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Emergency Exposure Indices for Industrial Chemicals

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ERRATUM

In Tables A3-1 (p.53), A3-3 (p.54) and A3-4 (p.55), the figures in the columns headed ppm (mg/m3) are in fact **ppm**.

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SUMMARY

This report examines the criteria for defining indices of exposure which could be used as guidance on the potential health effects from accidental chemical releases. It develops guidelines for their setting and use and provides examples for a few representative chemicals. Effects on the natural environment were deliberately excluded from consideration.

It was considered that the indices should relate to the whole population, including the very young and the elderly, the pregnant and those who are ill but not those whose health is so unstable that the outcome of their illness is unlikely to be related to the degree of chemical exposure. Three exposure indices were identified separating four zones of effect, thus

Death/Permanent Incapacity		*Disability*		*Discomfort*		*Detectability*
	EEI-3		EEI-2		EEI-1	

EEI(t_1)-1 is thus defined as "That airborne concentration for exposures lasting up to a specified exposure time (t_1) below which direct toxic effects are unlikely to lead to *DISCOMFORT* in the exposed population (including susceptible but excluding hypersusceptible groups) and above which, as the concentration increases, *DISCOMFORT* would become increasingly more common." and EEI(t_2)-2 and EEI(t_3)-3 for *DISABILITY* and *DEATH/PERMANENT INCAPACITY* respectively are defined similarly.

Guidance is given on the collection of experimental and human data, the evaluation of its quality and relevance, and on the selection of data for use in setting EEIs. Data on the toxic effects of exposure can be analysed in many ways; thus graphical, mathematical or computer techniques can be used. Various ways of deriving EEIs are considered and one, for chlorine, is worked through in detail as an example.

Expression of toxicological data in terms of numerical indices involves assumptions and simplifications of which those who use them must be aware. EEIs are only appropriate for excluding the likelihood of specified health consequences in the situation of accidental release and cannot be used for quantitative risk assessment purposes. The accuracy of EEIs in this predictive role will be greatest if toxicological data are available which relate to the relevant exposure duration.

It is possible to apply dispersion models iteratively or to plot exposure/time profiles for points of interest to determine the most appropriate exposure duration to use when setting EEIs. In relation to the use of EEIs, the isopleth envelope - the line surrounding successive concentration "contours" - defines an area outside which the effects relative to that EEI (i.e., Death/Permanent Incapacity, Disability or Discomfort) are unlikely to occur.

In order to test the comprehensibility of the EEI concept and the ECETOC guidance for setting them, a "ring test" was conducted to evaluate the consistency of values produced by different groups. Participants were asked to set EEIs for 15, 30 and 60 minute exposures (where possible) for phosphine, acrylonitrile and hydrogen fluoride. Eleven groups of one or, at best, a few people participated; there was considerable variability in the values. In general this variability resulted from different opinions on the validity or relevance of particular data. The variability would be overcome if EEIs were set by a larger, multidisciplinary group or by discussions between the several groups who had derived indices for the same chemical.

A. INTRODUCTION

In the field of occupational health and hygiene, atmospheric concentration limits have been established for a large number of gases, vapours and particulates to aid in the protection of workers' health. These concentration limits, generically termed "occupational exposure limits" (OELs), have a recognised place in evaluating and controlling occupational exposures to airborne chemicals. Some OELs refer to concentrations (8 hour - TWA) averaged over a normal working day and are set to protect against repeated exposures occurring over a working lifetime: other limits, such as Short Term Exposure Limits (STELs), are set to protect against the acute-toxic effects produced (e.g. ACGIH, 1989; Appendix 1).

To protect the health of communities from the effects of air pollution, more stringent standards have been promulgated for a smaller number of airborne substances which arise from industrial discharges to atmosphere, vehicle exhausts, domestic chimneys, farming and other activities (e.g. WHO, 1972). In the control of industrial discharges to the atmosphere the technique of mathematical modelling has been used to estimate the dispersion of discharges from industrial stacks under variable stack height, discharge concentration, volume rates and velocities and meteorological conditions. Models have been used to design stacks which will achieve adequate dilution of discharges before they reach ground level.

Over recent decades, during which standards for control of the workplace and the general environment have become more stringent, there have been a number of serious accidents resulting in chemical emissions which have involved the communities in the area surrounding the release. In 1976 at Seveso in Italy, an area of several hundred hectares was contaminated with 2,3,7,8-tetrachloro-dibenzodioxin (TCDD). Over 200 families were evacuated, 175 individuals developed chloracne and a large number of animals died and/or were disposed of to prevent TCDD entering the food-chain (Homberger et al., 1979). At Bhopal in India, in 1984, the release of methyl isocyanate is believed to have killed about 2,000 people and to have produced injury to the eyes and respiratory system of 10,000 - 20,000 individuals (Newman-Taylor, personal communication). Accidents such as these led authorities to develop legislation ("Seveso" Directive) on hazardous chemical installations (EEC, 1982, 1987, 1988). Over the same period of time, the availability of computers encouraged extension of the use of mathematical dispersion models in predicting the dispersion of atmospheric discharges in situations where there had been accidental release at ground level. These models may present their output as "contour lines" or "isopleths" of equal concentration which move with time. The term "isopleth" is used in this sense throughout this report. Alternatively, models may present the concentration at a specific point as a function of time.

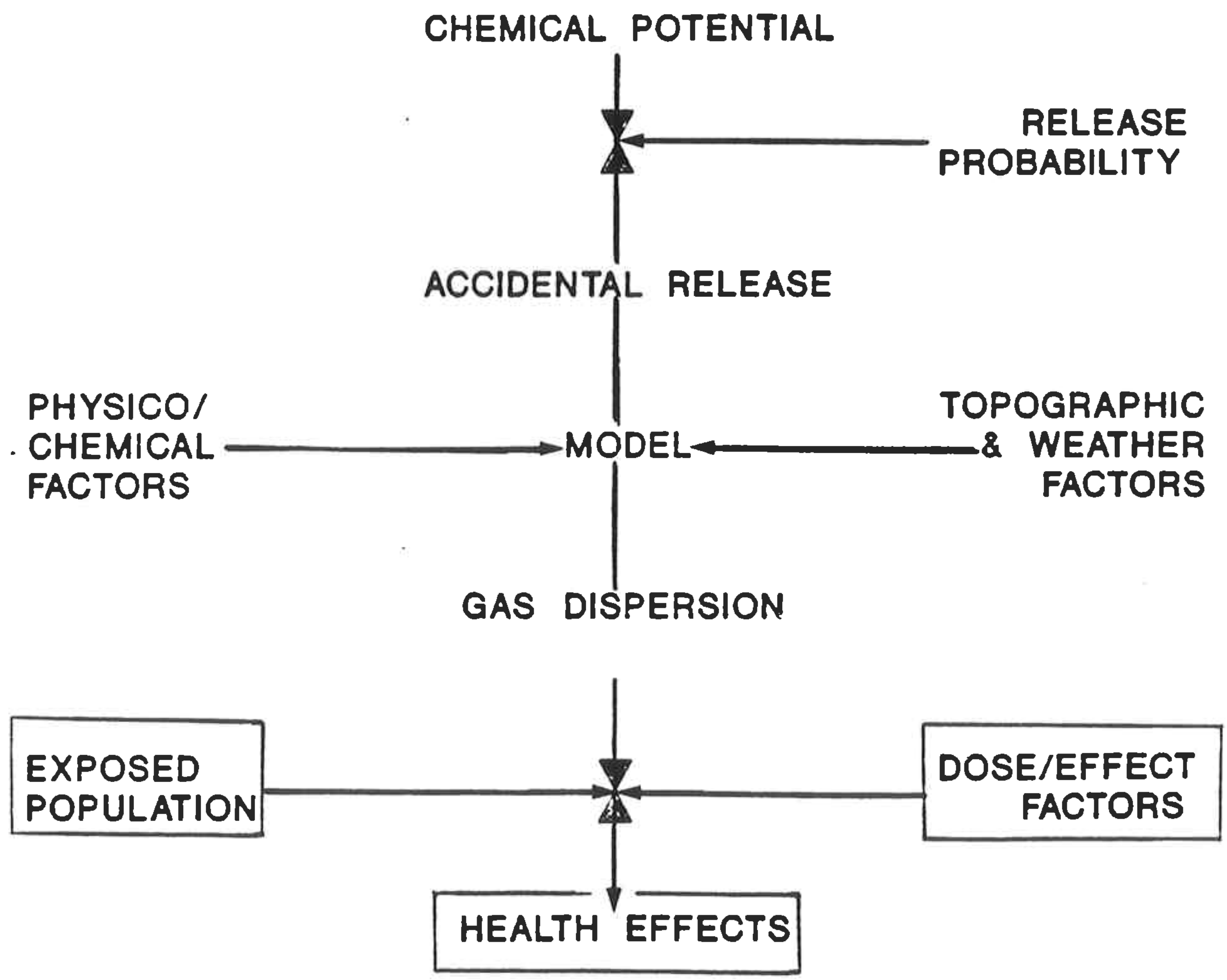
Under legislation such as that developed from the "Seveso" directive, the management of installations which constitute major accident hazards has been required:

- to assess and minimise the probability of an accident,
- to prepare (in conjunction with local authorities and emergency services) plans to mitigate its consequences and,
- to advise residents near such installations of the nature of the hazard and the measures taken to reduce the risks and the plans prepared to minimise the consequences of any accident.

Such action requires an evaluation not only of the probability of a release but also of its consequences in terms of effects on human life and health, environmental damage and material loss.

The effects on human health of an accidental release will depend on the toxicity of the substance, the concentration of substance in the atmosphere, the period of exposure and the distribution of people in the area surrounding the installation. The concentration in the atmosphere, as a function of time, will depend on the quantity released, the meteorological and other physical conditions including topography, obstacles, etc.. Mathematical models have been developed which help to predict the concentrations of gas or vapour occurring at different times at any point in the neighbourhood of an accidental release (cf Appendix 2). If these estimates are combined with data on population distribution, the numbers of individuals who may become exposed to various concentrations of substance can be assessed. To predict the severity of their injuries, knowledge of the adverse effects on health of various degrees of exposure to the substance is required.

The relationship of release, dispersion, exposure and health effects can be expressed in the following manner:



This report is concerned only with the factors contained in boxes.

The severity of an injury suffered by an individual will depend on:

- the actual exposure rather than the predicted exposure,
- the susceptibility to the effects of the chemical.

In relation to the first factor, the difference between actual exposure and predicted exposure will depend on the accuracy of knowledge on the quantity and rate of release, the reliability of the model and the local conditions which may produce deviations from the predictions, e.g. the immediate topography and whether the person is indoors or outdoors. In relation to the second factor, susceptibility may be influenced by age, nutritional state, preexisting illness, etc.. It is not therefore possible to predict the severity of the injury of a particular individual; "average" predictions for populations are more feasible.

The Scientific Committee of ECETOC recognised that there was a need for advice on how to derive exposure limits which could be used in evaluating the potential health effects on populations of airborne releases (of gases, vapours and dusts) of the type which could occur in major accidents. A Task Force was set up with the following Terms of Reference:

- to examine criteria for the defining of one or more exposure indices for both workers and the general population which can be used as guidance on the potential health effects resulting from accidental chemical release;

- to develop guidelines for setting such indices;

- to develop guidelines for use of such indices;

- to provide examples of indices for a few representative chemicals.

Effects on the natural environment were excluded although it was recognised that these are important when evaluating the total damage caused by any release and determining the necessary remedial actions. The factors required for evaluating the direct effects on human health are different from those considered when assessing the health effects arising from exposure to contaminated food or drinking water, or when assessing damage to plant and animal life.

Various atmospheric limits had been produced by several authorities for different purposes and these are detailed in Appendix 1. None of them was suitable as emergency exposure indices (Alexeeff et al., 1989). The basic concepts of suitable indices were therefore defined and the indices were termed "Emergency Exposure Indices" (EEIs). A closely similar concept was developed in parallel by the conjoint activities of the American Industrial Hygiene Association and Organisational Research Counsellors, Inc.. Their exercise has resulted in the definition of Emergency Response Planning Guidelines (ERPGs) and an administrative procedure for developing ERPGs for individual chemicals.

It was not the objective of this report to produce an extensive list of Emergency Exposure Indices for individual compounds, rather to recommend their definition and a procedure for setting them (Appendix 3) and to advise on their proper use. Steps have been taken to test the validity of the procedure by examining the consistency of figures produced by a number of groups who work in the field and who were provided with uniform data sets on the candidate chemicals (subsequently reported in Appendix 4).

EEIs as discussed in this report are intended to provide advice on the concentrations of gas etc. which, if not exceeded over the specified period of exposure, will avoid the clinical effects of interest. They do not provide evidence on the concentrations which will be needed to produce these effects. EEIs are therefore inappropriate for quantitative risk assessment (expressing the expected frequency of a clinical effect) and cannot be used for this purpose.

B. CRITERIA FOR ESTABLISHMENT OF EMERGENCY EXPOSURE INDICES

1. *CONCEPTS*

Any numerical index of toxic effect or any standard which is set to protect against toxic effects must reflect the relationship between:

- the population potentially exposed (i),
- the degree and pattern of exposure (ii),
- the nature and severity of the toxic effect(s) anticipated (iii),
- the proportion of those exposed who are subject to toxic effect(s) (iv).

Thus LC_{50} values refer to a specific animal species (i), an exposure concentration for a specified time (ii), the nature of the toxic effect is death (iii) and the proportion affected is 50% (iv). The TLV-STEL* values refer to workers (i), represent the exposure for 10-15 minutes by inhalation (ii), which is expected to be without significant toxic effects (iii) and in nearly all subjects (iv).

These four concepts necessary in establishing a definition for EEIs and the question of safety factors are considered in turn.

1.1. Population

The population concerned in any industrial accident involving the release of hazardous substances is the work force within the premises and the general public who live or work in the vicinity. The general public will contain groups who may be more susceptible to chemical exposure than the average person, e.g. the elderly, the young, the pregnant and those with minor acute illness or chronic illness compatible with participation in normal daily activities. The TF considered that EEIs set should take into account such susceptible groups but not more seriously debilitated, hyper-

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* Threshold Limit Values - Short Term Exposure Limits (ACGIH)

susceptible groups, e.g. those with pneumonia or myocardial infarction. Hypersusceptible groups of people have been excluded from this exercise because:

- such individuals are considered to be in a grave and unstable health condition and the outcome of their illness will not primarily be related to the degree of exposure. (When potentially exposed as a consequence of a major chemical release hypersusceptible people should, as a high priority, receive medical attention as a precautionary measure);
- data from experimental studies will not, normally, accurately predict the health effects of a chemical in a hypersusceptible individual.

Previous schemes have adopted similar criteria (Subcommittee Toxicity of the Dutch Committee for Prevention of Disasters by Hazardous Substances, 1974; AIHA, 1988).

1.2. Exposure

Following an accidental release of a quantity of a chemical, the concentration at any point to which the chemical disperses will be influenced by meteorological conditions and topography. As the gas-cloud passes and disperses the concentration at a particular point will generally rise to a maximum which will be sustained for a period and thereafter will fall towards zero. Indices of exposure could be the peak concentration, the average concentration over a specified time period or $\int_0^\infty C(t)dt$ (where C(t) is the instantaneous concentration at time t) or some other function of concentration and time.

It was considered that the most practical descriptors of exposure would be the exposure duration and a concentration which was not exceeded during the exposure. Emergency Exposure Indices would be most useful if the exposure period or periods to which they refer were of a duration pertinent to realistic scenarios for the installation under consideration. The description of these scenarios should incorporate both the evolution of release over time, as determined by product inventory, isolation and other mitigating devices, and dispersion factors as determined by meteorological and topographical conditions. In some cases, the exposure period will be fairly clear and similar for a wide range of concentrations. This will be the case when release is uniform and ceases abruptly and wind velocity is high. In other cases, exposure duration will vary considerably according to concentration of interest and in these cases an iterative process must be used to establish the appropriate duration for each EEI, beginning with an arbitrary period.

EEIs (for each toxic effect (see B.1.3)) should be established where the data allow it for a number of exposure periods up to 1 hour so that values most appropriate to predicted exposure periods may be chosen (few exposures will exceed 1 hour in duration).

Alternatively, the relationship between the EEI and time could be established (either as an equation or graphically) so that the EEI could be estimated for any relevant exposure period. Values should not be established where the data cannot support them and, where an equation or graphical relationship is established, the range of exposure durations for which it is considered valid must be defined.

1.3. Nature and Severity of Toxic Effects

Toxic effects can be of many different types and each can occur with varying degrees of severity. The type of exposure occurring in industrial accidents showed that the effects of importance are those that can occur in man following an acute exposure to an atmosphere containing the substance. Systemic effects will result chiefly from inhalation: local effects will involve the eyes, respiratory epithelium and skin.

In view of the public concern regarding carcinogens, the exclusion of carcinogenic effects from consideration in setting EEIs requires some comment. The TF recognised the importance of cancer as an endpoint but gave weight to the evidence showing that the probability of it occurring as a result of a single, short (accidental) exposure is extremely low.

The risk to the population would thus be small compared with that arising from the acutely hazardous effects of chemicals. The exclusion of cancer as an endpoint in setting EEIs does not reduce the protection of the public because EEIs are predictive in nature, rather than protective. With carcinogens as with other hazardous chemicals, the protection of the public will be achieved by substitution, inventory reduction and safe and secure storage and systems to minimise releases and reduce exposures should they occur. EEIs for carcinogens should be set on the basis of acute effects and it must be recognised that their role is confined to the prediction of the occurrence of acute effects.

There are limitless possibilities for describing the grades of severity of the immediate toxic effects of acute exposures. It is essential in defining EEIs that each should indicate a type of toxic effect which could clearly be seen to require a particular type of practical response. This approach is related conceptually to the clinical practice of triage in casualty management. In common with others working in this field (AIHA, 1988; Illing, 1989; Baxter et al., 1989), a need was recognised for three indices to represent the transitions between four graded effects.

Death/Permanent Incapacity is the most severe effect for which an exposure index could be provided; it is easily defined and is used by society to judge the severity of accidents. Two other grades of effect - disability and discomfort - though less well defined, place distinct demands on emergency and health care services. The term *disability* is used here to indicate that persons will require assistance or that effects of exposure will be more severe and/or prolonged without it. Persons suffering *discomfort*, though distressed and possibly requesting assistance, will not be dependent on it for minimising the severity or duration of the effect of exposure. Exposure insufficient to cause discomfort or adverse health effects may nevertheless be perceived by means of smell, taste or sensations (mild sensory irritation) which are not uncomfortable. This awareness of exposure might lead to anxiety and complaints and constitutes what is termed here *detectability*. Except for *death*, these graded categories of effect are not sharply demarcated but each merges into adjacent categories. The characteristics of the categories are set out