Epidemiology of work-related diseases and accidents

Tenth Report of the Joint ILO/WHO Committee on Occupational Health

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Geneva, 1–7 September 1987

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EPIDEMIOLOGY OF WORK-RELATED DISEASES AND ACCIDENTS

Tenth Report of the Joint ILO/WHO Committee on Occupational Health

1. INTRODUCTION

The Joint ILO/WHO Committee on Occupational Health met in Geneva from 1 to 7 September 1987 to discuss the epidemiology of work-related diseases and accidental injuries. Dr Lu Rushan, Assistant Director-General of WHO, and Dr A. David of the ILO Occupational Safety and Health Branch opened the meeting on behalf of the Directors-General of WHO and ILO. Dr Lu pointed out that the application of epidemiology would help improve reporting systems for occupational injury and disease, facilitate field investigations, and identify causal factors so that appropriate control measures could be introduced. These were important steps in WHO’s long-term objective for workers’ health, which was to make available to all workers, including those employed in remote areas, preventive health care, based on convenient and appropriate technology and worker participation. Dr David drew attention to the efforts of the ILO through its International Programme for the Improvement of Working Conditions and Environment (PIACT). In this context, epidemiology was viewed as a helpful tool in identifying problems, establishing objectives, defining strategies, mobilizing the multidisciplinary resources needed for improving work conditions and the work environment, and promoting workers’ health.

Dr Lu explained the reasons why the epidemiological approach to work-related diseases and accidental injuries had been selected for discussion by the Committee:

(a) Work-related accidental injuries can be caused by numerous environmental and human factors. Epidemiological research can help identify these factors and suggest effective control strategies. The most important element for control is prevention, through environmental protection in the workplace, safety education of workers and managers, the application of appropriate and safe work practices, and the application of basic ergonomic principles.
(b) Work-related diseases are often linked to various risk factors including workers’ life-styles, habits, and individual susceptibility. In the past, it was not difficult to identify specific occupational diseases since the causative factors in the workplace could be easily recognized. However, many diseases now recognized as being work-related have a more complex etiology that can be elucidated only through sound epidemiological studies. By means of such studies, it will be possible to provide guidance for the early detection and control of work-related diseases.

(c) Experience has shown that the involvement of both managers and workers and the proper organization of occupational safety and health services are essential for establishing and maintaining a safe and healthy working environment, and for optimizing physical and mental health in relation to work. Epidemiological data can be used to support arguments in favour of improving the working environment and providing workers’ health care.

The main objectives of the meeting were therefore:
— to review the causes of work-related diseases, accidents, and injuries,
— to propose epidemiological approaches for investigations, and
— to make appropriate recommendations.

1.1 Definitions of epidemiology, work-related diseases, and work-related accidents causing injury

The definition of epidemiology itself and of related terms has been recently addressed in the WHO publication entitled *Epidemiology of occupational health* (51). Epidemiology is defined as the study of the distribution and determinants of health-related states and events in populations, and the application of this study to the control of health problems. “As applied to occupational health, epidemiology thus has the dual task of describing the distribution of deaths, accidents, illnesses, and their precursors . . . [in the workforce] . . . and of searching for the determinants of health, injury, and disease in the occupational environment.”

Although epidemiology is multidisciplinary, it utilizes a specific methodology, which is discussed in this report and in previous WHO publications (48, 51).

Because the “work-relatedness” of a disease or injury is a major consideration for public health, medicine and the legal system, the terms “work-related accidental injury” and “work-related disease”
may have different meanings in different locations and settings. For this reason the definitions of these terms as used in this report are reviewed.

Work-related accidents and injuries have many causes. For several reasons, it is difficult to define the term "workplace accidents", as is discussed on pages 41-42. However, "work-related accidental injuries" have been defined by the International Labour Organisation as "those recordable injuries resulting from accidents occurring at the place of work and resulting in death, personal injury or acute disease". Although it is recognized that working conditions can contribute to accidents that occur away from the workplace, this subject is not dealt with in depth in the present report.

A WHO Expert Committee has suggested that the term "work-related diseases" may be appropriate to describe not only recognized occupational diseases, but other disorders to which the work environment and performance of work contribute significantly as one of several causative factors (109). When it is clear that a causal relationship exists between an occupational exposure and a specific disease or injury, that disease or injury is usually considered both medically and legally as occupational and may be defined as such. However, not all work-related diseases or injuries can be defined so specifically. Conceptually, they may be considered to comprise a wide range of diseases and injuries related in some way or other, not necessarily causally, to occupation or work conditions. Classical occupational diseases represent one end of the continuum, while disorders with only a very slight occupational connection represent the other extreme. Many of the diseases contained within the continuum have a multifactorial etiology and may be work-related only under certain conditions. It should be mentioned that work can also have beneficial rehabilitative effects on certain pathological conditions, provided the workers concerned are properly placed in jobs suited to their capacities and limitations.

In this report, classical occupational diseases are not discussed, and the Committee does not address a number of important classes of disease or condition that may be work-related, including infectious diseases, parasitic diseases, and certain cancers. These important topics are considered in other reports and publications. Rather, the Committee was asked to consider several groups of disorders that have received less attention even though they are quite common and are of great importance to workers' health, namely, chronic nonspecific respiratory disease, cardiovascular disease, and
musculoskeletal disorders. This report addresses the problems inherent in epidemiological research aimed at identifying and quantifying the work-related etiology of these three major disease categories and of accidental injuries.

1.2 Ethical considerations and confidentiality

The ethical, legal, and medical confidentiality aspects of epidemiological studies need to be considered carefully, as do provisions for the protection of trade secrecy. Such matters are important when designing, conducting, analysing, interpreting, and reporting epidemiological studies. There are also ethical considerations to be taken into account concerning the use of the findings of epidemiological studies. These matters were addressed when WHO, ILO, and the United Nations Environment Programme formulated and published guidelines for studies in environmental epidemiology (48). In all cases where scientific research involves human subjects, it is necessary to comply with the social and legal requirements applicable in the study location or locations, giving due consideration to ethical codes developed internationally.

A few key provisions for epidemiological studies need to be mentioned: informed consent should be given by participants; the study should be justified in terms of the benefits to the participants and to society; participants should be protected from potential harmful effects attributable to the study; each participant should be informed of individual study results and their interpretation; and personal health information must be held strictly in confidence and should be released only when authorized by the participant. Confidentiality concerns also apply to the use of existing clinical records for epidemiological purposes; the use of payroll, insurance, and other records kept by employers; and the linking of records by means of one or several computer-accessible stored data bases.

In any system for the collection of data, quality and completeness depend on the compliance of those supplying the data. Such compliance, in turn, depends on those involved understanding the motives for the data collection, the way the data are used and interpreted, who has access to the collected data, and the benefits that will result.
1.3 Aims of the report

Because it is possible to improve work conditions, work-related diseases and accidental injuries are, at least in principle, preventable. However, before there can be effective prevention, the problem must be identified and quantified. Epidemiological research has an important role to play in this process. Work conditions vary from one situation to another; hence the extent to which work-related factors contribute to the causation of a disease or injury also varies. This variation can lead to apparent discrepancies between the results from different studies, for example an occupational etiology may be identified in some studies but not in others on the same disease, and the degree of work-relatedness may vary in different settings. Therefore, for the efficient (especially cost-efficient) prevention of work-related disorders, it is important not only to identify the disorders but also to quantify the occupational etiological fraction, which varies with time and place (for definition, see section 2.1.1).

It is hoped that this report will provide a practical guide for occupational safety and health personnel at all levels: at the workplace, in occupational health centres, at research institutes, and at the national level. The report should be useful to occupational safety and health personnel who are not epidemiologists, as well as to workers and management personnel, since these groups may be involved in planning, implementing, and interpreting epidemiology studies or applying the results from such studies in practical intervention programmes.

It is also hoped that the report will help stimulate and guide efforts directed towards the improvement of reporting systems for work-related accidents and diseases and of epidemiological methods and models, with special emphasis on practical approaches.

The epidemiological approach can help guide all those concerned in their intervention efforts to prevent and control work-related diseases and work-related accidents. Epidemiology will be of further use in evaluating the effectiveness of such intervention efforts.

2. EPIDEMIOLOGICAL STUDY
OF WORK-RELATED DISEASES

This section is largely based on three recent publications on work-related diseases (3, 59, 109). It addresses the problems inherent in epidemiological research aimed at identifying and quantifying the
work-related etiology of chronic nonspecific respiratory disease, cardiovascular disease, and musculoskeletal disorders; these have been selected because (a) they are often work-related, (b) they have a diverse multifactorial etiology, and (c) they are common disorders.

2.1 General aspects

2.1.1 Occupational etiological fraction

An epidemiological study of a work-related disease conforms to epidemiological research in general, being predominantly nonexperimental and subject to inherent difficulties, especially in providing evidence for or against the causality of an observed association between two phenomena (36, 37, 40).

The demonstration of a slight increase in the occurrence of a common disorder among those exposed to a work-related factor requires a large study and a sharp design. The latter requirement means that random errors, such as sampling errors, non-differential misclassifications, and other measurement errors must be kept to a minimum. The sharper the design, the smaller are the work-related effects that can be demonstrated, but in general, occupational etiological fractions accounting for some 20% or less of an increase in the incidence of a disorder among the exposed population are very difficult or impossible to reveal by means of epidemiological methods.

The interpretation and synthesis of results from different studies must take into account both variations in the validity and sensitivity of single studies, and the fact that variations in exposure intensity between studies can account for seemingly inconsistent results. While the scientific community in general is alerted to look for biases, especially those creating a false-positive effect, usually little attention is paid to the identification of “false-negativity” in a study, which may be due to small sample size, insensitivity of design, random errors, or a combination of these factors (38). Failure to appreciate that variations between different studies in exposure intensity and duration can make study results seem inconsistent is frequently due to failure to realize how much poor-quality exposure data can mask true effects. Moreover, the genesis of multifactorial disease can indeed be complicated, and sometimes the lack of

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1 Bias is any effect at any stage of investigation or inference tending to produce results that depart systematically from true values.
knowledge on interactions between different "contributing" causes and of how "sufficient" causes are composed renders it difficult to explain why an occupational factor can be demonstrated in some instances but not in others. For example, several studies in Europe have shown that exposure to carbon disulfide is associated with an excess level of coronary heart disease, but this appears not to be the case in Japan. (100, 103) Modifying effects of other coronary risk factors that are asymmetrically distributed between Europe and Japan, e.g., diet, may explain this puzzling difference.

While the qualitative aspect of the work-relatedness of a disease is "abstract-general" (i.e., it should be possible to generalize data to a universal and permanent population having the same characteristics), the quantitative aspect is "particularistic" (bound to time and place). In other words, if one accepts the studies showing that exposure to carbon disulfide favours the development of coronary heart disease, then this is a generally applicable biomedical law. By contrast, the strength of this etiological factor varies with time and place. It is greater when exposure levels are high and it may be modified by other risk factors that vary among different populations, such as dietary fat intake and smoking.

The strength of any given etiological factor, or the etiological fraction (among the exposed population), can be computed for a single study using the following formula (69):

$$EF = \frac{(RR - 1)}{RR}$$

where $EF$ = the point estimate ("best guess") of the etiological fraction and $RR$ = the point estimate of the standardized relative risk. A confidence interval (e.g., the 95% interval) should also be given to indicate the precision of the "best guess". For example, the mortality from coronary heart disease in a Finnish cohort of male workers exposed to carbon disulfide was 2.22 times (CI95 1.03–4.77) that of a reference group during the first eight years of follow-up (78). Thus

$$EF = \frac{(2.22 - 1)}{2.22} = 55\%$$

with a 95% confidence interval of 3–79%. Hence exposure to carbon disulfide accounted for about half of the deaths, according to the "best guess"; it can be said with 95% certainty that it accounted for at least 3% and no more than 79% of deaths.

The computation of the point estimate is meaningful only if the study has good comparison validity, i.e., all other etiological risk
factors must be equally distributed between the study and reference groups. In other words, there must be no confounding. The occupational etiological fraction found in a study applies only to that particular study, because it depends on the exposure intensity in that study and on the strength of other etiological factors in that specific group. Moreover, the sum of different etiological fractions can exceed 100%, since many causes may not be "sufficient" causes, and their effects may become obvious only in the presence of other causes. The sum of the etiological fractions can therefore be any figure greater than or equal to 100% (16).

2.1.2 *Indicators of morbidity*

For research on work-related diseases, the indicator of choice is selected according to the problem under study, and may vary from the specific mortality rate to slight symptoms or changes in function. These indicators are considered either "hard" or "soft". Hard indicators such as death are often more reliable than soft indicators such as subjective symptoms and alterations of functional states, but hard indicators are crude and cannot reveal the work-relatedness of certain diseases, for example low-back pain, psychosocial disorders, and, in the main, chronic bronchitis. Soft indicators, being more sensitive, are generally better suited for such disorders, but may be more liable to errors and therefore need sophisticated equipment for measurement. The specific circumstances of each case determine whether the sensitivity or specificity of the indicator is more important, and hence its optimal "hardness".

Occupational mortality studies rely on hard indicators. Death is an unambiguous event, but cause-specific mortality is usually misclassified to some extent, depending, for example, on the quality of medical practice and the autopsy rate in the country in question. Occupational mortality has usually been studied by comparing the mortality of an exposed cohort\(^2\) with that of the age-standardized general population. This method creates a comparison bias, generally called the "healthy worker effect" (see, e.g., 40), which results in the underestimation of the true effect of the work-related exposed cohort.\(^2\)

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\(^1\) Confounding is the situation where the effects of two (or more) processes are not separated. It is the distortion of the apparent effect of an exposure or risk brought about by association with other factors that can influence the measured outcome.

\(^2\) A cohort is a study population, defined on the basis of a common exposure, whose morbidity is followed over a specified time period.
exposure, because any employed population seems a priori to be healthier than the average. Whenever possible, a more valid reference group should be used, i.e., a group that is selected for that specific study on the basis of its comparability. The disadvantage of this approach is that such a group is always much smaller than the general population; the result is that the confidence interval of the estimated relative risk of disease or death widens, or in popular terms, it becomes more difficult to reach "statistical significance".

The ideal ad hoc reference population should share all the relevant aspects of the study group except for the exposure in question (non-occupational and other possible occupational etiological factors should be equally distributed). However, such ideal reference groups are not always available, or their use may increase the costs of the study to an unacceptable level. Then other worthwhile alternatives must be found, such as local comparisons or comparisons with the active general population. Other ways of extracting information from a mortality study are within-cohort comparisons where differently exposed subcohorts are compared; this within-cohort analysis, however, requires a large study.

Occupational morbidity can also be studied from pensions registers, registers of certain diseases (e.g., myocardial infarctions), hospital discharge registers, etc. Unfortunately, few countries outside the Nordic countries have such registers, or if they exist, their use may be restricted by privacy legislation.

For studies of the work-relatedness of well-defined clinical conditions, such as coronary infarction, asthma, or tumours, a case-referent design can be used. Less well-defined disorders may sometimes also be studied in this way, but the less clearly they are defined, the more misclassification occurs. Non-differential misclassification masks any true effects.

Laboratory, clinical, and functional examinations can usually be done only in cross-sectional or prospective cohort studies where both the study group and the reference group are examined in a similar way. Well-designed longitudinal studies are the most informative in terms of revealing the work-relatedness of a disease. However, much of what has been published to date on work-related

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1 The ratio of the risk of disease or death among the exposed cohort to the risk among the unexposed population.

2 A case-referent study compares the exposure history of “cases” of a certain disease with that of referents without the disease, and derives an indirect estimate of the relative risk, among the exposed population, of developing the disease.
diseases has been derived from cross-sectional studies; this situation will for practical reasons probably continue. The typical problems of a cross-sectional study design severely affect its internal validity.\textsuperscript{1} The most serious problem is perhaps selective turnover of workers in the job under study: the more distressing the subjective work-related symptoms are, the more likely the worker is to leave the job. Such a situation results in the underestimation of the true prevalence of the disease. Therefore, cross-sectional studies are usually of limited value in proving the work-relatedness of a disease, although they may suggest hypotheses for further study. If, on the other hand, a cross-sectional study in spite of the collection bias can demonstrate increased morbidity among the exposed population, this points to a rather strong true effect.

The softest of the morbidity indicators, self-administered questionnaires and structured interviews, have rarely been used other than in cross-sectional studies. Questionnaires may give highly misleading results in inexperienced hands and their use requires careful standardization of the method and critical interpretation of the results. Nevertheless, interviews or questionnaires are well suited for the study of many types of problem, including many psychosocial problems, subjective symptoms indicative of the effects of chemical solvents, and symptoms of angina.

\subsection*{2.1.3 Measures of exposure}

The requirement for good exposure data, especially whenever a quantitative study is being planned, cannot be overstressed. In some instances, only recent exposure is of interest. In this case, the problem can be solved by including in the team an experienced hygienist, who is supplied with the proper equipment. In other instances, a lifelong exposure history is required. When this is the case, only estimates can be made if objective retrospective data are lacking; again, the aid of an experienced hygienist is invaluable.

Ideally, exposure to chemical or physical agents and forms of energy should be classified not only according to intensity, but also according to duration, fluctuations, and calendar time. Other concurrent exposures should be accounted for. When retrospective exposure data are poor or absent, some information might be obtained by comparing the current situation with judgements of past

\textsuperscript{1} An internally valid study is one in which systematic error (bias) can be ruled out.
conditions that are provided by old workers, supervisors, and safety personnel. Careful recording of the cumulative amounts of a chemical used by the company may also improve the estimation of exposure. In addition, the exact date when major improvements were made, such as the installation of effective exhaust ventilation, is usually listed in a company’s records. The result of such exposure assessment can never be more accurate than a rough classification into, for example, heavy, medium, light, and no exposure, which is usually insufficient for quantitative (dose–response) studies.

The assessment of exposure to mental stress or to strain caused by physical load is even more difficult since standardized systems have still to be developed. Job descriptions, which are useful for concurrent assessments, are usually of no value when evaluating past conditions because of the rapid change of job content.

Whenever poor-quality exposure data result in non-differential\(^1\) misclassification, the effect on the relative risk is always towards the null, i.e., true effects become masked. This masking effect is much stronger than is generally appreciated. For example, assuming a case–referent study where 40 cases out of 100 and 10 referents out of 100 have been exposed, the true odds ratio (an indirect measure of relative risk) is: \(\frac{40}{60}/\frac{10}{90} = 6.0\). A classification error of no more than 10% drops the observed odds ratio to 3.3, an error of 20% drops it to 2.2, and an error of 50% drops it to 1, that is the effect becomes totally masked. In an exposure-based study, non-differential misclassification of the disease has the same type of effect.

\(^{\text{1}}\) Random, non-systematic.

2.2 Chronic nonspecific respiratory disease

2.2.1 Definition

The WHO Expert Committee on Identification and Control of Work-Related Diseases (109) stated that “chronic non-specific respiratory disease (CNRD) is a general term used to describe the groups of conditions in which there is chronic sputum production and/or shortness of breath at rest and/or during exercise. These conditions include chronic bronchitis, emphysema, and bronchial asthma. All of these diseases may be acutely or chronically exacerbated and complicated by respiratory infections. Immunological mechanisms may be involved in some of them. They are
undoubtedly diseases of multiple etiology and represent a classic example of disorders that may mainly be occupational in origin or partly work-related, as well as related to the social phenomena of urbanization and industrialization.” The Committee drew attention to the fact that the same dust, e.g., cotton dust, can cause both a classical occupational disease (byssinosis) and chronic nonspecific respiratory disease. It should be added that another respiratory disease, asthma, when caused by a certain agent, may be classified as an occupational disease for the purpose of workers’ compensation in one country but not in another, even though it is caused by the same agent. In a similar way, bronchitis is classified as “occupational” in some, but not all countries.

2.2.2 Relation to work

The work-relatedness of chronic nonspecific respiratory disease was reviewed by the WHO Expert Committee on Identification and Control of Work-Related Diseases (109). The report concluded that several risk factors are important in the etiology and pathogenesis of chronic nonspecific respiratory disease, among them smoking, air pollution, weather, socioeconomic factors, familial and genetic factors, atopic predisposition (for asthma), bronchial reactivity, childhood respiratory disease, and occupation. The great number of factors involved often complicates identification of the occupational factor. Although the WHO Working Group on Early Detection of Chronic Lung Diseases (18) concluded that the contribution of general and occupational air pollution to the etiology of chronic nonspecific lung diseases was probably not large in comparison with that of smoking, there are many occupational groups for which the work-related etiological fraction is significant.

Occupational groups in which an elevated prevalence of chronic bronchitis has been shown include coal miners, other miners, steel workers, foundry workers, pulp-mill workers, bakers, farmers, and cotton workers (109). In many developing countries, exposure to vegetable dusts such as those of cotton, flax, grain, and wood is an important cause of the high occurrence of chronic bronchitis. Repeated infections during childhood due to overcrowding and exposure to smoke from cooking and baking in the home increase the sensitivity of many workers to organic dusts. Hence dusty workplaces seem to be connected with chronic bronchitis in all countries. Smoking is often an important cofactor; in some studies
the effects of dust are apparent in smokers only. Welders have also been studied extensively. There have been conflicting results from these studies, probably due to the variety of welding techniques, exposure intensities, and smoking habits reported in the different studies (e.g., 52, 95).

Work-related bronchial asthma, a disorder with generalized obstruction of the airways, is caused by the inhalation of substances or materials that a worker manufactures or uses directly, or are incidentally present in the workplace (71). There are several known causes of work-related asthma including exposure to metals, plastics, organic chemicals, pharmaceuticals, plant products, and animals. The prevalence of work-related asthma is in general unknown (13). However, data are available from some industries; for example, about 5% of workers exposed to volatile isocyanate develop asthma (73), and the prevalence of the disorder is reported to be between 10 and 45% among workers exposed to proteolytic enzymes and between 2 and 40% among workers exposed to grain dusts (12). The prevalence of laboratory animal allergy among animal handlers varied between 15 and 30% and that of asthma between 2 and 12% in seven studies of a total of 2075 persons (77). However, most of the available information on work-related asthma is derived from clinical records and case-reports and not from epidemiological studies.

Work-related asthma is often classified as an occupational disease for the purposes of compensation and would therefore be outside the scope of this section. However, the level of compensation varies depending on the causative agent involved, as well as between countries. Therefore, an unknown portion of work-related asthma remains unrecognized as an occupational disease in the strict sense and can hence be regarded as work-related.

2.2.3 Indicators of morbidity and their measurement

Although about 3% of all deaths, reported from 88 countries in 1972, were due to chronic nonspecific respiratory disease (94), mortality is too crude an indicator for the study of these work-related conditions. In countries with morbidity registers, disability due to chronic nonspecific respiratory disease can be studied. Chronic disability provides a better estimate of the occurrence of these conditions than do mortality figures. One could, for example, form exposure-based cohorts (e.g., foundry workers, cotton
workers), use person-numbers for identification, and then use a register to pick out those on disability pension and compare the result with the general population or a reference group. In some countries, e.g., Finland, one can, in addition, obtain data on cause-specific sick-leave and free medication, which is provided for a number of chronic diseases including asthma. However, effective control of confounding factors requires more precision than merely using crude register data. To achieve this, additional data, e.g., on smoking, infections, and concurrent exposures, must be collected from the study groups using questionnaires.

In principle, while confounding factors can be controlled, health-based selection out of the exposed jobs is a more difficult problem even in studies with a longitudinal design. Although the longitudinal design makes it possible to assess the level of turnover, those who remain in the job and consequently are most exposed represent a "survivor population".

As an alternative to a cohort study, a population-based case-referent study can be designed in which people with asthma (or nonspecific respiratory disease, which is more difficult to define) are compared with people without the disease with regard to past working history. This approach enables the researcher to find new causes of work-related lung disease, because the case-referent design makes it possible to study a great number of different exposures at one time. Similar studies could be designed for diffuse roentgenological fibrosis, impaired lung function (according to preset criteria), and some other conditions to which occupational factors may contribute.

However, in most instances our knowledge about the work-relatedness of chronic nonspecific respiratory disease and asthma is based on cross-sectional epidemiological studies (or clinical studies). In these studies, the morbidity indicators of respiratory disease usually have included questionnaires (or interviews), lung-function tests, radiographic examinations, and, in some instances, immunological tests. All these methods pose problems. The subject of questionnaires and interviews and of lung-function tests was discussed extensively by the 1983 WHO Expert Committee on Identification and Control of Work-Related Diseases when it considered chronic nonspecific respiratory disease (109).

The diagnosis of asthma is usually straightforward in hospitals, but in epidemiological studies the same thoroughness of examination is usually not possible, at least not in large populations.
It is important, therefore, to define strict criteria for a positive epidemiological diagnosis of asthma. These criteria should be applied in a similar way in both the exposed and the reference group; both groups should thus undergo the same examinations. A carefully taken history is essential. This can be obtained using either a standardized questionnaire or a structured interview. One should be aware that there are different patterns of reaction, namely immediate and non-immediate or late, as well as combined patterns. The immediate reactions occur 15–30 minutes after exposure and are of relatively short duration. The non-immediate or late reactions may
(a) begin about one hour after exposure and last for 2–3 hours,
(b) begin after 4–5 hours and last about 24–36 hours, or
(c) begin early in the morning for several days and subside during the day. The possibility that any of these different patterns may occur must be accounted for in the standardized history-taking. Asthma may also be of the hyperreactive type, which means that, for example, cold or irritant gases can provoke attacks without the involvement of an allergic mechanism.

Other allergic manifestations (rhinitis, atopic symptoms) should also be included in the history. The timing of lung-function tests should be such that the possible different patterns of reaction are taken into account. A standardized histamine or methacholine provocation can be used as a nonspecific test to study hyperreactivity of the airways. A specific provocation test gives an even better confirmation of the diagnosis, but is usually too complicated for field use. However, in some instances the diagnosis may still be difficult because airway obstruction may be persistent with no change in symptoms over weekends, vacations, or even after leaving the job. This is especially true for asthma caused by chemicals of small relative molecular mass such as di-isocyanates, which may cause persistent symptoms that seem to be of a nonimmunological origin.

Other tests that may be used for epidemiological surveys include the counting of eosinophilic granulocytes in blood or sputum and immunological tests. It is important to test allergenic extracts before their epidemiological use in order to exclude nonspecific irritant reactions. The use of positive and negative control tests is commendable. Sero-immunological tests are useful, but are much more expensive than skin tests.
2.2.4 Assessment of exposure

Whenever the study design is exposure-based, as in cohort and cross-sectional studies, it is assumed that the exposure in question is known in qualitative terms. For example, if the study concerns bronchitis among coal miners, the cohort is formed according to exposure to coal dust, and if the study is of asthma among mink farmers, exposure is supposed to be to fur dust or excreta from minks. However, when broader exposure categories are studied, such as welders or foundry workers, more detailed characterization of the type of exposure is necessary. For example, there are many different welding methods that produce fumes with very different chemical compositions, particle sizes, and other characteristics. In such cases, good characterization of the exposure is necessary to identify the specific conditions that are causing, for example, bronchitis. Failure to define the exposure may account for some of the discrepancies in the literature concerning respiratory symptoms among welders. It is also clear that exposure intensities should be measured, especially when the aims of the study are to establish exposure–response relationships and to define a no-adverse-effect level.

Exposures occurring concomitantly with the exposure in question should also be identified and, if possible, quantified, since they can modify the effects of the agent under study, or they can act as confounding factors if they are asymmetrically distributed across the study groups. For example, certain categories of foundry workers are exposed to the irritant agents formaldehyde and furans, as well as to sand dust and soot (108). It is therefore important to define exactly who is exposed to what and how much, when assessing the bronchitis-causing effects of foundry dust.

When work-related asthma is being studied, the causative allergen in the work environment should be identified. Sometimes this is quite straightforward, for example in bakeries, but sometimes the exposure is mixed. Alternatively, impurities and by-products may be the causative agents, in which case these have to be identified; this can be a difficult task. Quantitative aspects are not as important in allergic diseases as they are in chronic nonspecific respiratory disease, but for some chemicals that cause asthma, at least a crude exposure–response relationship exists and hyperreactivity is also dose-dependent.
2.2.5 Smoking

It is essential that any study of work-related respiratory disorders take into account the tobacco-smoking habits of the population under study. It should also be noted that passive smoking may cause or aggravate chronic nonspecific respiratory disease. Detailed data on past and current smoking habits should be obtained by questionnaire. It may be cost-effective to concentrate on heavy smokers and nonsmokers, excluding light and ex-smokers from the study. Frequently, the most important information can be obtained from comparisons between exposed and nonexposed heavy smokers, because the occupational exposure under study and smoking may act synergistically. In other instances, however, the effect of smoking on such a variable as closing volume may be so overwhelming that a weaker work-related etiological factor cannot be identified, in which case, comparisons between nonsmokers would yield the best information.

The classification of ex-smokers can pose problems. Sometimes they can be classified as nonsmokers (provided some time, such as a year or two, has elapsed), but often the effect of smoking is irreversible, e.g., in the case of emphysema. One should also remember that the person may have given up smoking for a health-related reason. If the study group is sufficiently large, ex-smokers should perhaps be left out completely. Passive smoking must also be accounted for. Passive smoking may be a work-related cause of chronic nonspecific respiratory disease, or it may act as a potential confounding factor in the study of other causes; in both cases detailed data are needed.

Other problems in the design of epidemiological studies of chronic nonspecific respiratory disease have been discussed by Hernberg (39).

2.3 Cardiovascular diseases

2.3.1 Relation to work

General aspects. Coronary heart disease is the major contributor to cardiovascular disease and even to overall mortality in most industrialized countries. Some well-known major risk factors account for about half of the known cases. These factors include demographic characteristics such as advanced age, the male sex, high
serum cholesterol values, high diastolic blood pressure, and tobacco-smoking. Other factors that affect risk are less well established, such as life-style variables, physical inactivity, personality type, diabetes, and social support (30). However, even when all these factors are taken into account, the complete etiology of coronary heart disease has not been explained, and work-related factors may well play a contributory role. Several work-related factors are already known and others certainly await identification.

Chemical factors. The exposures to various chemicals that have been linked to cardiovascular morbidity have recently been reviewed (61). These chemicals include: carbon disulfide (35, 100, 102), which is atherogenic and, in addition, can cause sudden death; organic nitrates (43), which can cause both coronary heart disease and sudden death on withdrawal from exposure; arsenic (4), which has been shown to cause a dose-dependent increase in cardiovascular mortality; and organic solvents (86), which may cause arrhythmias. Carbon monoxide is known to aggravate angina pectoris although its role in the causation of coronary heart disease is less clear. Cadmium and lead have been implicated in the causation of hypertension; however, the data are inconclusive (61).

Physical factors. Both heat stress and exposure to cold have been linked to cardiovascular morbidity.

Extremes of heat and humidity can have marked effects on the cardiovascular system, especially in subjects with underlying organic disease. Acclimatization to hot environments usually takes place within 10 days among healthy subjects, but people with impaired myocardial function may not be able to respond to heat exposure by increasing cardiac output. In spite of the very definite effects of heat on cardiovascular performance, especially in persons with cardiovascular disease, there is little if any epidemiological evidence available suggesting that there is increased cardiovascular mortality among populations exposed to high temperatures at work (30).

Exposure to cold has adverse effects on the cardiovascular system, by causing anoxia and vasoconstriction, which result in an increased cardiovascular work-load (19). Many patients with coronary heart disease are sensitive to cold and respond with an elevation of the heart rate and blood pressure. In the cold, the threshold for angina attacks is lowered (29). It has been repeatedly shown that cold weather increases coronary mortality. For example, in northern
Finland, mortality from coronary infarction was found to depend on both the month and the average temperature (74). Mortality was more than 20% higher in December, January, and February than in July and August. This effect was especially marked for those over 50 years of age. However, controlled cohort studies on workers occupationally exposed to cold are lacking.

*Physical activity.* Information on cardiovascular morbidity in relation to physical activity has recently been reviewed (50). Although physical activity has a proven beneficial effect on several biochemical and circulatory parameters involved in the pathogenesis of coronary heart disease, and although several studies have shown that physical activity protects against this disease, there is still some uncertainty as to whether it is physical activity itself or other factors associated with an active life-style that exert the preventive effect (50). Furthermore, physical activity is not always harmless since the risk of dying from coronary heart disease is markedly increased during and soon after strenuous exercise. In addition, very heavy work or a static work-load can be deleterious (41).

*Shiftwork.* Although some well-controlled studies have shown a higher risk of cardiovascular disease among certain types of shift worker than in day workers, the evidence cannot yet be regarded as conclusive. Much of the confusion is probably due to selection bias and other uncontrolled errors in study design (54). Such errors usually mask the true effect. In spite of this, several studies have suggested that there is a relationship between coronary heart disease and shiftwork and this association appears credible. Those studies that have shown no association have not properly considered the whole population, nor have they differentiated the morbidity with respect to the amount of exposure (54). The lack of demonstrated effect in these latter studies may therefore be due to negative bias or insensitive study design.

A relationship between shiftwork and coronary heart disease could be directly due to changes in the neuroendocrine system as a result of irregular working hours and disturbances in social life, or it could be indirectly due to adverse smoking and eating habits, indulged in because of the irregular life-style. Well-designed, prospective studies are still needed to provide a more convincing answer to this question.
Mental stress. Work-related psychosocial factors have repeatedly been shown to be related to cardiovascular disease (3, 109). Some of these associations may apply only to certain manifestations of cardiovascular disease. For example, air-traffic controllers have been shown to have an increased risk of hypertension, but no other manifestations of cardiovascular disease have been demonstrated in this group (22, 109). Work overload, such as being employed in two jobs, has been associated with angina pectoris and myocardial infarctions, but not with sudden death or hypertension (3, 90). However, work stress is often coupled to stress in private life. Moreover, since individuals experience stress in different ways, it is difficult to measure the amount of stress in an objective way. These circumstances mean that the study of work-related stress as an inducer of cardiovascular morbidity is extremely difficult. Indeed, many of the studies of associations between work-related psychosocial factors and cardiovascular morbidity are conflicting and difficult to interpret.

Although adverse psychosocial factors related to work seem to be risk factors for cardiovascular disease, the mechanisms responsible for the increased risk are hard to define (3). For example, adverse psychosocial factors may lead to an unhealthy life-style with abuse of tobacco and alcohol, overeating, and physical inactivity, or they may act directly via the neuroendocrine system.

2.3.2. Indicators of morbidity and their measurement

The work-relatedness of cardiovascular diseases can be studied epidemiologically at three levels:

(a) mortality,
(b) morbidity (infarctions, strokes, disability, electrocardiographic changes at rest and after exercise, angina, hypertension as endpoints), and
(c) risk factors (high levels of blood lipids, diabetes, obesity, hypertension as a precursor of stroke and coronary heart disease, physical inactivity).

In studies on the relationship between work-related risk factors and cardiovascular morbidity, extrinsic risk factors such as age differences and smoking habits must also be measured and controlled since they are potential confounding variables.
Occupational cardiovascular mortality can be studied using national registers in countries where death registration is satisfactory. The crudest method is to compare mortality for broad occupational categories. This is done routinely in the United Kingdom; the occupational mortality statistics have been published by the Registrar General for more than 100 years. Nowadays, such statistics are reviewed in relation to occupational information from the preceding decennial censuses (20). A recent study from Finland has shown rather wide variations in the standardized mortality ratio from 67 to 131 for cardiovascular mortality among broad occupational categories (92). However, since social and life-style effects are interwoven with occupational factors, and since the registered occupational categories are very broad, such studies are not very conclusive. At most, they can be used to stimulate hypotheses since they probably mask existing differences between narrower subcategories of worker because of their crudeness.

Ad hoc cohort studies are therefore needed to acquire more accurate data. First, an occupational cohort should be defined with a specified exposure, for example to carbon disulfide, shiftwork, foundry work, or a certain level of physical activity (or inactivity). The mortality of that cohort can then be checked from national mortality registers and compared with national data, or even better, with statistics derived from a well-selected reference cohort. If the cohort study is prospective, other indicators of morbidity can be studied at the same time, such as non-fatal infarctions, electrocardiographic findings, and angina. This was done in the Finnish study on the effects of carbon disulfide exposure on coronary heart disease (35, 78, 102). For exposed workers, the relative risk during the first five years of follow-up was 4.8 for fatal infarctions, 3.7 for all infarctions, and 2.8 for non-fatal infarctions. At the end of the follow-up period, the prevalence of angina was 2.2 times and that of "coronary" electrocardiograms 1.4 times the prevalence in a reference group of workers from a nearby paper and pulp mill. The use of indicators of different severities of the disease added information to that provided by mortality data alone. It could, for example, be shown that carbon disulfide not only increased the incidence of coronary heart disease, but also worsened its prognosis.

A similar approach could be used for prospective studies of the effects of shiftwork on cardiovascular morbidity. Mortality registers become especially important as the source of information when the
cohort is large, the follow-up period is long, and the turnover is great, because tracing all the deceased is very difficult or impossible by any other means. In countries where morbidity registers are kept, "heavy" morbidity (such as myocardial infarction) and disability pensions can be studied in a similar way.

Among milder indicators of coronary heart disease, angina and electrocardiographic changes have been studied the most. Specifically, the questionnaire on angina developed by WHO has been used widely (88). In addition, electrocardiography, either at rest or after standardized exercise, is included in most morbidity studies, although individual diagnoses cannot be made solely on the basis of isolated electrocardiographic findings. It has been recommended since the 1960s that electrocardiographic changes, especially those indicating past infarction or ischaemia, should be coded "blind", according to the so-called Minnesota code and its later revisions (9). This method avoids observer bias and ensures an objective reading. Lately, computerized techniques for the coding of electrocardiograms have been introduced; this has further improved the quality of readings.

Blood pressure measurements are very commonly included in surveys of cardiovascular morbidity. Although the measurement itself is simple, there are methodological requirements that should be observed. The manometer should be well calibrated and the cuff broad and long enough. The position of the subject should always be the same (either sitting or supine) and a rest of 15–20 minutes should precede the measurement. The reading of the diastolic pressure should be standardized. Blood pressure fluctuates normally during the day and the examination itself may cause it to rise. Repeated measurements may therefore be needed.

The morbidity parameters used in cardiovascular surveys are not selected on the basis of scientific considerations alone. Since there are many cardiological examination methods available, the investigator may be tempted to use several tests, particularly modern and sophisticated ones, while limitations of funds and available technicians may restrict the number of examinations carried out. Furthermore, an absolute requirement in epidemiological surveys is that there should be no risk to the subject. This requirement is more strict for epidemiological examinations than for clinical examinations where the patient benefits from the investigations and the risk considerations are therefore different. The requirement of complete safety further restricts the tests that can be recommended.
for epidemiological surveys; one may even consider whether maximal exercise electrocardiograms, cold provocations, and other tests of this kind are justified.

In the selection of tests to be used in a survey, it is important to consider what information can be obtained from each of the available alternatives. For example, increasing the sensitivity of electrocardiographic examinations by using a maximal exercise test may sometimes—but not always—sharpen the study. This test creates much extra work and possibly for some subjects a slight risk, the acceptability of which should be discussed. Unfortunately it is not always easy to predict in advance exactly what each examination will yield. In the Finnish study on workers exposed to carbon disulfide, for example, the inclusion of exercise electrocardiography did not yield any information that was not gained from less sensitive tests (41), but this fact did not become apparent until the data analysis stage.

2.3.3 Assessment of exposure

As far as chemical or physical factors are concerned, assessment of exposure is a matter of making careful measurements using conventional occupational hygienic methods. The main problem is how to secure retrospective exposure data, which are needed because at least the atherogenesis preceding cardiovascular attacks is a slow, chronic process that should be related to exposure over a long timespan.

In the case of shiftwork, it is important to describe exactly the specific type of shiftwork concerned and not to lump the different patterns of work together.

Any study of the effect of work-related factors upon cardiovascular morbidity should, of course, measure the known major risk factors for this group of diseases so that they can be statistically controlled. These measurements require much extra effort in terms of manpower and economic resources, but are nevertheless necessary to ensure the validity of the study.

In this context, it should be repeated that occupational factors may be either direct or indirect causes of cardiovascular disease. When designing a specific study, the researcher should take this into account. For example, if the issue under study is whether shiftwork causes coronary heart disease, mental stress is a possible etiological
factor. Controlling stress statistically would then block the effect. Therefore, the reference group chosen should be one that does not have exceptional stress. If, on the other hand, the question is whether exposure to carbon disulfide causes coronary heart disease, mental stress is an extrinsic factor probably not significantly involved in causation. In this situation, mental stress should be controlled as a potential confounding variable, i.e., the reference group should be exposed to the same amount of stress (e.g., in the form of shiftwork) as the exposed group, or different stress levels should be analysed separately.

2.3.4 Other aspects of study validity

Experience with cardiovascular epidemiology in general has helped the design of valid studies on work-related problems. For example, information on the relative importance of the “heavy” risk factors such as smoking, hypertension, and hyperlipidaemia, and of others such as diabetes, physical inactivity, and gout is useful for the control of potential confounding variables in studies of work-related cardiovascular morbidity. The better non-occupational factors are controlled, the greater will be the sensitivity of a study to detect work-related factors. However, overmatching on possible intermediate factors in the etiological chain should be avoided since it leads to the masking of a true effect (35).

Selection may be a problem in studies of work-related cardiovascular morbidity. Cardiovascular diseases cause a strong “healthy worker effect” (68), partly because early symptoms may force a worker to quit a job or to seek lighter work, and partly because high-risk individuals can be identified at an early stage. Such people may not be employed, or they may be more likely to be made redundant, especially during periods of economic depression. This leads to lower mortality in the remaining working population; also, the milder manifestations of disease, especially angina, become under-represented. Therefore, it is important to define a reference group in which the same types of selective force operate.

Studies of the relationship between shiftwork and cardiovascular morbidity are considered to be especially vulnerable to selection bias. A rapid turnover of workers may be due to self-selection on health grounds; this results in low exposure for most of the cohort, which in turn “dilutes” the results (34). Also, selection into shiftwork
may be difficult to control for. To remedy this problem, workplaces with few possibilities for transfer should be favoured for study. Furthermore, the analyses should be made separately for different lengths of employment in shiftwork; this will increase the demands on cohort size. Big enterprises located in remote areas, such as some paper mills in the Nordic countries, could provide good opportunities for research, because there are usually few alternative job opportunities in such areas.

The case-referent design has perhaps not received enough attention in cardiovascular epidemiology. It is not the best design to use for indicators such as sudden death, where the work history must be obtained from the next-of-kin. However, the design would be useful if the cases were defined as survivors of coronary infarctions, for example. It is especially cost-effective when many etiological factors should be studied or controlled for simultaneously, because exposure data need be gathered only for the cases and their referents and not from the whole population base. This allows a more thorough appraisal of specific etiological factors. For example, psychosocial factors could be explored in great detail. A serious problem with this approach is that of controlling the recall bias, which may be especially difficult when the interview concerns mental stress. However, this bias can be at least partly controlled if some equally severe disease, known not to be related to stress, is used as the referent condition. Another problem is that it may be impossible to obtain data on some coronary risk factors, such as predisease levels of blood lipids and blood pressure. This will make the control of confounding factors impossible.

2.4 Musculoskeletal disorders

2.4.1 Low-back pain

Low-back pain is a complex syndrome of multifactorial etiology that is common throughout the world, in all age groups, in all social strata, and in all occupations. In the United States of America, musculoskeletal disorders are the leading cause of disability of people in their working years, afflicting 19 million persons each year (3). Back problems represent a significant proportion of these disorders. The symptom of back pain has many causes; it can result from inflammatory, degenerative, neoplastic, and traumatic disorders and may sometimes even be of psychogenic origin (109).
Back problems are more commonly found among those doing heavy work than among those doing light work. Accidents and repeated microtraumas are important causes of low-back disorders. Young, unskilled, and inexperienced workers have a higher incidence of injury than older, skilled, and experienced workers (104). Stooping, sitting, and lifting (especially unexpectedly heavy loads) are also factors that contribute to back pain. Whole-body vibration, e.g., tractor or truck driving, is another probable cause (104). However, sedentary work and physical inactivity have also been implicated as causes of low-back pain. Biological factors such as physical size, strength, fitness, range of motion, work endurance, and the integrity of the musculoskeletal system each play a role, and back pain can result when there is a discrepancy between the worker’s capabilities and the work demands (3). This complex picture renders the epidemiological study of low-back pain extremely difficult.

2.4.2 Neck and upper limb disorders

A variety of conditions, some of them ill defined, constitute neck and upper limb disorders. Among them are shoulder pain, tension neck, tenosynovitis, peritendinitis, and lateral epicondylitis or the tennis elbow syndrome. All these syndromes have multiple causes, and several predisposing factors increase the chances of developing pain. Among the causes of shoulder and neck pain are inflammatory reactions in the synovial membrane and bursa system, as well as degenerative disorders of the cartilage, ligaments, and tendons. In addition, muscular, vascular, and neurological disorders may cause shoulder pain, and there may be referred pain from the chest organs (109).

Shoulder and neck pain is a common cause of absenteeism among industrial workers (2). Poor ergonomic design of the workplace and poor work practice are important work-related causes. Several studies have linked work where the arms are held above the horizontal level to these symptoms. Likewise, holding the head too close to the work material and repetitive actions such as mopping and swabbing can cause pain in the neck and shoulder. The importance of precipitating injury has also been considered, but the studies are not conclusive (2).

Peritendinitis and tenosynovitis are often due to overexertion or a change in the daily routine, such as the undertaking of new tasks or a return to work from leave (101). Blunt trauma and sprain can
also cause these symptoms. The tennis elbow syndrome is usually triggered by exertion of the finger and wrist extensors (60). Repetitive manual tasks have been incriminated in the causation of the tennis elbow syndrome, but there is little, if any, valid evidence to support this assumption (107).

2.4.3 **Osteoarthrosis**

Osteoarthrosis is a common cause of impairment, although it is under-recorded in morbidity statistics (2). This may be due, in part, to diagnostic confusion. Arthritis can be defined as the presence of radiographically demonstrable osteophytes in a joint; however, most individuals over 50 years of age have these osteophytes but are nevertheless free of symptoms.

Osteoarthrosis is a disease of the elderly. Apart from advanced age, risk factors include obesity, a family history of the disease, and occupational strain. Frequent heavy lifting, work in awkward postures, vibration, repetitive strain, and heavy work in general appear to be work-related causes of osteoarthrosis (2). For example, farmers have a higher-than-average risk of developing osteoarthrosis of the hips, cotton pickers may experience degenerative changes of the fingers, miners may have elbow and knee problems, and arthrosis of the elbow is associated with certain foundry occupations where heavy, vibrating tools are used. The cause of osteoarthrosis does not seem to be hard labour alone, but a combination of this and repetitive activity (110).

2.4.4 **Indicators of morbidity and their measurement**

Low-back pain comprises a variety of different disorders (72); a prolapsed lumbar disc may have quite a different etiology to spondylosis, muscle spasms, or inflammatory processes. The diagnostic procedures used to differentiate each syndrome are complicated. Kersley (53), for example, could not classify more than 60% of a group of 404 patients with chronic back pain, even after thorough examinations. Such examinations are rarely, if ever, affordable for epidemiological surveys. For follow-up studies, in particular, simple and reliable tests would be needed to discriminate between the various syndromes causing low-back pain and to provide repeatable assessments of the back’s condition; no such tests exist at present. Ethical considerations often prevent the use of
certain examinations (e.g., radiographical examinations) for subjects with no clinical symptoms. However, in case-referent studies, ethical restrictions are fewer because the “cases” are ill, and examinations can be more elaborate because there are far fewer subjects. Nevertheless, in follow-up studies it is not usually possible to devote more than 10–15 minutes to each subject, and all tests must be completely safe. Another serious problem is the lack of good methods for the quantitative assessment of a condition.

There are also individual differences between subjects in any epidemiological study of work-related musculoskeletal disorders, for example in natural motor skill, muscular strength, and psychological factors, such as risk-taking and neuroticism. In addition, differences in anatomical and physiological features occur—in the size of the spinal canal, leg length, bony abnormalities, and collagen and glycosaminoglycan composition. These factors, alone or together, often result in variations whose effects can be much greater than those of the occupational factors under study.

The study of neck and upper limb conditions poses similar problems because of the variety of underlying causes and the lack of accurate and repeatable diagnostic tests. Even the terminology is not standardized, which creates great confusion and makes it difficult to compare the results of different surveys (2).

In view of these problems, epidemiological surveys are difficult to plan since a compromise must be made between accuracy and feasibility. The development of standardized interviews and questionnaires for symptoms is an urgent task. However, the diagnosis cannot rely on symptoms alone. Objective examinations should also be standardized, such as how to assess pain and tenderness, and how to ensure repeatability of measurements of mobility. For example, although seemingly consistent and detailed criteria have been proposed for epicondylitis (24), achieving repeatability of the examinations has proved difficult. Problems arise because neither the questions on symptoms nor the methods for performing single tests (e.g., location and force of palpation, positioning of the arm in functional tests) have been standardized (107).

However, there have been attempts to develop standardized screening tests for neck and upper limb disorders for epidemiological use. For example, a study of slaughterhouse workers was so designed that a trained physiotherapist first gave each subject a preplanned physical examination and then interviewed the subject on the same
occasion (106). The screening diagnosis was made according to a predetermi ned set of criteria. For example, according to these criteria, the epicondylitis syndrome was defined as “local pain during rest and/or movement, local tenderness at the lateral/medial epicondyle, pain during resisted extension/flexion of the wrist and fingers”. If the screening diagnosis was positive, the subject was submitted to additional tests that were carried out by a physician. In the case of elbow pain, these tests comprised measurement of the free and painless range of movement, palpation of the olecranon bursa, palpation of the radial nerve at the edge of the superficial supinator muscle (the arcade of Frohse), and measurement of the strength of the middle finger extension. In addition, the criteria for a clinical diagnosis were preset. In the case of epicondylitis, they were the same as for the screening diagnosis, but for some other disorders they were more elaborate. In fact it was found that, in many cases, a thorough physical examination did not reveal any disorders not already discovered using the epidemiological screening method, with the exception of carpal ganglia. It was concluded that the validity of the screening methods used could not be tested, since the clinical and screening diagnoses were based partly on the same tests. Objective findings were made only rarely in the absence of subjective symptoms. Hence an interview about symptoms could be used alone as the screening procedure, which would save efforts and costs in field surveys. However, in elderly persons, degenerative changes cause symptoms and signs that cannot be singled out in a physical examination. Thus the screening method described is best suited for young populations.

The diagnosis of osteoarthritis is difficult in epidemiological studies, not least because X-ray examinations, which would be necessary, are nowadays considered unethical for “healthy” individuals. If X-ray examinations cannot be used in an epidemiological study, the diagnosis must be based on a history of pain, tenderness, and mobility restriction, all of which are nonspecific and inaccurate measurements. Furthermore, in osteoarthritis, mobility measurements and radiographic examinations are often conflicting. This has been shown in an experimental study on rabbits (105); while the X-ray findings indicated a steady deterioration, the mobility and the macroscopic anatomical findings did not always follow the same course.

For osteoarthritis, an alternative approach would be to conduct a case–referent study in which patients with diagnosed
osteoarthritis of some specific joint(s) are compared with subjects without the disease with regard to work history. Such an approach would give relative risks for different worker populations and thus identify dangerous tasks.

2.4.5 Assessment of exposure

In studies of back pain, assessment of the degree of "exposure" of the back to various types of trauma, strain, and stress throughout the patient's life is difficult, if not impossible. Even if standardized exposure ratings had been developed, the patient would probably not be able to remember sufficient detail of every exposure. The effects of different exposures and their latent periods are very variable: lifting may or may not have an immediate effect; trauma can produce both immediate and delayed effects; and the symptoms caused by whole-body vibration may appear only after a long period of latency. Frequently there are combinations of various occupational exposures, and leisure-time exposures such as sports injuries and unaccustomed intensive gardening may act as confounding factors. In addition, physical activity can have beneficial effects on the back if it is not excessive. This complicated pattern makes occupational exposure difficult to assess in studies of back pain.

Similar problems are encountered in the study of disorders of the neck and upper limb and also of arthrosis. This is especially true for disorders that require a long "exposure time" or repeated small traumas to develop. More acute disorders, such as peritendinitis and the tennis elbow syndrome, are easier to relate to current occupational activities. Thorough and detailed job descriptions are of great help in studies of such disorders. An even better method would be to analyse the work by means of a videotape. Although many methods for systematically describing manual work have been developed, the analysis of work methods is difficult and laborious. Work movements are many and complex even in monotonous manual tasks. Therefore the study of such exposure is time-consuming and difficult to standardize and relate to measures of disease.

Other problems in the design of epidemiological studies of musculoskeletal disorders have been discussed by Hernberg (39).
3. EPIDEMIOLOGICAL STUDY OF WORK-RELATED ACCIDENTS

3.1 General aspects

Most researchers (for example, 6, 25) define an accident as a sequence of unplanned events. The Committee stressed the multifactorial nature of occupational accidents, which were considered as statistically foreseeable consequences of technical–social failure of the work system. Although the number of work-related accidents may seem large, from the statistical viewpoint accidents are relatively rare events and this is the reason for using accident-like events, near-accidents, and dangerous occurrences as criteria for safety performance.

There are many causes of accidents, with many interactions between causal and contributing factors (28). Causal and contributing factors always include both human and environmental aspects (27). The two may be combined in a system design that models the work process for production and determines the effects of altering either the elements of the system or the ways in which they interact. In this manner, the materials employed, the techniques used, and human factors can be related to production levels as well as to accidents and losses. To improve production, reduce economic losses, or reduce accidents requires that changes be made to the system design; these changes are often of a similar nature. The task of epidemiology is to determine which errors in the system require correction.

3.1.1 Multifactorial etiology of work-related accidents

The workers, the workplace and its equipment, and the physical and psychosocial environment are the components of a multifactorial system (7, 66, 99), within which are to be found the determinants of work-related accidents. These determinants may not be stable over time and changes in one may bring about changes in others.

Environmental factors include the external agent involved in the injury and other factors in the physical working environment such as lighting, noise, and temperature as well as in the social environment, e.g., the management system.
The nature of the work itself is a contributing factor. Different types of accident are associated with different kinds of work tasks. Ergonomic equipment design and workplace layout and appropriate work organization and practice should minimize production time, errors, accidents, and fatigue.

The safety management approach to accidents is that the immediate cause(s) of an accident (unsafe conditions and unsafe behaviour) are only symptoms of the true root cause(s) which exist in management function. For example, there may be errors in the areas of management policy, the setting of goals, staffing, housekeeping, responsibility, use of authority, line and staff relationships, accountability, rules, and initiative (34). It is apparent that controlling the frequency and severity of accidents and controlling the quality and quantity of product have much in common. In many cases, the same faulty practice is incriminated in both accident occurrence and unsatisfactory production.

*Human factors.* Most human activity requires active avoidance of errors that could result in injuries or material damage. To avoid an accident an individual must observe and recognize danger, decide on a course of action, and act promptly to avoid the danger. An accident may result if a hazard is not seen, recognized, or understood to be dangerous, or if the person involved does not take the responsibility for personal action, does not know how to act or, for other reasons, does not decide to act. This “human factors” model should be understood to be applicable to managers, designers, supervisors, and workers. When a systems approach is taken, it is very important, at the design stage, to avoid problems that could lead to human errors in the operation of equipment. Problem avoidance should be included as a subject in the training of workers and supervisors, and in operating instructions, manuals, etc. (56).

3.1.2 *Magnitude of the problem*

No reliable global figure for the number of work-related accidents is available, even for fatal work accidents, but it is estimated that about 180,000 workers are killed and 110 million are injured in occupational accidents each year (111).

In some developing countries, work-related fatality rates are relatively high and may be increasing. In agriculture, where about half the working population is engaged, ILO estimated for 1980 that
there were 33,000 fatalities and 8 million injuries in developing countries; these figures do not include China (111). Occupational accidents and the injuries resulting from such accidents remain a significant health problem for many countries. In Brazil, there has been some improvement, i.e., lowered rates for accidents and fatalities, in the larger workplaces covered by the social security system since 1970; however, less is known about changes in small businesses not covered by the reporting system. These businesses may well be potentially more hazardous.

In Europe, about 10 million occupational accidents occur every year, of which about 20,000 are fatal.

These figures show that occupational injury is a serious national problem in terms of human suffering and social costs. The medical and societal importance of accidents is emphasized by the fact that they often involve young people and cause long periods of disability and loss of a large number of working years. Those killed and disabled as a result of work-related accidents are taken from the most productive segment of the population. The losses to the national economy caused by all accidents may amount to 1–4% of the gross national product (85). The human, public health, and economic consequences of accidents make their prevention one of the most worthwhile priority areas of preventive health policy, both for public health and for occupational health and safety.

Technological progress is associated with the use of increasing amounts of energy. At the same time, it seems to lead to a decrease in accident rates. This is because the newer production systems are more effective and require less human effort and also because the human involvement is more remote from the point of action (93). However, the accidents that do occur in newer systems may be more serious. For example, chemical and nuclear accidents in major hazard plants may have devastating effects on the surrounding communities. In general, the accident risk is tending to be focused on smaller population groups, but these groups may be at even higher risk than in the past (91).

In developing countries, the adoption of heavy industry and the introduction of agricultural machinery have accounted for some of the increase in severe and fatal accidents. Conversely, the increase in the proportion of persons working in service industries rather than in manufacturing may have helped the decline in traumatic injuries documented in developed countries (79).
3.1.3 Present recording systems

*Traditional statistical methods and International Labour Statistics.* Article 11(c) of ILO Convention 155 (the Occupational Safety and Health Convention, 1981) (47) requires signatory Member States to undertake the “production of annual statistics on occupational accidents and diseases”.

Employment injury statistics have been collected nationally in some industrialized countries for at least 60 years and they are regularly reported in the ILO *Year book of labour statistics*. These statistics, now provided by some 70 ILO Member States, are mainly based on workers' compensation systems and provide information on the prevalence of employment injuries, the number of persons injured fatally, and the number of workdays lost. For fatal injuries, where the data are less controversial, the incidence is also reported. It is then possible to evaluate the fatal accident trend in certain branches of industry of a given country, although these data do not usually permit intercountry comparisons to be made.

The major advantage of using international codes and classifications at the national level is that international comparisons can be made. In this way, countries that might benefit from international assistance can be identified and rarer associations or causative mechanisms may be revealed when the data are appropriately aggregated. If national authorities exclusively use their own nationally developed classifications, then these processes of international comparison and aggregation are not possible.

The great importance of reporting fatal and permanent injuries is not always taken into consideration. According to ILO statistics, fatal injuries have been decreasing in manufacturing industries in many industrialized and some developing nations. Thanks to the activities of the International Conference of Labour Statisticians, significant results have been achieved in the standardization of definitions, methods of recording, and routine collection of data, particularly at regional or subregional level, as for example in the European Community (82).

At the enterprise level, statistical investigations of employment injuries have provided information on the distribution of injuries by age, sex, job, work activity, and part of the body injured.

However, the deficiencies in quality, completeness, and coverage of routinely collected injury statistics considerably limit their use in
epidemiological analyses. Unless efforts are made to improve data
gility this situation will persist.

Problems with present statistical collections of data. The
standardization of data collection criteria and definitions becomes
most important if epidemiological studies are to be useful as
comparators for different enterprises. Where there is apparent
harmonization or comparability between enterprises or industries,
lack of validation mechanisms can be a major barrier to
epidemiologically sound studies.

There are many kinds of differences and biases in national
accident statistics that make it difficult if not impossible to make
comparisons between different countries. The same is also true
within each country; statistics taken at the enterprise level are not
usually easy to compare. The main problems are:

—Not all occupational accidents are included in the statistics, and
the statistical requirements and procedures vary among different
countries and among different enterprises within countries where
there are different workers' compensation systems. The self-
employed are not usually included in compensation statistics.
—There is always some under-reporting of accidents at both the
national and the enterprise level. The reasons for under-reporting
may be both individual and organizational and they may vary
between countries, between enterprises, and even between
departments of one enterprise.
—The basic data from the accident reports produced in workplaces
are often poor, particularly with regard to the description of the
accident sequence and contributing environmental factors.
—Statistical classifications may differ regarding both the type of
accident and the events preceding injury.
—Classifications of branches of industry and occupations are wide,
and high-risk groups can be concealed by the aggregate figures.
—Measurements may not take into account the severity of injury.

Defining what is, or is not, a work-related accident has itself
proved contentious. This is partly because present recording systems
may be designed for the purpose of justifying compensation for
injured workers, rather than for elucidating future preventive
strategies. Thus, in some countries, accidents occurring during
journeys to and from work are included in national statistics of
work-related accidents, whereas in other countries, they are excluded.

The definition of a fatal work-related accident also varies from country to country. In some countries, to be recorded as a fatal accident, death must occur shortly after the accident. In other countries, a death which can be attributed to an accident that occurred up to one year previously is recorded as a fatal work-related accident. In yet other countries, once compensation has been paid to an accident victim, subsequent death is not recorded as being attributable to the accident even though accidental injury may be the underlying cause of death.

The ILO has proposed the standardization of many definitions and the collection of basic sets of accident data by all national governments over the past 60 years, since the matter was first considered in detail by the First International Conference of Labour Statisticians in 1923. The Tenth International Conference of Labour Statisticians in 1962 passed a resolution concerning standard terminology, definitions, and concepts, as well as defining guiding rules for the measurement of employment injuries aimed at achieving a higher degree of comparability at both national and international levels (98).

Unfortunately, progress towards the harmonization of definitions and agreement on the minimum data set to be collected has been slow. Recent studies reported from the Commission of the European Communities (44, 82) illustrate the differences within even the relatively homogeneous Western European nations. It is apparent that quite large relative risks revealed in some countries, when comparisons are made using their published national statistics, may be entirely due to artefacts resulting from different methods of recording (10).

The classification of occupations has received a great deal of attention, mostly because of the necessity of considering economic factors related to labour-market statistics. International and national classifications of occupations are usually based on labour-market parameters, such as qualifications, skills, and training required, rather than on a system that can usefully define risks encountered in particular occupations. Some occupational classifications relate to specific tasks from which exposure to certain hazards can be deduced; however, most do not, and rubrics often cover persons carrying out tasks that involve dissimilar hazards and safety risks. However, the International Standard Classification of
Occupations can be regarded as a major reference on which comparative data could be based (49a).

Within certain international groupings, such as the European Economic Community (76), and in some individual countries, quite detailed classifications of economic activity have been developed, allowing more or less precise identification of the work done by workers in particular industries (and, by inference, of the risks involved). The classification developed for the European Economic Community (76) is based on, and to the two-digit level of the four-digit rubric is comparable with, the International Standard Industrial Classification of Economic Activities (49b). However, the calculation of accident rates, e.g., number of accidents per million hours worked, or per thousand workers exposed to the risks, or per unit of output, requires denominator data on these economic indicators that are often not available, or are only available from economic sectors that cannot be compared to those yielding the numerator.

More rarely, industries, through employer organizations, have developed detailed occupational classifications based on exposure criteria. One example is the Job Dictionary developed by the American Petroleum Industry for epidemiological studies on workers in that industry. Considerable epidemiological work has recently been done on classifying jobs according to risk of exposure to various physical and chemical hazards (42). However, the principal aim of this work is to improve the quality of job descriptions to facilitate the study of work-related disease rather than work-related injury at this stage, and many of the proposed methods or models (1, 81, 97) presume that a high level of epidemiological expertise and other resources are available.

3.2 Role of epidemiology in the prevention of work-related accidents

3.2.1 Data collection and evaluation of control strategies

The uses of epidemiology have been described by many authorities (48, 70). Three matters stand out in relation to the prevention of occupational accidents:

(1) Good descriptive and comparative epidemiology can focus attention on the trades, occupations, or tasks that are the most dangerous. Qualitative and quantitative methods can be used to
describe more accurately the size of the problem and its consequences, and to define priority areas for further research or application of control systems.

(2) It is possible to identify the causes of accidents within particular occupational environments using analytical epidemiology. Apparently simple questions about the causation of accidents (37) require not only thorough and systematic investigation of each relevant accident, but also the application of epidemiological methods to the data derived from these accidents, if they are to be answered properly and provide information that will be useful in the future.

(3) Control strategies and methods that have been developed or implemented for accident prevention can be tested for their effectiveness using rigorous epidemiological methods.

Through the use of epidemiology, more reliable information can be gained about work-related accidents and can be used to develop strategies for preventive action (26). Epidemiological methods may be used to improve the quality of data, facilitate agreement on definitions, and make the evaluation of control strategies more reliable. Unfortunately, control strategies that are currently in use either have not been evaluated in any way or have been evaluated by inadequate methods.

Programmes of action required to reduce work-related accidents usually involve commitment by competent national authorities, employers and their organizations, and workers and their representatives. Credibility and consequent acceptance of the data by these sometimes conflicting groups therefore become major issues, and depend to a large extent on the confidence the parties have in the methods used and the way the data are collected and reported.

At the enterprise level, emphasis should be given to the collection of a more extensive range of data on all work-related accidents as recommended by the ILO Conferences of Labour Statisticians. The greatest priority should be given to the collection of factual information identifying the type of work involved and its characteristics, along with other etiological determinants. Data collection systems and definitions that are related to economic aspects, such as occupational classifications and compensation records, tend to be more complete and reliable for epidemiological analysis.
Prevalence or incidence studies are often carried out on specified types of accident occurring within national boundaries in different units (enterprises, companies, departments) where workers carry out the same tasks or similar economic activity. To improve the quality of results, epidemiological attention should be given to the stratification of the sample, to validation of the data, and to the completeness of returns. Particular attention should be paid to the collection of denominator data from which accident rates and relative risks could be calculated. Studies of this type would help competent authorities, employers, and workers and their representatives to determine priorities and to generate hypotheses for further research on causation.

Cohort studies are recognized to be among the most powerful tools for investigating causal relationships. In relation to accidents, they have rarely been attempted. They may be used to investigate the relationships between workers, factors in their work environment, and their accident experience. Not only physical or technological factors can be investigated in a scientific way, but also work practices and supervisory and managerial factors. One of the few well-documented attempts at causal investigation was a study of 2000 accidents in manufacturing industries in the United Kingdom. However, this study lacked comprehensive epidemiological input as the accidents happened (84).

The case-referent design of study has been used relatively rarely, but it may be applied to testing associations between specific factors in the working environment or work practices and a specified health outcome, which in the present context would be an accidental injury. In studies of this type, cases and referents—with and without the injury under study—may be drawn from the type of work or work-setting containing the factors to be studied as determinants of injury. However, a basic problem is the selection of appropriate referents. One adaptation of the accident case-referent study might be to select enterprises or tasks where the accident rate is high as “cases” and those with a low accident rate as “referents”.

Cases and referents are usually matched or stratified for confounding variables and are compared with regard to risk factors in the working environment that are thought to be important. This study design may appear deceptively simple in execution, but demands both competence and skill in planning and in the interpretation of results. When properly applied, this method has considerable potential as a way of identifying and assessing accident
risk factors at work. The conclusions of such studies would logically lead to the development of prevention strategies.

*Intervention studies* can be used to investigate the effects of changes in the work environment, work practices, or accident prevention activities. One cautionary note is that these studies tend to be prolonged, expensive, and very dependent on expert epidemiological design and execution.

Certain characteristics of good safety control at the enterprise level are generally agreed and accepted, and could be possible areas for epidemiological investigation regarding their relative effectiveness. These include: *(a)* commitment and control by the management; *(b)* hazard detection and elimination; *(c)* auditing and inspection of the enterprise and its work system; and *(d)* training of personnel at all levels.

Conclusions and recommended actions resulting from risk estimates derived from epidemiological studies can be expected to be quite specific, although accompanied by confidence limits (8). A major advantage of using epidemiology is the ability to build a reliable body of knowledge by a series of studies that aim to narrow progressively the confidence limits given by earlier work. This can only be done if standard definitions and comparable data are used, so that studies carried out at a later date are truly comparable with earlier work.

Problems concerning the completeness of any data set, its validation, and its comparability with other apparently similar data remain the greatest obstacles to a better analysis and understanding of work-related accidents and their control.

3.2.2 *Some current uses of statistical data bases*

Routine accident statistics can be used to describe the distribution of events that have occurred and to discern occupational groups or industries at high risk, including agriculture, construction, mining, and quarrying. However, they cannot usually give warnings of new types of accident or potentially catastrophic events. There are three main reasons for this: the time lag between accident occurrence and the publication of statistics; new risk factors are concealed by the aggregate figures; and information on the potential severity of accidents has not been gathered. For warning purposes, it should be possible to get quick and detailed data on important individual
accidents. Modern data-processing technology makes this possible, and information data banks have been set up by competent authorities in some countries, e.g., in the United Kingdom and in Finland.

*Evaluating safety programmes at the enterprise level.* Some efforts have been made to use statistical data bases to evaluate factors leading to successful safety programmes at the enterprise level (e.g., 96). The results have revealed a number of factors related to superior plant safety performance. Briefly, plants with low accident rates: (1) had greater management commitment and involvement in plant safety matters; (2) displayed greater skills in managing both material and human resources; (3) used a humanistic approach when dealing with employees, including the encouragement of more informal worker/supervisor interaction; (4) had better management, including “housekeeping”, than plants with higher accident rates and a greater awareness of the importance of environmental factors; (5) had lower worker turnover and absenteeism and a more stable work force than the plants with high accident rates; and (6) had better relations between the trade unions and the plant management. The conclusions from such studies can be used at the enterprise level as a check-list against which the performance of the enterprise in question can be measured.

*Identifying accident risk by branch of industry.* The percentage contributed by different branches of industry to the total number of accidents and to accident fatalities varies greatly in different countries. Taking all the European statistical data together, mining accounts for only 4% of all accidents, but 8% of fatal accidents; agriculture accounts for 9% of all accidents and 14% of fatal accidents; manufacturing accounts for 44% of all accidents, but only 27% of fatal accidents. It is generally agreed that both accident frequency and accident severity vary among different industries. However, the results of studies must be critically evaluated. For instance, in some industrialized countries, workers in the food industry, such as butchers and meat preparers, have the highest accident rate (11). However, the severity of those accidents is one of the lowest; in more thorough studies of the problem, it has been found that most of the injuries are minor hand injuries, mainly caused by knives.
Other determinants of accident risk. Many factors that could be worthy of further epidemiological study have been identified from statistical data as determinants of accident risk. A national population census makes it possible to obtain information about the economically active section of the population by occupation, industry, sex, and age. If the same classifications of occupation and industry are used both for collecting occupational accident statistics and for conducting the census, it is possible to combine these data to describe the accident risks among different groups (11).

Differences in accident risk rates exist for many factors such as age, sex, and work tasks (14, 34, 62, 63).

3.3 Developing and promoting epidemiology for the prevention of work-related accidents

3.3.1 Epidemiological methods and concepts

Information requirements of an injury-reporting system. For accident prevention purposes, the injury-reporting system should provide adequate information for the following functions: (1) to show the significance of occupational injuries as health, social, and economic problems; (2) to recognize the high-risk groups; (3) to show the significance of different types of accident and injury; (4) to give a warning of new hazards associated with, for instance, new products and new production technologies; (5) to give a warning of potential catastrophic accidents; and (6) to enable in-depth studies to be carried out of accident hypotheses, sequences, causes, and risk factors. The demand for detailed information increases from the first function to the last.

There are many other problems for the epidemiologist who is attempting to establish cause–effect relationships (31) and there is no reason to believe that there will be fewer problems in relation to work on occupational accidents than there are for work on occupational diseases.

National epidemiological studies of fatal accidents. Fatal accidents have long been regarded as a special category, and all countries have attempted to record them separately. The International Conference of Labour Statisticians in 1982 reaffirmed that fatal accidents should be recorded separately. The historical reasons for this separate recording are mainly to be found in the legal systems set up in each
country to register all deaths and to establish the circumstances surrounding each particular death. Thus, the deaths of workers are caught up in these legal provisions, and the circumstances of these deaths are more carefully recorded and investigated than is the case for work-related non-fatal injuries.

Consequently, fatal accidents are often the only class of accident that is recorded with any degree of completeness (17). Under-reporting of fatal accidents does occur, for all the same reasons that under-reporting of other work-related accidents occurs, but to a much lesser degree. Under-reporting of fatal non-work-related accidents has been observed in many industrialized countries such as the USA, where epidemiological methods have been used to obtain more accurate figures (5). The ability to obtain almost complete data sets makes fatal accidents of particular interest to the epidemiologist. Identical accident situations can result in injuries ranging from the most minor to the catastrophic, and this effect is largely independent of the underlying causes of the accident. Therefore, the study of fatal accidents by epidemiological methods can be expected to yield inferential information about many other accidents.

However, drawing conclusions at the enterprise level from fatal accident records (or indeed from other accident records) that have not been collected using epidemiological methods can be misleading. This is because for enterprises in which an equal rate of potentially fatal accidents occurs the distribution of actual fatal accidents is random, both in place and time. Thus, because fatal accidents are always rare, an observer may record a cluster of fatal accidents, or conversely, a period when there are no fatal accidents, when in reality there is no change in the actual safety level in the enterprise between the periods being studied. Similarly, attempting to compare the safety performance of different enterprises using the occurrence of serious or fatal accidents during a given time period can lead to false conclusions unless epidemiological considerations relating to sample size and validity are taken into account.

In contrast, at the international and national levels, the study of fatal accidents using epidemiological methods can be most valuable. The completeness of data has been discussed previously; in addition, it may be relatively easy to enlarge the volume of information collected about each fatal accident. The infrastructure necessary to collect the data is already available because it is required by law for the purpose of death registration; all those involved, for legal and emotional reasons, are likely to respond to requests for extra
information; and the recording process, from the moment of tragedy onwards, is likely to be more thorough and careful than is the case for non-fatal accidents. The statistical problems inherent in investigating small numbers of accidents with many variables are avoidable at the national level when all fatal accidents from particular economic groupings can be studied together. The numbers collected at the international or national level may be sufficient to allow the generation of hypotheses regarding causality, which can be tested by further epidemiological research.

The limited data to be collected on every fatal accident might comprise:

—minimum demographic data,
—classification of occupation using the International Standard Classification of Occupations (49a),
—classification by economic sector using the General Industrial Classification of Economic Activities within the European Communities (76), and
—classification of cause of death according to the “E” codes of the International Classification of Diseases (46).

National epidemiological studies of fatal accidents can be used to provide the best assessment of whether a safety hazard is present or not and to predict the level of risk in particular industries or demographic groups. An additional advantage of improving the completeness of recording of a limited data set on fatal accidents only is that it will result in the same data being collated and used at the international level. The ability to improve the use of epidemiological techniques on this limited data set will more than outweigh the disadvantage of studying fewer accidents. The quality of knowledge obtained for both national and international use will thereby be improved.

If national figures indicate that an industry has a high rate of fatal accidents, then employers, safety professionals, and workers in that industry should assume that their own particular undertaking is also similarly dangerous, irrespective of their own immediate experience or the recent records of the undertaking. Such knowledge, if possessed by the competent national authority, needs dissemination to employer and other organizations, in order to generate preventive action at the enterprise level.
**Reporting of near-accidents.** Time considerations are important in accident-risk identification. The risk should be identified before accidents occur. One way to do this is to report and investigate near-accidents.

The methods used to collect data on near-accidents are observation, interviews with workers, and self-reporting. The most reliable data can be gathered by observation, but this is a rather costly method for the investigator (58). The use of interviews has been quite an efficient way of identifying near-accidents; more have been identified by interviews than by self-reporting.

Voluntary self-reporting is used both as a research method and as a routine procedure in workplaces. Under-reporting, which tends to be greater with minor accidents, always exists. Reliability may be improved by applying anonymous reporting (55, 89). Perhaps the most important factor is to define the near-accidents under study as well as possible to the participating population (91).

**Dangerous occurrences.** "Dangerous occurrences" is the term used to define certain specified categories of incident or event that commonly cause accidents, e.g., the derailment of rolling stock or the collapse of construction scaffolding. In some countries, a list of specified dangerous occurrences must be reported for investigation to the competent authority, despite the fact that no injury has been caused. The United Kingdom has had regulations covering some of these incidents since 1931 and revised regulations covering about 25 categories of dangerous occurrence were introduced in 1985 (33). Simple analysis of the data collected through this system has yielded much information about the precursors of accidents resulting from such dangerous occurrences.

**The concept of potential severity.** The severity of an accident is normally considered to be the same as the severity of the resulting injuries. However, the severity of injury resulting from an incident is largely determined by chance. Death is the severest possible consequence of a certain sequence of unplanned events, and no injury the minimum consequence. This maximum possible consequence has been called "the potential severity" of an incident (accident or near-accident), and its use makes it possible to identify the more severe risks to individuals on the basis of slight accidents, near-accidents, and identified hazards (63, 65, 80).
3.3.2 Essential infrastructure and prerequisites for epidemiological studies

The categories of infrastructure. The successful use of epidemiological methods requires a certain infrastructure. Applying new methods in the absence of an infrastructure may prove impossible, or may provide erroneous conclusions leading to useless or even detrimental recommendations.

The infrastructure required includes:

— trained personnel,
— epidemiological techniques and tools,
— reliable and comprehensive data sets,
— a suitable social climate, and
— appropriate financial and administrative resources.

A recent study by the International Social Security Association has indicated that the epidemiological human resources currently available are insufficient to deal with the problem of work-related injuries and disease. The teaching of epidemiological methods is heavily weighted towards health workers concerned with work-related disease rather than injury, and instructional and reference materials are similarly oriented.

At the enterprise level, many people may influence safety and therefore need training in aspects of the epidemiology of occupational injuries. It is at this level that most data are generated, and where it is most effective to apply validation techniques and to make efforts to obtain more complete data. The people who may need training include managers, supervisors, workers’ representatives, personnel administrators, and occupational health and safety personnel. The first requirement is that they are able to seek out, understand, and utilize the existing data that are relevant to the work systems in their own enterprises. These data may be in national collections or at the industry level. The second requirement is that they possess the relevant skills for assisting in the collection of better data from the enterprise.

Reliable and comprehensive data sets are products of systems that are set up specifically to provide information. At present, many countries do not have these systems. Reference is made elsewhere to the need for national authorities to improve the reporting or registration of work-related accidents. Some parallels may be seen in the development of cancer registries over the past two decades. New
knowledge about cancer and its prevention and effective treatment has emerged from the study of data gathered by population-based cancer registries. Their development has been aided by the incorporation of epidemiological principles into data collection methods (23), as well as by the size and nature of the cancer problem.

The existence of a suitable social climate is particularly important for epidemiological studies carried out on work-related problems. In the industrial setting, data collection is often dependent on the voluntary participation of employers, employees, employer organizations, and the representatives of workers. Completeness of data, either from the sample or from the whole population under study, is one of the keys to gaining epidemiologically sound information (15). Even where the competent authorities require the provision of information, an element of voluntary compliance is involved in full reporting. Those who are the subjects of the reports, together with those who must report, need to understand the reasons for the report and be convinced that the information gained will be of some future use to them.

Epidemiological studies, by their very nature, are often difficult for the non-specialist to understand, and are dependent on long-term commitment by the members of the study population and other participants. These factors make the preparation and presentation of explanations to the participants of great importance, ranking equally with such matters as correct methods and careful validation of data, in the successful completion of a study (15).

It is necessary to stress the importance of providing appropriate financial and administrative resources for epidemiological tasks. Problems relating to data collection, validation, and drop-out rates in long-term studies may become insurmountable if the underlying support systems are deficient. Almost all epidemiological work involves effort and commitment of resources that will yield a return only at some future date. This concept of investment to gain future return, inherent in most industrial systems, could be applied to the concept of epidemiological investment.

*Making use of pre-existing infrastructure.* It may be useful to look at the infrastructure that exists within industries or individual enterprises for the purpose of production, to see whether it can be used also for epidemiological tasks. This industrial infrastructure may include communication systems, data collection systems, personnel systems, and training and other facilities. Payroll systems
can be useful channels of communication for identifying populations and reaching the workers involved. Facilities for data acquisition and storage can often be found in industry and used at little additional cost. Increasingly, computing systems are being used in industry, and it may be possible to use these for epidemiological work. In some countries, insurance agencies produce, or have access to, the most comprehensive data available, i.e., those derived from the system for workers' compensation.

A further source of epidemiological data is the records of workers' organizations and trade unions. However, in many countries these records, which have been collected for membership purposes, cannot provide denominator figures from which accident rates and relative risks can be calculated. It appears likely that the specific role and powers allocated to trade union representatives in some countries under national occupational health and safety legislation will lead to the adaptation of trade union record systems so as to facilitate future epidemiological studies.

Existing data sets do not necessarily emanate from health or safety sources. In some countries there may already be available several sources of data on work-related injuries (17).

*Developing new infrastructure.* At the enterprise level, the occupational health and safety professional can obtain and analyse more detailed data than is possible at the national or international level. Serious accidents resulting in permanent disability, accidents resulting in temporary disability, minor injuries, and near-accidents may all be studied if suitable reporting systems within the enterprise can be established. Classification by disability has been used extensively as a measure of the seriousness of an accident, where disability is defined as loss of time from work. This is an economic measure, often routinely recorded through records of pay or compensation. One major advantage from the epidemiological viewpoint is that these records are often more reliable and more complete than is the case for recording systems set up within the health services.

The development of computer software that can assist relatively unskilled workers in the solution of problems is proceeding rapidly. Specific software may help those conducting studies at enterprise or industry level to apply epidemiological techniques, and may also facilitate the spread of epidemiological expertise.
Aggregation of uniform data already existing within a well-defined industry can enlarge the data set available for analysis, while maintaining its reliability. Prevalence or cross-sectional studies on these data sets can focus on specific categories of accident or injury and their relationships to identifiable tasks (75). It may be possible to use an existing data set for cohort and case-control studies in an industry, or the acquisition of new items of data may be required, entailing additional use of resources. However, for practical and economic reasons, most countries collect only data that:

—can be put to effective use,
—meet confidentiality and security concerns, and
—are agreed to be important by workers and their representatives and by employers and their organizations.

National custom and practice and relevant labour laws may all affect the epidemiologist's ability to function effectively. In a few countries, particularly in Scandinavia (21), both social custom and legislative mechanisms exist that facilitate cooperation in data collection.

Conversely, barriers to epidemiological studies exist in many countries. Legislation may restrict access to death certificates or the acquisition and storage of all confidential personal data. Additional problems may be superimposed in the industrial setting, where bipartite or tripartite relationships need to be considered. In some countries, workers and trade unions may need to be formally consulted and their active support and resources enlisted in the project. In others, government authorities alone can gain access to the necessary vital statistics, making government control or participation essential. Various ILO directives—such as Convention 155 (the Occupational Safety and Health Convention, 1981) and the associated Recommendation 162 and Convention 161 (the Occupational Health Services Convention, 1985) and the associated Recommendation 171 (47)—have referred to the need for joint consultation on matters relating to safety and health.

International aggregation of epidemiological data from industry-specific sites has provided important information on industrial processes or activities where relatively small numbers of persons are involved, e.g., in the production of man-made mineral fibres and in deep-sea diving. International studies are particularly important in relation to potentially hazardous installations. Events leading to catastrophic accidents in such plants have often been dependent on
relatively rare faults or failures, and no single plant or even one country is likely to accumulate enough experience to be able to predict sensibly when things are likely to go wrong.

The need to quantify the economic cost of work-related accidents. It may be particularly useful to enhance efforts to quantify the economic cost of work-related accidents. Although the ultimate cost of accidents is human suffering, the high economic costs involved must be recognized. These costs are borne by the injured worker, the enterprise, and the general community.

Economic data on work-related accidents can provide a powerful incentive to decision-makers with the power to change to safer equipment and working methods. Economic data generally are more clearly understood, and can be related to other information received concerning the operation of the enterprise (67). The most favourable climate for change is where improved safety can be shown to be attainable at little or no additional cost, or where the cost can be shown to be balanced by improved productivity, such as following the introduction of newer, more productive and safer equipment or work methods. Measurement of cost requires no less epidemiological rigour than does measurement of more traditional medically oriented characteristics.

Priority areas for action that are identified as a result of consideration of economic data have an additional advantage. Resources that are nominally allocated for economic development may be available for application to programmes for the prevention of work-related injury, where these can be shown to be cost-effective for the economic sector or enterprise. At an international level, bodies such as the International Social Security Association or the World Bank may be willing to provide resources to less-developed countries under various economic programmes, such as ILO’s International Programme for the Improvement of Working Conditions and Environment (PIACT).

3.3.3 Epidemiological data collection and analysis

Improving data collection and analysis. The purpose of any epidemiological study of work-related accidents is: to collect relevant facts; to assemble and analyse them; and to disseminate conclusions drawn from them to people who can make the necessary changes (64). The collection of all the information about every
accident is not feasible. The extensive data sets proposed by ILO statisticians have achieved only limited acceptance in a few countries. A new approach is now required that is within the resources of most countries but that still allows more sophisticated data collection if desired. Analyses based on relatively reliable facts, even where these are very basic, can lead to effective action (32).

A different epidemiological approach is to use sample survey information, rather than to rely on the data collected on all accidents (84). Epidemiological surveys of statistically valid samples of accident data allow resources to be concentrated more effectively on those areas of validation, data comparability, and completeness that are essential for correct conclusions to be drawn. The selection of statistically valid samples from available data collections or from survey work and the use of appropriate epidemiological methods may ultimately utilize fewer resources than the present tendency to attempt to collect more data on all accidents.

**Efforts to achieve comparable data.** In the work of national authorities, it is particularly important that attention is paid to stratification of accident data into correct occupational and economic classifications. Some national authorities have used data from similar industries in other countries as comparators for their own data. For example, the US Bureau of Mines has compared fatality rates in coal mining in the USA with rates in West European coal industries, in terms of both millions of hours worked and millions of tons of coal mined. This type of comparison is particularly useful, since it means that attention is being given to the differences in task and in control strategies being used. Questions of international comparability of data then become paramount.

**Efforts to ensure validation of data.** In epidemiology, validation of data is accepted as being of great importance if any reliability is to be placed on the conclusions or recommendations made. Rarely is this need for constant validation understood by workers or by their supervisors or employers. Typical problems that can result in false or misleading data being collected by occupational health and safety services from different workplaces include:

— different recording criteria set by local managers,
— different recording facilities available,
— different types of personnel assigned to do the work,
— incomplete transmission of data to the collection point, and
—falsification of records, perhaps as a result of bonus or penalty provisions that have been made dependent on the recorded safety performance.

3.3.4 Dissemination and utilization of epidemiological information

*International level.* At the international level, the United Nations agencies can utilize comparable accident data from different countries for purposes that include assisting less-developed nations to achieve safer working conditions, in accordance with ILO’s International Programme for the Improvement of Working Conditions and Environment (PIACT); determining priority industries or nations where international cooperation or assistance may be most valuable; and providing information regarding the economic impact of accidents that can be used in determining priorities for international economic assistance plans.

The major United Nations agencies with an interest in the collection, assessment, and dissemination of data on work-related accidents are ILO, which has formulated many international standards on accidents, e.g., Convention 155 (the Occupational Safety and Health Convention, 1981) (47), and WHO, which plays a direct role in planning for the health care and rehabilitation of injured workers.

In addition, both WHO and ILO have set objectives or goals that implicitly require the dissemination of reliable data, which can only be obtained through the application of epidemiological techniques. For example, WHO has identified the need to support Member States in improving the surveillance of workers’ health and the reporting of occupational hazards. ILO has prepared and adopted many Articles within Conventions that will be highly dependent on the collection and analysis of reliable data.

Article 4 of ILO Convention 155 (47) requires the formulation of national policy “to prevent accidents and injury to health arising out of, linked with or occurring in the course of work”, and Article 11 specifies the functions of competent authorities which will require epidemiologically sound information. For many national governments, advisory services, information, and training provided through the activities of ILO may be the most feasible method of progress, and ways of delivering these support systems using new information and communications technology should be discussed (67).
Other United Nations agencies that either need accident data or have an interest in the consequences of accidents include the World Bank (economic assistance programmes and productivity implications), the United Nations Children’s Fund (especially in relation to rural economies where many children are killed and injured during family work on farms), and the Food and Agriculture Organization of the United Nations (implications for agricultural productivity). In addition, the International Social Security Association, a nongovernmental organization, is directly concerned with matters such as the prevention of injuries, compensation for injured workers, and social security for the disabled.

Epidemiological data should be used and the results presented by ILO/WHO to national governments in such a way that there is a rapid and effective response at the enterprise level. At both international and national levels, many countries have economic development and assistance programmes and activities, few of which have ever been directed towards the reduction of economic losses due to work-related injuries. It is evident that a reduction in economic loss can be as important to economic development as an improvement in productivity or the development of new products or markets, all of which are among the accepted goals of programmes for assistance with economic development.

In some areas of activity, such as ergonomic design of simple equipment and procedures for manual handling, a synergistic effect of raising productivity and reducing work-related injuries may result from appropriate research and development. Epidemiological techniques have already yielded useful information about this problem in Europe, and could be used to evaluate the effectiveness of preventive measures (45).

International cooperation should be encouraged between scientific bodies working in the field of work-related accidents and disease so as to improve international knowledge of causation and of any successful control strategies available. A Scientific Committee on Epidemiology has met for several years under the auspices of the International Commission on Occupational Health; this organization has now established a Scientific Committee on Accident Prevention. The establishment of dialogue and closer links between epidemiologists and those who have been more traditionally engaged in the field of work-related accidents may stimulate research and the exchange of knowledge.
National level. At the national level, information about work-related accidents is required principally for the purpose of defining which of the economic sectors or types of operation should be accorded priority for inspection services or for research into prevention, or to determine where and at what level treatment and rehabilitation services should be provided. However, priorities for national action or deployment of resources cannot be solely determined by accident or injury data.

Article 9 of ILO Convention 155 (47) requires that national governments should secure “the enforcement of laws and regulations concerning occupational safety and health and the working environment . . . by an adequate and appropriate system of inspection”. Inspectorates need, and are uniquely placed in a position to collect, data on accidents and dangerous occurrences and to disseminate the conclusions drawn from such knowledge. National governments need to train their inspectorates in the appropriate use of the data collected, so that the inspectors can advise on adequate levels of safety in the design and operation of workplace practices. The results of this approach in terms of accident prevention depend on the validity of the data, and the conclusions drawn from their analysis.

Within their boundaries, national authorities also play the principal role in the dissemination of information on work-related accidents to the enterprise level; it is at this level that the most effective accident prevention strategies can be instituted. Mechanisms of disseminating information are themselves worthy of epidemiological study, particularly with regard to the role of workers and their representatives, workers’ organizations, and employers and their organizations.

A special concern of national governments, which has been highlighted in recent years by major accidents and disasters such as at Bhopal in India or the PeMex plant in Mexico City, relates to rare but catastrophic events in major hazard installations. The collection and analysis of injury data in such plants, even when carried out over many years, may be a quite inappropriate method of assessing this type of risk. A recent report of ILO has highlighted the need to supplement accident data with information on “near-misses” which, by expanding the volume of data collected, may allow the dissemination of predictive information concerning relatively rare events posing a threat to major hazard installations (87).
The refinement of national statistics can yield information pinpointing individual enterprises that have a safety performance well above, or below, the average for the particular economic sector or industry. Those with good performance records may be studied to determine the reasons for their success. Those below the average should receive government advice, information, and inspection.

The collection and application of national data for this purpose require epidemiological input, if cause and effect mechanisms are to be clearly demonstrated. Without the epidemiological approach, conclusions and recommendations could be disseminated that are at variance with reality, leading at best to no change in the risk factors beyond that which would occur by chance, and at worst to the waste of economic resources on useless safety efforts.

**Enterprise level.** At the enterprise level, locally generated accident and injury data are principally required for two purposes. Firstly, they are used to measure performance over sequential time periods as an indicator of environmental, supervisory, and managerial changes and the effectiveness of such changes; and secondly, to elucidate cause and effect mechanisms so as to generate ideas for accident prevention.

Reliable national data can be used at the enterprise level for comparison with local performance, or to draw attention to areas within the enterprise that might require special attention or regular inspection because they have been identified as potential problems in national reports. Some important or especially dangerous events are so rare that they are never experienced more than once by any one person during a working lifetime. This leads to the situation where personal experience is a poor guide to possible future accidents, and only national collections of data can provide the necessary warning.

The application of the knowledge gained from accident statistics and epidemiology is often of more importance for accident prevention at the enterprise level than is the conduct of new studies. Existing knowledge can be used to formulate questions or check-lists for the evaluation of the risk of accidents in the workplace or when carrying out a task. Many such check-lists have been drawn up for different industries and work situations.
3.4 Role of occupational health and safety services

3.4.1 Epidemiological studies

Occupational health and safety services can use epidemiological methods to carry out many of the functions listed in Article 5 of ILO Convention 161 (the Occupational Health Services Convention, 1985) (47), which include identification and assessment of the risks from health hazards in the workplace, surveillance of the factors in the working environment and the working practices that may affect workers' health, and surveillance of workers' health in relation to work. However, in most countries, relatively few workers are covered by an occupational health and safety service that has a high-level capability in epidemiological techniques. Nevertheless, even relatively simple techniques can prove useful when applied to common problems such as sprains and strains of the musculoskeletal system or injuries associated with manual handling (112). Such studies can be used in the day-to-day setting of priorities and allocation of resources for the occupational health and safety service, and to provide numerical data to justify enterprise policy and programmes.

3.4.2 System concepts

It may be methodologically useful at the enterprise level for occupational health and safety personnel to consider accidents as an unwanted side-effect of the production system, and to investigate and manage them in the same way as other unwanted side-effects, such as defective units of production, machinery breakdown, spoilage, and wastage. Knowledge of epidemiological principles required for the study of accidents or injuries, such as the need for care in data collection, sampling, and validation procedures, can also be applied to other aspects of production such as quality control and preventive maintenance.

3.4.3 Using internal comparisons

Employers and employees and their representatives may be justifiably reluctant to act on evidence that has demonstrable methodological flaws in its acquisition or comparison. One way to avoid this problem is to use internal comparators wherever possible. It is often practicable to compare safety performance, e.g., accident rates or scores in safety audits, between sequential time periods or
between separate geographical units in the same enterprise and for
workers carrying out the same tasks. For example, comparisons
could be made between accident rates for maintenance staff in
different mines, or between groups of workers comparable in every
sense except in the level of training they have received.

3.5 Conclusions

1. Accident control at the national level will almost certainly
require the combined efforts and interest of government leaders and
economic planners, engineers, designers, architects, and health
professionals, as well as of employees and employers. Neither the
interest nor the confidence to act will be generated without reliable
information.

2. In view of the magnitude of the problem of work-related
accidents, there is a remarkable scarcity of epidemiological research
dealing with mechanisms and prevention of injuries caused by such
accidents.

3. A prerequisite for scientific studies of work-related accidents is
the acquisition of valid data on which to base priorities and research.

4. Continuous, systematic data collection is essential for sur-
veillance and for planning and evaluating preventive programmes.
Such data collection is needed at international, national, and
enterprise levels and also for specific industrial branches or areas of
economic activity.

5. For the successful identification and management of workplace
conditions leading to work-related accidents, competent specialists
are needed in medical, behavioural, and technical fields of science;
competence is also required at the enterprise level among managers,
employees, safety personnel, and health professionals.

4. RECOMMENDATIONS

1. Efforts should be made to assess the magnitude of the problem
of work-related diseases and accidents in each country.

2. Epidemiological studies on work-related diseases and accidents
should identify causal factors and describe them in qualitative terms.
Efforts should be made to measure objectively, whenever possible,
the environmental and human factors that serve as risk indicators
for work-related diseases and accidents.
3. Efforts should be made to develop research directed towards the identification of high-risk groups by studying the human characteristics and environmental factors that are predictors of increased risk.

4. The subject of work-related diseases and work-related accidents, and the role of epidemiology in their control, should be included in the training of health and safety professionals, workers' representatives, managers, and engineers who are concerned with design and production. This training should address the issues of etiology, risk factors, prevention, rehabilitation, and return to work.

5. Health and safety education programmes for the prevention of work-related diseases and accidents should be instituted at the enterprise level for workers and management.

6. Research should be directed towards identifying effective intervention and control strategies for dealing with known risk factors for work-related diseases and accidental injuries.

7. Efforts should be made to improve techniques for assessing the health impact and economic consequences of work-related accidental injuries, in particular permanently disabling and fatal injuries.

8. In view of the deficiencies of existing reporting systems, standardized systems should be developed for the reporting of work-related diseases and accidents. WHO and ILO should consider developing a programme addressing this issue.

9. Accurate information on occupation should be routinely incorporated into death certificates; this information should be in a form that can be linked with other data sources to allow for a more complete assessment of occupational history.

10. International agencies such as WHO and ILO should consider cooperating with national governments, when requested, to undertake research and training and to develop educational materials, standard reporting models, and guidelines for the identification and prevention of work-related diseases and accidents.

11. Systems for the collection of data should be developed that give priority to work-related accidents with a fatal outcome or with serious consequences to health or the community.

12. National authorities should be encouraged to make statutory provisions for reporting on "dangerous occurrences". In the further development of data collection and reporting systems for work-related accidents, the potential for utilizing minor injuries and near-
accidents as indicators of serious risks should also be exploited whenever feasible.

13. At the enterprise or industry level, emphasis should be given to collecting a more extensive set of data than is required at the national or international level. Particular attention should be paid to specific hazards in the industry or enterprise concerned.

14. At all levels of data collection, measures should be taken to ensure that collected data are of adequate quality, in terms of completeness and attention to nomenclature and classification.

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