A TOXICITY HAZARD INDEX

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The development of a toxicity hazard index is described. The index sets out to provide a simple means of ranking the acute toxicity potential of sections of a plant or process. The assessment is based on a combination of the worst case release and consequent generation of vapour and a limiting tolerable concentration which is judged not to cause irreversible effects. Weighting factors based on material, process and layout features of the unit are assigned and the final index value is derived using a simple formula. A seven point ranking scale is provided, based on comparison with a selection of actual units. There is a close analogy with the ranking of fire and explosion hazards by the Mond Index, and this toxicity index can be used alongside the Mond Index.

KEYWORDS: Toxicity; Hazard Index; Ranking; Mond Index.

INTRODUCTION

The chemical industry continually reviews and develops the range of methods that can be used to identify hazards and assess risks on plant and processes. The last 25 years have been particularly fruitful, producing such methods as HAZOP, HAZAN, FMEA, Safety Audits and Rapid Ranking. Each of these methods has a different purpose and scope; an important managerial skill is the selection of appropriate methods to use for a new design, a process review or a modification. For certain tasks it is valuable to have a general purpose method for intercomparison of units within a plant or of processes throughout a business. To provide for this a number of indexes have been developed, the two best known being the Dow Index (1) and the Mond Index (2). These primarily consider fire and explosion hazards and have been in use and refined sufficiently by experience to be reliable indicators for these hazards. The Mond Index includes an allowance for toxicity effects but does not attempt to rank toxicity hazards or generate a separate toxicity index. There is a separate index used

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by the Dow Chemical Company, called the Chemical Exposure Index. This has been described in outline by Gowland (3a) and a brief description has been given by de Graaf (3b). It is based on five factors - for acute toxicity, quantity, molecular weight, distance from area of concern and process variables. Each of these is assessed for each single source which is identified as a possible source of a chemical release. For each factor a scale number between 0 and 5 is assigned and the product of these is used to determine which of four levels of action is required by plant management.

For many plants toxic effects will be considerable, perhaps the most far-reaching in potential. The lack of a toxicity index is not surprising in that the consequences of fires and explosions are well understood and can be related to the amount and condition of material in a straightforward way. Toxic effects are quite different. There are many possible effects, including both chronic and acute; there are several different routes of exposure and the length of exposure and frequency may be of importance; individuals may differ markedly in response to a particular dose; finally there is often difficulty in getting an agreed dose-response relationship for humans. Given these difficulties the task of constructing a meaningful toxicity index is formidable and, we believe, can only be done in a manner which resembles the existing fire and explosion indexes by carefully defining the scope. The fire and explosion indexes are concerned with the potential hazard related to fire or explosion, i.e. to acute effects related to the major conceivable incident that could be associated with the unit under assessment. The parallel for toxicity is an index which assesses the potential for immediate toxic effects to humans from the material within the unit. This has been done using the Mond Index as a model with the intention that the toxicity index can be used, when required, alongside the fire and explosion index, whilst remaining independent. It has been devised in such a way that, wherever appropriate, the factors in the fire and explosion index are used but additional factors have been added specifically related to toxicity and an entirely different base is used.

THE MOND INDEX

This Index was developed in the mid-1970s from the Dow Index with the intention of widening the range of applications, particularly to include oxidants such as chlorine, to cover a wider range of processes and to give more detailed staged indexes as part of its output. The estimates of MPPD (maximum probable property damage) and MPDO (maximum probable days outage) which feature in the Dow Index are not incorporated into the Mond Index although many other features were retained, albeit in a considerably modified form. Both indexes divide the plant into discrete units, identify the key hazardous materal within the unit and then derive a base factor named the Material Factor. In the Mond Index this is based on the heat of combustion or another exothermic process. Weighting (penalty) factors are then determined relating to special material hazards, general and special process hazards, quantities and layout. Combinations of the Material Factor and these weighting factors are then used to generate values for a fire index, for separate internal and aerial explosion indexes and finally for an overall "hazard" index. After review and confirmation the next stage in the full application of the index is to review and assess the safety and protective features of the process. Each feature is given an offsetting weight (of <1.0) and formulae are provided to adjust each of the original index values so giving new, reduced values for each index. Both the original and the revised index values can be interpreted on a descriptive scale. These scales have been calibrated by using the judgement of experienced analysts. There are from five to eight categories for the different indexes, rating the potential from "light" to "extreme". Experience has shown that very few operating units reach or exceed the fifth grade (of eight) in the overall risk index and this provides a useful basis for judgement and comparison. Use of the Mond Index is quite straightforward as it was intended to be used by experienced engineers as well as by safety specialists; there is an extensive manual giving explanations and examples for each stage (2).

Not surprisingly, when the Mond Index was developed to include such materials as chlorine, an attempt was made to include the potential toxicity hazards. Thus the first edition included a toxicity index. Experience in the use of this showed that there were severe limitations, partly due to the manner in which the penalty weighting factors were applied, but also to a reliance on the threshold limit value (TLV) to measure the toxicity of the key material. This is not always an appropriate measure for the potential effects from an intense short term release and so many anomalies appeared in the assessments. In the second edition of the Mond Index the toxicity index was discarded and toxicity features only as a source for a penalty factor based on the possibility that the presence of a toxic hazard will probably increase the response time in the event of an emergency and increase the difficulties of dealing with the resulting situation.

Experience with using the Mond Index has shown that there are many instances where a toxicity rating method would be valuable and so we describe here the development of such an Index. Our method attempts to rank the toxicity potential of a unit, considering only short term events and acute effects. It has been developed from first principles and, like the fire and explosion indexes, does not pretend to be a precise measure of the scope or range of effects from an incident. Instead it sets out to provide a broad ranking for different units and for different materials. As with the other indexes the scales are relative and based on experience, not on any absolute scale. It deliberately adopts the basic style of the Mond Index, using common factors wherever possible, so that it can easily be used alongside the Mond Index as an optional extra.

Basis for the Toxicity Index

The potential hazard due to toxic effects from a short term incident has been taken as the potential harm to any humans involved. Whilst this ignores the potential for environmental harm - an aspect of growing emphasis - it does cover the first concern and the one of most general occurrence in any release. It is also necessary to select the overriding route of exposure which can lead to effects. In most cases this is due to inhalation of vapour or mist. Skin effects - either absorptive, corrosive or scalding - can be very severe but are usually confined to a very short distance from a release point whereas inhalation effects may be important over a considerably greater range and are much more likely to extend off-site. Thus the inhalation route was selected as the basis for assessing toxic hazard potential.

In a fully quantitative analysis of the effects of a release of a toxic material the area affected by the release would be estimated. This requires firstly knowledge of the rate of vapour formation from the released material, secondly a limiting tolerable concentration (or dose) and then a suitable method of modelling the dispersion process. All these stages raise difficulties. In reality the release and vaporisation rates can only be approximately estimated due to lack of precise knowledge of the conditions at an unintended release point. Also the setting of the tolerable toxic concentration is a very subjective matter. Finally, dispersion is affected by many variables, including the weather, the nature, position and manner of release of the toxic material, the initial density of the released gas relative to air, local turbulence and adjacent structures. Whilst various computer programs are available to provide projection dispersion patterns it is still necessary to have expert interpretation if reliable conclusions are to be drawn.

Thus a good overall analyis requires inputs from several disciplines including engineers, occupational hygienists and mathematicians and modellers. Fortunately a fine level of detail in not required for a toxicity index; indeed it could be misleading to attempt to include an estimate of the range of a specified release, tempting the casual user to conclusions which may not be justified. Remembering that the purpose of the Index is to rank and compare units we can be satisfied with a measure of the area within which an intolerable concentration could be reached under standard conditions. It is argued below that this is proportional to the ratio of the rate of vapour generation and the toxic concentration. From these two parameters an initial toxicity factor is derived to be used as the base factor in the index in the way that the Material Factor is used in the Fire and Explosion Index. The formula used to generate the numerical value for this factor is arbitrary and is justified by the results.

THE TOXICITY INDEX

The index has been constructed so that the overall pattern closely follows the framework of the Mond Index. The stages are:

1 Divide the plant into units, each to be analysed separately.

2 Identify the dominant toxic material within the unit.

3 Estimate the maximum rate of vapour generation (Q) using the guidelines.

4 Select an appropriate value for the limiting vapour concentration (X).

5 *Calculate the base toxicity factor (T) from Q and X.*

6 Allocate penalty factors for material, process and layout features.

7 Determine the final index value by combination of T and these penalty factors; use the given scales to rank the toxic hazard as one of seven ranges from LOW to EXTREME.

These stages are discussed below.

Division of the plant into units.

The process of division into units should match changes of process conditions or operations within the overall plant, allow for changes which affect possible release rates in a significant way and separate materials of different toxic potential. Unnecessary divisions create extra work of analysis but it is important not to mask units of high potential by including them within a large section with materials of lower toxicity so that a low toxicity factor is used in the index. Normally it is expected that the units used in this index will correspond to those in the Mond Index.

Identifying the dominant toxic material within the unit.

In making this selection it must be remembered that it is the hazard from vapour dispersion which matters. Hence solids or liquids of high toxicity will not dominate unless the process conditions are such that vapour would be generated in a loss of containment incident or there is an unusual dispersion mechanism. Mixtures must be evaluated on the basis of the component which will give the greatest hazard. If fire products must be considered, as is certainly the case for pyrophoric materials, it is the toxicity of the combustion products which matter. This problem has been reviewed by Purser & Giddings (4). The first effect of importance from smoke products is, for our purposes, sensory irritation, followed by more severe consequences at higher concentrations. The level at which sensory irritation becomes significant for many smokes is at a level of *ca* 1×10^{-3} kg m^{-3} for a 5 minute exposure. We suggest this value is used whenever smoke products are considered to be dominant.

Estimating the rate of vapour generation.

This is now a routine part of any consequence analysis for incidents involving loss of containment. For virtually all conditions there are standard formulae or procedures for quantitative estimation and computer programs are available for the calculations. Examples of such programs are WHAZAN (Technica), CHEMS-PLUS (Arthur D Little) and EFFECTS (TNO). To make the estimate the physical properties of the material are needed in addition to the conditions at the release point. These will include the size and shape of the release orifice. External conditions may affect the vapour generation rate, for example when a cold liquid is spilled and the vapour generation rate depends on the area covered and the rate of heat flow from the ground into the spilt material. For the purpose of the Index it is assumed that, unless some worse case exists, the release is from a guillotine fracture of the largest pipeline within the unit. This is obviously a pessimistic selection but, when used consistently, should give a reasonable relative ranking of the hazard from unit to unit.

Selecting the toxic concentration.

A very simple basis has been taken, namely the concentration that over a 5 minute period of exposure would not normally lead to permanent injury nor inhibit an individual's ability for self-rescue within that period. The basis of the five minute period is that in an incident it can be expected that within that time a worker on a chemical plant or process would either have escaped from the affected area or have donned protective equipment. It is often difficult, however, to find a reliable assessment of the appropriate toxicity concentration for this period and then a more cautious estimate may have to be used. Occupation exposure limits (5) are not derived with single short periods of exposure in mind. Even the STEL values, intended for 10 minute exposure, may be unduly cautious since they allow repeated short period exposures within a lifetime subject to the other conditions of their use. However, the basis for these limits, when available as Toxicity Reviews (6) should be consulted since the required information for a tolerable level for a single short exposure may be provided. Another useful source is the IDLH (immediately dangerous to life or health) listing (7) which gives an indication of the concentration which ".....represents a maximum concentration from which, in the event of respirator failure, one could escape within 30 minutes without experiencing any escapeimpairing or irreversible health effects." The 1985 edition lists values for almost 400 compounds. More recently the American Industrial Hygiene Association has issued ERPG (emergency response planning guidelines) values for some common industrial materials (8). Three levels are given corresponding to different health effects. The middle value, the ERPG-2, is described as "The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action." As both IDLH and ERPG-2 values refer to a longer time than the 5 minute period selected for use here, there can be little doubt that use of these would be acceptable for the shorter period and would give a conservative estimate of the potential, i.e. tending to rank the hazard on the high side.

If neither of these values is available it will be necessary to review the toxicity data for the material and to make an estimate of the concentration which is tolerable over 5 minutes. This will involve consideration of the OES/MEL values and such other toxicity data as may exist. One common form is an LC_{50} value, usually based on a 30 minute or 1 hour period for rat or mouse. Expert opinion is needed in any conversion of such values for use in the index since the factor to be used depends greatly on the health effects induced by exposure and by the possibility of disablement at much lower concentrations than those producing death.

The principles which should be followed in deriving a value have recently been set out in the ECETOC Technical Report No.43 entitled "Emergency Exposure Indices for Industrial Chemicals" (9). This recommends that three levels are sought, set for the onset of discomfort, disability and death/permanent incapacity, to be known respectively as EEI-1, EEI-2 and EEI-3. Each value must be related to a particular time of exposure, which may be chosen for the intended use. Our requirement is for an EEI(5 min)-2. The Report provides guidance 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. The application of this Toxicity Index will be greatly facilitated if EEIs are established for a range of industrial used materials.

For illustration some readily available toxicity values are set out in Table 1 for four materials. This table illustrates a common problem, namely that there is usually a wide spread of values with the ratio between different measures varying from compound to compound. In addition, for less common or less widely used materials there may be a paucity of data. For such cases a possible approach, illustrated by Thomas (11), is based on a review of a considerable number of materials of different types, using the 1 hour LC_{50} value divided by 300. This normally gives a very conservative estimate. If this is done and the resulting value is below the short term exposure limit (STEL) in reference 5 then the STEL should be used.

TABLE 1
Some illustrative toxicity values

Material	OEL/MEL (10 min. STEL)	IDLH	EPRG-2	LC_{50}
Chlorine	1 (OEL)	30	3	293 (rat/1 h) 137 (mus/1 h)
Ammonia	35(OEL)	500	200	7340-16600 (rat/1 h) 4230-4840 (mus/1 h)
Formaldehyde	2 (MEL)	-	10	813 (rat/30 min)
Hydrogen fluoride	2 (OEL)	30	20	1276 (rat/1 h) 342 (mus/1 h)

Data taken from references 5 - 8, 10. All values in ppm.

Calculating the base factor (T) from Q and X.

The overall intention is to relate T to the area within which the chosen limiting concentration would be exceeded. In principle this requires modelling the dispersion process. Here, this is avoided through use of two simplifications. Firstly the wide range of weather conditions which produce such a large number of possible dispersion scenarios in real life can be ignored since it is only the relative ranking of the hazard potential within units which is sought and, if numbers are required, a standard set of conditions can be used. An example of these might be category D weather, ground level release, wind speed of 3 m/s etc. Secondly the differences between dense gas and neutral buoyancy releases are ignored. The justification for this is that, as table 1 indicates, the levels of interest are likely be tens or perhaps a few hundred ppm. In any dispersion modelling which stretches to these low concentrations the modelling process will have switched from a heavy gas model to a neutral buoyancy model well before the end of the calculation. It is then found that the estimated area affected by a dense gas release, calculated by a simple model which ignores heavy gas effects, is much the same as the value calculated by a better model (11). The differences lie in the shape of the footprint and the concentrations in the early part of the dispersion near the source. These are very important in a full analysis of a release but are not important for this Index where relative effects are being compared. For our purposes it is the total area that is of relevance. Finally it is noted (11) that the area affected is principally determined by the ratio of the limiting concentration and the rate of vapour generation. Thus a measure of the area potentially at risk from a release from a particular unit is the ratio (Q/X) of the rate of vapour generation (Q) and the toxic concentration (X). We have used this number as the first indicator of toxic hazard potential, measuring the rate of vapour generation in kg/s and the tolerable toxic concentration in kg/m^3. Values of Q/X which might be experienced in practice range over a very wide range since Q could vary from <1 to >1000 kg/s and X could also vary over a 1000fold range for different materials. To avoid having widely varying values of the "base" quantity for the Index a number of arbitrary functions of Q/X were tested to find one which gave a reasonably compressed range. The one selected and given the symbol T throughout this paper was $T = 2.\ln(Q/X) - 3$ using Q and X in the units specified above. This is unlikely to give a negative value (a minimum value of T=1 should be used) and limits the upper range to about 50.

Allocating penalty factors for material, process and layout features.

Material properties, process features, process hazards and layout aspects were selected for consideration. Wherever appropriate, direct use is made of the penalty factors used in the Mond Index but a number of additional ones have been added. The four categories are briefly described below.

Material properties: penalty factor M Only two factors had to be taken into account in this category. Firstly, although it has been argued previously that dense gas releases do not give major differences in affected areas from equivalent rates of releases of neutral buoyancy materials, there is a qualitative difference in the way a dense gas behaves near the source. For example such a release may back-up against a slope or move upwind and it can generate hazardous pockets which do not easily disperse. A positive penalty factor is recommended for such materials. In the opposite sense is the effect of a high level release. Provided this is of neutral buoyancy the groundlevel area affected will be reduced. Hence a negative factor may by justified. (The range of factors recommended is shown in Table 3.)

General process features: penalty factor P This is intended to allow for features of the plant and process which may affect the likelihood of a release or its magnitude. Here many of the features of the Mond Index are relevant and have been used. They cover the type of pipeline and the number of equivalent lines in the unit, the type of operation and handling, any reaction characteristics and the multiplicity of reactions or operations carried out in the unit and whether pumps or materials handling are used.

Special process factors: penalty factor S This section is intended to make allowance for features such as extremes of temperature or pressure since these make loss of containment more likely or more difficult to control. Material strength, corrosion and erosion effects as well as vibration and load cycling are included here. In addition material properties relating to flammability and any special operating conditions, e.g. closeness to the flammable region, are covered. Again, most of the features and factors mirror those in the Mond Index.

Layout features: penalty factor L Aspects covered here include effects on neighbouring units, below ground features, enhancement of impact damage, the site population density and distribution as well as an allowance for offsite consequences.

Most of these are specific to this toxicity index and could not be taken from the Mond Index. Two examples are discussed here. Thus it was considered necessary to include a factor to differentiate between the consequences of a release on a lightly populated site, e.g. a tank farm, from those of a similar release on a more densely populated site perhaps including more operators as well as personnel in control rooms, offices, canteens etc. A scale of penalty factors is suggested to cover these, the values depending on the type of plant, whether operators at high levels may be exposed, the closeness of other operating units and the distance to control rooms, etc. For offsite effects two conditions are used to determine the penalty factor. The first is the distance of the unit from the nearest site boundary beyond which non-employee exposure could occur. The second is the population density beyond the boundary. An analysis by Petts et al (12) suggests three levels of density, namely roads with isolated farms, sparse detached housing and dense terraced or semi-detached housing. Since the type can be easily established using as Ordnance Survey map, this classification has been used as the basis for recommending the penalty factors.

Determining the final index value.

This is done by combining T with the penalty factors using a formula based on those used succesfully in the Dow and Mond Indexes. The formula used for the toxicity hazard index value (THI) is:

$$\text{THI} = T \,.\, (1 + M/100) \,.\, (1 + P/100) \,.\, (1 + S/100 + L/100)$$

In this equation it can be seen that the penalty factors M, P, S and L, are used as percentage weighting factors on the original base factor, T. The final step, which is useful but not essential, is to interpret the THI value into a qualitative description of the hazard as shown in Table 2.

TABLE 2
Conversion factors for THI values

THI range	*Toxicity group*	*Qualitative ranking*
<25	1	LOW
<75	2	MILD
<150	3	MODERATE
<250	4	HIGH
<375	5	VERY HIGH
<550	6	SEVERE
≥550	7	EXTREME

The basis for the division of the THI range was done by an analysis of 7 units which had earlier, and independently, been given a qualitative ranking by two of the authors (PD/TRG) and for which sufficient information was available for a full analysis to be carried out. The units included storage units, distillation units, reactors and tanker off-loading. They included one in each of the groups described above.

Three of these units are briefly described below and the details of the ranking by this toxicity index are given in Table 3.

Case 1 Storage tanks holding methyl methacrylate.

The worst realistic scenario is an extensive spillage into the bund. The vaporisation rate was calculated from the exposed area and vapour pressure, making reasonable assumptions about the windspeed and ambient temperature. For methyl methacrylate the IDLH is 4000 ppm and this has been used. The penalty factors in this case are few, being assigned for flanged pipework (25), a flammable material (25), nearby plant with normal works level of manning (50) and a very small factor for an offsite effect (10). These give a THI value of 8.

The judgemental ranking was 1/7

Case 2 EDC still operating at 10 psig and up to 110 °C.

Fracture of the largest pipe on this unit would lead to a rapid loss of material which, at the operating temperature would partially flash. Taking the vapour generation rate as the flash rate of the escaping liquid gives a generation rate of 0.29 kg/s. The IDLH for EDC is 1000 ppm and this has been used although it is noted that a value of 1000 ppm is given in reference 10 for an LC_{50} (inh-rat 1000 ppm/7 h) whilst the STEL value is 10 ppm. Thus a first calculation of the THI has been made using the IDLH value of 1000 ppm but is has also been repeated using an intermediate value (100 ppm). This system attracts penalty factors for dense gase (25), multiple flanged pipework (25 + 50), the type of operation (10), flammable material above its boiling point (50), a nearby control room and other closely spaced units (275) and a relatively short distance to the site boundary (50). Using X = 1000 ppm as the base toxicity level leads to a THI of 60 whilst use of X = 100 ppm gives a THI value of 111.

The judgemental ranking was 3/7

TABLE 3

	CASE STUDY	1	2	3
	UNIT: Pressure Temperature	Storage tank ambient ambient	Still 0.7 barg 110 C	Chlorinator 2.7 barg 110 C
MATERIAL:		MM	ClCH2CH2Cl	chlorine
MOLECULAR WEIGHT	M/(g/mol)	100	99	71
MODE OF RELEASE:		Vapour from bunded liquid	7% flash off liquid release	Vapour 25 mm hole
RELEASE RATE	Q/(kg/s)	0.45	0.29	1.11
TOXICITY VALUE ESTIMATED BY:		IDLH	see text	ERPG-2
TOXICITY LIMIT (ppm)	X/ppm	4000	100	3
TOXICITY LIMIT	X/(kg/m3)	1.59E-02	4.19E-04	9.02E-06
TOXICITY FACTOR	T = 2.ln(Q/X)-3	3.56	10.09	20.44
SPECIAL MATERIAL HAZARDS, M				
4.1 Dense gas	0 - 50		25	50
4.2 Neutral bouyancy, high level	0 to -50			
	M =	0	25	50
GENERAL PROCESS HAZARDS, P				
5.1 Type of pipeline	0 - 50	25	25	50
5.2 Multiplicity of pipelines	0 - 50		50	50
5.3 Physical operations	0 - 25		10	
5.4 Handling and material transfer	0 - 150			
5.5 Reaction characteristics	0 - 100			50

5.6 Multiplicity of reactions	0 - 50				
5.7 Transportable containers	0 - 100				
5.8 Gear pump	0 - 50				
		P =	25	85	150
SPECIAL PROCESS HAZARDS, S					
6.1 High pressure factor	p - as in Mond Inde		1	1	4
6.2 Low temperature	0 - 100				
6.3 High temperature					
6.3.1 Flammable materials	0 - 50		25	50	25
6.3.2 Material strength	0 - 25				
6.4 Corrosion/erosion hazards					
6.4.1 Internal corrosion	0 - 150				
6.4.2 External corrosion	0 - 100				
6.5 Vibration/load cycling	0 - 100				
6.6 Reaction control difficult	0 - 300				20
6.7 Operation in/near flammable	0 - 225				
6.8 Above average explosion hazard	0 - 250				
		S =	26	51	49
LAYOUT HAZARDS, L					
7.1 Works population density	0 - 550		50	275	200
7.2 Below ground features	0 - 100				
7.3 Structure design	0 - 100				100
7.4 Impact damage	0 - 200				50
7.5 Offsite effects	0 - 200		10	50	
		L =	60	325	350
		THI=	8	111	383
Judgemental rank (on range of 1 - 7)			1	3	5

Case 3 A train of chlorination reactors.

This set of vessels posed a problem in that there is a steadily changing composition from one reactor to the next. To obtain a balanced assessment a mid-composition reactor has been taken and analysed. Line fracture in this system would lead to the release of chlorine vapour at just over 1 kg/s. The limiting concentration used in the assessment was the ERPG-2 value of 3 ppm (see Table 1) but an evaluation was also made using the IDLH of 30 ppm. The penalty factors are given for a very dense gas (50), for the type and multiplicity of pipelines (50+50), a high pressure factor (4), a flammability penalty for the other material present (25), a small factor (20) associated with control problems, and three layout penalties - for the high local density on this old plant with an aggregation point nearby (100+100), for the enclosure (100) and for its vulnerability to impact damage (50). There was no offsite effects penalty due to a combination of the siting of the unit within the plant boundary and also due to the enclosure of the units in a building. This unit gave the highest THI value of the three discussed here, namely 383 (or a THI of 296 if the IDLH concentration is used).

The judgemental ranking was 5/7

DISCUSSION

The application of the index has raised few problems. In particular, for anyone familiar with the Mond Index, the process of division of a plant into units and the evaluation of the penalty factors is quite straightforward. For the units we have evaluated it has not been difficult to identify the key toxic material, even when mixtures were present. Few difficulties will be encountered here. Similarly it did not prove difficult to estimate the rate of vapour release since simple rules have been proposed to select the worst release and so standard methods and formulae can be applied to derive the vapour generation rate. The major problem, as illustrated above, lies in the selection of the limiting toxic concentration. The outcome for the three case studies is summarised below:

TABLE 4

Overall results for case studies 1 to 3

Case study	THI values	THI rank (1 to 7)	Judgemental rank (1 to 7)
1	8	1	1
2	60 (111)	High 2 (mid 3)	3
3	383 (296)	Low 6 (mid 5)	5

It is notable that even with a tenfold change in the value taken for the limiting toxic concentration - as illustrated in cases 2 and 3 - results in a change of the THI rank of only half a category. Such a difference is not a major problem in using the Index given that its intention is to rank the relative acute toxic hazards of different units. Whilst it is reassuring that there is good agreement between the ranks derived using the Index and the judgemental ranking of the three units it must be remembered that these are three of the seven units chosen to "calibrate" the THI values and to divide them into the seven categories of LOW to EXTREME.

CONCLUSIONS

A working acute toxicity index has been generated which closely follows the pattern of the Mond Index. It has been tested on a range of units and found to be easy to apply. The selection of the most appropriate limiting toxic concentration may affect the final ranking by about half a category. It has been found that selecting this limiting concentration is the most difficult aspect of using the index. The index has been tested on a small range of units; its usefulness can only be demonstrated by application to a much wider range and the authors would cooperate in any opportunity to do this. Then, as with the Dow and Mond Indexes, a refined version of proven value should emerge.

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