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Chemical codes: a methodology for generic risk assessment of wastes

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Abstract

Over half of the 10^{13} kg of solid waste generated in the United States each year is classified as 'nonhazardous industrial waste' and is regulated under Subtitle D of the Resource Conservation and Recovery Act (RCRA). The common designation of 'nonhazardous' is misleading because these wastes often contain the same toxic and carcinogenic compounds found in Subtitle C 'hazardous industrial wastes'. This research developed a quantitative method to determine the toxic risk of Subtitle D wastes. Also, we used trial and error to devise a waste classification scheme, which resulted in an algorithmic classification of waste streams into nine categories based on component properties. These two types of analyses were applied to a 'training set' of 2605 waste streams and a total of 8000 waste streams. Fewer than 10% of waste streams (163/2605 = 6.3% in the training set, 571/8000 = 7.1% of all waste streams) had low toxic scores, and might be termed 'nonhazardous'. Of the remainder, about two-thirds (63%) of both the training set (1549/2422) and total set (4703/7429) were moderately toxic. The rest are of the most concern because they are large-volume (>10 000 kg/month) and high relative toxicity waste streams. Together, over 90% of the Subtitle D waste streams which are commonly termed 'nonhazardous industrial waste' were found to be toxic.

Keywords: Subtitle D of the resource conservation and recovery act (RCRA); Subtitle D waste toxicity and volume; Waste classification system; Industrial waste management

1. Introduction

Over half of the 10^{13} kg of solid waste generated in the United States each year is classified as 'nonhazardous industrial waste' and is regulated under Subtitle D of the Resource Conservation and Recovery Act (RCRA). The common designation

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of 'nonhazardous' is misleading because these wastes often contain the same toxic and carcinogenic compounds found in Subtitle C 'hazardous industrial wastes'. Subtitle D wastes are not regulated at the federal level, and are the purview of each state. State programs vary widely in respect to the level of regulation, permit system for disposal of wastes, and the effectiveness and progressiveness of the program [1].

Estimates of the quantity of Subtitle D industrial wastes, and the paucity of data on the nature and composition of these wastes, prompted the Industrial Waste Branch of the US Environmental Protection Agency (USEPA) to undertake several studies to assess the available data on these wastes and to better understand their characteristics. The Illinois Hazardous Waste Research and Information Center (HWRIC) analyzed the toxicity of over 8000 Subtitle D industrial waste streams from Illinois for 1988–1990, and developed a prototype national database [2]. This paper reports a method to characterize and rank the relative environmental risk of Subtitle D industrial wastes.

2. Methods

2.1. 'Degree of hazard' (DOH) analysis

The 'degree of hazard' (DOH) analysis was the response to a mandate from the Illinois legislature to establish a system for classifying and regulating Industrial D wastes based on the magnitude of their potential hazard. The DOH analysis estimates a waste stream's hazard using the waste volume, ignitability, leaching potential (pH), and toxicity [3–6]. The toxicity subscore, the equivalent toxic concentration (CEQ), is the sum of the percentage of each component in the bulk waste divided by its toxicity (usually, the oral LD_{50} in mg/kg). The CEQ is divided by 300 so that the toxicity of 100% copper sulfate, the reference toxicant, is 100. This is multiplied by the quantity (Q, in kg/month) to give the toxic amount, which is then assigned a DOH score of 0, 1, 2, or 3 based on its magnitude and adjustments for environmental fate. The calculations can be carried out on a calculator (Illinois Administrative Code, Section 808, Appendix B) or using a computer program [3], available from the HWRIC. This paper terms this procedure the 'original' method.

The original DOH analysis above adjusts the toxicity using a correction for environmental fate, and then weights the result by volume to give a toxicity score. Because so many factors enter the calculation before the score is derived, it is difficult to ascertain if the score is due to a few highly toxic substances in the waste stream, or is attributable to the volume of the waste. To make certain that the relationship between toxicity and chemical composition of the waste was not obscured, we excluded the environmental fate factor and decoupled toxicity (CEQ) from quantity (Q) [7]. The individual contributions of these factors to the toxicity score could then be examined. With these factors decoupled, the DOH analysis is easily adjusted to incorporate other factors, such as size of disposal area and hydrogeology, setting the stage for ecological risk analysis [7].

2.2. Waste stream data

Data on Subtitle D industrial wastes generated and managed in Illinois are maintained by the Illinois Environmental Protection Agency (IEPA). Information from several types of reporting forms comprise the database on Subtitle C and Subtitle D industrial wastes. The waste stream permit application provides data on the generator, process/operation in which the waste was produced, characteristics and components of the waste (percentage of six major bulk components, and total concentration and TCLP analytical results for numerous analytes), receiving facility, and waste management. Data from the waste manifest are the number and type of waste containers, and the total quantity of waste (gallons or cubic yards) for each shipment. The generator, transporter, and receiving facility are also identified. Annual reporting provides information about the types and quantities of wastes generated, and assigns a specific waste management category to several types of waste generated and managed in Illinois.

Manifest and permit data were received from the IEPA on seven tapes containing 1.7 million manifest records and nearly 45 000 permit records totaling over 800×10^6 bytes. The manifest files were summarized by grouping on shipment-year, permit number, waste volume units, and quantity. The permit and manifest files were linked using permit number as a common index. The years (1988–1990) and the waste type (nonhazardous) were selected for analysis. The final data file had a record for each unique permit number, shipment-year, and waste volume. Quantities of Subtitle D industrial wastes manifested in Illinois exceeded 3×10^6 cubic yards (2.16×10^6 m^3) in each of those years.

Selected fields from the data file, including the permit number, date, quantity, and the six component name and percentage fields, were transferred to dBase (Borland International, Scotts Valley, CA). Fields were added for Chemical Abstract Services (CAS) numbers for each component. These data were used for the DOH analysis.

Generators often used multiple copies of a manifest (representing individual shipments). Because this study determined the toxicity of unique waste streams, only the first replicate of a manifest was used. This accounts for the differences in the numbers of manifests and permits, and the numbers of unique waste streams in the database (8730) or used in the analyses.

The permit application allows free text entry for the bulk components, so there were many combinations of component name misspellings, typographical errors, and entry of multiple components in a single component field [4, p. 94]. To 'normalize' the component names required spell checking the list using a word processor, removal of extraneous punctuation, synonym reconciliation, and context-based judgments of what was intended. The original list of 22 000 unique component names was reduced to about 3300 after this first normalization. Next, the 3300 names were matched against the list of substances in the DOH database (which contained 500+ chemicals and their CAS numbers by the end of the project; see below). The CAS number was added to each waste component that matched a compound in the DOH list.

2.3. Identification of subsets of data for analysis

Of the initial 8730 waste streams, 730 were dropped because less than 20% of the composition was components listed in the final DOH database. Of the 8000 usable waste streams, 2605 had nonzero unadjusted toxic scores (UTS), i.e., were waste streams with at least some amount of toxicity. This subset was used for the development of the Illinois Waste Categorization System, and is termed the 'training set'. The remaining 6395 waste streams is termed the 'prediction set'.

2.4. Waste stream component toxicity

Over half (4728) of the 8000 waste streams were classified with a CEQ-rank of 11 (CEQ = 0–100). This group of wastes would likely be considered innocuous, so it was important to determine if it comprised a single group of waste streams with similar toxicity characteristics. If there were two groups with different toxicity characteristics within the CEQ-rank 11 group, it was logical to separate waste streams with CEQ = 0 from those with CEQ = 1–100. Discriminant analysis showed these groups to be well separated, so CEQ-rank 0 was assigned when CEQ = 0.

2.5. Development of chemical codes (CCodes)

Given the vast array of chemical components in the database, developing rules for assigning wastes to categories would involve thousands of individual chemicals; a formidable task by any measure. To minimize this problem and develop a general method for waste type and toxicity characterization, the grouping of individual chemicals was undertaken. This started by reviewing waste categorization systems (see below). Later, the groupings (halogenated solvents, fats and waxes, coal-derived fly ash, etc.) took on more autonomy and had similar chemical properties, i.e., heavy metal salts, dyes and pigments, etc. By trial and error, the list evolved into 52 chemical codes (CCodes; Table 1). The intent was to bridge between CAS numbers and waste codes using a short list reflecting waste components having similar chemical properties, and, by inference, roughly similar health and environmental risks in the DOH analysis.

2.6. Use of CCodes to estimate waste stream toxicity

The most important use of CCodes was as generic components for making DOH estimates. This was investigated for several reasons, including:

(1) the lack of toxicity data for many waste components;

(2) due to misspelling and for other reasons, it is usually easier to assign CCodes than specific CAS registry numbers;

(3) a short list (52) of CCodes is easier for a generator to use correctly in assigning waste components than is a CAS-based list of several hundred compounds;

(4) programming is greatly simplified if a small database of CCodes is used rather than one or more large databases containing data on hundreds of components.

For all wastes having $> 0\%$ of the jth CCode, average CEQs (Av_CEQ) were computed for CCode as

$$\mathrm{Av\_CEQ}_j = \Sigma(\mathrm{CEQ} \times \mathrm{percent})_j / \Sigma(\mathrm{percent})_j. \tag{1}$$

The Av_CEQs (Table 1) were used as coefficients in a regression equation to estimate the CEQ (CEQ_est) for each waste stream. The correlation between the logarithms of CEQ and CEQ_est was 0.71 ($N = 7282$, $P < 0.001$). The CEQ_est values were converted to scores using the CEQ definitions.

2.7. *Assignment of waste codes*

A waste categorization system was developed in several steps. The Pennsylvania waste code list was chosen as a starting point, and was cross-referenced with lists from Illinois, Texas, the Pacific Materials Exchange, and Japan to create the Illinois Waste Categorization System (IWCS). Initially, the IWCS had 72 three-digit waste categories. Later, as initial rules were developed for classifying a waste stream into a category, some categories were merged or deleted, and others were added.

Assignment of Illinois' waste streams to these categories involved several lengthy data manipulations. Initially, the process of assigning wastes to the categories used the waste stream descriptor and the six bulk chemical components (after spelling and typographical corrections). Toxicological and environmental fate data for components in the DOH database were reviewed. Environmental fate data were added for over 100 components, carcinogenic potency (TD50) [8] was added for most of the carcinogens, and mutagens were identified.

Initially, waste codes were assigned manually to the training set using the waste stream descriptor, but accurate and consistent assignment required more information. Consequently, the six waste stream components and their percent composition were used along with the waste stream descriptor and, in some cases, the SIC code. Certain waste categories were further defined, and others were added, deleted, merged, or renumbered.

Rules were then written which described the process used to assign waste streams to categories. After automating the rules, it became clear that 72 categories were unwieldy and unnecessary for these waste streams and data. Because many of the categories were the industrial process that generated the waste while others used the content of the waste, the description and chemical composition for many of the wastes fit logically into more than one category. With the overlap between categories this created, it was difficult to develop rules to delineate and categorize waste streams. Based on repeated trials and statistical analysis, the 72 categories were collapsed into nine.

Table 1
Definition of chemical codes (CCodes)

CCode	Name	ΣComp%	ΣCEQ[a]	Av_CEQ
Unknown		31 407.3	1 577 432.7	50.2
1	Iron, steel, ferrous scrap	29 344.7	34 639.0	1.1
2	Other metals, excluding mercury	5507.7	1 097 520.8	199.2
3	Heavy metal salts	48 643.2	14 841 000.0	305.0
4	Alkaline metals (including NH_4) and salts	21 524.1	14 857 900.0	690.2
5	Sand, soil, earth, clay, river sediment/silt	53 411.3	0.0	0.0
6	Monomers, resin, latex	17 866.8	430 027.9	24.0
7	Oil, petroleum, fuels, etc.	63 362.9	185 920 000.0	2934.2
8	Acids	462.2	56 020.7	121.2
9	Alkalis	3392.7	562.1	0.1
10	Organics, excluding PCBs, petro-related	6603.1	654 312.4	99.0
11	Pesticides	9.8	63.7	6.5
12	Act. carbon, diatom. earth, other filter aids, absorbents	29 445.3	63.8	0.0
13	Halogenated solvents	272.7	81.3	0.2
14	Nonhalogenated solvents	237.9	2569.3	10.8
15	Explosives	500.6	248.6	0.4
16	Plastics, nonhalogenated	7311.4	6 798 306.1	929.8
17	Plastics, halogenated	8810.1	0.0	0.0
18	Rubber, elastomers	1524.5	1 813 857.2	1189.8
19	Food, plant fiber, animal tissue, leather rosin	19 345.5	2102.0	0.1
20	Lime	4793.6	575.2	0.1
21	Water	26 164.9	0.0	0.0
22	Coal fly ash	562.0	0.0	0.0
23	Concrete, brick, construction debris, dust, sweepings	30 106.9	2 607 021.1	86.5
24	Other inorganic chemicals, nonmetallic	4628.6	6218.5	1.3
25	Cyanide	67.0	377.2	5.6
26	Catalyst	1385.3	900 000.0	649.6
27	Surface coating wastes	33 303.4	1994.4	0.0
28	Industrial waste water treatment sludge	4048.9	0.0	0.0
29	Water treatment sludge	2122.5	13 303.6	6.2
30	Other industrial sludge	19 964.6	451 061.3	22.5
31	Coal	385.5	0.0	0.0
32	Dyes and pigment	5601.6	9 481 200.0	1692.5
33	Ash (other than coal fly ash)	5372.1	0.0	0.0
34	Pharmaceutical waste	3111.4	0.0	0.0
35	Refractory materials, metallurgical	13 645.4	17 462 000.0	1279.6
36	Coal tar, coke	2316.2	6 487 200.0	2800.7
37	Carbon black (not used)	—	—	—
38	Detergents, soap, cleaning agents	6083.2	355.8	0.0
39	Paper	9492.4	0.0	0.0
40	Asphalt, creosote	1131.6	3 394 800.0	3000.0
41	Printing waste	917.0	0.0	0.0
42	Asbestos	2985.5	8 956 500.0	3000.0
43	Polychlorinated biphenyls (PCBs)	5445.5	1306.9	0.2
44	Batteries	534.0	882 000.0	1651.6
45	Tank bottoms	974.0	154 500.0	158.6
46	Metallic baghouse dust	1831.8	12.0	0.0
47	Ceramic waste	2237.5	564 000.0	252.0
48	Halogenated organics (other)	25.8	0.0	0.0
49	Petroleum- contaminated waste	13 580.0	35 502 600.0	2614.3
50	Foundry sand	7000.7	0.0	0.0
51	Slag	1881.7	0.0	0.0
52	Coolant	4676.8	2 315 900.0	495.1

[a] Divided by 300 ≡ CEQ for copper sulfate.

Table 2
Waste code categorization rules, using CCodes (Table 1), in the order they are applied. Waste categories are arbitrarily numbered to approximately correspond with Pennsylvania codes

Waste category number/description	Rule
5 Special handling residues	Any amount of CCodes 15, 26, 36, 42, 43, 44; OR description is CATALYST; OR CCode 31 $\geqslant$ 25%
6 Oil-contaminated waste or soil	$\geqslant$ 10% CCodes 7, 49
0 Combustion residues	$\geqslant$ 50% of CCodes 33, 22 after water has been removed; OR description is ASH
7 Contaminated soil and construction materials	$\geqslant$ 50 CCodes 5, 23 and <25% CCode 31
2 Sludges, scales	$\geqslant$ 50% CCodes 5, 12, 19, 21, 30, 52 (unless 52 is already greater than 80%); OR description is WASTEWATER, WASTE WATER, FILTER CAKE, FILTER CAKE, BOTTOMS, WTP; OR description includes SLUD and CCode 50 is <30%
1 Metallurgical process residues	If the two-digit SIC code is 33–37 then 20%, otherwise $\geqslant$ 50% of CCodes 1, 2, 35, 46, 50, or 51 after water has been removed; OR description is GRINDING, FOUNDRY, or SLAG
3 Chemical wastes	$\geqslant$ 50% CCodes 3, 4, 6, 8, 9, 10, 11, 13, 14, 15, 20, 24, 25, 27, 32, 34, 37, 38, 48, 52 after water has been removed
4 Generic, manufacturing or production wastes	$\geqslant$ 50% CCodes 5, 16, 17, 18, 23, 24, 32, 39, 40, 41, 44, 47, 52 after water is removed
8 All others (undefined, uncategorized)	Waste streams unassigned by the above rules

2.8. Use of CCodes for automated assignment of waste codes

Rules based primarily upon waste stream composition were then developed for assigning waste streams to the nine categories in Table 2. The rules used a combination of CCodes and key words in the generator's description of the waste. They were applied in a logical sequence. A waste stream was classified into the first category for which it met the rules, without consideration for subsequent rules (Table 2). To determine the 'best' definitions and the sequence for applying the rules, over 25 iterations were carried out with the training data; the criterion for best was maximization of the consistency between wastes in each computer-assigned category.

When the rules were applied to the prediction set, over 4000 new components (of various spellings) appeared. An iterative process similar to that for the training data was used to add new compounds to the database and assign CCodes and CAS numbers. This resulted in assigning CAS numbers to 74.4% of the original 22 000 components and CCodes to 90.0% of these. With this high level of component identification, the automated rule base was then used to assign waste codes to all 8000 waste streams.

Table 3
Risk scores for combinations of CEQ-rank by *Q*-rank. The number of waste streams from the training and total sets are given for each risk score

Toxicity	Low quantity (1)			Medium quantity (2)			High quantity (3)		
	Risk score	Training	Total	Risk score	Training	Total	Risk score	Training	Total
Low (11)	11	42	352	22	417	2598	33	379	1778
Medium (12)	12	26	61	24	332	583	36	178	291
High (13)	13	95	158	26	800	1522	39	336	657
Sum		163	571		1549	4703		893	2726

3. Results

3.1. Waste stream data

Many inconsistencies and problems in the Illinois data were identified during the analysis. These problems include missing, inconsistently entered, and meaningless or invalid data. About half of the permits left blank the Standard Industrial Classification (SIC) code, waste code, flash point, waste management code, and process code fields. It is not known if these data were simply not completed, inadvertently omitted during data entry, or unknown or unavailable to the generator.

Data submitted in free format text, such as the fields for the generic waste name and the six chemical components, often led to inconsistent or imprecise data. Text descriptions often failed to accurately describe the waste stream or its components. Industry acronyms or jargon were difficult to interpret. Misspellings and synonyms were common, and some components were given as combinations, i.e., 'oil, hair, rags'. The use of terms such as 'misc. debris', 'unknown chemicals', 'toxic', or 'waste' yielded little or no information about waste stream composition.

3.2. Ranking the relative hazard of waste streams

A new ranking system for Subtitle D industrial waste streams was developed using the training set. Waste streams were divided into three groups based on quantity (*Q*-rank) and three groups based on toxicity (CEQ-rank). The risk score was then obtained from the unique product of the *Q*-rank times the CEQ-rank (according to Ref. [7]). The new DOH was calculated for all 8000 nonhazardous waste streams in the total data set. Table 3 shows that fewer than 10% of waste streams (163/2605 = 6.3% of the training set, 571/8000 = 7.1% of all waste streams) had low toxic scores, and might be termed 'nonhazardous'. Of the remainder, about two-thirds (63%) in both the training set (1549/2422) and the total set (4703/7429) were moderately toxic. The rest are of the greatest concern because they are large-volume (> 10 000 kg/month) and high relative toxicity (CEQ > 10 000) waste streams. Together, over 90% of the Subtitle D waste streams which are commonly termed 'nonhazardous industrial waste'

Table 4
Distribution of risk scores by waste code

Waste code type	CEQ-rank				
	0	11	12	13	Total
0 Combustion residues	90	99	4	12	205
1 Metallurgical process residues	98	125	173	85	481
2 Sludges, scales	1234	1155	476	544	3409
3 Chemical wastes	175	558	85	186	1004
4 Generic manufacturing wastes	174	71	15	53	313
5 Special handling residues	31	105	14	119	269
6 Oil-contaminated waste and soil	54	32	3	1258	1347
7 Contaminated soil/construction debris	447	121	159	78	805
8 All others	80	79	6	2	167

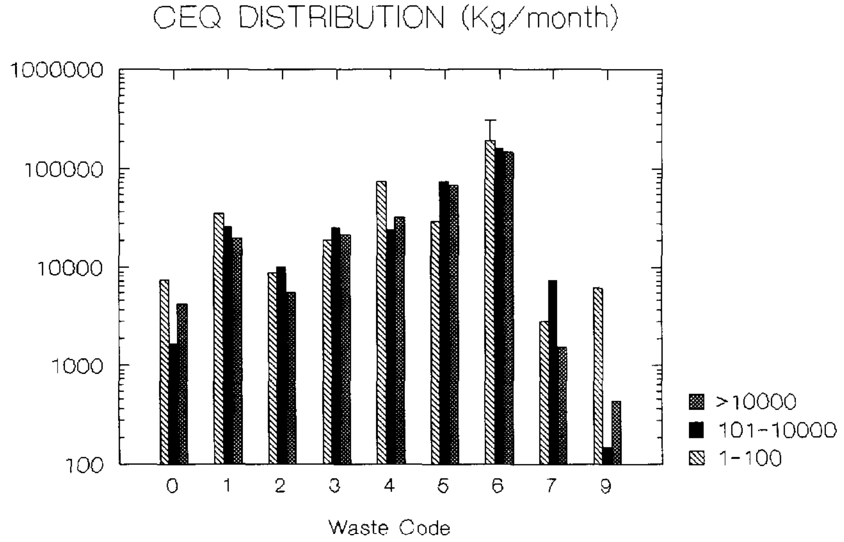

Fig. 1. Distribution of mean toxicity (CEQ) for waste streams in each of the nine waste categories. Data are presented for each of three quantity rank (*Q*-rank) groups.

were found to be toxic. These figures possibly underestimate their total hazard because the toxicity was not adjusted for environmental fate (which usually is an upward adjustment), or for the other characteristics (e.g., flammability, leaching potential) included in a complete DOH hazard assessment [5].

Table 4 gives the distribution of risk scores by waste code. The distribution of waste stream toxicity among waste categories for each quantity group (*Q*-rank) is given in Fig. 1. For most waste categories, toxicity and quantity were independent, i.e., the heights of the bars (CEQ) were very similar for the three quantity categories (*Q*-rank) within a given waste category. However, toxicity (CEQ) differed with waste

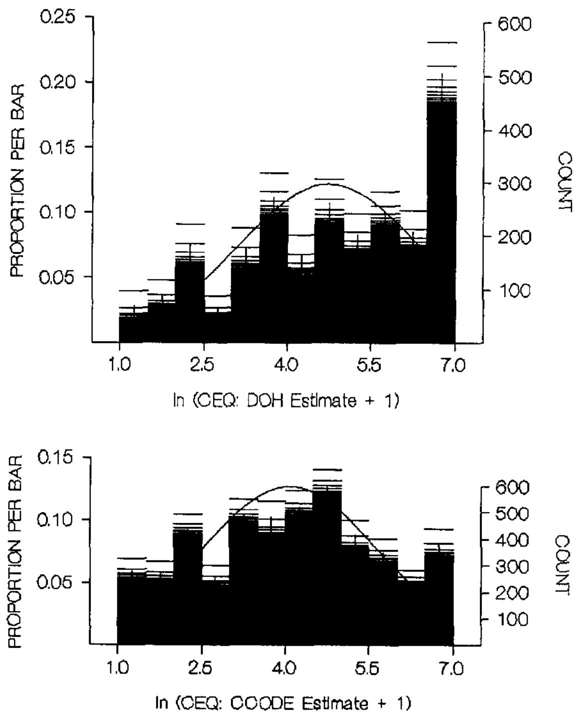

Fig. 2. Histograms of the logarithm of the CEQ estimated using actual bulk components (top) and using weighted average toxicity for the CCodes as defined in the text (bottom) for 8000 waste streams. The fuzzy histograms display the variability in the data, and the smooth curves are the fit of a normal distribution.

category; the order was generally 8 (all others) < 7 (contaminated soil/debris) < 0 (combustion residues) < 2 (sludges and scales) < 1 (metallurgical process residues) ≈ 3 (chemical wastes) < 4 (generic manufacturing wastes) ≈ 5 (special handling residues) < 6 (oil-contaminated waste and soil). This ordering seems to be subjectively 'correct' and 'reasonable'. Thus, qualitative information (relative ordering of waste categories), quantitative information (CEQ and quantity for each waste code), and subjective judgment indicate that the results are 'reasonable' and the analysis produced 'valid' and 'consistent' estimates. The results showed that every waste code included a range of toxicities and quantities, and that no waste code was *always* the most (least) toxic (or hazardous), although it may be so *on average*.

3.3. Ranking the relative hazard of waste streams

The agreement is shown in Table 5 and in Fig. 2. In Table 5, the first line for each estimated CEQ score is the number of occurrences and the second is the percent of the total estimated occurrences of that score. The results are encouraging: (1) the agreement is good, even though regression coefficients were not optimized; and

Table 5
CEQ score (rows) by score for CEQ regression estimates

CEQ from DOH[a]	CEQ regression estimates from CCodes[b]				
	0	11	12	13	Total
0	**927**	526	978	333	2768
%	**33.5**	19.0	35.3	12.2	
11	29	**491**	615	657	1792
%	1.6	**27.4**	34.3	36.7	
12	0	21	**666**	195	882
%	0.0	2.4	**75.5**	22.1	
13	0	0	71	**1769**	1840
%	0.0	0.0	3.9	**96.1**	
Total	956	1038	2330	2958	7282

[a] CEQ calculated using actual toxicity data for each component.
[b] CEQ estimated using average toxicity data for component CCodes.

(2) disagreements between DOH and estimated CEQ values increased with the estimated CEQ.

4. Policy implementation

The research provided data on the reporting, composition, quantity, and toxicity of Subtitle D wastes. Both the data and the lessons learned in working with generator reports were used to conceptualize a national industrial Subtitle D waste database system for implementation by USEPA. The system consists of reports, models, and informational databases, and is entirely electronic. Generators/disposal sites and states would use a PC to download selected data to a national waste stream management and reporting system maintained by USEPA. *Only* those data needed to make sound management and regulatory decisions would be added to the national database. PC-resident informational databases and models downloaded from the national system would be used to describe and characterize waste streams, and automatically assign waste codes, risk factors, and management codes. This system goes beyond the minimal criteria identified by Raleigh and coworkers [1].

The downloaded databases would include relevant environmental laws and regulations; a broad spectrum of case studies; journal article abstracts covering topics such as waste segregation, equipment modification, on-site recycling, waste water reduction, and raw material substitution; describe disposal technologies; and identify disposal sites licensed to take those types of wastes and carry out the selected disposal option(s). The system would intelligently select those abstracts and case studies that are relevant to a generator's SIC category, their process codes, or their waste stream composition.

A DOH analysis would be used for risk and 'what if' toxicity reduction studies of waste streams to evaluate how process changes would affect waste characteristics in relation to environmental policy and legal requirements. The results would allow waste generators/disposal sites and regulators to examine the relative economic impacts and liabilities associated with current waste stream practices and those resulting from the use of alternative technologies, methods, and materials. The feedback from this analysis, in combination with other information in the system, could be used to provide a strong incentive for industry to pursue, and for government to encourage, the use of alternative materials, processes, and waste reduction techniques.

5. Discussion

These results are not directly comparable with earlier analyses [4, 5] because different waste streams were used in each study and for other reasons[1]. However, our results are qualitatively and quantitatively similar to theirs. A majority of these supposedly 'nonhazardous' Subtitle D wastes have a high degree of hazard. Plewa et al. [4] found that Subtitle C and Subtitle D waste streams had similar quantity distributions. The 'degree of toxic hazard' distributions were nearly identical: high = 89.7%/77.8%, moderate = 5.2%/3.7%, low = 5.1%/18.5%, for Subtitle C ($n = 213$)/Subtitle D ($n = 168$).

The results of these analyses support the reasoning used in both conceptualizing and assigning chemical codes. Thus, we conclude that CCodes provide an appropriate component surrogate for assigning component toxicities and developing a systematic and consistent set of rules for categorizing wastes with similar toxicity characteristics. The results also suggest that, with refinement of the CCodes and toxicity data in the DOH, CCodes could be used to estimate DOH scores when toxicity data are unavailable. This analysis validates both the basis and the implementation of the approach: the development of CCodes, their use in waste type categorization, and use of CCodes to estimate 'degree of hazard' toxicity scores when specific component toxicity information is not available.

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[1] Plewa et al. [4; Table 2-1, p. 29] found that only 30.7% (168/547) of Subtitle D and 75.5% (213/282) of Subtitle C waste streams provided sufficient component data for analysis. By requiring that only 20% of the waste stream components be known, we were able to use data from 91.6% (8000/8730) of Subtitle D waste streams. If we used criteria similar to theirs, e.g., > 50% of the components and SIC codes to be known, then only 40.1% (3574/8730) of the waste stream data were usable.

Furthermore, in the original DOH analysis, the risk score is determined from the value of $\mathrm{CEQ} \times Q$ (kg/month), where the CEQ is corrected for environmental fate. In this study, the toxicity (CEQ scores) and quantity (kg/month) were separately converted to scores, and the risk score = toxicity score × quantity score.

6. Conclusion

This new waste categorization system uses the content of the waste streams rather than the originating industry or process producing the waste. Most categorization systems include some categories and sub-categories that are specific to a particular industry or industrial process. They also include categories that are content based. It is therefore possible that a waste stream will accurately fit into more than a single category. By using a more concise system that is content based, each waste stream logically fits into only one category. When it is not feasible to exactly identify contents by CAS numbers, chemical codes can be used to identify the contents of any waste stream. A content-based system is better for categorizing waste streams, and SIC codes and process codes can be used to show where and how the waste stream was generated. This separation of the two types of categorizations provides more flexibility in creating logical rules that can be applied to categorize the wastes and more accurately predict their risk.

A rule-based approach to waste stream categorization allows any number of waste codes to be developed and used. Our current system of nine waste codes could be increased or decreased as deemed appropriate to meet the needs of Subtitle D industrial waste management at the federal level. It is important to note that the descriptive names associated with the nine categories are remnants of other systems used during development. Ideally, the descriptors for these categories and any others added, should reflect waste stream content, not necessarily the industry or process that generated the waste.

It is our considered judgment that the most important result of this research is that CCodes can be used in place of specific component toxicity data to estimate a degree of toxic hazard. The results in Table 5 (and others in Ref. [2]) suggest that the agreement between the toxicity estimates using component toxicological data and CCode average toxicities could be improved with refinements of the CCodes. For example, selected chemicals with high concentrations for several different uses could be assigned to multiple CCodes using context-based rules, e.g., ethylene glycol and a few other chemicals.

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References

[1] L. Raleigh, R. Knox and L. Canter, Environ. Profess., 15 (1993) 364.

[2] P. Tazik, M. Bailey and D.J. Schaeffer, Subtitle D industrial waste: Data analysis, toxicity evaluation and development of prototype national database, Hazardous Waste Research and Information Center, Champaign, IL, 1994.

[3] M.B. Bailey, L.J. Case and G.D. Miller, Degree of Hazard Evaluation Program Users Guide Version 1.1, TN 92-002, Hazardous Waste Research and Information Center, Champaign, IL, 1992.

[4] M. Plewa, P. Dowd, D. Andes and E. Wagner, Assigning a degree of hazard ranking to Illinois waste streams, HWRIC RR 013, Hazardous Waste Research and Information Center, Champaign, IL, 1986.

[5] M. Plewa, R. Minear, D. Andes-McInerney and E. Wagner, Refining the degree of hazard ranking methodology for Illinois industrial waste streams, HWRIC RR-029, Hazardous Waste Research and Information Center, Champaign, IL, 1988.

[6] K.R. Reddy, Special waste categorization study, HWRIC RR 005, Hazardous Waste Research and Information Center, Champaign, IL, 1985.

[7] D.J. Schaeffer, H.W. Kerster, E.E. Herricks, K.A. Reinbold, E.W. Novak and R.S. Wentsel, J. Hazard. Mater., 18 (1988) 1.

[8] L.S. Gold, T.H. Slone, N.B. Manley, G.B. Garfinkel, E.S. Hudes, L. Rohrbach and B.N. Ames, Environ. Health Perspect., 96 (1991) 11.