INTRODUCTION

An accident is an unwanted, undesirable unanticipated sudden event that results in an undesired outcome such as property damage, bodily injury or death (ILO, 2000). Every year, throughout the world, millions of occupational accidents occur. A large number of those occur due to handling of material manually, which results in staggering costs in terms of loss of life, pain and suffering, lost wages for injured worker, damage to production facilities & equipments and lost production opportunity (Gordon, 1949). Some of those accidents are fatal and other result in varying degrees of disability. Every accident causes suffering to the victim, a considerable proportion must cause anguish to their families and many especially those resulting in death or permanent disablement may have a catastrophic effect on family life (Evans, et al, 2001; Hale & Hale, 1972).

Varying views of the concepts accident and injury

The literature concerning accidents shows variation in the use and definitions of the concepts accident and injury among researchers. This has also been pointed out by several authors (Keller, 2001; Hagberg et al., 1997; Andersson, 1996; Larsson, 1995, Laflamme, 1990). Hagberg (1997) emphasises that some of the confusion and controversy in occupational injury research may be attributed, in part, to the lack of clearly defined terms and concepts.

Epidemiological research takes diseases as its point of departure. For this reason, it naturally focuses on the injury and attempts, for descriptive or analytic purposes, to relate injuries statistically to various individual and environmental factors. In this view, the accident event itself is often reduced to a mere parenthesis between the injury and a variety of conceivable causal factors (Andersson, 1991). Hagberg (1997) emphasises that some of the confusion and controversy in occupational injury research may be attributed, in part, to the lack of clearly defined terms and concepts.

The terms accident and injury, are often used interchangeably and there is increasing confusion concerning their implications (Andersson, 1996). It has even been
proposed to use *injury* as a concept including both the accident (event) and the outcome (the injury) (Ozanne-Smith, 1995; Robertson, 1983). This impedes comparison of statistics and obstructs understanding of the literature.

**Different opinions about the accident and injury:**

One explanation can be that investigation of the accident process is multidisciplinary territory (Larsson et al., 1993). Researchers and practitioners from different fields and disciplines have focused on different parts of this phenomenon depending on their profession and their specific interest. The variation in the use of the concepts reflects the differences in starting point, but also how the user defines the concept. One contributing factor that might explain some of the confusion over the concepts of *accident* and *injury* is the short time, often just a second or less, between the accident and the injury. This means, when referring back to the occurrence of an accident (the event) or the onset of an injury (the outcome), that the *place*, the *time* and the *task* performed are identical. For example, a MMH worker while with load overhead suddenly loses his balance during lifting, carrying or lowering and the worker tries to stop or balancing the load from falling and thereby injury occurs at neck, vertebral column or back due to over-exertion. In this case the accident occurs during a transfer or balancing the load, but so does the onset of the injury.

This does not mean that accident and injury are interchangeable. The term *accident* should be reserved for the event and the term *injury* for the outcome. Some researchers have suggested avoiding the word *accident* as having connotations of randomness, referring to the Oxford Dictionary which includes in its definition of accident, unforeseen contingency, chance, and fortune (Hornby, 1989; Langley, 1988), also as having the connotations of inevitability and lack of apparent cause (Ozanne-Smith, 1995). These assertions have been questioned by Andersson (Andersson, 1996), and no one has so far suggested a synonym for accident, covering the same concept, which the other researchers in the area have accepted.
Accidents may be unwanted, but they are not or should not be unexpected (Waller, 1985). Random factors no doubt contribute to the factors and events leading to an accident, and it is therefore generally not possible to predict when an accident will occur. However, this randomness does not mean that it is impossible to analyse the accident process after the accident has occurred, and to explain how and why it happened. Even if some contributing factors will still remain unknown, it may be possible to eliminate the risk of future accidents of a similar type by eliminating a necessary condition for them.

Safety and Accidents

Stating a definition of safety is often overlooked in safety research, and the concept of safety is not as obvious as it may seem, often being associated merely with the absence of risk (Adams, 1995; Lees, 1996; IEC 61508, 2000). The IEC defines risk as a combination of the probability of an occurrence of harm and the severity of this harm. Harm is subsequently defined as physical injury or damage to the health of people either directly, or indirectly as a result of damage to property or to the environment (IEC 61508, 2000).

Determination of risk can be made by questioning three factors; event, likelihood and consequences:
What can go wrong? (event)
What is the probability of occurrence? (likelihood)
What are the consequences? (consequences)

However, all three questions are subjective to those who are asked to give an answer to the questions. Risk is thus relative to the observer and also has to do with both likelihood and consequences (Kaplan, 1981). There are multiple and varied understandings of risk and the concept that each individual chooses to adopt is subject to various value judgments and interpretations. No single definition of risk can claim to be universal. Risk means different things to different people and may be better understood.
as, risk perception™. Therefore, risk is not defined in one dimension. Unambiguously defining which combinations of likelihood and consequences of an event have a higher risk than the other combinations of both dimensions is not possible. Therefore, a standard of acceptable risk is not exclusively determined by the current state of the art in technology, but also by the desires and aspirations of the individual and of society, (Pasman et al., 2003) 26. In this thesis, risk is taken to includes two dimensions that of likelihood and consequences, and is expressed as: risk (event) = (likelihood, consequences).

Safety may be defined as the absence of risk and can also be expressed as the inverse of risk, i.e. the lower the risk the higher the safety. Based on this relationship, it is justified to use either one. Moreover, safety is context specific, for example: In the street safety means; walking around without being assaulted by people. Whilst in traffic safety means: driving your car without being involved in a car accident. In this research, the main focus is safety in a chemical company handling hazardous substances. The risks of accidents or other events during processes involving hazardous substances (flammable, toxic, or explosive) or activities where extreme conditions are used (like high/low pressures or high/low temperatures), are subject of this research. Process safety is the absence of risk from events with these hazardous substances and activities with extreme conditions. Non-process safety or process risk is often measured by accidents, incidents and near misses and this concept will be discussed in the following sub-Section.

Accidents, incidents and near misses

The concept of accident and incident are commonly used in safety research, but because various definitions of these concepts exist it is important to state them here. Accident and incident are both defined as unexpected sudden sequences of events with undesired outcomes, inflicting damage to people, property and/or the environment. The short duration of the onset distinguishes accidents and incidents (sudden events) from health™ and industrial diseases like asbestosis, etc.
Like risk, accidents and incidents are context specific concepts, which are subjective, and strongly depend on peoples perceptions. The difference between incidents and accidents is that accidents are the outcome of an incident or series of incidents having, high consequences. Therefore, incidents can develop into an accident according to van der Schaaf (Schaaf van der, 1991)\textsuperscript{27}, who also recognizes an intermediate state as a near miss. He defines a near miss as a situation in which an ongoing sequence of events is prevented from developing further into an event with, high consequences.

He combined the concepts of near miss, incident, and accident, as depicted in Figure1, van der Schaaf (Schaaf van der, 1992)\textsuperscript{28}. Incidents are in this respect the combination of near misses and accidents. Figure 1 shows that an organization may prevent dangerous situations from developing into an accident by various measures and tools (defences). If these defences are not adequate, the situation develops into an event with, low perceived consequences (incident). From here on it is often the operator who may adequately recover the situation, which means the incident, becomes a near miss. However, if no adequate recovery takes place, the incident will be able to develop into an event with, high perceived consequences (accident).
SOME THEORIES OF ACCIDENTS

The single event theory: This theory is based on the assumption that an accident consists of a single event that has a cause. Find the cause, and you have explained the phenomenon. The investigative task is easy: find the cause and correct it, and you will prevent accidents.

This perception seems rooted in primitive history. If an unusual phenomenon occurred, and there was no ready explanation for it, the survivors sought a scapegoat as the "cause" of the occurrence. Find the "cause" (read scapegoat) and the victims are
satisfied. History offers numerous examples, including acts of God precepts which carry over into present day insurance policies. Anyone who has observed the media’s handling of an accident will recognize some evidence of this perception. While largely discredited by the scientific community, vestiges of this theory can be widely observed. Accidents are still frequently defined as an “event” in safety publications and military investigation manuals, for example. Many aspects of our legal system in the highway safety field also provide evidence of this perception, such as police citations for accidents, and some of the arguments about “no-fault” insurance legislation. Publication of accident cause statistics reinforces this view, and the use of these statistics in the media perpetuates it. It is a world-wide perception, as evidenced by the World Health Organizations classification of the causes of death. The principal difficulty is that the view encourages an incomplete examination of the accident phenomenon.

The chain-of-events theory: The perception of sequential events is a popular perception of the phenomenon, widely recognized. Most of us have heard about the sequence that goes “for want of a nail the shoe was lost; for want of a shoe the horse was lost,” etc. The concept was adapted by Heinrich, who gave it the term “domino” theory, in 1936. His premise was that if a set of “unsafe conditions” set up a row of vulnerable dominos, an “unsafe act” would start them toppling. Under this concept, the investigator looks for information that will help reconstruct the chain of events that constituted the accident. Then as now, the unsafe conditions lack criteria, as do the unsafe acts. These terms represent the investigator’s conclusions, rather than observations of the phenomenon. How investigators arrived at these conclusions was not disciplined by principles or criteria that would provide consistent and reproducible findings. The conclusions were descriptive, and usually symptomatic, rather than etiologic. As evidence, the interested reader is encouraged to review the taxonomy and choice of entries in the American National Standards Institute’s standard for reporting of accidents for technical precision and consistency. The indiscriminate mixture of events, conditions, factors and other kinds of entries does not facilitate understanding of the accident phenomenon or development of countermeasures, for this researcher (Heinrich, 1936).
The determinant variable theory: The work of Greenwood and Woods and Newbold suggested the factorial view of the phenomenon. Their “accident proneness” concept was statistically inferred by examination of available data. The focus on static conditions reflected the view expressed by Thorndike of the search for the experimental ideal of the single independent variable, and set the goal and ideal of an accident investigation as the gathering of data in such a way that statistical comparisons will permit fair estimates of the influence of variables in a particular factor on the probability of an accident. This included precursor conditions of the actors involved in the accident. The view assumes that some common factors are present in accidents, and that they can be discerned from the right accident data. This view led to the admonition to investigators to “get all the facts” about an accident. Hypotheses can only be generated after the fact. By not prescribing the scope, relevance tests and other data specifications, the theory and its operation require the investigator to make these decisions according to the investigator’s best judgment. The result is that no accidents are reported in a reproducible manner, even when trained investigators use reporting forms. Such reports are almost totally dependent on the conclusionary findings and judgments of the causes or causal factors.

The branched events chain theory: About 1960, the need to predict accident events in the military missile program stimulated development of the “fault tree” analytical method for analyzing missile safety. The method is generally credited to Watson. It was based on the perception that an accidental launch would occur with some likelihood if a pathway to inadvertent firing were available. The events could flow in a chain-like sequence from a variety of origins in the system toward the undesired, accidental launch event. The method of displaying the events chains that could lead to the “top” event in the “fault tree” pyramid was a significant predictive advance. This procedure provided for organization of the events and conditions data into a visible, easily critiqued and readily understood display. It also provided for testing the predicted events against their sequential logic, and provided a basis for identifying data needs in the event of a system failure. Its significance is that, while it is an adaptation of the chain-of-events theory, it establishes data requirements that facilitate prediction of the accident possibilities in a given system. It also provides guidance during investigations.
The multilinear events sequences (Process) theory: Recent work by the author suggests that accidents are a segment of a continuum of activities, and proposes a process view of the accident phenomenon. The accident phenomenon is viewed as the transformation process by which a homeostatic activity is interrupted with accompanying unintended harm. The process is described in terms of specific interacting actors, acting in a sequential order with a discrete temporal and spatial logic. The procedures for analyses are defined in terms of changes of state and events (event = actor + action) that produce the change of state, and techniques for generating hypotheses are linked to the procedures. Both the investigative and analytical procedures are based on the premise that “everyone and everything always have to be someplace doing something,” (Benner’s First Law.) This perception formalizes many of the crash trauma concepts advanced by Haddon and others in the medical field, and borrows heavily from the medical perception of homeostasis. It is also easily integrated into some of the risk-based concepts emerging in the safety field.

These, briefly, are the highlights of the five theories discerned by the author. For convenience, they are summarized as

1. The single event perception and “cause theory.”
2. The chain—of-events perception and “domino theory.”
3. The determinant variable perception and “factorial theory.”
4. The branched events chains perspective and “logic tree theory.”
5. The multilinear events sequences perspective and “process theory” or “p-theory.”

IMPLICATIONS FOR ACCIDENT RESEARCH

From this discussion of accident theories, though abbreviated, several significant implications for accident researchers can be inferred. For convenience of the reader, they are arranged into three categories of interest:
investigative traps, data traps, and methodology traps.

Investigative traps:

Each different theory affects the purpose, scope and method of investigation of accidents. The "cause theory" requires the investigator to search for "the" cause of one aspect of the accident phenomenon, usually the crash or collision. The scope of the investigation is limited to this aspect of the phenomenon and the setting, and as soon as the investigator has "sufficient" evidence to support his conclusion of "cause," the investigation is terminated and the report prepared. The method of investigation is usually an informal, single person, interview— dominated data search, and the conclusions reported on a predetermined check list or accident reporting form. A comprehensive explanation of the accident is rare, discovery of safety problems even less frequent, and the data are essentially presented as the investigator's conclusions, except for the accident identifier data, such as time, location, etc.

Much the same comments apply to accidents governed by the "domino theory." The designations of the beginning and end of the chain of events are usually left to the discretion of the individual investigator, or they are implicitly specified by the entries called for on the report forms. When this perception is combined with the "cause theory," the selection of the one event in the chain as the cause or a causal factor is purely subjective, even when manuals with indicated entries are available. As soon as the chain is complete in the eyes of the investigator or the investigative team, the investigation effort is terminated. The reconstruction technique provides some discipline for the data search, but criteria for this reconstruction technique are imprecise and unlikely to assure reproducible results.
The "factorial theory" is even less clear with respect to purpose and scope, from the point of view of the investigator. Every "factor" not a part of the accident mechanism is a judgment call. The same beginning and end problems arise. How much is enough data in a given accident is not predetermined nor hypothesized, with few exceptions. Of all theories, this provides the least guidance for the investigator.

The "logic tree theory" focuses on information that helps identify the critical path of events to the undesired event. No criteria exist for designating the undesired event, so the beginning or end of the accident phenomenon are again left to the judgment of the individual investigators. This also has the effect of confining the purpose and scope of the investigation. However, the search and display methods focus investigative effort on relevant data (data needed to complete the tree) as it is being gathered — a powerful improvement over the other procedures. It also facilitates discovery of new knowledge during the investigation, and organizes speculations if data are not available.

The "P-theory" defines the beginning and end of the phenomenon being investigated, and has a method for identifying the data needed and for testing data relevance as the investigation unfolds. The procedures incorporate the logic tree benefits, and also show time relationships among the events. While the theory provides for a full explanation of what happened, the needs of the investigator may require added information to satisfy extensive "why" questions of an institutional or management nature, and the origins of these influences on the specific phenomenon being studied.

The traps for both the researcher and the investigator occur when two or more of the theories influence an investigation and its reports. Both parties need to be aware of the effects of shifts from one theory to another during an investigation or research project, and need to watch for such shifts. This is particularly important with respect to the data generated by "shifty" investigations, and to hypotheses generated from such data. An example of such shifts can be found in many research reports if one is alert to the theories and investigative problems described above. One research report of the development of a comprehensive causal network model contained three such shifts on a
single page. The conclusions, by the way, included a call for additional data from new accident investigations, and a study of the time structure to quantify interactions.

Data traps:

Each theory produces different data at the end of the investigation. The causal theory produces conclusions about cause(s). The domino theory produces conclusions about a chain of events and "unsafe conditions" or "unsafe acts" affecting the chain of events — all judgment calls. The factorial theory produces a list of "factors" which can be events, conditions, changes of state, social circumstances, hereditary characteristics, personal attitudes, actions, failures, errors or anything else judged to be potentially "causal" by the investigator or researcher. The logic tree theory produces a display of the most likely and alternate "critical paths" leading to what the investigator decides is the undesired event or even the most undesired event. The P-theory leads to a display that shows the actions of each actor who or which played a role in the accident, and the relationships among these actions in a logical time and spatial sequence, to a level of detail judged adequate by the investigator.

Thus, each theory has its data promises and problems. Perhaps the most difficult trap for the researcher to avoid is the shift between investigative observations and investigators' conclusions. For example, the conclusion "following too close" is not useful for identifying countermeasures until the data on which the conclusion was predicated are available in process form. The aggregation of such conclusionary data for the purpose of drawing new conclusions can lead to spurious or worse results.

A second trap is the classification of conclusionary data reported about accidents. For example, the variety of taxonomies used to categorize the role of alcohol in traffic accidents reflects the problems with the handling of conclusions in reports, and until the role of alcohol is understood in the context of the driving actions by drivers involved in accidents, through improved accident analysis or simulations, the most effective taxonomy will elude us.
A third data trap relates to the generation of hypotheses. The use of conclusions of accident investigators and their investigation reports as a basis for new hypotheses seems highly risky, at best, and could be utterly futile — depending on the data. If the criteria for the investigator's decisions are vague, arbitrary or non-existent, the likelihood of futile results increases. A review of the quality of the conclusionary data in research reports suggests that this is a serious research problem in the accident research field.

Methodology traps:

The scientific method is based on observation—of phenomena — and the subsequent formulation of hypotheses, then experimentation and validation of the hypotheses, and ultimately control of the phenomenon. In the accident research field, the phenomena are observed — albeit retrospectively—by accident investigators who conduct the investigation. And these investigators operate to at least five differing perceptual sets or combinations of these sets. The criteria for recording observations vary from set to set, ranging from essentially no criteria to tightly defined criteria. The chaotic state of the available accident data base is easy to understand. Accidents are generally considered uninstrumented experiments. However this does not mean that changes of state are unrecorded. They can often be observed or logically inferred from surviving people or things after the "experiment" is over. Until rules of procedure for recording observations of the accident phenomenon are formulated for investigators, users of the data run a high risk of futile research.

Users also run the risk of applying solutions offered by their disciplines to the wrong problems. Accident theories drive research methods too. For example, the factorial theory demands statistical analysis methodologies, while the P-theory demands operations research, task analysis and other methodologies. More subtly, they influence evaluations of alternative methodologies. For example, a strong statistical and factorial theory bias obscures strengths of alternative theories in a research report on methods for studying pre-crash factors in highway safety research or near miss reporting system. The methodology used for research must match the underlying theory that drives the
investigative data. Most investigators do not think in terms of the subsequent research use or methodologies that will be fed by their data. If they did, their data would surely improve, and more disciplined investigative methods would result (Schaaf van der, 2004).30

Models of accident investigation and analysis:

Models for occupational accident processes –

Several models exist for investigating occupational accident processes. However, according to Laflamme all accident models have three standpoints in common (Laflamme, 1990):31

1. A distinction should be made between an injury and an accident.
2. There might be similar sequences of events in the genesis of accidents, these sequences being initiated by disturbances in the production flow or process.
3. Disturbances and accident sequences are influenced by factors related not only to the immediate working situation but also to work organization, in a broader sense.

Kjellén et al. (1980)32 have suggested a model for analysis of accidents, the OARU model (Occupational Accident Research Unit). In this model a distinction is made between three phases in the accident process: two pre-injury phases – the initial and concluding phase- followed by the injury phase, i.e. the pathogenic outcome of physical damage in a person (Figure 2) (Kjellen, 1983; Kjellen, 1996; Kjellen & Larsson, 1980)33, 34. The initial phase starts when there are deviations from the planned or normal process. The concluding phase is characterized by loss of control and the ungoverned flow of energy. The injury phase starts when energies meet the human body and cause physical harm.

Initial Phase ———— Concluding Phase —— Injury Phase

◄——— Pre-injury Phase ————►

Figure-2: Sketch of OARU Model (Kjellen, 1996)34
Injuries are the result of a culmination of a set of circumstances and pre-existing conditions which may best be understood as a chain of events (Ozanne-Smith, 1995)\textsuperscript{16}. Haddon's matrix provides a conceptual framework, which schematically represents this chain of events. Haddon's model also consists of three phases: pre-event, event and post-event combined with the three factors human, vehicle (product) and environmental (Robertson, 1983)\textsuperscript{17}. Haddon (1970)\textsuperscript{35} has also developed ten basic strategies for injury prevention to apply in different phases and to the different factors in the matrix. Some recommended strategies are to separate in time or space, and to protect by a physical barrier between the hazard and that which is to be protected. The model has been particularly useful in determining appropriate points for intervention in order to prevent or alleviate injuries. The point of intervention is not necessarily early in the chain of events; it should be where the intervention is possible, or ideally where it will be most effective (Ozanne-Smith, 1995)\textsuperscript{16}. Haddon (1970)\textsuperscript{35} remarks that the larger the amounts of energy involved in relation to the resistance to damage of the structures at risk, the earlier in the countermeasure sequence the strategy must lie. Regarding prevention, Gjerstland has introduced the concept of primary, secondary and tertiary prevention (Gjestland, 1955)\textsuperscript{36}. Primary prevention is given before the person meets the hazard e.g. use of vaccine. Secondary prevention is used to reduce the symptoms and tertiary prevention to rehabilitate the person. Ozanne-Smith notes that the three phases in Haddon's matrix are generally equated with primary (pre-event), secondary (event) and tertiary prevention (post-event) (Ozanne-Smith, 1995)\textsuperscript{16}.

\textit{A conceptual model for safety research}

This model gives a schematic and general overview of how individuals with an interest in the safety research area differ in their focuses and approaches. The overview is intended to explain some of the variations in how the concepts are defined.

A): When the focus is on preventing the accident and thereby on finding the most efficient preventive measures, the factors contributing to the accident process will be carefully investigated. Less or no interest will then be spent on the outcome, the injury
caused by the accident. This is often described in general terms, for example by indicating which part of the body was injured. The accident process has most often been seen as a technical, behavioural or social phenomenon, and has mostly been studied by the appropriate specialists (Backström, 1996; Backström and Jensfelt-Döös, 1990; Kjellen, 1996; Laflamme, 1996; Larsson, 1990; Sundström-Frisk, 1996)\textsuperscript{37,38,39,40,41}.

B): Medical personnel have a professional focus on the injury and the injured person. In clinical work the injury will be carefully investigated and a diagnosis made, followed by treatment. The cause of the injury is also of interest, but will seldom be carefully investigated, and the causes will be stated in general terms, e.g. over-exertion, falls, trips and slips etc. In epidemiological studies the focus is also often on the injury and its consequences e.g. type of injury, incidence and sick leave (Jensen, 1986; Pines et al., 1985; Stout, 1992)\textsuperscript{42,43,44}.

C): during rehabilitation there might be even less interest, or none at all, in the accident process, as the focus is now on the goal of getting the injured person back to work, or improving quality of life.

Tree based techniques

Fault tree analysis: The concept of fault tree analysis (FTA) was originated by Bell Telephone Laboratories in 1962 as a technique with which to perform a safety evaluation of the Minutemen Intercontinental Ballistic Missile Launch Control System. A fault tree is a logical diagram which shows the relation between system failure, i.e. a specific undesirable event in the system, and failures of the components of the system. It is a technique based on deductive logic. An undesirable event is first defined and causal relationships of the failures leading to that event are then identified. (Watson, 1971)\textsuperscript{45}
Figure 3: A fault tree depicting the event "Fire breaks out".

Fault tree can be used in qualitative or quantitative risk analysis. The difference in them is that the qualitative fault tree is looser in structure and does not require use of the same rigorous logic as the formal fault tree. Figure shows a fault tree with top event "Fire breaks out". This method is used in a wide range of industries and there is extensive support in the form of published literature and software packages, such as CARA.

**Event tree analysis:** Event tree analysis is a method for illustrating the sequence of outcomes which may arise after the occurrence of a selected initial event. This technique, unlike fault tree uses inductive logic. It is mainly used in consequence analysis for pre-incident and post-incident application. The left side connects with the initiator, the right side with plant damage state; the top defines the systems; nodes (dots) call for branching probabilities obtained from the system analysis. If the path goes up at the node, the system succeeded, if down, it failed.

ETA has seen application in the nuclear industries for operability analysis of nuclear power plant as well as accident sequence in the Three Mile Island-2 reactor's accident.

**Cause-Consequence Analysis:** Cause-consequence analysis (CCA) is a blend of fault tree and event tree analysis. This technique combines cause analysis (described by fault trees) and consequence analysis (described by event trees), and hence deductive and
inductive analysis is used. The purpose of CCA is to identify chains of events that can result in undesirable consequences. With the probabilities of the various events in the CCA diagram, the probabilities of the various consequences can be calculated, thus establishing the risk level of the system.

This technique was invented by RISO Laboratories in Denmark to be used in risk analysis of nuclear power stations. However, it can also be applicable to analyze accidents in different industries like heavy engineering, automated and manual machinery based industries etc in the estimation of the safety of a protective or other system.

**Manual Material Handling and accidents:**

The scientific definition of manual material handling (MMH) as given in the “Material Handling Hand Book” (1958) is the movement and storage of material at the lowest possible cost through the use of proper method and equipment. It can be described as lifting, lowering, pushing, pulling, holding or carrying load, because of the high stress associated with it, many workers are injured and often are forced to quit their jobs. (Tighe et al. 2006, Gangopadhyay et al. 2003)

Handling of heavy materials manually is a frequent mode of work in all spheres of life in India. One may find that more than 70% of the total populations of India are directly engaged in MMH. If one could bring about even slight improvement in this mode of work, it would benefit to the people in India. (Gangopadhyay et al. 2003)

There are mainly two different types of material handling e.g. mechanical and manual. MMH tasks are quite strenuous as in most cases postures adopted during activity create great pressure on the musculoskeletal system and cardiovascular system.

Sen (1979) showed that MMH by man utilizes energy from food which is about 100 to 2000 times more costly than the fuel sources of energy such as diesel, petrol, coal electricity, etc. used by big machines handling materials mechanically. But these
machines are very costly and fossil fuels, electricity, oil, etc. are becoming scarcer day-by-day. Therefore, MMH which is practiced extensively in India using human labour could not be estimated and could be eliminated and would remain a major mode of work in the foreseeable future.


MMH with the repetitive movements gives rise to an increased risk for strain to the back, neck, arms and shoulders (Korwoski et al, 1986; Putz Anderson, 1988; NIOSH, 1981). David (1985) studied in U.K. national statistics on handling accident and lumber injury at work. From this study of accidents due to handling in different factories in U.K, 19 cases of fatality were collected. Fatality during MMH is mainly due to overexertion, which is one of the prime causes of accidents during MMH. A diverse number of occupational groups are exposed to MMH stresses and consequently a diverse number of industries have significant over exertion injury claims (Ayoub et al, 1989). Over exertion injuries and accidents arising from industrial activities are frequently related to handling of materials manually (Laflamme et al, 1990; Laflamme, 1991). Fatality during MMH is mainly due to over exertion and different limb injury, which is one of the prime causes of accidents (Muggleton et al, 2000).
Stranberg & Lanshammar (1981) and Manning (1983) found from official statistics that slipping, tripping, stumbling were the most common causes of accidents. Other injuries increased when the worker loses grip on a work piece.

Very few studies have been recorded in India on the analysis of MMH accident (Sen & Gangopadhyay, 1989; Gangopadhyay & Sen, 1997). But detailed studies on causative factors on this aspect have not been carried out yet. In the present investigation an effort will be given to make a detail analysis of accident and to find out the effect of work environment, work mode on the causation of MMH accident.

In 1979 by a special analysis, accidents were classified as due to ‘overexertion’ and it represented 20% of all reported accidents. Of these, 67% resulted from lifting and carrying and further 19% from pulling or pushing objects and materials.

The back was the site of injury in 61% of ‘overexertion’ accidents and of these 74% resulted from ‘lifting’ etc. and 15% from ‘pushing’ and ‘pulling’. (Karwoski, 1986).

In developed countries various sophisticated and very costly experiments have been undertaken on MMH, like analysis of stress in MMH by ‘FUZZY- Modelling’ (Karwoski et al. 1984). Although no such sophisticated and costly experiments have been done in our country to find out the stress of Indian manual material handling workers, Sen and Gangopadhyay, (1985, 1989) found by simple experiments that the stress of MMH workers viz. handcart pullers was very severe as indicated by their pulse rate of as high as 180 beats/min when a load of about 3000 kg on the hand-cart was pulled on the streets of Calcutta.

Overexertion is one of the causes of back injuries and back pain. Several studies have been done in different parts of the world on this ailment which are discussed below.
Different studies of Asfour (1984)\textsuperscript{72} and Borg (1978)\textsuperscript{73} demonstrated that MMH was quite a strenuous work and it was also one of the most hazardous tasks from the occupational and safety point of view. Ghoshal and Gangopadhyay (2005)\textsuperscript{74} observed from the study on accidents in some hot industries in West Bengal that a large number of accidents were caused every year by MMH in different factories in that state.

From detailed analysis of accidents in Great Britain, it has been found that about 26\% of the accidents were due to manual handling. From further statistical analysis it was observed that trunkal injuries constituted about 35\% of the handling accidents, comparable to 38\%, which involved the upper limb and hand (Kumar, 1990; Singleton, 1982)\textsuperscript{75,76}.

Strandberg and Lanshammar (1983)\textsuperscript{77} found from official statistics that slipping was one of the most common causes of accidents. In 1995, in Sweden it was observed that a total 315 cases of death due to fall at the same level from slipping, tripping or stumbling occurred. David (1985)\textsuperscript{78} studied on U.K. national statistics on handling accidents due to manual handling of load in different factories in UK by female workers, 19 cases of fatality were collected.

Fatality during MMH is mainly due to overexertion, which is one the prime cause of accidents during MMH.

Accidents leading to over-exertion back injuries were observed to be a great problem among MMH workers. During the period 1983 to 1986 13,000 cases reported an over-exertion injury. The body part most frequently injured was the back (McGill 1997)\textsuperscript{79}. Many other studies have shown that MMH worker have a high prevalence of back pain and occupational back injuries compared to other occupational groups (Dehlin et al., 1976; Harber et al., 1985; Ljungberg et al., 1989)\textsuperscript{80,81,82}.

Nicholson (1985)\textsuperscript{82} performed detailed accident analysis in different British industries. He investigated handling accidents, back injuries and back pain of workers in
different factories and compared their results. It was observed that in construction industries maximum accidents were due to handling material manually.

Troup et al. (1988) gave a model for the investigation of 'back-injuries' and 'manual material problems' at work. This model was based on the Merseyside Accident Information Model (MAIM) which required identification of the first unforeseen event involving the injured person: the activities and movements of the casualty at the time of the first unforeseen event, including data on what object or objects were associated with that first event and whether or not such an object was being lifted or handled at the time. In order to evaluate this model, 257 cases of accidents or injuries had been investigated.

From the official data of incidence of injuries associated with manual handling in UK, it was observed that 24.4% of the total number of accidents occurred due to handling of materials in the year 1980. This proportion was further increased to 27.7% by 1985 when work force of the factories was further increased from 5 million to 6 millions. Since then, until 1987, the proportion of accidents due to handling varied between 26% to 30% of the total.

Lin et al (2006) and Pransky et al, (2000) studied the low-back stresses during load lifting. Low-back is stressed maximally during the lifting task. Specifically the lower lumber segments of spinal column and their associated muscles and ligaments are highly stressed. It was reported that low-back in origin range from 15% for all US industries to as high as 30% for certain industries studied in Sweden Ghista (1982).

Schaub and Rohmert (1991) evaluated the working postures by their 3D computer-aided man model HEINER. It was observed that the bio-mechanical models, implemented in the HEINER system, were quite suitable for the evaluation of working postures and low back stress.

Mayer and Flenghi (1991) investigated the functional capacities of the lumber spine in populations occupationally exposed to strains. The results showed a significant impairment of lumber spine mobilities in two populations: women in manual handling tasks and men exposed to whole body vibration. Besides these back injuries, fatality
mainly caused due to injuries in cervical region of the vertebral column (Splittstoesser et al. 2007).

**Injuries in Vertebral column**

To examine the association between stressful events and occupational accidents vertebral lesion and compression was studied. Skeletal lesions were classified into five main types: i) compressed or wedged vertebrae; ii) Burst or comminuted vertebrae; iii) Unilateral facet dislocation; iv) bilateral facet dislocation; v) hyper extensional lesions.

Compressed fracture in which vertebral body is severely compressed anteriorly. It occurs both in the cervical and thoraco-lumbar portions of the spine. Burst fracture is frequently seen in the cervico-thoracic regions. Unilateral facet dislocation, when a force applied to the head or body exerts both flexion and rotation to the thoraco-lumbar regions, it may produce dislocation of the inter-vertebral joints with or without fracture of the articular process or pedicle. This type of injuries occur much more frequently in the lower cervical spine (from C5-C7) than elsewhere. Bilateral facet dislocation due to much greater force bilateral dislocation of the apophyseal joints with fracture and disruption of the posterior ligaments occurs. Hyperextension Lesion: Extension lesions are apparently very common in the cervical segment but much less in the thoraco-lumbar area. (Cordeiro and Dias 2005)

Duthie and Bentby (1983) defined different types of paralysis, monoplegia, paraplegia and hemiplegia etc. A monoplegia, when paralysis of one limb occurred, is rare. When both legs are paralysed it is called ‘Paraplegia’, but if paralysis is found on the same side of arm and leg, then it is described as right or left hemiplegia. Triplegia denotes involvement of three limbs, one arm and both legs; and when all four show less of normal control and functions, then it is denoted as quadriplegia.

Edmonson and Crenshaw (1980) described that the most common site of dislocation was between the 5th and 6th cervical vertebrae. They further described that fracture dislocation of cervical spine was more serious than uncomplicated dislocations. Hughes (1983) came to the conclusion that cervical spine injuries of two types flexion
and extension types. Flexion type injuries are rarely serious and are less common in the cervical spine than elsewhere. Extension injuries occur when head is violently driven backwards. Besides these cause (back and cervical injuries), there are several other cause for fatal accidents in different industries.

Injury reports provide the basis for statistics about accidents and the injuries they cause, but are seldom used to initiate preventive changes. Statistics on the incidence of accidents give some insight into the magnitude of the problem as it appears nationally, but little or no information about the causes of accidents or suggestions for preventive measures. One reason for this lack of information is that the data rely on reports from individuals who are unlikely to be trained in accident investigation (Troup, 1988)\(^93\). The information given in an accident report is therefore often inadequate, both for understanding the factors and events involved in the accident process, and as a basis for initiating preventive measures.

For a reported accident to have an impact on safety work, the injury report should not be the end product, but should rather serve to initiate an investigation of the accident process and be a way of collecting information useful for preventive strategies. It is only a careful investigation of the circumstances involved in the accident process that makes it possible to suggest preventive measures to avoid a risk situation, or to block a process once started.

Occupational injuries entail great costs (Bigos et al., 1991; Biogs et al., 1986; Dempsey et al., 1997; Simpson, 1988; Spilling et al., 1986)\(^90, 91, 92, 93, 94\). For society they entail sick pay, medical care, insurance, sickness pension, etc. For the employer they lead to costs for sickness benefit, over-time, recruitment of new personnel, etc. For the individual worker they lead to loss of income as well as physical and mental suffering as a result of the injury. In Sweden costs due to acute low back pain were calculated to 47,500 SEK ($5,523) per patient. Of the total costs, 90% was indirect costs due to sick leave (Seferlis, 1999)\(^95\). NIOSH stated that work-related musculoskeletal disorders represent a major part of the costs of work-related illness in the United States. Back pain
is by far the most prevalent and costly musculoskeletal disorder among U.S. industries today (Bernard, 1997). The mean cost was $8,321 per case of compensable low-back pain during 1989 in the U.S., while the mean cost for other musculoskeletal disorders was $4,074 (Webster et al., 1994). With the aim of preventing injuries among nursing personnel, it is therefore of greatest importance to identify the factors involved in the accident process leading to an injury, and to identify the risk and protective factors and how they are connected. This is the main aim of the present thesis.

**Study of Fatal accidents:**

Andersson (1996) analyzed from official documents 198 fatal occupational accidents which occurred in Sweden. It was observed that proper action after a severe accident could reduce fatalities by about one sixth. Manning (1983) critically reviewed the death cases and injuries caused by slipping, tripping and falling. From the record it was found that in 1979 there were 5886 fatal falls in England, Wales and Scotland. It was also recorded in the United State that there were 13.6 million falls in 1972.

King and Hudson (1985) recorded the accidents as percentage of study group and fatalities to steel structure erectors in British factories. From their study it was revealed that due to fall over 2 meters from steel work in 4 years (1970 to 1973) the number of injuries were 11, 12, 15, 11 respectively and the number of fatalities were 5, 4, 5, 3 in respective years. They further observed that in construction industries maximum number of fatal accidents occurred due to falls of persons. In 1974-76, the number of fatal accidents by fall of persons were 217 or 43.8% of all types of accidents due to different causes, where as in 1977-79, it was 200 or 54% of all types of accidents due to various causes. Several other causes have been identified for MMH accidents, although, all of them do not lead to fatal causes but regular loss of production.

Videman et al., (1999) made a review of Swedish Research on near miss accidents reporting. From this study it was observed that occupational accidents accounted for 75% of all occupational injuries and diseases in Sweden in 1997-98 and were responsible for more than 200 deaths. The information on near miss accidents was
obtained by intervening activity. In our country very few reporting on near or non-reportable accidents are recorded in different factories.

**PHYSIOLOGICAL EFFECTS OF MMH**

Astrand and Rodahl (1970)\(^{100}\) stated that when a young adult male is working and using 50% of his maximum aerobic capacity, his HR is likely to be about 130 b/m. A reasonable estimate of the permissible weight of load required to be carried manually can therefore be made from the data presented on this basis. The permissible weight of load is around 30 kg. For manual carriage can also be obtained from the recovery patterns of pulse rates of the subjects taken just before each minute of the continuous five minutes of observation. The average pulse rate measured one minute after cessation of carrying a 30 kg. load was found to be only 98 b/m and well under the limit of 110 b/m proposed by Brouha. The corresponding pulse rates of the subjects carrying 40 kg. or 50 kg. weights exceed this value. The average recovery pulse rate after one minute was 112 b/m, slightly above Brouha’s limit. The recovery pulse rate after five minutes was also still considerably elevated than the resting values.

Heart rate has been used to demonstrate the effect of work on cardiac performance since early 1900’s (Bower, 1904)\(^{101}\). It has been shown later by various investigators (Brouha et al, 1961; Brouha and Maxfield, 1962)\(^{102},^{103}\) that the rate of oxygen consumption is not necessarily a reliable indicator of the physiological strain induced by work, whereas heart arte reflects the degree of strain.

Manual tasks performed in working environments can be characterized by various combination of dynamic and static muscular effort. This is particularly true in daily life activities in load carrying and lifting. Over the years, ergonomists and occupational safety and health professionals have extensively utilized the measurement of heart rate (Sanchez et al, 1979; Mass et al, 1989)\(^{104},^{105}\) and systolic blood pressure (Asfour et al, 1986)\(^{106}\) to determine the physical effort involved in different types of manual work.
Based on the measurements of HR, it was proved that cardiovascular responses to load carriage were substantial in homeostatic balance (steady state). Gamberale et al (1987)\textsuperscript{107} also concluded that a rise in workload resulted in a linear increase in both exertion and heart rate. The highest attainable heart rate during performance of heavy muscular work depends upon age and state of training. At the age of 20 years, the maximal heart rate is about 200 b/m, which is reduced to 155 b/m at the age of 70 years. So it is clear that heart rate decreases with advancement in age (Rasch and Wilson, 1968)\textsuperscript{108}.

Astrand and Rodahl (1986)\textsuperscript{109} proposed the following table wherein the category of work and the corresponding heart rate have been shown.

TABLE 1: CATEGORY OF WORK AND HEART RATE

<table>
<thead>
<tr>
<th>Category of work</th>
<th>Heart rate (beats/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light work</td>
<td>Up to 90</td>
</tr>
<tr>
<td>Moderate work</td>
<td>90-110</td>
</tr>
<tr>
<td>Heavy work</td>
<td>110-130</td>
</tr>
<tr>
<td>Very heavy work</td>
<td>130-150</td>
</tr>
<tr>
<td>Extremely heavy work</td>
<td>150-170</td>
</tr>
</tbody>
</table>

The circulatory organs may also be affected during the lifting of heavy loads, particularly if they are already in poor shape; the HR and blood pressure rise in each and every person and brain haemorrhage has been reported in some older arteriosclerotic persons.

Although measurements of blood pressure immediately after carrying loads (up to 20% of the body weight) did not show any significant difference, but after sometime
there was a rise in SBP (Hong et al, 2000). SBP rises in direct proportion to rises in exercise intensity (Rowel, 1986).

Dynamic exercise is used for those types of physical activities where muscle groups undergo repetitive and continuous muscle contraction involving a change in muscle length. During acute bouts of dynamic exercise there is a steady increase in SBP, which is, proportional to the exercise intensity while DBP does not change significantly (Dehn and Mitchell, 1979; Dlin, 1986). Blood pressure levels are dependent primarily on the relationship of SV, HR and TPR. During transition from rest to exercise, or during exercise of increasing intensity, cardiac output increases in both SV and HR, blood pressure increases are offset to some degree by decreases in TPR (Keul et al, 1981).

It is stated that during exercise or activities, blood pressure increases linearly as a result of an increase in cardiac output. Both nervous as well as chemical influences bring about these increases. It is also observed that exercise or activities affect SBP than DBP or MBP. This is due to the fact that during exercise the resistance to blood flow is decreased. The decreased resistance is the result of vasodilatation that takes place in the arterioles or the working muscle (Shaver, 1982).

**EFFECTS OF ENVIRONMENT ON MMH WORKERS**

**Effects of Temperature and Work Performance:**

As a homiotherm, human beings possess an amazing thermoregulatory mechanism that maintains an internal thermal balance in spite of large environmental temperature variation. Nevertheless, thermal changes may sometimes cause injuries and illness to the exposed individuals. Extensive studies have been done on the effect of thermal changes and these studies provide the basis for the prevention of health impairment and physiological damage to workers. (Stephenson et al, 1974).
An elevated ambient temperature or humidity level increases the cardiovascular load of a materials handler and a low temperature can substantially reduce finger flexibility and accuracy. An ideal thermal comfort zone is affected by a number of factors in addition to temperature and humidity. Among these are air velocity (producing a windchill effect), workload, radiant heat sources and amount and type of clothing. In general, the body’s core temperature should not vary by more than 1° C in either direction, and the above factors should be adjusted to accommodate this range (ACGIH, 1996)\(^{117}\).

Heat stress elevates core temperature and in turn metabolism of the body (Q10 effect). Other associated physiological effects include rise in heart rate, rise in blood circulation and increased sweating. Prolong exposure to heat may result in heat cramp, heat exhaustion and heat stroke etc. Hot and humid ambient environmental conditions reduce the physical performance capabilities of the worker (McArdle et al, 1996)\(^{118}\); while cold weather reduce hand dexterity, joint movement and thus negatively impact on lifting and carrying capability of personnel (Wilson and Corlett, 1992; Hancock and Vasmatzidix, 1998)\(^{119,120}\).

Heat stress also considerably affects physical and cognitive performance (Hancock, 1981; Ramsey and Kwon, 1988)\(^{121,122}\). According to the researchers the type of work actually mediates the effect of heat stress on performance. The reduction of heat stress can be accomplished by a systematic and comprehensive approach. Frequent rest breaks in a cooler environment is necessary. Limiting the total time spent in a hot environment could also serve the purpose.
TABLE 2: PERMISSIBLE HEAT EXPOSURE THRESHOLD LIMIT VALUE [WBGT (°C)] (ACGIH, 1994) 123

<table>
<thead>
<tr>
<th>Work-Rest Regimen</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light</td>
</tr>
<tr>
<td>Constant Work</td>
<td>30.0</td>
</tr>
<tr>
<td>75% Work, 25% Rest each hour</td>
<td>30.6</td>
</tr>
<tr>
<td>50% Work, 50% Rest each hour</td>
<td>31.4</td>
</tr>
<tr>
<td>25% Work, 75% Rest each hour</td>
<td>32.2</td>
</tr>
</tbody>
</table>

A number of heat stress indices have been formulated, for e.g. heat stress index of Belding and Hatch (1955) 124, predicted four hour sweat rate (Mc Ardle et al, 1947) 125, WBGT index (Yaglou and Minard, 1957) 126 and effective temperature (Yaglou, 1927) 127. All these indices try to quantify heat stress in a steady state, while taking into account air temperature, relative humidity, radiant heat for calculating heat stress (Mc. Cormick, 1992) 128.

The temperature of air is referred to as the dry-bulb temperature and is measured by using different measuring devices such as mercury or alcohol in glass thermometer, thermo electronic thermometers, thermocouples and thermistors (Khogali and Karim, 1987) 129. The relative humidity can be assessed if the dry and wet bulb temperatures are known. They can be measured by the use of a sling, whirling psychrometer or a motor driven psychrometer or the aspirating psychrometer.

Air speed is determined by the use of anemometers. When the air is turbulent (multidirectional) it is preferable to use a hot wire anemometer or a Kata thermometer is the instrument of choice.

The radiant temperature is measured by using a black Globe Thermometer. To estimate the MRT, the determination of the dry-bulb temperature and air speed at the same time and in the same place with the globe thermometer is essential. Bedford and
Warner (1934)\textsuperscript{130} computed MRT from the globe thermometer, air speed and air temperature measurements and these calculations are now embodied in the nomograms, which are used to calculate the MRT. MRT is by far the major cause of heat-load gain in the tropics and subtropics.

**Heat Stress Indices:**

**Effective Temperature (ET):** One of the first practical scales was designed by Yaglou in the 1920s and is called the Effective Temperature scale. The ET index is mainly based on subjective assessment of the environment, combining temperature, humidity and air movement. The dry and wet bulb temperatures and air speed should be recorded before determining the ET.

Bedford (1936)\textsuperscript{131} modified the ET scale when he included a factor for radiation. The CET is determined by using the same method, but by substituting the globe temperature in place of the dry bulb temperature.

**Belding and Hatch Index:** The scale that can be used indoor particularly in industry is the Belding and Hatch (1955)\textsuperscript{124} index. This index is effective over a wide range of temperatures but it is complicated to evaluate. For this reason it has not been as widely used in industry as it should have been.

**The Predicted Four Hour Sweat Rate (P4SR):** P4SR is a scale based on the physiological response of the individual. It was developed from many experiments carried out in climatic chambers by Mc Ardle et al (1947)\textsuperscript{125}. From measurements of the sweat rate of subjects wearing particular clothing and doing specific work over a 4 hour period- nomograms were constructed. From this empirical approach, it is possible, by measurement of the dry and wet bulb temperatures together with air movement to predict 4-hour sweat rate. The scale is particularly useful in very hot and humid conditions, but there are some limitations, which are due to the way the scale was determined.
Nevertheless, in spite of this, experience has shown that the P4SR is a reliable index and one that has been used in a wide variety of situations with many different subjects (Kerslake, 1972).\(^{132}\)

**Wet Bulb Globe Thermometer (WBGT) Index:** The WBGT index is used worldwide, specially in industrial safety and occupational health. This was also designed by Yaglou together with Minard (1957)\(^{126}\) and was intended as a simple scale to be used out of doors. It is a simple and appropriate technique to measure the environmental factors, which correlate with deep body temperatures and physiological response to heat. WBGT was adopted by the American Conference of Governmental Industrial Hygienists and used to develop the TLV for heat stress.

WBGT index is the simplest and the most convenient index having a fairly intimate correlation with physiological responses. Individual differences in heat tolerance, type of work, clothing, air circulation vary within a wide range, but in spite of this, 'safe' heat exposure limits based on WBGT index have been recommended by agencies like ACGIH (1994)\(^{123}\) and NIOSH (1986)\(^{133}\).

**NOISE LEVEL AND WORK PERFORMANCE**

The workers frequently complain that there is too much noise and that distracts them from their jobs. Loudness is directly related to the mechanical pressure transmitted to the eardrum, although the sound frequency and other characteristics of sound determine the degrading effect it has on performance. The less predictable and controllable the sound, the more annoying it is.

Sound levels above 50 dBA may become increasingly intrusive, objectionable and fatiguing, depending on their frequency and predictability. Sound levels that exceed 85 dBA and continue for as long as 8 hours may cause hearing loss. If noise levels routinely exceed 85 dBA, it is necessary to control the sound source or provide other means of
hearing protection. Workers should not be exposed to sounds above 115 dBA (ACGIH, 1996)\textsuperscript{117}.

Many dye casting industries, involving manual mode of work, have generated high levels of noise in the range of 80-100dBA. This has resulted in physiological effects leading to reduced performance. The level of noise and load both were having statistically significant effect on human performance (Muzammil et al, 2004; Cordeiro et al, 2005)\textsuperscript{134,135}.

According to Persson et al (2001)\textsuperscript{136} the quality of work performance and perceived annoyance may be influenced by a continuous exposure to low frequency noise at commonly occurring noise levels.

Dias et al, (2006)\textsuperscript{137} reported that the risk of having a work accident was about twice as high among workers exposed to noise, after controlling for several co-variables. Occupational noise exposure not only affected auditory health status but was also a risk factor for work accidents.

**ILLUMINATION LEVEL AND WORK PERFORMANCE**

The amount of light required to perform a specific task without feeling visual fatigue is a function of the visual difficulty of the task at the desired work speed and quality and the visual acuity of the worker. Degree of visual difficulty is typically determined by i) the contrast between the target and its backgrounds; ii) the spatial resolution and iii) the size of the target.

One or more of the following symptoms and signs may accompany a general feeling of tiredness of the eyes: oculomotor changes (esophoria, exophoria); ocular pain, itching, tearing, reduced ability of the eyes to accommodate and converge properly; headache and complementary colour reversals. Although ocular symptoms from over
work do not cause permanent eye damage, yet these symptoms can affect productivity
and a worker's sense of well-being.

**TABLE 3: RECOMMENDED RANGES OF ILLUMINATION FOR VARIOUS
TYPES OF TASKS (Eastman Kodak Company, 1983)**

<table>
<thead>
<tr>
<th>Type of Activity or Area</th>
<th>Range of Illumination* (Lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public areas with dark surroundings</td>
<td>20-50</td>
</tr>
<tr>
<td>Simple orientation for short temporary visits</td>
<td>&gt;50-100</td>
</tr>
<tr>
<td>Working spaces where visual tasks are only occasionally performed</td>
<td>&gt;100-200</td>
</tr>
<tr>
<td>Performance of visual tasks of high contrast or large size: reading printed material,</td>
<td>&gt;200-500</td>
</tr>
<tr>
<td>typed originals; rough machine work; ordinary inspection; rough assembly</td>
<td></td>
</tr>
<tr>
<td>Performance of visual tasks of medium contrast or small size: reading pencil handwriting, poorly printed material; difficult inspection; medium machine work; medium assembly</td>
<td>&gt;500-1000</td>
</tr>
<tr>
<td>Performance of visual tasks of low contrast or very small size: reading hard pencil handwriting on poor quality paper, very poorly printed material; very difficult inspection</td>
<td>&gt;1000-2000</td>
</tr>
<tr>
<td>Performance of visual tasks of low contrast and very small size over a prolonged period: fine assembly, highly difficult inspection, fine machine work</td>
<td>&gt;2000-5000</td>
</tr>
<tr>
<td>Performance of very prolonged and exacting visual tasks: the most difficult inspection, extra fine machine work, extra fine assembly</td>
<td>&gt;5000-10000</td>
</tr>
<tr>
<td>Performance of very special visual tasks of extremely low contrast and small size: some surgical procedures</td>
<td>&gt;10000-20000</td>
</tr>
</tbody>
</table>

* The choice of a value within a range depends on task variables, the reflectance of the environment and the individual's visual capabilities.
Common and recommended light levels indoor: The outdoor light level is approximately 10,000 lux on a clear day. In the building, in the area closest to windows, the light level may be reduced to approximately 1,000 lux. In the middle area its may be as low as 25 - 50 lux. Additional lighting equipment is often necessary to compensate the low levels.

Earlier it was common with light levels in the range 100 - 300 lux for normal activities. Today the light level is more common in the range 500 - 1000 lux - depending on activity. For precision and detailed works, the light level may even approach 1500 - 2000 lux. The table below is guidance for recommended light level in different workspaces.

**TABLE 4: RECOMMENDED RANGES OF ILLUMINATION IN DIFFERENT WORKSPACES**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Illumination (lux, lumen/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouses, Homes, Theatres, Archives</td>
<td>150</td>
</tr>
<tr>
<td>Easy Office Work, Classes</td>
<td>250</td>
</tr>
<tr>
<td>Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories</td>
<td>500</td>
</tr>
<tr>
<td>Supermarkets, Mechanical Workshops, Office Landscapes</td>
<td>750</td>
</tr>
<tr>
<td>Normal Drawing Work, Detailed Mechanical Workshops, Operation Theatres</td>
<td>1,000</td>
</tr>
<tr>
<td>Detailed Drawing Work, Very Detailed Mechanical Works</td>
<td>1,500 - 2,000</td>
</tr>
</tbody>
</table>
DUST AND FUMES HAZARDS AND WORK PERFORMANCE

Occupational injuries of foundry workers might occur due to a variety of inherent hazardous conditions in foundries (Zakaria, 2003). The working environment of foundries is hazardous and characterized by multiple simultaneous chemical, physical and mechanical hazards exposure, which would lead to injuries of foundry workers.

The results obtained during the same operations of iron and steel foundries were similar. The distribution of the workers into various exposure categories, the content of respirable dust and quartz, the correlation between respirable dust and total dust, and the correlation between respirable silica and total dust concentrations are discussed. Observations concerning dust suppression and control methods are briefly considered.