injuries and victim is breathing
    - tilt their head back and keep their arms at right angles to the body
    - raise their legs to about 12 inches
  - Loosen any tight clothing.
  - Keep the victim warm if it is cold outside.
  - Encourage the victim to lie down for few minutes.
  - If the victim does not regain consciousness within one minute
    - call for medical help
    - check breathing
    - perform chest compressions, if necessary

Don'ts

- Do not allow the victim to get up quickly after gaining consciousness.
- Do not give the victim anything to eat or drink.
- Do not allow any crowding around the victim.

13.3 FIRST AID TRAINING AND FACILITIES IN MINES

Despite the fact that the aims of first aid are the same in all countries, the training arrangements and equipment required in mines may vary. Countries follow first aid rules framed by either by their own government or organization.

13.3.1 International Labour Organization

The International Labour Organization (ILO) has developed the "Safety and health in underground coal mines" code for the protection of workers' safety and health,

which includes the guidelines for first aid in mines (ILO, 2006). The first aid guidelines cover the arrangements for first aid both underground and at the surface, transportation of injured workers, inspection of equipment, and training of workers. The general guidelines set out are

- First aid-trained personnel should be available for all shifts at the site.
- The first aid boxes should be
  - available near the working areas and should be
  - clearly marked
  - protected from dust, heat, humidity, and any other damage
- Equipment for immobilizing an injured worker and for transportation should be provided.
- The first aid program at the site should be designed in coordination with the medical facility, which provides the continuing care for its injured workers.
- The employer should communicate the following information to all the workers:
  - the first aid facilities available at the site
  - the person in charge of the first aid facility
  - the locations of the first aid facility and first aid boxes
  - in the case of an accident, what the workers must do and what information must be communicated, as well as how to communicate the accident and to whom
  - the location of escape routes

First aid training should be provided to all new entrants to the mining industry. Refresher training should be provided to all other workers to keep them up-to-date with new techniques. A worker with a valid first aid certificate should be able to handle the following:

1. a preliminary assessment and evaluation of the medical condition of the victim
2. apply a dressing
3. treatment for electric shock
4. burns
5. shock
6. use of emergency equipment
7. record keeping
8. inspection and maintenance of equipment

The following first aid arrangements should be provided:

1. Surface of mine: first aid center
   a. near the mine entrance with access to persons carrying a stretcher
   b. room for waiting, rest, storage of equipment, and treatment
   c. should only be used for first aid treatment or other medical work

The first aid center should be furnished with the following:

- furniture, such as table, chairs, treatment chair, lamp, screen, couch
- non-slippery floor and easily cleanable walls
- cupboards for dressings
- first aid box
- rest chair
- doors should facilitate the stretchers
- sinks with running water
- easy access to storage room

2. Underground
   The workers should be adequately trained in first aid and a sufficient number of first aid certified persons should be available at all times at the working areas underground. First aid-trained personnel should carry a first aid pouch, which should contain the following items:
   - sterile dressings and bandages
   - two triangular bandages
   - gloves
   - adhesive plasters
   - cotton

The first aid equipment underground should be put in storage, where it should be kept dust-free, moisture-free, hygienic, and it should be easily accessible to all the workers.

The mine management should immediately make the necessary arrangements to transport any injured persons from underground to the surface of the mine and, if necessary, from the surface to the nearest hospital or dispensary.

13.3.2 India

First aid training and arrangements in Indian mines should be provided according to Rules 40 to 45 of the Mines Rules, 1955, as shown in Table 13.1 (DGMS, 1955).

The duties of the mine owner, agent, or manager are as follows:

- To provide arrangements and training facilities for the training of persons in first aid.
- To provide first aid rooms at every mine employing 150 persons or more.
- To provide first aid stations at the surface, below ground and in opencast working areas.
- To provide first aid equipment in the first aid rooms and first aid stations.
- In the case of an accident or injury, ambulance, van and other arrangements should be made for the speedy removal of the victim(s) from the mine to the nearest hospital or dispensary.

In Indian mines, only persons with a valid first aid certificate of the standard of St. John's Ambulance Association (India) are allowed to provide first aid, as well as the medical doctor or nurse. Workers such as the overman, sirdar, shot-firer, electrician, and mechanic should also possess a first aid certificate. Every person with a valid first aid certificate should always carry a first aid outfit containing sterilized dressings and a container with antiseptic solutions.

TABLE 13.1
First Aid Rules According to the Mines Rules, 1955

Rule 40	Arrangements for training persons in first aid, etc.
Rule 41	First aid qualifications
Rule 42	First aid personnel
Rule 43	First aid rooms
Rule 44	First aid stations
Rule 45	Carrying of first aid outfits of by officials

A first aid room should be provided at every mine that employs more than 150 persons and it should be under the control of an appropriate person in charge. If the number of workers are more than 1,000, then a medical doctor together with a nurse, dresser, or compounder should be placed in charge. The first aid room should be situated at a convenient place at the surface of the mine. The following first aid equipment should be provided in the first aid room:

- a stretcher and a table on which to place the stretcher
- blankets and hot-water bottles
- a bench or chairs
- a screen
- a supply of tincture of iodine or other antiseptic solution
- sets of splints and triangular bandages
- a supply of suitable sterilized dressings, cotton wool, bandages, and adhesive plasters
- a glazed sink with water readily available
- soap, towel, and nailbrush
- a supply of drinking water and a drinking vessel
- a syringe
- an eyebath
- an adequate supply of anti-tetanus serum and morphine ampules
- a tourniquet, scissors, and safety pins
- a pair of artery forceps
- 2 clinical thermometers
- first aid boxes
- a stove or other apparatus for boiling water

First aid stations should be provided at every opencast and underground mine. In opencast mines, one first aid station should be provided for every 50 workers employed.

In underground mines

1. Above ground: a first aid station should be provided
   a. at the top of every mine entrance-like shaft or incline
   b. in every workshop
   c. at every screening plant and loading place
   d. at every other place where more than 50 persons are employed at any one time

2. Below ground, one first aid station should be provided
   a. at the bottom of every shaft
   b. near the drive end of every haulage

The following first aid equipment should be provided in the first aid station:

- sets of splints and triangular bandages
- a stretcher with 2 blankets;
- first aid boxes containing, as a minimum
  - large and small sterilized dressings and burn dressings
  - roller bandages
  - sterilized cotton wool and adhesive plasters
  - carbolic soap
  - tincture of iodine or other antiseptic solution
  - tourniquet scissors and safety pins

13.3.3 The United States

The Mine Safety and Health Administration (MSHA) has not framed any policy related to first aid in mines. First aid training and arrangements for US mines are provided according to "Code 30 of Federal Regulations" (CFR, 2017; MSHA, 2018a). The regulations relating to first aid in mines are presented in Table 13.2.

In US mines, a person with valid first aid training should be able to perform patient assessment, control bleeding, provide artificial respiration, and treatment for cuts or wounds, shock, musculoskeletal injuries, and burns. A trained person should be available for all shifts.

For both underground and opencast mines, the mine operator should provide the following:

- Training for interested miners and selected supervisory employees within 60 days from selection. The training program should include ten hours of theory training in a class.
- Training materials and instruction on first aid should be provided to all miners within six months of the date of employment.
- Refresher first aid training for selected supervisory employees: this should include five hours of training in a class.

In mines, the first aid equipment should be provided at specific locations, as follows:

1. In underground mines
   a. near the mine entry or the mine dispatcher's office
   b. at the bottom of the shaft or incline, if the bottom is more than 1,000 feet from the surface
   c. near the active working face

TABLE 13.2
First Aid Regulations According to CFR 30

30 CFR 56.18010	Safety and Health Standards – Surface Metal and Non-Metal Mines	First aid
30 CFR 57.18010	Safety and Health Standards – Underground Metal and Non-Metal Mines	First aid
30 CFR 77.1703,	Mandatory Safety Standards, Surface Coal Mines and Surface Work Areas of Underground Coal Mines	First aid training and supervisory employees
30 CFR 75.1713	Mandatory Safety Standards – Underground Coal Mines	First aid training and supervisory employees

2. In opencast mines
   a. at every surface installation where ten or more workers are employed
   b. near the working place where coal is mined
   c. the coal preparation plant

At all the locations, the following first aid equipment should be provided:

- stretcher
- 1 broken-back board
- 1 rubber blanket or equivalent substitute
- 2 cloth blankets
- 24 triangular bandages
- 8 2-inch bandage compresses
- 8 4-inch bandage compresses
- an approved burn remedy
- 12 1-inch adhesive compresses
- a 1-ounce bottle of aromatic spirits of ammonia or 12 ammonia ampules
- 2 tourniquets
- the necessary complements of arm and leg splints or 2 each of inflatable plastic arm and leg splints

13.3.4 Canada

In the Canadian mining industry, the first aid training and arrangements are carried out according to Regulation 854 (Mines and Mining Plants) under the Occupational Health and Safety Act (OHS, 2018).
Under Regulations 281.1 and 281.3, the duties of mine employers are

- to ensure a first aid room is provided and maintained properly; the first aid room should be provided near the entrance of the underground mine entry
- to ensure proper first aid equipment is provided
- to ensure that the first aid equipment is inspected regularly
- to keep a record of all the inspections

The first aid room in opencast and underground mines shall be equipped with

- St. John Ambulance first aid manual
- surgical dressings, plasters, splints, absorbent cotton, triangular bandages
- denatured ethyl alcohol
- bash basins
- enamel foot bath
- stretcher
- blankets
- first aid box

The first aid box should contain

- adhesive dressings
- gauze bandages and pads
- triangular bandages
- roll-up splint

13.3.5 The United Kingdom

The Health and Safety Executive (HSE) has developed the Health and Safety (First Aid) Regulations, 1981, an approved code of practice to provide adequate first aid provision to all the coal mine workers in the United Kingdom (HSE, 1981). The HSE (1981) regulations are shown in Table 13.3.

The duty of the employer to make provision for first aid are as follows:

- An employer should
- Provide adequate first aid equipment and facilities.
- Ensure an adequate number of suitable workers is available for rendering first aid in the case of an accident or injury. For this purpose, the worker should have undergone
  - first aid training and have a qualification the HSE can approve
  - additional training for specific cases
- Ensure one first aider is appointed for every 25 workers in a shift in mines. If more than 25 workers are at work, then additional first aiders should be appointed, so that the ratio of workers working to the first aiders does not exceed 25:1.

TABLE 13.3
First Aid Regulations According to HSE (1981)

Regulation 3	Duty of employer to make provision for first aid
Regulation 4	Duty of employer to inform his employees of the arrangements made in connection with first aid
Regulation 8	Application to mines

- Ensure that there is a first aid box for the first aider appointed below ground. The box should contain
  - 1 oral resuscitation protection aid
  - 2 large and small plain wound dressings
  - clinical waterproof protective gloves
  - 4 finger dressings
  - 6 adhesive wound dressings of an approved type and of assorted sizes
  - 2 triangular bandages

The employer should ensure the following arrangements made in connection with first aid are known:

- The location of the first aid facility on the site should be informed to all the mine workers, including newly employed workers. In the case where a worker changes to a new site, then they should be informed of the facilities available at that site.
- The first aid room and first aid equipment should be clearly identified with a safety sign.
- The list of first aiders should be posted in the first aid room.

According to the HSE Regulations, if 25 or more people are working at any one time, then the employer should provide a first aid room, waiting accommodation, and sanitary conveniences at the mine surface.

1. The first aid room should
   - be located near to and easily accessible from the mine shaft
   - be approachable by ambulances
   - have a floor area not less than 14 sq m
   - have interior surfaces in dust-free condition
   - have a sink with water facility
   - have a telephone facility
   - have a safety sign displaying the words “First Aid”
2. The waiting accommodation should
   - have seats
   - be indoors
   - be accessible to the first aid room
3. The sanitary conveniences should
   - be near the first aid room
   - have hot and cold water facilities
   - be properly ventilated
   - be clean and properly maintained

If the number of people working at any one time is 24 or less, then the employer should provide a first aid room at the mine surface. The first aid room should contain hot and cold water facilities, potable water, be properly ventilated, and should be free

from dust and moisture. Irrespective of the number of people working, every first aid room should be equipped with

- a stretcher and blankets for carrying injured persons
- appropriate bandages, adhesive dressings, cotton wool, and padding
- equipment for the immobilization of injured workers
- sterilized eye patches
- suitable couch and chairs
- disposable towels, soaps, nailbrush
- scissors and safety pins
- waterproof gloves
- suitable containers for the disposal of sharp objects such as syringes, clinical waste or biological waste
- sandbags
- potable water

In underground mines, first aid stations for equipment should be selected at appropriate parts of the mines such as the pit bottom, near the working face, each inbye district, and traveling road. The first aid station should contain the following equipment:

- a stretcher and blankets for carrying injured persons
- equipment for the immobilization of injured workers
- a suitable container, with a “First Aid” sign, containing as a minimum
- 6 large and small plain wound dressings, finger dressings
- sterile eye wash
- 1 oral resuscitation protection aid
- 2 extensive burns dressings
- 1 large roll of cotton wool
- waterproof gloves
- sandbags

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Appendix A: Safety Nomenclature

ACCEPTABLE RISK

Level of loss from an industrial process that is considered tolerable by the management.

ACCIDENT

An undesired and unplanned event.

ACCIDENT MANAGEMENT

Focuses on on-site consequence mitigation and off-site consequence mitigation.

ALARP OR ALARA

ALARP is short for "As Low As Reasonably Practicable." ALARA is short for "As Low As Reasonably Achievable." The two terms mean essentially the same thing. ALARP describes the level at which we expect to see workplace risks controlled.

AUDIT

Audit is a systematic and, wherever possible, independent examination to determine whether activities and related results conform to planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve the organization's policy and objectives. "Independent" here does not necessarily mean external to the organization.

BEHAVIOR-BASED SAFETY

The application of the science of behavior change to real-world safety problems.

CODE OF PRACTICE

A body of rules for practical guidance only and not having the force of law, although failure to comply may be used in evidence in legal proceedings. The management, unions, and health safety executives of an organization would prepare it.

COMPETENT PERSON

A practical and reasonable person with sufficient documented training and experience, who knows what to look for, how to recognize it when they see it, and how to deal with it to make it safe. They also know and work within the limits of their competence.

COMMUNICATION AND CONSULTATION

Continual and iterative processes that an organization conducts to provide, share, or obtain information and to engage in dialogue with stakeholders regarding the management of risk (ISO 31000, 2018).

CONSEQUENCE

a) outcome or impact of an event (HB 436, 2004)
b) outcome of an event affecting objectives

CONTROL

a) an existing process, policy, device, practice, or other action that acts to minimize negative risk or enhance positive opportunities
b) a measure that modifies risk

CONTROL ASSESSMENT

Systematic review of processes to ensure that controls are still effective and appropriate.

DANGER

A state or condition in which personal injury and/or asset damage is reasonably foreseeable.

DEATH

Fatality resulting from an accident.

DECISION-MAKER

A person or group with the power or authority to make decisions (CAN/CSA, 2002).

DIALOGUE

A process for two-way communication that fosters shared understanding. It is supported by information.

DISABLING INJURY

An injury causing disablement extending beyond the day of shift on which the accident occurred.

ERROR

A mistake or error of judgment leading to action resulting in an accident and its subsequent effects.

ESTABLISHING THE CONTEXT

Defining the external and internal parameters to be taken into account when managing risk, and setting the scope and risk criteria for the risk management policy.

ETA

Event tree analysis, a quantified risk assessment technique.

EVENT

Occurrence or change of a particular set of circumstances

EXTERNAL CONTEXT

The external environment in which the organization seeks to achieve its objectives.

FACE

The moving front of any working place or the inbye end of any drive, level, crosscut, raise, or winze.

FAILURE

This is the inability of an item/system to operate within stated guidelines.

FAILURE RATE

Is the frequency with which a system or component fails, expressed in failures per unit of time.

FATAL ACCIDENT

An accident that causes someone to die.

FATAL ACCIDENT RATE

An indicator of accidents used to classify the dangerousness that is a measure of individual risk expressed as the estimated number of fatalities per 100 million man-hours of the same activity.

FIRST AID

The assistance given to any person suffering a sudden illness or injury, with care provided to preserve life, prevent the condition from worsening, or to promote recovery.

FMEA

Failure mode and effects analysis, a quantified risk assessment technique.

FTA

Fault tree analysis, a quantified risk assessment technique.

FREQUENCY

A measure of the number of occurrences per unit of time.

HARM

Injury or damage.

HAZARD

A source of potential harm, or a situation with a potential for causing harm, in terms of human injury, damage to health, property, the environment, and other things of value, or some combination of these.

HAZARD CONTROL

A means of reducing the risk from exposure to a perceived hazard.

HAZARD IDENTIFICATION

The process of recognizing that a hazard exists and defining its characteristics.

HAZARD RATE

The ratio of the change in the number of items/units that have failed to the number of items/units that have survived at time t.

HAZOP

Hazard and operability study, a quantified risk assessment technique.

HUMAN ERROR

The failure to perform a specified task (or the performance of a forbidden action) that could lead to the disruption of scheduled operations or result in damage to equipment and property.

INCIDENT

An undesired event that almost caused damage or injury.

INCLINE

An inclined passage or road either on the surface or below ground.

INITIATING EVENT OR TRIGGER EVENT

The actual mechanism or condition that causes an accident to occur.

INJURY SEVERITY RATE

The number of lost workdays experienced per 100 workers.

INTERMEDIATE EVENTS

The events that may propagate or ameliorate an accident.

INTERNAL CONTEXT

The internal environment in which an organization seeks to achieve its objectives.

LEVEL OF RISK

The magnitude of a risk or combination of risks, expressed in terms of the combination of consequences and their likelihood.

LIKELIHOOD

a) used as a general description of probability or frequency
b) the chance of something happening

LOSS

Any negative consequence or adverse effect, financial or otherwise, injury or damage to health, property, the environment, or something else of value.

MAN-HOURS WORKED

The total number of employee hours worked by all employees working in the industrial premises.

MINE

An excavation from which minerals or ore is extracted.

MONITOR

To check, supervise, observe critically, or measure the progress of an activity, action or system on a regular basis in order to identify change from the performance level required or expected

NEAR MISS

An unplanned event that has the potential to cause, but does not actually result in, human injury, environmental or equipment damage, or an interruption to normal operation.

NEGLIGENCE

The omission to do something that a reasonable person, guided by those considerations that ordinarily regulate the conduct of human affairs, would do, or something that a prudent and reasonable person would not do.

OPEN-PIT MINING

A form of operation designed for extracting minerals that lie near the earth's surface.

OCCUPATIONAL ACCIDENTS

Accidents occurring in the workplace.

OCCUPATIONAL DISEASES

Harmful effects of work that are not due to an accident, such as over-exertion injuries, allergies, or hearing complaints.

ORE

Any natural combination of minerals.

ORGANIZATION

a) a group of people and facilities with an arrangement of responsibilities, authorities, and relationships
b) a company, corporation, firm, enterprise, or institution, or part thereof, whether incorporated or not, public or private, that has its own functions and administration

POLICY

A statement of corporate intent that will be/has been adopted and pursued as advantageous or expedient.

PRELIMINARY EVENTS

Any event that influences an initiating event.

PROBABILITY

A measure of the chance of occurrence expressed as a number between 0 and 1.

PROBABILISTIC RISK ASSESSMENT

A systematic and comprehensive methodology to evaluate risks associated with a complex, engineered technological entity.

QUALITATIVE ANALYSIS

Uses non-quantifiable methods to evaluate risks and make decisions.

QUANTIFIED RISK ASSESSMENT

Resulting from calculations allied to error rate predictions.

QUANTITATIVE ANALYSIS

Uses quantifiable methods, via statistical, mathematical, or computational techniques, to evaluate risks and make decisions.

RESIDUAL RISK

The risk remaining after the implementation of risk treatment

REVIEW

Activity undertaken to determine the suitability, adequacy, and effectiveness of the subject matter to achieve established objectives.

RISK

a) the chance of something happening that will have an impact on objectives
b) the chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property, the environment, or other things of value
c) effect of uncertainty on objectives

RISK ANALYSIS

A systematic process to understand the nature of and to deduce the level of risk

RISK ASSESSMENT

The overall process of risk identification, risk analysis, and risk evaluation.

RISK ATTITUDE

An organization's approach to assess and eventually pursue, retain, take, or turn away from risk.

RISK AVOIDANCE

A decision not to become involved in, or to withdraw from, a risk situation.

RISK COMMUNICATION

Any two-way communication between stakeholders about the existence, nature, form, severity, or acceptability of risk.

RISK CONTROL OPTION

An action intended to reduce the frequency and/or severity of injury or loss, including a decision not to pursue an activity.

RISK CONTROL STRATEGY

A program that may include the application of several risk control options.

RISK CRITERIA

Terms of reference by which the significance of risk is assessed

RISK ESTIMATION

The activity of estimating the frequency or probability and consequences of risk scenarios, including a consideration of the uncertainty of the estimates.

RISK EVALUATION

a) the process by which risks are examined in terms of costs and benefits, and evaluated in terms of the acceptability of the risk, considering the needs, issues, and concerns of stakeholders
b) the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude are acceptable or tolerable

RISK IDENTIFICATION

a) the process of determining what, where, when, why, and how something could happen
b) the process of finding, recognizing, and describing risks

RISK INFORMATION LIBRARY

A collection of all information developed through the risk management process. This includes information on the risks, decisions, stakeholder views, etc.

RISK MANAGEMENT

a) the culture, processes, and structures that are directed toward realizing potential opportunities whilst managing adverse effects
b) the systematic application of management policies, procedures, and practices to the tasks of analyzing, evaluating, controlling, and communicating about risk issues
c) The coordinated activities to direct and control an organization with regard to risk

RISK MANAGEMENT FRAMEWORK

The set of components that provide the foundations and organizational arrangements for designing, implementing, monitoring, reviewing, and continually improving risk management throughout the organization

RISK MANAGEMENT PLAN

A scheme within the risk management framework specifying the approach, the management components, and the resources to be applied to the management of risk.

RISK MANAGEMENT POLICY

A statement of the overall intentions and direction of an organization relating to risk management.

RISK MANAGEMENT PROCESS

The systematic application of management policies, procedures, and practices to the tasks of communicating, establishing the context, identifying, analyzing, evaluating, treating, monitoring, and reviewing risk

RISK OWNER

A person or entity with the accountability and authority to manage a risk.

RISK PERCEPTION

The significance assigned to risks by stakeholders. This perception is derived from the stakeholders' expressed needs, issues, and concerns.

RISK PROFILE

A description of any set of risks

RISK REDUCTION

The actions taken to lessen the likelihood, negative consequences, or both, associated with a risk.

RISK RETENTION

The acceptance of the burden of loss, or benefit of gain, from a particular risk.

RISK SCENARIO

A defined sequence of events with an associated probability and consequence.

RISK SHARING

Sharing with another party the burden of loss, or benefit of gain, from a particular risk.

RISK SOURCE

An element that alone, or in combination, has the intrinsic potential to give rise to risk.

RISK TREATMENT

The process of selection and implementation of measures to modify a risk

SAFETY

The conservation of human life, the maintenance of its effectiveness, and the prevention of damage to items/systems according to specified requirements.

SAFETY ASSESSMENT

The qualitative or quantitative determination of safety.

SAFETY ANALYSIS

A systematic procedure for analyzing systems to identify and evaluate hazards and safety characteristics.

SAFETY AUDIT

The monitoring of the implementation of a safety policy by subjecting each area of an activity to a systematic critical examination with the purpose of minimizing loss and providing a quantified assessment of performance.

SAFETY CASE

A formal explanation of methods to be adopted to reduce the risk of accident often used in high potential risk situations.

SAFETY COMMITTEE

A committee representative of all staff with the objectives of promoting cooperation in investigating, developing, and carrying out measures to ensure the health, safety, and welfare of the employees.

SAFETY CULTURE

The collection of the beliefs, perceptions, and values that employees share in relation to risks within an organization such as a workplace.

SAFETY INSPECTION

A systematic assessment of safety standards for plant, place of work, or working carried out by a manager and not a safety officer or engineer.

SAFETY MANAGEMENT SYSTEM

It is a comprehensive management system designed to manage safety elements in the workplace.

SAFETY MONITORING

Periodic checks on the observance of corporate safety standards and procedures.

SAFEGUARD

This is a barrier guard, device, or procedure developed for protecting people.

SAFETY PLAN

The implementation details of how the safety requirements of the project will be satisfied.

SAFETY POLICY

A written statement by an employer stating the company's commitment for the protection of the safety of employees and the public.

STAKEHOLDER

Any individual, group, or organization able to affect, be affected by, or believe it might be affected by, a decision or activity; the decision-maker(s) is a stakeholder

TASK ANALYSIS

The analysis of how a task is accomplished, including a detailed description of both manual and mental activities, task and element durations, task frequency, task allocation, task complexity, environmental conditions, necessary clothing and equipment, and any other unique factors involved in or required for one or more people to perform a given task.

TOP EVENT

The incident that occurs as a result of a hazard.

UNCERTAINTY

The state of being uncertain.

UNSAFE CONDITION

Any condition that, under the right circumstances, will result in an accident.

UNSAFE ACT

An act that is not safe for an individual/worker.

WORKING

Any excavation made or being made in a mine for search of or obtaining coal/metallic ore.

WORKING PLACE

Any place in a mine to which any person has lawful access.

ZERO ACCIDENT VISION

Zero accident vision is a philosophy that states that nobody should be injured due to an accident. It is more a way of thinking rather than a numerical goal.

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