HAZARD RATING OF SUBSTANCES SYSTEMS DEVELOPED BY NIOSH'S RTECS-NOHS AND USEPA

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ABSTRACT

This research study attempts to evaluate the hazard rating of substances systems developed by NIOSH's (National Institute for Occupational Safety and Health) RTECS-NOHS (Registry of Toxic Effects of Chemical Substances – National Occupational Hazards Survey) and USEPA (United States Environmental Protection Agency). Evaluation on rating methodologies and parameters used by both NIOSH and USEPA's systems reviewed that both systems aim at ranking common industrial organic compounds used or released into the atmosphere with special focus on chemical toxicological health effects. The NIOSH's RTECS-NOHS system solely emphasizes on health risks depending on chemical toxicological effects pertaining to eight health effect endpoints, whilst USEPA's system considers toxicological effects, occupational standards, chemical production rate, fraction of production loss and chemical's volatility characteristics. It is also found that NIOSH's system allows users great flexibility in defining toxicological priorities by assigning a multiplier or/and adding in the constants. The scoring system developed by USEPA for the individual parameters considered in the priority ranking range from zero to five without providing flexibility for users in defining toxicological priorities or assigning multipliers. It is also found that certain modifications must be made to account for fundamental differences between worker and population exposures for application purposes.

Keywords : *Exposure Index, Hazard Rating, Health Effect Endpoints, Preliminary Scoring, Priority Ranking, Toxicological Health Effects*

1 INTRODUCTION

The identification of the relative toxicities of chemicals currently used by a facility or for the whole industry within the Commonwealth of Massachusetts was accomplished by reprocessing the computer-based NIOSH's RTECS-NOHS data files (extracting the relative toxicity indices of the chemical compounds that matched with those currently listed in the Massachusetts TRI (Toxic Chemicals Release Inventory) data base) [1]. The NIOSH data were first compiled in 1982 and NIOSH scientists are updating the RTECS-NOHS using the most recent chemicals identified in the industry and the most updated RTECS toxicological data from time to time. All of the toxic chemicals recorded in the USEPA TRI [1] data bases, reported under the Toxic Chemical List defined in Section 313 for the U.S. Emergency Planning and Right-To-Know Act (SARA Title III) were identified [3]. In Massachusetts, a total of 97 different organic and inorganic compounds were identified which were reported as large quantity generators based on 1989 TRI data. The 1983 RTECS-NOHS chemical relative toxicity data were matched to the 97 chemical compounds in the Commonwealth that reported under SARA Title III [3]. Thus, a rank-ordered list of relative Health Risk Index Numbers (*HRIN*s) was generated.

Environmental persistency of chemicals in the air is an integral part of the model. The method of estimation of the atmospheric fate of a chemical preferred by USEPA is the use of chemical reactivity data [4]. For most organic chemicals, degradation rate constants are generally derived based upon the reactions with the hydroxyl radical (OH) and ozone (O3). Howard et al. (1991) on behalf of the USEPA completed compiling the rate constants for chemicals of anthropogenic origin for individual abiotic and biotic degradation processes. Typical half-lives in the atmosphere are on the order of hours [5].

2 NIOSH'S RTECS-NOHS SYSTEM

One of the primary elements in the development of the toxic chemicals prioritization model is the adoption of the existing "Hazard Rating of Substances System" developed by NIOSH (October, 1983), generally known as "NIOSH's RTECS-NOHS SYSTEM" [6]. This system was developed by NIOSH as an instrument to use the National Occupational Hazards Survey (NOHS) data for surveillance [7]. NOHS was conducted from 1972 to 1974 in approximately 5,000 industrial facilities throughout the United States of America, and the data collected were used to estimate the extent of worker exposures, that is, number of chemicals to which workers are potentially exposed, duration of the potential exposure, and percent of worker in the industry who are potentially exposed. In order to completely reflect the relative impacts of the individual chemicals on the workers, NIOSH used these data to calculate an exposure index for each substance found in a given industry and RTECS. This exposure index is the multiplied by a hazard rating (Hazard Risk Index Number or HRIN) calculated from NIOSH's RTECS.

2.1 Specific Test Classes

For each chemical, the RTECS database includes one record of citation for each type of toxicity test in the literature. The RTECS data are input to a computer file, and January 1981 computer tape version of RTECS contains positive effects of 45,156 different chemicals. Each report of toxicity (that is, test record) is characteristically expressed in terms of:

- the daily or single dose of the chemical;

Table 1: Test classes

	Route	Species	Test	Toxic Effect		Route	Species	Test	Toxic Effect		Route	Species	Test	Toxic Effect
1.	ANY	ANY	ANY	CAR	34.	IPR	RAT	TDLO	TER	67.	ORL	RAT	TD	ETA
2.	ANY	ANY	ANY	ETA	35.	IPR	RAT	LD50	AT	68.	ORL	RAT	TDLO	CAR
3.	ANY	ANY	ANY	KED	36.	IVR	CAT	LDLO	AT	69.	ORL	RAT	TDLO	ETA
4.	ANY	ANY	ANY	TER	37.	IVN	CAT	DL50	AT	70.	ORL	RAT	TDLO	NEO
5.	ANY	ANY	ANY	TFX	38.	IVN	DOG	LDLO	AT	71.	ORL	RAT	TDLO	TER
6.	ANY	ANY	CTT	MUT	39.	IVN	DOG	LD50	AT	72.	ORL	RBT	LDLO	AT
7.	ANY	ANY	DLT	MUT	40.	IVN	GPG	LDLO	AT	73.	ORL	RBT	LD50	AT
8.	ANY	ANY	DND	MUT	41.	IVN	MUS	LDLO	AT	74.	PAR	MUS	LDLO	AT
9.	ANY	ANY	MSC	MUT	42.	IVN	MUS	LD50	AT	75.	SCU	CAT	LDLO	AT
10.	ANY	ANY	OTR	MUT	43.	IVN	RAT	LDLO	AT	76.	SCU	DOG	LDLO	AT
11.	ANY	ANY	SCE	MUT	44.	IVN	RAT	LD50	AT	77.	SCU	FRG	LDLO	AT
12.	ANY	ANY	VIT	MUT	45.	IVN	RST	LDLO	AT	78.	SCU	GPG	LDLO	AT
13.	ANY	ANY	VIV	MUT	46.	IVN	RST	LD50	AT	79.	SCU	GPG	LD50	AT
14.	ANY	HAN	CTT	MUT	47.	IVN	MUS	DND	MUT	80.	SCU	MUS	LDLO	AT
15.	ANY	HMN	CTT	MUT	48.	ORL	BRD	LDLO	AT	81.	SCU	MUS	LD50	AT
16.	ANY	HMN	DNS	MUT	49.	ORL	BRD	LD50	AT	82.	SCU	MUS	TDLO	CAR
17.	ETE	RST	SSSS	PI	50.	ORL	CAT	LDLO	AT	83.	SCU	MUS	TDLO	ETA
18.	IHL	GPG	LCLO	AT	51.	ORL	CAT	LD50	AT	84.	SCU	MUS	TDLO	NEO
19.	IHL	HMN	TCLO	TFX	52	ORL	DOG	LDLO	AT	85.	SCU	RAT	LDLO	AT
20.	IHL	MUS	LCLO	AT	53.	ORL	DOG	LD50	AT	86.	SCU	RAT	LD50	AT
21.	IHL	MUS	LC50	AT	54.	ORL	GPG	LDLO	AT	87.	SCU	RAT	TD	ETA
22.	IHL	RAT	LCLO	AT	55.	ORL	GPG	LD50	AT	88.	SCU	RAT	TDLO	ETA
23.	IHL	RAT	LC50	AT	56.	ORL	HMN	LDLO	AT	89.	SCU	RAT	TDLO	NEO
24.	IPR	GPG	LDLO	AT	57.	ORL	HMN	TDLO	TFX	90.	SCU	RBT	LDLO	AT
25.	IPR	GPG	LD50	AT	58.	ORL	MUS	LDLO	AT	91.	SCU	RBT	LD50	AT
26.	IPR	MUS	LDLO	AT	59.	ORL	MUS	LD50	AT	92.	SKN	MUS	TD	ETA
27.	IPR	MUS	LD10	AT	60.	ORL	MUS	TDLO	CAR	93.	SKN	MUS	TDLD	ETA
28.	IPR	MUS	LD20	AT	61.	ORL	MUS	TDLO	ETA	94.	SKN	MUS	TDLO	NEO
29.	IPR	MUS	LD50	AT	62.	ORL	MUS	TDLO	NEO	95.	SKN	RAT	LD50	AT
30.	IPR	MUS	TDLO	NEO	63.	ORL	MUS	TDLO	TER	96.	SKN	RBT	LDLO	AT

NIOSH, 1981 [8]

- the species of animal tested and/or cell type used in the test;
- the route of entry;
- the test procedure; and
- the health effect endpoint (e.g., Lethal Dose (LD), Lethal concentration (LC)).

In RTECS [8], the route of entry or administration, test species, test procedure and health effect endpoint (such as LD_{50}) are defined as a "test class." For a given chemical test class, the database includes only one record, the record with the lowest reported dosage producing the health effect. To prevent the fact that test classes with small populations of data would be of far less use than those that have data on many chemicals (in attempt to use the data from different test classes to compare and rank chemicals), only data derived from the methods or test classes where at least 65 different chemicals have been tested are included. However, this led to an exclusion of a significant part of the chronic test classes while all of the test classes with acute toxicity end-points were included. In order to include the chronic test classes, those test classes that were excluded by the 65 chemicals threshold were combined by grouping all of the test species of animals and routes of entry into an "any" classification. A total of 96 classes were produced as listed in Table 1.

2.2 Dose Unit Consideration

In RTECS, different units are used in reporting doses that produce toxic effects. In this RTECS-NOHS model, an attempt was made to compare the data from chemical to chemical by standardising the units: a) all dose units for the inhalation route were converted to parts per million; and b) all dose units on data other than inhalation were converted to milligrams per kilogram of body weight, and then to molar form (i.e., millimoles per kilogram of body weight that correspond directly to the number of molecules which produced the observed effect). This would enhance the toxicological activity of the chemical.

2.3 Normalisation of Dose Data

Due to the fact that chemicals have been tested in a number of ways and a large number of the individual chemicals have been tested in two or more test classes, the doses of these tests could be regarded as a direct measure of the relative toxicities of the chemicals. In addition, the test classes span a number of toxic effects such as acute toxicity, carcinogenicity, mutagenicity, etc. Thus, in order to compare dose data across test classes and from chemical to chemical within a test class, the dose data were normalised so as to eliminate the effects of using specific test species and routes of administration.

Data normalisation was carried out in such a way that each of the test classes was considered separately. The observed dose; d_i in each specific test class was expressed in terms of the lowest dose, the average dose or the range of the doses in the class. Since each test class was normalised in the same manner, doses from across test classes become more comparable and chemicals could be ranked. The normalised dose dn was calculated as follows:

$$d_n = \frac{d_{\max} - d_i}{d_{\max} - d_{\min}} \quad (1)$$

where d_i = observed dose; $d_{\max}$ = maximum observed dose in the test class; and $d_{\min}$ = minimum observed dose in the test class, in which all doses in Equation 1 are expressed as the natural logarithm of the dose, as described in the preceding discussion.

The difference between the highest dose and the observed dose in the test class is divided by the difference between the maximum and minimum doses in the test class (the range of doses in the class). Thus, the normalised dose; d_n ranges from zero for the highest dose (the least toxic chemical) to one for the lowest dose (the most toxic chemical). The same function was used to produce normalised dose data in each of the 96 test classes as shown in Table 1.

Since the wide variation in doses from the least toxic chemicals to the most toxic within a class was as much as fourteen significant figures, and with extremely small differences in doses for the relatively more toxic chemicals, the doses were converted to logarithmic scale. This not only produced dose numeric within two orders of magnitude, but also made possible to recognise the negligible differences in doses that exist for relatively more toxic chemicals. As all the normalised doses d_n produced in Equation 1 were negative values, a constant of 30 was added to assure that all values would be positive. All units in the computations were either in millimoles per kilogram of body weight or parts per million. Table 2 illustrates an example of the calculated logarithm values in addition to showing the minimum (most toxic dose) and maximum (least toxic dose) logarithm values for each test class, and with the RTECS accession number for the chemicals. The corresponding number of test citations in each test class was also displayed in Table 2.

The results derived from the RTECS data preparation in terms of normalised dose and test class data showed that the best classes that met the criteria (test class, Table 1) are divided into groups pertaining to eight health effect endpoints (called the Health Risk Index, or HRI Algorithm). They are: (1) acute toxicity (*AT*); (2) carcinogenicity (*CAR*); (3) equivocal

Table 2: Test classes showing dose Log values, RTECS chemical reference cited and number of records per test class

Testclass no.	Minimum (130.00) log value	Minimum log value RTECS accession no.	Maximum (130.00) log value	Maximum log value RTECS accession no.	No. of test citations
1.	22.566498	RP5950000	39.774017	DV4900000	299
2.	22.090057	KG2975000	39.483154	K10175000	418
3.	19.255035	HH2625000	37.786942	X07350000	253
4.	15.708064	HP3500000	34.117218	DJ5800000	300
5.	14.211206	TJ2800000	37.774139	ZC0110000	360
6.	20.531967	KE4100000	33.413162	EZ6475000	108
7.	18.636520	KE4390000	35.916260	LZ6500000	83
8.	13.820038	RB7875000	40.296600	MU7175000	189
9.	17.499817	FZ3675000	41.818069	BZ8580500	114
10.	17.499817	FZ3670000	31.169800	PB2100000	70
11.	10.375351	TP2450000	33.688873	IQ0525000	88
12.	19.724854	AV9800000	38.070892	KU9625000	102
13.	15.105679	AB1925000	33.493240	RC8965000	142
14.	17.754761	YY8050000	40.126617	RS2060000	150
15.	10.663040	DK7175000	35.562271	KQ6300000	139
16.	16.184479	UZ9850000	34.605164	QH4560000	72
17.	16.739517	EJ8225000	31.987122	KL5600000	1454
18.	27.723434	DT7000000	41.512924	PA8400000	102
19.	25.355911	RN1140000	41.091431	PC1400000	89
20.	27.271454	DT7000000	43.458832	K11100000	375
21.	19.947906	LI8524000	43.764206	KU5340000	173
22.	27.812057	DTI7000000	43.704575	FG4920000	424
23.	27.908203	TA0700000	48.927490	TE7000000	219
24.	20.140060	BO8785750	34.463669	KQ6300000	110
25.	23.002609	WII6650000	34.479172	MA1575000	171
26.	20.081467	CB9459000	34.978333	ZF0800000	1760
27.	11.068497	VC3968770	30.315033	AF1710000	434
28.	22.160370	AU1490000	29.777191	TX7020000	83
29.	14.339328	RT6475000	36.516541	Q12975000	12495
30.	25.502625	CH1795065	33.905306	MH7700000	82
31.	20.898514	AU1575000	35.331802	LQ2100000	103
32.	20.939194	AR5950000	34.659348	KN9275000	865

NIOSH, 1977 [7]

tumorigenic agents (*ETA*); (4) mutagenicity (*MUT*); (5) neoplasticgenicity (*NEO*); (6) primary irritation (*PI*): (7) teratogenicity (*TER*); and (8) other toxic effects (*TFX*).

The Health Risk Index Number (*HRIN*) is based on the potency of a chemical compound in producing each of the eight different health effect endpoints. Potency is measured numerically between zero and one (highest potency requiring the lowest dose is rated as one), which is the relative daily single dose of a chemical compound (millimoles of substance per kilogram of body weight of species or parts per million) compared to doses of all other chemical compounds in RTECS that have been tested for the same endpoints using the same methodology. The summation of all the relative potencies for each chemical over all the endpoints is termed as the Health Risk Index (HRI), representing a number form 0.000 to 1.000 for individual endpoints. Thus, the sum of all endpoints weighted equally would range from 0.000 to 8.000.

Since one of the main objectives of NIOSH is that any of the algorithms in the model is responsive to user needs, constants and multipliers are introduced, and the final HRI algorithm is expressed as:

$$HRIN = (aAT + b) + (cCAR + d) + (eETA + f) + (gMUT + h) + (iNEO + J) + (kPI + l) + (mTER + n) + (oTFX + p) \quad (2)$$

where, for each test within each chemical, *AT* = the average of all acute toxicity normalised doses; *CAR* = the average of all carcinogenic normalised doses; *ETA* = the average of all equivocal tumorigenic agent normalised doses; *MUT* = the average of all mutagenic normalised doses; *NEO* = the average of all neoplasticgenic normalised doses; *PI* = the average of all primary irritation normalised doses; *TER* = the average of all teratogenic normalised doses; *TFX* = the average of all other toxic effect normalised doses; "+" = an addition which is performed only if the associated sub-*HRIN* is not equal to zero. Lowercase letters "*a*" through "*o*" indicate variable numerical factors (values 0 to 9) for the enhancement of suppression of individual sub-*HRIN* values.

The HRI algorithm illustrated in Equation 2 would produce a Health Risk Index Number (*HRIN*) that is related directly to the overall observed toxicity of the chemical compound; the higher the *HRIN*, the higher the toxicity. In order to allow the user great flexibility in defining toxicological priorities, one can always assign a multiplier (*a, c, e, g, i, k, m*, and *o*) in Equation 2, or one can totally eliminate any sub-HRIN from the equation by assigning a multiplier of zero. To offer more flexibility, the expression allows the user to rank or prioritize the terms by adding in the constants (*b, d, f, h, j, l, n, and p*).

To be consistent with the most recent 1989 TRI data, the list of toxic chemicals manufactured, used or processed in the Commonwealth of Massachusetts in 1989 covered under the SARA Title III were matched with the 1981 RTECS-NOHS chemical list. About twenty of the toxic chemicals (regardless whether they are carcinogens or not) that appeared on the 1989 Massachusetts TRI list did not appear on the 1981 RTECS-NOHS list. The attempt to produce a complete list of chemicals (covered by the SARA Title III) obtained from the 1989 Massachusetts TRI database was further complicated by the fact that a number of the 1981 RTECS-NOHS list chemicals were then not identified as carcinogens or suspected carcinogens, but are now confirmed as carcinogens. In order to obtain comparatively reasonable chemical relative toxicity indices, the index numbers for the "additional" (1989 TRI) and "unidentified carcinogens" (1981 RTECS-NOHS) chemical compounds were computed with the following assumptions:

1. All known and suspected carcinogens that were added onto the 1981 RTECS-NOHS list were substituted with the MEDIAN value derived from the carcinogen HRIs of the existing 1981 RTECS-NOHS list. The value of the median was calculated to be 0.269 (CAR = 0.269).

2. The non-carcinogens included in the 1989 Massachusetts TRI list but not on the 1981 RTECS-NOHS list were added onto the 1981 RTECS-NOHS by accounting only *AT, PI* and *TFX*. The *AT, PI* and *TFX* were compiled by taking the averages of the HRIN of the individual categories.

3. For carcinogens that were not identified as carcinogens in the 1981 RTECS-NOHS list, the same calculations as performed in (1), the median of *CAR* = 0.269 would be used, and *AT, PI*, and *TFX* would be derived the same ways as in (2) above.

The summary of the additional and amended *HRIN* computations for chemical compounds as described in the previous discussion is demonstrated in Table 3, which is self-explanatory. In the 1981 RTECS-NOHS reports, where more than one study was done for the same chemical compound, same test methodology and same health effect, the RTECS general policy is to limit the entries for the chemical reporting the highest potency (i.e., the lowest dosage) for each test class. The quality of research such as test animal strain and sex, detailed information on dose preparation and administration, purity of test chemical, and comparison with other similar tests reported in the literature were not evaluated before inclusion in the RTECS [9]. Since the RTECS data were compiled in 1981, it could be interpreted as reflecting the research priorities of the prior decade or two [11]. Five out of eight HRI health effect endpoints rate the potency for deoxyribo nucleic acid (DNA) damage including carcinogenicity, mutagenicity, teratogenicity, neoplasticity, and equivocal tumor acitivity. There is one endpoint for primary irritation effects (which is limited to eye and skin irritation) and one for acute toxic effects. However, the category of "other toxic effects" (*TFX*) includes all other chronic effects such as liver damage, kidney damage, neurotoxic effects, or blood cells effects. For *TFX*, most data were gathered from literature of actual human experiences rather than animal studies [9].

Table 3: Estimations of HRIN for chemicals not included in 1972 NOHS to 1974 NOHS

	AT	CAR	PI	TFX
KNOWN & SUSPECT CARCINOGEN	0.241	0.269	0.14	0.165
NON-CARCINOGEN	0.241	0	0.14	0.165

NIOSH, 1977 [7]

Averaging the ratings for each endpoint to obtain the "averaged rating" for the particular endpoint (e.g. *CAR*), would

result in values biased toward those chemical compounds with a single high score for one endpoint, but with extremely small or no data in other areas. In addition, averaging the ratings of such nature would give rise to assigning relatively low values for chemicals that have been thoroughly studied with detailed toxicological data [10]. Given the nature of the methodology, the system is not designed to prioritise or rank newly introduced chemicals with little toxicological information, but would rather implicitly assume that only the well-studied chemicals are among the ones posing most adverse health effects.

3 EPA'S PRELIMINARY SCORING OF SELECTED ORGANIC AIR POLLUTANTS

In the "Preliminary Scoring of Selected Organic Air Pollutants," the Environmental Protection Agency (EPA) performed a study to develop a methodology of ranking a total of 637 organic compounds potentially released into the atmosphere from chemical manufacturing plants only [10]. An attempt was made to determine which of these compounds are most likely to cause adverse health and environmental effects. A scheme of ranking of those organic compounds was primarily based on three parameters: (1) facility production rate; (2) volatility of organic compounds; and (3) chemical toxicological ratings. The overall score is the product of the individual parameters [11].

Table 4 illustrates the scoring system for the individual parameters considered in the priority ranking of industrial organic chemicals [12]. In all cases, the scoring system range from zero to five for all the individual parameters regardless of emission rates, chemical volatilities or compound toxicities. Toxicological data included in this ranking system are LD50 for Acute Toxicity I, LC_{50} for Acute Toxicity II, non-lethal effects from acute exposures, carcinogenicity, mutagenicity, and teratogenicity. For acute toxicities, depending on the levels of exposure, a range of "weights" or "scores" from zero to five are assigned; LD50 (in mg/kg) Acute Toxicity I for effects noted from <50 to ≥10000, and LC_{50} (in mg/kg) Acute Toxicity II for effects noted from <100 to ≥ 5,000. Scores of 1 and 2 are assigned for non-lethal acute mild and sever effects, respectively. As far as known and suspected carcinogens are concerned, a score of 2 is assigned for suspected (not tested) carcinogens, a score of 3 is assigned for suspected carcinogen undergoing testing, a 4 for those that produce neoplasms, and a 5 for agents confirmed as carcinogens. A score of 5 would be assigned for confirmed mutagens and teratogens; otherwise a zero would be assigned [12].

4 DISCUSSION

Assessment on rating methodologies and parameters used by both the NIOSH and USEPA's chemical scoring systems shows that there are differences and similarities between the two systems. One of the greatest similarities of both systems could be attributed to the fact that both aim at ranking those common industrial organic compounds used or released into the atmosphere based on chemical toxicological health effects with special focus on CAT, MUT and NEO.

However, two rating systems differ in primary objectives, i.e., NIOSH's system emphasizes more on toxicological health effects and the USEPA's system focuses on adverse environmental effects. Also, NIOSH's RTECS-NOHS system solely focuses on health risks which depends on chemical

Table 4: USEPA's Scoring system for priority ranking of industrial organics chemicals

Annual U.S. Production (10^6 lbs)	
Range	Score
< 1	0
> 1 ≤ 10	1
> 10 ≤ 25	2
> 25 ≤ 50	3
> 50 ≤ 100	4
> 100	5

Fraction of Production Lost	
Range	Score
< 0.01	1
≥ 0.010 < 0.015	2
≥ 0.015 < 0.02	3
≥ 0.020 < 0.03	4
≥ 0.020 < 0.03	4

Volatility (Vapor pressure in mm/g at normal temp)		
State	Range	Score
Solid	-	1
Liquid	≤ 24	2
Liquid	≥ 24 ≤ 100	3
Liquid	> 100	4
Gas	-	5

Acute Toxicity I (LC_{50} in mg/kg)	
Range	Score
< 50	5
≥ 50 ≤ 250	4
≥ 250 ≤ 1000	3
≥ 1000 ≤ 5000	2
≥ 5000 ≤ 10000	1
≥ 10000	0

Acute Toxicity II (LC_{50} in mg/kg)	
Effects Noted	Score
< 100	5
≥ 100 ≤ 200	4
≥ 200 ≤ 1000	3
≥ 1000 ≤ 3000	2
≥ 3000 ≤ 5000	1
≥ 5000	0

Non-lethal Acute Effects	
Type of Effect	Score
Mild	1
Severe	2

Carcinogenicity	
Effects Noted	Score
Carcinogenic	5
Produces Neoplasm	4
Under Test	3
Not Tested	2
Negative	0

Non-lethal Acute Effects	
Status	Score
Mutagenic	5
Not Tested	0
Negative	0

Teratogenicity	
Status	Score
Teratogenic	5
Not Tested	0
Negative	0

Occupational Standards (TWA in ppm)	
Range	Score
< 5 or Carcinogen	5
> 5 ≤ 10	4
> 10 ≤ 25	3
> 25 ≤ 100	2
> 100 ≤ 20	1
> 2	0

(Source: Brown, et al. 1978 [12])

toxicological effects that are divided into groups pertaining to eight health effect endpoints (i.e., *AT, CAR, ETA, MUT, NEO, PI, TER*, and *TFX*), whilst USEPA's system takes into consideration toxicological effects arising from *CAT, MUT* and *NEO*, occupational standards measured in Time-Weighted Average (TWA) exposure, individual chemical production rate of a facility, fraction of production loss, and individual chemical's volatility characteristics. Additionally, NIOSH's system encompasses all common chemicals that are potentially released or encountered at any industrial settings, and USEPA's system includes only those organic compounds that are potentially released into the atmosphere from chemical manufacturing plants only.

One of the main objectives of NIOSH is that any of the algorithms in the model is responsive to users' needs, and thus constants and multipliers are introduced. In order to allow the user great flexibility in defining toxicological priorities, one can always assign a multiplier (*a, c, e, g, i, k, m*, and *o*) in Equation (2), or one can totally eliminate any sub-*HRIN* from the equation by assigning a multiplier of zero. To offer more flexibility, the expression allows the user to rank or prioritise the terms by adding in the constants (*b, d, f, h, j, l, n*, and *p*). The scoring system developed by USEPA for the individual parameters considered in the priority ranking of industrial organic chemicals range from zero to five for all the individual parameters regardless of emission rates, chemical volatilities or compound toxicities without providing flexibility for users in defining toxicological priorities or assigning multipliers.

Despite the differences in rating parameters of both systems, the toxicological scoring indexes of both could serve as basic references for chemical prioritisation purposes. For instance, USEPA's toxicological scoring system is particularly useful for assigning the "multipliers" in Equation 1 developed by NIOSH. The ranking methodologies cited in both the systems had been integrated by P.L. Law in an attempt to rank the toxicological data for development of "A Model for the Prioritisation of Toxic Chemicals: Chemical Toxicity, Chemical Atmospheric Fate, Population and Worker Exposures as Ranking Factors" [13].

In terms of applicability of both scoring systems, certain modifications must be made to account for fundamental differences between workers exposure and population exposure. Since the average in-plant exposure is much higher than the average nearby population exposure, the assigned weights for HRI multipliers should be different between nearby population exposure and workers exposure. It is always believed that there is no lowest safe dosage for certain agents including carcinogens, neoplasticity agents, mutagens, teratogens and equivocal tumorigenic agents, their HRI multiplier weights are identical for both population and worker exposures. In the case of nearby population, the annual average pollutant concentrations are expected to be so low that the public is very unlikely to experience any acute toxicity or primary irritation problem, and thus these multipliers are assigned as zero. However, nearby population could be affected by some long-term chronic effects for non-carcinogens, and thus, the "other toxic effects." HRI algorithm multiplier should be given a weight such as one (Table 5). For worker exposure multipliers, it is suggested that nominal values shall be chosen for acute toxicity as 3, primary irritation as 2, and other toxic effects as 2 (Table 6).

Table 5: Nominal population exposures HRI (Endpoints) multipliers

NO.	HRI ALGORITHMS	ABBREVIATION	POPULATION EXPOSURE MULTIPLIERS
1.	CARCINOGENICITY	CAR	5
2.	NEOPLASTICITY	NEO	4
3.	MUTAGENICITY	MUT	5
4.	TERATOGENICITY	TER	5
5.	ACUTE TOXICITY	AT	0
6.	PRIMARY IRRITATION	PI	0
7.	EQUIVOCAL TUMORIGENICITY	ETA	3
8.	OTHER TOXIC EFFECTS	TFX	1

Table 6: Nominal worker exposures HRI (Endpoints) multipliers

NO.	HRI ALGORITHMS	ABBREVIATION	POPULATION EXPOSURE MULTIPLIERS
1.	CARCINOGENICITY	CAR	5
2.	NEOPLASTICITY	NEO	4
3.	MUTAGENICITY	MUT	5
4.	TERATOGENICITY	TER	5
5.	ACUTE TOXICITY	AT	3
6.	PRIMARY IRRITATION	PI	2
7.	EQUIVOCAL TUMORIGENICITY	ETA	3
8.	OTHER TOXIC EFFECTS	TFX	2

5 CONCLUSIONS

Assessment on methodologies and parameters used by both the NIOSH and USEPA's scoring systems concluded that both systems aim at ranking common industrial organic compounds used or released into the atmosphere based on chemical toxicological health effects with special focus on CAT, MUT and NEO. The system developed by NIOSH's RTECS-NOHS focuses on health risks or effects depending on chemical toxicological effects that are divided into groups pertaining to eight health effect endpoints, whilst USEPA's system, apart from *CAT*, *MUT* and *NEO* toxicological effects, this system also considers occupational standards, chemical production rate, fraction of production loss and chemical's volatility characteristics. It is also found that NIOSH's system allows the user great flexibility in defining toxicological priorities by assigning a multiplier (*a, c, e, g, i, k, m*, and *o*) in Equation (1). To offer more flexibility, the expression allows the user to prioritise the terms by adding in the constants (*b, d, f, h, j, l, n,* and *p*). The scoring system developed by USEPA for the individual parameters considered in the priority ranking range from zero to five for all the individual parameters without providing flexibility in defining toxicological priorities or assigning multipliers.

It is also concluded that certain modifications must be made to account for fundamental differences between worker exposures and population exposures for application purposes. For instance, carcinogens, neoplasticity agents, mutagens, teratogens and equivocal tumorigenic agents, their HRI multiplier weights could be identical for both population and worker exposures; for nearby population, multipliers could assigned as zero for any acute toxicity or primary irritation problems, and "other toxic effects" HRI algorithm multiplier could be given a weight such as one. For worker exposure multipliers, it is suggested that nominal values shall be chosen for acute toxicity as 3, primary irritation as 2, and other toxic effects as 2. ■

REFERENCES

[1] Commonwealth of Massachusetts, *Toxics Use Reduction Act (TURA), House No. 6161, Chapter 211, Commonwealth of Massachusetts,* New England, Boston: 1989.

[2] United States Environmental Protection Agency (USEPA), *Toxic Chemicals Release Inventory (TRI) which is included in the Toxicology Data Network (TOXNET), Computerized system of toxicologically-oriented databanks operated by NLM as part of the MEDLARS system,* Washington D.C.: USEPA 1989.

[3] Congress of the United States of America (US Congress), *Superfund Amendments and Reauthorization Act (SARA Title III),* Washington D.C.: U.S. Congress, pp. 92-500, 1986.

[4] S.L. Brown, B.R. Holt and K.E. McCaleb, *System for Rapid Ranking of Environmental Pollutants. Selection of Subjects for Scientific and Technical Assessment Reports,* Washington D.C.: EPA-600/5-78-012, pp.143, 199-200, June 1978.

[5] P.H. Howard, R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, *Handbook of Environmental Degradation Rates* New York: Lewis Publishers, Inc., 1991.

[6] U.S Department of Health and Human Services. *A Model for the Identification of High Risk Industrial and Occupational Groups using RTECS and NOHS Data.* Public Health Service. Centers for Disease Control, National Institute for Occupational Safety and Health (NIOSH), Division of Surveillance, Hazard Evaluations and Field Studies, Cincinnati: 1983.

[7] National Institute for Occupational Safety and Health (NIOSH), *National Occupational Hazard Survey (NOHS), DHEW Publications No. 74-127, May 1974, (NIOSH) 77-213, July 1977*; and (NIOSH) 78-114, December 1977, Cincinnati: NIOSH, 1977.

[8] National Institute for Occupational Safety and Health (NIOSH), *Registry of Toxic Effects of Chemical Substances (RTECS), DDHS Publication No. 81-116*, Cincinnati: NIOSH, 1981.

[9] D. Pedersen, R. Young and D. Sundin. *A Model for the Identification of High Risk Occupational Groups using RTECS and NOHS Data*, Cincinnati: U.S. Department of Health and Human Services, NIOSH, October 1983.

[10] F B. Fuller, J. Hushon, M. Kornreich, R. Quillette, L. Thomas and P. Walker. *Preliminary Scoring of Selected Organic Air Pollutants, Report No. EPA-450/3-77-008a*, Durham: United States Environmental Protection Agency (USEPA), 1978.

[11] J.R. Froines, C.A. Dellenbaugh, S.S. Seabrook and D.H. Wegman. *A Profile of Occupational Health Experience in Los Angeles Country*, Washington D.C.: Department of Health Services, State of California, 1984.

[12] S.L. Brown, B.R. Holt and K.E. McCaleb. *System for Rapid Raking of Environmental Pollutants, Selection of Subjects for Scientific and Technical Assessment Reports, EPA-600/5-78-012, pp.143, 199, 200*, Washington D.C.: USEPA, June 1978

[13] P.L. Law, A Model for the Prioritization of Toxic Chemicals: Relative Chemical Toxicities, Chemical Atmospheric Fate, Nearby Population and In-plant Workers Exposure as Ranking Factors, Doctoral Dissertation (WE-1, 1993), Lowell: Department of Work Environment, College of Engineering, University of Massachusetts, 1993.

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