# THE MEDICAL CONTRIBUTION TO PLANT DESIGN

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The role of health advisers in the design of chemical plant is discussed. The inherent limitations of biological information as a source of quantitative guidelines for the designer are noted. Separation of hazard assessment from decisions on the acceptability of risk is considered and the difficulty of keeping these stages separate is described.

## INTRODUCTION

The designer of process plant will wish to minimise the adverse effects of the plant on those working or living in its vicinity. He will also need to ensure that safe and efficient operation of the plant is within the physical and mental capabilities of those operating it. To design within these limitations the engineer requires guidelines based on biological and medical studies. In recent years a number of disciplines have developed which allow the interactions between man and the working environment to be quantified and used in plant design.

### Health Advisers

Ergonomists have investigated the human requirements for effective work using studies of actual working conditions and laboratory investigations into the effect of physical, chemical and social factors on comfort and performance. Systems for information display and response to information have also been studied.

Toxicologists have provided information on the effects of chemical agents on health, derived from animal studies and human experience. In some cases this has enabled the risks at defined levels of exposure to be estimated.

Occupational hygienists have improved our ability to recognise and measure exposure to chemical and physical hazards and they have played an important part in devising control measures for hazards.

Epidemiologists and occupational physicians have collected and analysed human data on the health consequences of occupational exposure

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to hazards. Medical surveillance and emergency treatment procedures have also been developed for a number of hazards. Inevitably with novel materials clinical medical studies will be of little use at the design stage but a programme of surveillance may form an important part of the operating procedures to confirm that proposed safeguards are adequate.

All these disciplines bridge the gap between human biology or pathology and the physico-chemical world of the designer. They attempt to quantify biological responses in a way which allows an assessment of the consequences of both occupational and community exposure to be made.

## DEFINITION OF HAZARDS

The designer wishes to have sound numerical guidelines applicable to the process conditions which are capable of being justified to authorities and critics. Design guidelines for health risks can only be produced by defining and attempting to quantify hazards and then taking a view on the probability, frequency and severity of risk which can be accepted.

It is important to recognise those aspects of biological systems which restrict our ability to define and quantify health risks or limitations on performance. Any assumptions or uncertainties in risk assessment will be carried over into the decisions on acceptability and standards. Failure to appreciate the biological perspectives may be a cause of misunderstanding between the designer and his health advisers.

### 1. Exchange

Living organisms are in a continuous state of exchange with their surroundings. The lungs exchange respiratory gases, the lungs' anatomy and physiology also determine the site at which irritants cause their effects and the degree of absorption of contaminants into the blood. Physical features of exposure which are of little relevance to engineering design such as the proportion of dust in the 1 - 7 micron range, which is capable of penetration deep into the lung or the formation of droplets within a vapour release, may be fundamental to assessing biological hazards.

The skin, which will be considered separately, plays an important part in temperature regulation and this may be an important constraint on the use of personal protective equipment.

Specialised sense organs such as the ear and eye are susceptible to overload by noise and light. Features such as noise frequency and intensity are critical in assessing risk and will need to be specified to equipment suppliers. Non damaging patterns of noise and lighting can have major effects on performance and safety.

### 2. Variability

As individuals pass through life capabilities and vulnerabilities alter. Because the young and the old are specially vulnerable to the effects of respiratory irritants the presence of residential areas in the vicinity of a plant may influence the emission standards which need to be applied. Increasing attention is now being directed to the special problems of pregnancy, where both mother and foetus must be considered. The sex and age of workforce may need to be specified in some circumstances.

Within a group of employees there is often a considerable diversity of response to a given exposure. On the rare occasions when this diversity can be predicted control measures may include specific tests for susceptibility and standards may be set on this basis. In the case of substances causing allergic sensitisation there may be a more than thousand fold difference in the concentration causing effects in the least and most sensitive. The development of sensitisation is not a static phenomenon and will depend both on inherited traits and previous exposure history.

At the behavioural level it is well recognised that one man's stress is another man's stimulus. Many of the widely used comfort criteria such as those for temperature are based on the level at which an equal number of people complain of being too hot and too cold!

3. Repair

Growth allows the body to repair itself. In many circumstances chemical or physical damage can occur with little lasting effect because dead cells are readily replaced and function is maintained. Hence the endpoint for deciding whether an effect is important requires careful consideration especially with ever more sensitive biochemical techniques. Where repair is effective a clear threshold below which important effects do not occur may be defined. Some types of damage may affect areas such as the visual cortex of the brain where function is highly localised and repair limited. In this case a threshold may not exist. Similarly where the response to damage is an escape from the normal controls on cell growth causing a tumour the frequency of effect will decrease with lower dose but detection of a no effect level may be impossible.

4. Response Time

The damage caused by an agent usually depends on the concentration in the most sensitive part of the body. This is turn depends on the balance between absorption and metabolism or excretion. With substances such as cyanides the critical concentration may be rapidly reached and fatal damage may follow in a matter of seconds. Other substances such as lead may equilibrate over longer periods before causing effects, or, as in the case of noise, damage may be a response to repeated insults. On occasion, as with blue asbestos, a short period of exposure can cause effects but these will not be manifest for decades.

Where long term effects are possible an estimate of risk from a particular level of exposure can only be made where there is a well documented history of exposure and its effects. Inevitably this limits the possibility of quantifying the risks for substances which do not have a long history of widespread use.

5. Causation

Disease or death may be attributable to more than one agent. This is especially so in the case of some of the common causes of disability such as heart disease and cancers. Multiple risk factors can be identified from epidemiological studies and, as with the effects of smoking and asbestos exposure on the development of lung cancer, they may be more than simply additive. Attribution of disease to exposure may be possible only as a statistical concept where an excess incidence of a condition found

in the general population is identified in an occupational group. While this may be adequate for identifying a hazard it will not allow attribution of each case to a single cause and discussion about causes and effects will be clouded with uncertainties, as with lung cancer in asbestos workers who smoke.

Firm proof of causation can only be obtained from rigorous experimental study. This type of investigation is rarely justified in man and almost all human data are based on the study of conditions which already exist. Association between exposure and disease may be demonstrated and sometimes the features of the association make a single cause the only feasible explanation of the pattern of disease, as in the case of mesothelioma of the lung in those exposed to blue asbestos.

## 6. Extrapolation

The rigorous experiments needed to demonstrate causal relationships make use of animals as models for human exposure. Animal studies have played an important part in aiding our understanding of the hazards of occupational exposure and they are now becoming a regulatory requirement for new industrial chemicals. There will always be problems in extrapolating results obtained on animal species under laboratory conditions to man with an exposure pattern at work supplemented by the diversity of risk factors administered during leisure time. Animal studies are effective at identifying types of damage caused by exposure but they are less reliable as indicators of the extent of effects in man at a given concentration. Hence they may often indicate the effects of over exposure without providing firm guidance on the concentration of contaminant which is unlikely to cause adverse effects.

Both animal studies and historic human experience often provide information that adverse effects occur at relatively high levels of exposure. It is far more difficult to identify a level at which adverse effects do not occur, especially for long term effects which show themselves in only a proportion of those exposed, such as the development of tumours. Attempts are frequently made to extrapolate information on low dose effects from information derived from high level exposure. This may be the only route to an assessment of risk but is is one which is rarely free from criticism.

Any statement on the biological effects of working conditions will inevitably be limited in both precision and applicability. In some cases this relationship can be expressed in quantitative terms, for instance: a certain level of noise may be expected to cause deafness severe enough to interfere with speech in a stated percentage of those exposed eight hours a day for five days a week over a period of twenty five years. Such precision is rare and can only be justified when based on very sound investigations.

In practice the information on hazard will vary from a complete lack of information through qualitative description of effects to a quantitative description of the natural history of the response which may or may not be linked to measurements of exposure.

The quality of information required to provide useful advice to a plant designer will vary, depending on the scale of the process, the degree of containment and the scope for exposure.

## PREPARING GUIDELINES

Where the relationship between exposure and hazard can be described adequately it is possible to consider the preparation of a guideline or standard as a separate step. A judgement is made about the level of risk which can be accepted and a standard is set based on an acceptable level of protection (Lowrance (1)). Here the scientific and professional/political aspects of the process are distinct except insofar as a complete absence of risk may be demanded and the scientific data will only be capable of estimating the probability of any adverse effect.

Frequently the definition of hazard is too imprecise to allow risk assessment and standard setting to be separated because uncertainties about risk have to be carried forward and form part of the judgement about acceptability.

For established industrial hazards guidelines are available from a variety of sources including professional bodies (American Conference of Governmental Industrial Hygienists, British Occupational Hygiene Society) and Government departments (Health and Safety Executive, USA Occupational Safety and Health Administration). These standards vary in both legal status and soundness and can only be evaluated by reference to their supporting documentation. Some recent standards have used consultative processes which emphasise the political components in making judgements on the acceptability of risk. Where they exist such standards usually form the basis for design, but allowance should be made for future changes.

In many cases no standards are available or the basis for existing standards may be inappopriate, for instance where very short high level exposures are considered (Ferguson (2)). A procedure may therefore be required by which standards can be generated specifically for use in plant design. These design guidelines are likely to be produced by the medical, toxicological and hygiene advisers of the company or by outside consultants. They need to be in a form that identifies the limitations of the standard in terms of population at risk, duration and severity of exposure. Supporting information should be referenced and any judgements about the acceptability of risk noted.

Design guidelines are an important means of communication between designer and health adviser. It is therefore essential to have a procedure which ensures that all agents have their hazards reviewed and this review should form part of the information presented when a project is authorised. Such a procedure will be described in a later paper.

The responsibility of the health adviser does not end with the provision of quantitative and qualitative information on hazard to the designer. Work practices have to be developed which minimise health risks and provide effective treatment in emergency. In addition surveys of the working and general environment around new plant will be required to check that guidelines have been met and to provide information on employee and community exposure. Exposure data should complement medical records to identify any adverse effects as soon as possible.

## HUMAN PERFORMANCE

I have considered the control of agents which have adverse health effects, other speakers will amplify this aspect. A similar understanding of biological response and the development of design guidelines is essential if those working on a process are to operate and maintain it safely and effectively. Optimum lighting levels, temperature and instrument layout can be investigated and specified. The social organisation of work-management structure and hours of work may also require study - and may be a major influence in the acceptability of innovation.

In both the control of hazards and maximisation of performance aspects which are non-rational or unrelated to health protection, such as the perception and fear of risk and the allocation of benefits from improved performance may loom large. (Ashby (3)).

It is essential that these very human responses to innovation are perceived and considered throughout the design process.

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