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A scheme of hazardous chemical identification for transportation incidents

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Abstract

Because of the unexpectedness, the chemical involved in a hazardous incident is often not known immediately and can hardly be derived directly from the information at the scene. This situation is especially true for transportation incidents. As the result, hazardous chemical incidents can generate additional property damage and human injuries. Therefore, identification of the hazardous chemical should be an important step, to be made before any subsequent decisions. The present paper proposes a scheme for chemical identification in transportation hazards. In the scheme, all possible kinds of information from the scene are considered, including general information, shipment documents, observable properties of the hazard and the chemical, and clinical manifestations. With a practical example, it is shown to be possible, in a successive and interactive manner, to establish a computer module for such an identification. © 1997 Elsevier Science B.V.

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1. Introduction

Despite rules and regulations for their use, storage and transportation, hazardous chemicals may be involved in industrial and transportation incidents at any time and anywhere. These incidents can cause severe damage to property, be extremely harmful to human life and health, and create panic among the public. Therefore, for many years, studies on hazard preparedness, emergency management and consequence assessment have been drawing worldwide attention. These efforts include establishment of databases;

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screening and ranking of hazardous chemicals; setting up regulations for use, storage and transport; theoretical and experimental studies on the physical and chemical processes at different stages of various chemical incidents; and development of a computer-aided system for preparedness planning or emergency management, etc. In respect of consequence analysis [1–8], there is the important problem of hazard identification. That is, no matter how good the following consequence analysis might be, one must firstly know the type of incident, the name of the chemical, the release rate and duration of the spill. Typically, for transport on roads or highways, it is often the case that not enough information is available at an incident scene [9]. Hazard identification has been recognized as very important [9,10]. However, possibly due to the difficulty, efforts to aid identification of the chemical are relatively scarce [11,12].

Hazardous chemical incidents are diverse in type, physical and chemical behavior, and effects on human beings. The only common characteristic is the uncertainty. Before an incident actually happens, we never know when or where, under what kinds of terrain and meteorological conditions, what type of hazard, which chemical is released, how violent the release rate, how long it lasts, etc. Some of these questions can be answered immediately after an incident has started, including the time, location, meteorological and terrain conditions, and perhaps the incident type, e.g. explosion, fire, toxic chemical release etc. Some questions are still uncertain: which chemical, its release rate, amount or duration. When a chemical is known, methods have developed to classify failure cases, to estimate the release rate and duration. Because of the uncertainty, the estimation is usually based on a conservative consideration. For the chemical name, referred to here as chemical identification, it is easier in practice to obtain the corresponding information when an incident happens in an industrial area. Chemical identification becomes much more difficult when the chemical is under transportation.

Chemical identification is firstly a problem of necessity [9,10,13]. In fact, at any incident where there is some kind of emergency management, the responder must have made some kind of judgment in taking actions. It is important for him to judge whether the chemical is flammable, explosive, or toxic; the level of the danger; how to avoid further hazard and to evacuate people. This is also a kind of identification, usually based on intuition and the experience of the responder, based on directly observable phenomena. For subsequent action, there is always the requirement for identifying the chemical by name. Secondly, we all know that most hazardous chemical incidents can finally be identified. For transportation cases, the identification can be made simply from the shipping document provided by the driver, or by a comprehensive chemical analysis of a sample collected at the scene, or on the basis of the clinical symptoms and professional analysis for the injured people. Therefore, chemical identification is possible. Depending on when sufficient information can be collected and whether the responder is capable of making the right decision in time, the identification could be completed at the very beginning, or during the incident, or several hours later, or even a few days after. Thirdly, for accurate and quick identification, all possible kinds of information should be gathered, and all possible methods are encouraged. The information can be as direct as a carrier placard or a shipment document, or sensible phenomena of the hazard, observable physical or chemical properties of the released material, chemical analysis of collected samples, symptoms and analysis of injured people or other biological systems, etc. Finally, the identification should be made in a successive and interactive manner. In other words, on-scene reports would be made continually. Unless definite information is available, the responder would need to modify or improve his judgment from time to time. In many cases, it is also necessary for the responder to choose between several possible identifications.

Rao and Raj [11] proposed a computer interface for identifying accident chemicals for consequence analysis. In their design, the observable behavior of the hazard and the atmospheric conditions were utilized to determine the properties of the chemical, then the chemical itself. It is true that the observable behavior of a hazard is related to the physical/chemical properties of the chemical and the atmospheric conditions. Therefore this information is necessary to identify the chemical. However, it seems rather weak to rely only on observable characteristics. Similar phenomena can be generated by quite different chemicals. Because observations are personal, different people at the same scene might give different reports. Therefore, it is difficult to conduct such a backward search without other kinds of information.

The present study aims to extend the computer interface idea of chemical identification to the inclusion of all possible kinds of information, and to the consideration of the progressive manner of reporting. In the following sections, we describe the idea and structure of the proposed scheme. An example is provided to show the feasibility of the scheme.

2. Chemical hazards at transportation incidents

Based on the data and experience accumulated over many years, a number of handbooks or databases for hazardous chemicals are now available. Each entry of such a database usually includes a code, such as the UN or DOT number, also the name and formula of the chemical; its physical and chemical properties; types of hazard it may present; effects on humans or animals; the proper treatment or method to control the hazard, etc. These books and databases can be taken as the background for the identification scheme. We need to make sufficient use of all possible information from a hazard incident scene, and to modify the structure of conventional databases to allow backward searching.

Hazardous chemicals are classified according to their physical and chemical properties, and the type of hazards they may present. For example, the classification of the United Nations defines classes and divisions: explosives (massive, projection, etc.); gases (flammable, nonflammable, and poisonous); flammable liquids; flammable solids or substances (flammable solid, liable to spontaneous combustion, or emitting flammable gases when wet); oxidizing substances (oxidizer, organic peroxide); poisonous substances and infectious substances; radioactive materials; corrosives; and other dangerous substances [13]. Therefore, if the class/division is known, it is possible to search for a group of chemicals. Although the number might be large, it provides a screening from thousands of chemicals. Furthermore, each chemical has been assigned a UN number. Since a UN number does not correspond to a unique chemical, an available UN number may lead to a small group of chemicals. Regulations are set up for the type and size of container or package for hazardous chemicals. Labels are required to be attached to packages. Placards are required for trucks or tanks. Shipping documents should accompany the transportation. It is possible to find the class, UN number or shipper contact number at the incident scene. However, although this information is the most reliable, the name of the chemical is usually not directly available. And it is often the case that placards are missing, destroyed, obscured or incorrect; or that the shipping papers are missing, incorrect, incomplete, inaccessible or destroyed; or the driver is unable to provide correct information, etc. [9,14].

At the scene of an incident, many observable phenomena of the hazard and the behavior or properties of the chemical provide important clues to the identification. The problem is that the incident happens all of a sudden. There are no independent observers at the scene. Naturally, the reports come in succession and in an incomplete manner. For example, there might be a first report of an explosion. Then comes the next report on whether it is a massive explosion, a projection, or a minor blast. It is expected that the first on-scene report could include light, sound, shock, smoke, cloud, color, odor, and injuries. Then come the reports that might be prepared by some experienced people with more detail, such as the specific color and odor of the chemical, and the clinical findings relating to the injured people. All this information could point towards a fingerprint of the chemical. On the other hand, on the consequence analysis side, chemical hazard event trees are constructed to study the physical and chemical processes following a release. The flammable gas event tree, toxic gas event tree, flammable liquid event tree and toxic liquid event tree are considered in WAZHAN [3]; and the failure case definition tree is considered in ref. [10]. The sequential processes of different types of hazard are illustrated in the form of tree stems. This is supposed to enable the elimination of the impossibles in the on-scene report. However, there is some deficiency in the structure of these trees. For example, if there were a fire involving a flammable gas, it would not be considered as toxic [3]. In an actual incident, combustion is often incomplete, and some chemicals become more toxic when there is a fire or thermal decomposition.

At the incident scene itself, human injuries often receive more attention than damage to property. When casualties are exposed to toxic chemicals, the clinical manifestations (symptoms) can also provide important clues to identification. Because of their molecular structure, hazardous chemicals are found to present various kinds of effects in varying degrees to human bodies. In the medical sense, these chemicals can be grouped, for example, as skin irritants, eye and mucous membrane irritants, severe pulmonary irritants, nervous system depressants, asphyxiants etc. [15]. Therefore, the clinical manifestations from the injured people should also be part of the information for chemical identification. For example, on the basis of the tables provided in ref. [15], the 20 chemicals in WAZHAN's primary database can be coded as shown in Table 1. The trouble is that there might be more than one chemical corresponding to one code. For example, five chemicals possess the same code 56, and seven chemicals possess code 1. However, it is understood that this is only a simple illustration. The table may be constructed with more detail. Other kinds of possible information have not yet been included, such as the fact that ammonia is easily distinguished from chlorine by its odor. On the other hand, it is incidental that the seven chemicals with code 1 are all simple

Table 1
An example of the coding for 20 chemicals, based on clinical manifestations

Chemical name	SK	MD	SP	CN	PN	AS	Binary	Decimal
propane	0	0	0	0	0	1	000001	1
n-butane	0	0	0	1	0	0	000100	4
n-hexane	1	1	0	1	1	0	110110	54
n-heptane	1	0	0	1	0	0	100100	36
ammonia	1	1	1	0	0	0	111000	56
chlorine	1	1	1	0	0	0	111000	56
phosgene	0	1	1	0	0	0	011000	24
methane	0	0	0	0	0	1	000001	1
ethane	0	0	0	0	0	1	000001	1
n-pentane	0	1	0	0	0	0	010000	16
ethylene	0	0	0	0	0	1	000001	1
propene	0	0	0	0	0	1	000001	1
butylene	0	0	0	0	0	1	000001	1
ethylene oxide	1	1	0	1	0	0	110100	52
carbon monoxide	0	0	0	1	0	1	000101	5
sulfur dioxide	1	1	1	0	0	0	111000	56
hydrogen sulfide	0	1	1	0	0	1	011001	25
hydrogen fluoride	1	1	1	0	0	0	111000	56
methyl isocyanate	1	1	1	0	0	0	111000	56
hydrogen	0	0	0	0	0	1	000001	1

SK—primary chemical irritants of the skin; MD—mild irritants (eye, mucous membranes);
SP—severe pulmonary irritants; CN—central nervous system depressants;
PN—neurotoxins producing peripheral neuropathy; AS—asphyxiants.

asphyxiants. Except for hydrogen, the other six chemicals are also similar in their properties. Relatively little difference exists between them, such as vapor density. Therefore, it is difficult to distinguish them by their properties and effects on humans. However, there might be other kinds of restrictions. For example, according to the use, storage and transport in a prescribed area, it might already be known that three of the six are impossible to be present. Then the responder has to choose from one of the three remainsing chemicals. On the other hand, because they present similar hazards, it is unnecessary in practice, for emergency management, to identify exactly which of them is involved. In the analysis of atmospheric dispersion processes, the density effect is essentially considered at the initial stage. When a pressure tank has ruptured, the release of the liquefied gas causes violent evaporation which is endothermic, so that the gas becomes much cooler than the surrounding air. In other words, dense gas dispersion is considered to depend mainly on the endothermic effect, not on the vapor density.

3. The proposed scheme

A scheme for incident chemical identification is proposed that uses most of the possible kinds of information in a successive manner and with user interaction. The primary structure of the scheme is illustrated in Fig. 1.

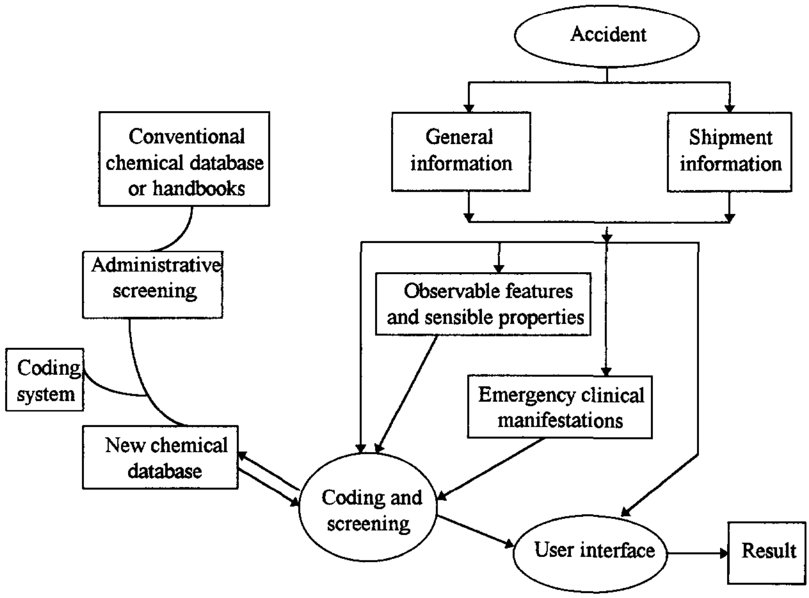

Fig. 1. Sketch of the chemical identification scheme.

As shown in the figure, four kinds of information items are considered: (a) general information; (b) shipment information; (c) observable features of the hazard and sensible properties of the released chemical; (d) and emergency clinical manifestations. In the case where the shipment information directly gives the chemical name, it is the user's decision whether to bypass the operation of the module.

These information items are divided into two orders. The items of the primary order are necessary for running the module. The secondary order items are initially assigned either with representative values or with a code corresponding to 'not reported' or 'not applicable'. Without the necessary information items, we do not expect that an automatic identification could provide non-trivial results. However, there is always the possibility of a lack of certain information during an incident. Therefore, this module is designed to be able to run with incomplete secondary order items. As is obvious, the less complete the information items, the stronger should be the user's interaction. The design of the hierarchy of ordered information items represents the successive characteristics of this identification scheme. For the screening operation, we design a coding system for these items, illustrated in Section 4. The codes found in such a system are to be matched with the codes of the new chemical database.

As is also shown in Fig. 1, a new database is to be established for hazardous chemicals. This new database is not only comprehensive in content but also has a new relational structure that allows 'backward' searching. Conventionally, given the name of a chemical, we can use handbooks or computer databases to list its physical and chemical properties, the hazard it could present, and the effect it might produce on human bodies. However, these databases usually do not allow inquiries based on a given property such as an acute clinical manifestation. For the present identification scheme, the new database should include the corresponding class and UN number of each chemical, and allow searching based on physical and chemical properties, phenomena of the incident, or clinical manifestations. Therefore, these properties and characteristics should be re-examined carefully and assigned with proper codes. The detail of the coding system designed for the new database is also illustrated in Section 4. Here we note only that, for screening purposes, the two coding systems, on-scene information and chemical database, should be similar. However, in the coding for on-scene reporting, the manner in which details emerge must be sufficiently accounted for.

Furthermore, there are thousands of hazardous chemicals. The result of 'backward' searching through an ordinary chemical database usually yields a long list of chemicals. To minimize the number of chemicals, there must be a preliminary screening process with respect to the specific region of interest. We call it 'administrative', because in a prescribed area the name and amount of hazardous materials that are in storage, use and transport can be obtained by administrative requests. According to the degree of hazard that these chemicals might present in an incident, a selection of chemicals can be determined. For example, WHAZAN selected 20 chemicals in their database. It might be the case that the programmer has considered these chemicals to be the most widely used worldwide. Another example is more practical. In the following section, we present an example of a coding system that includes 80 hazardous chemicals. These chemicals are based on the 100 chemicals selected by the Shanghai Municipal Civil Defense Office in 1992 with an inventory study. Although preliminary screening restricts the applicability of the identification scheme, we consider it is necessary and important to make the scheme practical.

4. Information items and coding systems

Four groups of information items are considered in the module. Each group is divided into two orders. In the group of general information, meteorological data are to be used to infer the stability status of the atmosphere and to relate to some of the characteristics of the hazard. Monthly averaged data are assigned as the default to the secondary meteorological items. Data on the surrounding circumstances are not used at present, so these secondary items are not assigned with default values. For the group of shipment information, special codes are designed to indicate whether these secondary order items are reported. If the chemical name is already given, say in the shipping document, the responder should decide whether this name is acceptable and the module operation can be bypassed.

With the consideration of successive information, two orders of items are designed for the other two groups of information. In particular, we suggest the earliest information from the scene would include the most directly sensible characteristics of the hazard and the released chemical. These primary order items are mainly used to describe the hazard type and the class of the chemical. The secondary order items are expected to be used when the hazard has lasted for a while, the properties and effects of the hazard are becoming more evident, and probably trained rescue teams have arrived. For example, the earliest report might tell whether there is an explosion, and if the chemical has an odor. The second report might tell whether the explosion is thermal or BLEVE, and the odor can be determined specifically. On the other hand, clinical reports are able to provide more useful information, but to collect this information takes more time. Some difficulties arise from the fact that a stronger exposure to a mild irritant might produce similar symptoms to a lighter exposure to a severe irritant. The information items are listed as follows.

1. General information:
   Primary order: date, time, location, estimated wind speed and direction, wetness
   Secondary order: meteorological conditions (humidity, temperature, wind speed, wind direction, cloudiness); surrounding circumstances (terrain, orography, vegetation, land use, other potential hazardous material sites).
2. Shipment information:
   Primary order: transportation type (railway, highway)
   Secondary order: carrier/container/package (type, size, appearance); label/placard (class, UN number); shipping document (class, UN number, chemical name); driver/technician description (class, UN number, chemical name).
3. Observable characteristics of the hazard and the released chemical:
   Primary order (default value = 0, corresponding to not reported): sound (non-specific, leakage, breaking, explosion, mass explosion); odor (not perceptible, unpleasant, irritating, pungent, suffocating); fire (not observed, pool fire, jet fire, fireball, mass fire); explosion (not observed, projection, explosion, mass explosion); smoke (not observed, light, moderate, heavy); cloud (not observed, normal dispersion, dense gas dispersion); intoxication (not found, injury, coma/fatal).
   Secondary order (default value = 0, corresponding to not observed/non specific): physical state (gas, compressed gas, non-cryogenic liquefied gas, cryogenic liquefied gas, volatile liquid, mobile liquid, ordinary liquid, viscous/oily liquid, solid); color (colorless/white, yellow, red/brown, greenish, blue/black); specific odor (non-specific, aromatic, fishy, ammoniac, gasoline, almond, rotten egg, garlic, alcoholic, musty); corrosivity (non-corrosive, corrosive, strongly corrosive).
4. Emergency clinical manifestations:
   Primary order: exposure level, stain, skin, eye, respiratory, digestive, neuropathy
   Secondary order: skin color (non-specific, jaundice, pall, red, blue); skin effect (irritation, corrosion, burn, frostbite); eye (irritation, lacrimation, corneal effect); respiratory (irritation, cough, dyspnea, wheezing, pneumonitis, asphyxia); digestive (salivation, nausea, vomiting, abdominal pain); neuropathy (dizzy, headache, coma, convulsion).

In designing these two orders of items, we have considered the most natural way in reporting an incident. For example, when an incident starts, it is often the case that the first report cannot provide accurate information on the physical state of the released chemical. Therefore, the physical state and the color of the chemical are considered as second order items. In fact, the most directly sensible phenomena of an incident are its sound (failure of the container, explosion), light (fire or explosion), smoke or cloud, smell, and whether there are any casualties due to intoxication. On the other hand, since this is for emergency response, the intoxication must be acute. Therefore, clinical manifestations respective to chronic exposure, or symptoms which would appear as distress with a relatively delayed period, are not considered. It is also noted that the coding based on these items is not directly used in screening, but is processed in the module to generate the codes which are comparable to that of the chemical database. For example, the flammability of a chemical can be perceived if there is a kind of fire or a thermal explosion. When there is no explosion or fire, in emergency management, it is more appropriate to consider the chemical as a gas or a volatile liquid. However, if there is a fire, sometimes the physical state can be inferred from the type of fire: pool fire refers to a liquid; jet fire refers to liquefied gas; fireball refers to a BLEVE, which is relevant to a flammable, volatile liquid.

One of the important reasons why the responder must decide on immediate actions is based on the clinical manifestations of injured people. To ensure these information be collected quickly and correctly, it is suggested to design a proper form, and to establish a regulation that the medical rescue team should have the responsibility to report its findings to the responder. The item 'exposure level' might be decided by the responder: (a) based on the observable level of the incident, the position of the injured person relative to the release site, and the time interval that the person is known to be exposed in the incident; or (b) based on directly observable clinical manifestations.

The coding system for the chemical database is designed on the basis of available handbooks on the properties of hazardous chemicals and their effects on human health. This coding is therefore more direct. For example, we can code the flammability of a chemical as flammable, or danger of explosion, or danger of mass explosion. We can also specify whether a chemical presents an odor, whether it is specific, and what kinds of specific effects it might have on human bodies. As described previously, this module is considered to tolerate incomplete information, so that the coding for the chemical database is also of two orders. Many items are similar to that of the information items. This allows screening by on-scene information in the same order.

To illustrate the design of the coding system for chemicals, an example is provided below. In 1990, the Shanghai Municipal Government began to carry out the APELL program (Awareness and Preparedness for Emergencies at Local Level), which was initiated by the United Nations and the Central Government of China. The objective of APELL is to improve the awareness and preparedness of the public, enterprises and communities, so as to reduce the damage done by industrial incidents, especially chemical incidents. In the implementation, necessary data were collected from all of the concerned enterprises in Shanghai. The analysis was made by the Shanghai Chemical Accident Emergency Rescue Specialist Committee. According to the circumstances of use, storage, physical and chemical properties and toxicity of the chemicals, 100 chemicals are recognized as the most important in Shanghai. Some of these chemicals are similar so that, in the present paper, we list the coding for 80 of them. Tables 2 and 3 give the two orders of codes for observable characteristics, while Tables 4–8 refer to effects on human health. It is found that, except for the table for the secondary codes on skin effects (Code 8), the codes are assigned with binary values. It is also shown that, for the secondary codes, the respective medical manifestations are listed in order of severity from right to left. For example, the respiratory effects are listed from right to left: irritation, cough, dyspnea, wheezing/bronchospasm, pneumonitis, then asphyxia. In

Table 2
First-order coding for observable characteristics (Code 1)

Chemical name	ST	OD	FL	SM	CD1	Chemical name	ST	OD	FL	SM	CD1
acetaldehyde	2	3	2	0	2320	hydrochloric acid	2	2	0	0	2200
acetic acid	2	2	2	0	2220	hydrogen chloride	3	3	0	0	3300
acetone	2	3	2	0	2320	hydrogen cyanide	3	2	2	0	3220
acrylamide	1	3	0	0	1300	hydrogen fluoride	3	2	0	0	3200
acrylonitrile	2	2	2	2	2222	hydrogen sulfide	3	3	2	0	3320
allyl chloride	2	3	2	0	2320	iodine	1	2	0	0	1200
ammonia	3	3	0	0	3300	LPG	3	1	2	0	3120
aniline	2	3	2	0	2320	methyl acrylate	2	1	2	0	2120
arsine	3	1	2	0	3120	methyl alcohol	2	1	2	0	2120
barium	1	0	0	0	1000	methylamine	3	3	2	0	3320
benzene	2	3	2	0	2320	methyl bromide	3	2	0	0	3200
biphenyl	1	0	1	0	1010	methyl chloride	3	0	2	0	3020
bromine	2	2	0	1	2201	methylene chloride	2	3	3	0	2330
n-butyl alcohol	2	2	1	0	2210	methyl methacrylate	2	1	2	0	2120
carbon disulfide	2	2	2	0	2220	naphthalene	1	2	1	0	1210
carbon monoxide	3	0	2	0	3020	nitric acid	2	2	0	1	2201
carbon tetrachloride	2	2	0	0	2200	nitrobenzene	2	0	2	0	2020
catechol	1	0	1	0	1010	nitrogen dioxide	3	2	0	0	3200
chlorine	3	2	0	0	3200	oxalic acid	1	0	0	0	1000
chlorobenzene	2	1	2	0	2120	phenol	1	1	1	2	1112
chloroform	2	3	0	0	2300	*p*-phenylenediamine	1	0	1	0	1010
chromium metal	1	0	0	0	1000	phosgene	3	2	0	0	3200
crude oil	2	0	1	3	2013	phosphoric acid	2	0	0	0	2000
cyanides	1	2	0	0	1200	phosphorus trichloride	2	2	1	1	2211
cyclohexanone	2	2	3	0	2230	propene	3	3	2	0	3320
1,2-dichloroethylene	2	0	2	0	2020	*n*-propyl alcohol	2	1	1	0	2110
dimethyl sulfate	2	0	1	0	2010	propylene oxide	2	0	2	0	2020
dimethylamine	3	2	2	0	3220	sodium hydroxide	1	0	0	1	1001
dinitrotoluene	1	1	2	0	1120	styrene, monomer	2	1	2	0	2120
epichlorohydrin	2	1	1	0	2110	sulfur dioxide	3	3	0	0	3300
ethyl alcohol	2	1	1	0	2110	sulfuric acid	2	2	0	1	2201
ethyl chloride	3	3	2	0	3320	toluene	2	1	1	2	2112
ethylene	3	1	2	0	3120	toluene-2,4-diisocyanate	2	2	1	0	2210
ethylene dichloride	2	3	1	2	2312	*p*-toluidine	2	0	1	0	2010
ethylene glycol	2	0	0	0	2000	1,1,1-trichloroethane	2	3	0	0	2300
ethylene oxide	3	1	2	0	3120	trichloroethylene	3	1	2	0	3120
fluorine	3	1	0	0	3100	trimethylamine	3	1	2	0	3120
formaldehyde	3	2	2	0	3220	trinitrotoluene	1	0	2	0	1020
formic acid	2	3	2	0	2320	vinyl chloride	3	1	2	0	3120
gasoline	2	1	2	3	2123	xylene	2	1	2	2	2122

ST—physical state: 1—solid, 2—liquid, 3—gaseous; OD—odor: 0—odorless/mild, 1—unpleasant, 2—irritating, 3—pungent, 4—suffocating; FL—flammability: 0—non-flammable, 1—flammable, 2—flammable/explosive, 3—strong explosive; SM—smoke: 0—smokeless, 1—fuming, 2—moderate, 3—heavy.

such a manner, the resulting code increases in value when the respiratory effects are reported to be stronger. This is designed to account for the fact that, at the same incident, injuries may result from different degrees of exposure, and that a severe

Table 3
Second-order coding for observable characteristics (Code 2)

Chemical name	ST	CL	OD	CR	CD2	Chemical name	ST	CL	OD	CR	CD2
acetaldehyde	6	1	0	0	6100	hydrochloric acid	7	1	0	2	7102
acetic acid	7	1	0	1	7101	hydrogen chloride	2	1	0	0	2100
acetone	5	1	2	0	5120	hydrogen cyanide	3	1	9	0	3190
acrylamide	9	1	0	0	9100	hydrogen fluoride	3	1	0	2	3102
acrylonitrile	7	1	0	0	7100	hydrogen sulfide	2	1	6	0	2160
allyl chloride	6	1	0	0	6100	iodine	9	5	0	0	9500
ammonia	3	1	3	0	3130	LPG	3	1	0	0	3100
aniline	7	1	0	0	7100	methyl acrylate	5	1	7	0	5170
arsine	2	1	9	0	2190	methyl alcohol	5	1	8	0	5180
barium	9	1	0	1	9101	methylamine	3	1	3	0	3130
benzene	5	1	1	0	5110	methyl bromide	3	1	0	0	3100
biphenyl	9	1	0	0	9100	methyl chloride	3	1	0	0	3100
bromine	7	3	0	0	7300	methylene chloride	7	1	0	0	7100
n-butyl alcohol	7	1	8	0	7180	methyl methacrylate	6	1	2	0	6120
carbon disulfide	5	1	0	0	5100	naphthalene	9	1	0	0	9100
carbon monoxide	1	1	0	0	1100	nitric acid	7	2	0	2	7202
carbon tetrachloride	7	1	0	0	7100	nitrobenzene	7	2	5	0	7250
catechol	9	1	0	1	9101	nitrogen dioxide	2	3	0	0	2300
chlorine	3	4	0	0	3400	oxalic acid	9	1	0	1	9101
chlorobenzene	5	1	5	0	5150	phenol	9	1	1	1	9111
chloroform	5	1	0	0	5100	*p*-phenylenediamine	9	1	0	0	9100
chromium metal	9	3	0	1	9301	phosgene	3	1	9	0	3190
crude oil	8	2	0	0	8200	phosphoric acid	7	1	0	1	7101
cyanides	9	1	5	0	9150	phosphorus trichloride	6	1	0	1	6101
cyclohexanone	7	1	0	0	7100	propene	2	1	0	0	2100
1,2-dichloroethylene	6	1	0	0	6100	*n*-propyl alcohol	7	1	8	0	7180
dimethyl sulfate	7	1	0	1	7101	propylene oxide	5	1	2	0	5120
dimethylamine	3	1	3	0	3130	sodium hydroxide	9	1	0	2	9102
dinitrotoluene	9	2	5	0	9250	styrene, monomer	8	1	1	0	8110
epichlorohydrin	6	1	2	0	6120	sulfur dioxide	3	1	0	0	3100
ethyl alcohol	7	1	8	0	7180	sulfuric acid	7	1	0	2	7102
ethyl chloride	3	1	0	0	3100	toluene	7	1	1	0	7110
ethylene	3	1	1	0	3110	toluene-2,4-diisocyanate	7	1	0	0	7100
ethylene dichloride	7	1	0	0	7100	*p*-toluidine	7	2	0	0	7200
ethylene glycol	8	1	0	0	8100	1,1,1-trichloroethane	7	1	0	0	7100
ethylene oxide	3	1	2	0	3120	trichloroethylene	6	1	0	0	6100
fluorine	2	2	0	0	2200	trimethylamine	3	1	3	0	3130
formaldehyde	7	1	0	0	7100	trinitrotoluene	9	2	0	0	9200
formic acid	7	1	0	1	7101	vinyl chloride	3	1	1	0	3110
gasoline	5	2	4	0	5240	xylene	5	1	1	0	5110

ST—Physical state in more detail: 1—gas, 2—compressed gas, 3—non-cryogenic liquefied gas, 4—cryogenic liquefied gas, 5—volatile liquid, 6—mobile liquid, 7—ordinary liquid, 8—viscous/oily liquid, 9—solid; CL—color: 1—colorless/white, 2—yellow, 3—red/brown, 4—greenish, 5—blue/black; OD—specific odor: 0—non-specific, 1—aromatic, 2—ethereal, 3—ammoniac, 4—gasoline, 5—almond, 6—rotten egg, 7—garlic, 8—alcoholic, 9—musty; CR—corrosivity: 0—non-corrosive, 1—corrosive, 2—strongly corrosive.

Table 4
First-order coding for effects on human health (Code 3)

Chemical name	SK1	SK2	EY	RS	DI	NP	AC	CD3
acetaldehyde	0	1	1	1	1	0	1	61
acetic acid	0	1	1	1	0	0	0	56
acetone	0	0	1	1	0	1	1	27
acrylamide	0	1	1	1	0	1	0	58
acrylonitrile	0	1	1	1	1	1	1	63
allyl chloride	0	1	1	1	0	1	0	58
ammonia	0	1	1	1	0	0	1	57
aniline	1	0	0	0	0	1	0	66
arsine	1	0	0	0	1	1	1	71
barium and compounds	0	1	1	1	1	0	0	60
benzene	0	0	0	0	0	1	1	3
biphenyl	0	1	1	1	1	1	0	62
bromine	0	1	1	1	1	0	1	61
n-butyl alcohol	0	0	1	1	1	1	0	30
carbon disulfide	0	0	0	0	0	1	1	3
carbon monoxide	1	0	0	0	1	1	1	71
carbon tetrachloride	0	0	0	0	1	1	0	6
catechol	0	1	1	1	0	1	0	58
chlorine	0	1	1	1	1	1	1	63
chlorobenzene	0	1	1	1	0	1	0	58
chloroform	0	0	0	0	1	1	1	7
hexavalent chromium	0	0	0	1	0	0	0	8
crude oil	0	0	0	0	0	0	0	0
cyanides	0	1	1	1	1	1	1	63
cyclohexanone	0	0	1	1	0	0	0	24
11,2-dichloroethylene	0	0	0	1	0	1	0	10
dimethylamine	0	1	1	1	0	0	0	56
dimethyl sulfate	0	1	1	1	0	0	0	56
dinitrotoluene	1	0	0	0	1	0	0	68
epichlorohydrin	0	1	1	1	1	0	0	60
ethyl alcohol	0	0	1	1	0	1	0	26
ethyl chloride	0	0	0	0	0	1	0	2
ethylene	0	0	0	0	0	1	1	3
ethylene dichloride	0	0	0	0	1	1	1	7
ethylene glycol	0	0	1	0	0	0	0	16
ethylene oxide	0	1	1	1	1	1	0	62
fluorine	0	1	1	1	0	0	0	56
formaldehyde	0	0	1	1	1	0	0	28
formic acid	0	1	1	1	0	0	0	56
gasoline	0	0	1	1	0	1	0	26
hydrochloric acid	0	1	1	1	0	0	0	56
hydrogen chloride	0	1	1	1	0	0	0	56
hydrogen cyanide	1	0	0	0	1	1	1	71
hydrogen fluoride	0	1	1	1	0	0	1	57
hydrogen sulfide	0	0	1	1	0	1	1	27
iodine	0	1	1	1	0	0	0	56
LPG	0	0	0	0	0	0	1	1
methyl acrylate	0	0	1	0	0	0	0	16
methyl alcohol	0	0	1	1	0	1	0	26

Table 4 (continued)

Chemical name	SK1	SK2	EY	RS	DI	NP	AC	CD3
methylamine	0	1	1	1	0	0	1	57
methyl bromide	0	0	0	0	1	1	0	6
methyl chloride	0	0	0	0	0	1	0	2
methylene chloride	0	1	1	1	0	1	0	58
methyl methacrylate	0	1	1	1	0	1	0	58
naphthalene	0	0	1	0	1	1	0	22
nitric acid	0	1	1	1	0	0	0	56
nitrobenzene	1	0	0	0	0	1	0	66
nitrogen dioxide	0	0	0	1	0	0	1	9
oxalic acid	0	1	1	1	0	0	0	56
phenol	0	1	1	0	0	0	0	48
p-phenylenediamine	0	1	1	1	0	0	0	56
phosgene	0	1	1	1	1	0	1	61
phosphoric acid	0	1	1	1	0	0	0	56
phosphorus trichloride	0	1	1	1	0	0	0	56
propene	0	0	1	1	0	0	1	25
n-propyl alcohol	0	0	1	1	0	1	0	26
propylene oxide	0	1	1	1	1	1	0	62
sodium hydroxide	0	1	1	1	0	0	0	56
styrene monomer	0	1	1	1	0	1	0	58
sulfur dioxide	0	1	1	1	0	0	0	56
sulfuric acid	0	1	1	1	0	0	0	56
toluene	0	0	0	0	1	1	1	7
toluene-2,4-diisocyanate	0	1	1	1	1	0	0	60
p-toluidine	1	0	0	0	0	1	0	66
1,1,1-trichloroethane	0	0	0	0	0	1	1	3
trichloroethylene	0	0	0	0	0	1	0	2
trimethylamine	0	0	1	1	0	0	0	24
trinitrotoluene	0	0	0	0	0	0	0	0
vinyl chloride	0	0	0	0	1	1	0	6
xylene	0	0	1	1	0	1	0	26

SK1—skin color, SK2—skin effect, EY—eye effect, RS—respiratory system, DI—digestive system, NP—neuropathy effect, AC—asphyxia/coma.
Value: 0—not observable, 1—observable. The codes are transformed from their binary forms.

exposure to a mild irritant may present the same symptoms as that of a light exposure to a severe irritant. Comparing these tables with the list of on-scene information items, we find some difference. This implies that a submodule is needed to derive codes that are comparable with those in Tables 2–8 from the information items. The manifestation codes are to be determined by the diagnostician after the victims arrive at the hospital. Some of the clinical manifestations appear after some delay, however. This also leads to another difficulty for an emergency response. The submodule is to be constructed with an eliminating mechanism for 'impossible' chemicals. However, it could happen, at the stage when a decision must be taken, that there are still several chemicals remaining in the eliminating buffer. It would then rely on the experience and intuition of the first responder to select the right chemical.

5. An application example

To illustrate the feasibility of the proposed scheme, an example is analyzed on the basis of a prototype incident. At a small town named Shaxi in Jiangxi Province,

Table 5
Second-order coding for eye effects (Code 4)

Chemical name	CO	LC	IR	CD4	Chemical name	CO	LC	IR	CD4
acetaldehyde	0	0	1	1	hydrochloric acid	0	0	0	0
acetic acid	0	1	1	3	hydrogen chloride	1	1	1	7
acetone	0	0	1	1	hydrogen cyanide	0	0	0	0
acrylamide	0	0	1	1	hydrogen fluoride	0	1	1	3
acrylonitrile	0	0	1	1	hydrogen sulfide	1	1	1	7
allyl chloride	0	1	1	3	iodine	0	1	1	3
ammonia	1	1	1	7	LPG	0	0	0	0
aniline	0	0	0	0	methyl acrylate	0	1	1	3
arsine	0	0	0	0	methyl alcohol	0	0	1	1
barium and compounds	0	0	1	1	methylamine	1	1	1	7
benzene	0	0	0	0	methyl bromide	0	0	0	0
biphenyl	0	0	1	1	methyl chloride	0	0	0	0
bromine	1	1	1	7	methylene chloride	0	0	1	1
n-butyl alcohol	0	1	1	3	methyl methacrylate	0	1	1	3
carbon disulfide	1	1	1	7	naphthalene	0	0	1	1
carbon monoxide	0	0	0	0	nitric acid	0	0	0	0
carbon tetrachloride	0	0	0	0	nitrobenzene	0	0	0	0
catechol	0	0	1	1	nitrogen dioxide	0	0	0	0
chlorine	1	1	1	7	oxalic acid	0	0	1	1
chlorobenzene	0	0	1	1	phenol	1	1	1	7
chloroform	0	0	0	0	*p*-phenylenediamine	0	0	1	1
hexavalent chromium	0	0	0	0	phosgene	0	1	1	3
crude oil	0	0	0	0	phosphoric acid	0	0	1	1
cyanides	0	0	1	1	phosphorus trichloride	1	1	1	7
cyclohexanone	0	0	1	1	propene	0	0	1	1
1,2-dichloroethylene	0	0	0	0	*n*-propyl alcohol	0	0	1	1
dimethylamine	1	1	1	7	propylene oxide	1	1	1	7
dimethyl sulfate	1	1	1	7	sodium hydroxide	1	1	1	7
dinitrotoluene	0	0	0	0	styrene	0	0	1	1
epichlorohydrin	1	1	1	7	sulfur dioxide	0	1	1	3
ethyl alcohol	0	1	1	3	sulfuric acid	1	1	1	7
ethyl chloride	0	0	0	0	toluene	0	0	0	0
ethylene	0	0	0	0	toluene-2,4-diisocyanate	0	1	1	3
ethylene dichloride	0	0	0	0	*p*-toluidine	0	0	0	0
ethylene glycol	0	0	0	0	1,1,1-trichloroethane	0	0	0	0
ethylene oxide	0	1	1	3	trichloroethylene	0	0	0	0
fluorine	1	1	1	7	trimethylamine	0	1	1	3
formaldehyde	0	1	1	3	trinitrotoluene	0	0	0	0
formic acid	1	1	1	7	vinyl chloride	0	0	0	0
gasoline	0	0	1	1	xylene	0	0	1	1

IR—irritation, LC—lacrimation, CO—corneal effect. Values: 0—not observable, 1—observable. The codes have been transformed from their binary forms.

southeast China, 650 people were intoxicated, with 39 deaths, in a severe accidental release of a toxic chemical. Among the casualties, 8 died right at the scene. It was in the early morning, 2:30 am on 3 September 1991, when a truck carrying a tank filled with

Table 6
Second-order coding for effects on the respiratory system (Code 5)

Chemical name	AS	PU	WE	DY	CF	IR	CD5	Chemical name	AS	PU	WE	DY	CF	IR	CD5
acetaldehyde	1	1	1	1	1	1	63	hydrochloric acid	0	0	0	0	0	0	0
acetic acid	0	1	1	1	1	1	31	hydrogen chloride	0	1	1	1	1	1	31
acetone	0	0	0	0	0	1	1	hydrogen cyanide	0	0	0	0	0	0	0
acrylamide	0	0	0	0	0	1	1	hydrogen fluoride	1	1	1	1	1	1	63
acrylonitrile	0	0	0	0	0	1	1	hydrogen sulfide	1	1	1	1	1	1	63
allyl chloride	0	0	0	0	0	1	1	iodine	0	0	0	0	1	1	3
ammonia	1	1	1	1	1	1	63	LPG	0	0	0	0	0	0	0
aniline	0	0	0	0	0	0	0	methyl acrylate	0	0	0	0	0	0	0
arsine	0	0	0	0	0	0	0	methyl alcohol	0	0	0	0	0	1	1
barium and compounds	0	0	0	0	0	1	1	methylamine	1	1	1	1	1	1	63
benzene	0	0	0	0	0	0	0	methyl bromide	0	0	0	0	0	0	0
biphenyl	0	0	0	0	1	1	3	methyl chloride	0	0	0	0	0	0	0
bromine	1	1	1	1	1	1	63	methylene chloride	0	0	0	0	1	1	3
n-butyl alcohol	0	0	0	0	1	1	3	methyl methacrylate	0	0	0	0	1	1	3
carbon disulfide	0	0	0	0	0	0	0	naphthalene	0	0	0	0	0	0	0
carbon monoxide	0	0	0	0	0	0	0	nitric acid	0	1	1	1	1	1	31
carbon tetrachloride	0	0	0	0	0	0	0	nitrobenzene	0	0	0	0	0	0	0
catechol	0	0	0	1	1	1	7	nitrogen dioxide	1	1	1	1	1	1	63
chlorine	1	1	1	1	1	1	63	oxalic acid	0	0	0	0	1	1	3
chlorobenzene	0	0	0	0	0	1	1	phenol	0	0	0	0	0	0	0
chloroform	0	0	0	0	0	0	0	*p*-phenylenediamine	0	0	0	1	1	1	7
hexavalent chromium	0	0	0	0	1	1	3	phosgene	1	1	1	1	1	1	63
crude oil	0	0	0	0	0	0	0	phosphoric acid	0	0	0	0	1	1	3
cyanides	1	1	1	1	1	1	63	phosphorus trichloride	0	1	1	1	1	1	31
cyclohexanone	0	0	0	0	0	1	1	propene	0	0	0	0	0	1	1
1,2-dichloroethylene	0	0	0	0	1	1	3	*n*-propyl alcohol	0	0	0	0	0	1	1
dimethylamine	0	0	0	1	1	1	7	propylene oxide	0	0	0	1	1	1	7
dimethyl sulfate	0	1	1	1	1	1	31	sodium hydroxide	0	1	1	1	1	1	31
dinitrotoluene	0	0	0	0	0	0	0	styrene	0	0	0	0	1	1	3
epichlorohydrin	0	1	1	1	1	1	31	sulfur dioxide	0	1	1	1	1	1	31
ethyl alcohol	0	0	0	0	1	1	3	sulfuric acid	0	1	1	1	1	1	31
ethyl chloride	0	0	0	0	0	0	0	toluene	0	0	0	0	0	0	0
ethylene	0	0	0	0	0	0	0	toluene-2,4-diisocyanate	0	1	1	1	1	1	31
ethylene dichloride	0	0	0	0	0	0	0	*p*-toluidine	0	0	0	0	0	0	0
ethylene glycol	0	0	0	0	0	1	1	1,1,1-trichloroethane	0	0	0	0	0	0	0
ethylene oxide	0	1	1	1	1	1	31	trichloroethylene	0	0	0	0	0	0	0
fluorine	0	1	1	1	1	1	31	trimethylamine	0	0	0	1	1	1	7
formaldehyde	0	1	1	1	1	1	31	trinitrotoluene	0	0	0	0	0	0	0
formic acid	0	1	1	1	1	1	31	vinyl chloride	0	0	0	0	0	0	0
gasoline	0	0	0	0	1	1	3	xylene	0	0	0	0	0	1	1

IR—irritation, CF—cough, DY—dyspnea, WE—wheezing/bronchospasm, PU—pneumonitis, AS—asphyxia.
Values: 0—not observable, 1—observable. The codes have been transformed from their binary forms.

2.4 tonnes of liquefied methylamine under 3 to 4 atm pressure was being driven from Shanghai to a factory in Jiangxi. The driver violated the rules and tried to steer the truck into the town. In the dark, the top of the truck hit a branch of a large tree. The pressure valve broke and this led to a rapid release of the chemical, creating a fire and a thick

Table 7
Secondary coding for effects on neuropathy systems (Code 6)

Chemical name	CV	CM	HD	DZ	CD6	Chemical name	CV	CM	HD	DZ	CD6
acetaldehyde	0	0	0	0	0	hydrochloric acid	0	0	0	0	0
acetic acid	0	0	0	0	0	hydrogen chloride	0	0	0	0	0
acetone	0	1	1	1	7	hydrogen cyanide	1	1	1	1	7
acrylamide	0	0	1	1	3	hydrogen fluoride	0	0	0	0	0
acrylonitrile	1	1	1	1	15	hydrogen sulfide	1	1	1	1	15
allyl chloride	0	0	0	0	0	iodine	0	0	0	0	0
ammonia	0	0	0	0	0	LPG	0	0	0	0	0
aniline	0	0	1	1	3	methyl acrylate	0	0	0	0	0
arsine	0	1	1	1	7	methyl alcohol	0	0	1	1	3
barium	1	0	0	0	8	methylamine	0	0	0	0	0
benzene	1	1	1	1	15	methyl bromide	1	0	1	1	11
biphenyl	0	0	1	1	3	methyl chloride	1	0	1	1	11
bromine	0	0	1	1	3	methylene chloride	0	0	0	1	1
n-butyl alcohol	0	0	1	1	3	methyl methacrylate	0	0	1	1	3
carbon disulfide	0	1	1	1	7	naphthalene	0	0	1	1	3
carbon monoxide	0	1	1	1	7	nitric acid	0	0	0	0	0
carbon tetrachloride	0	0	1	1	3	nitrobenzene	0	0	1	1	3
catechol	1	0	1	1	11	nitrogen dioxide	0	0	0	0	0
chlorine	0	1	1	1	7	oxalic acid	1	0	0	0	8
chlorobenzene	0	0	0	1	1	phenol	0	0	0	1	1
chloroform	0	1	0	1	5	*p*-phenylenediamine	0	0	0	0	0
hexavalent chromium	0	0	0	0	0	phosgene	0	0	0	0	0
crude oil	0	0	0	0	0	phosphoric acid	0	0	0	0	0
cyanides	1	1	1	1	15	phosphorus trichloride	0	0	0	0	0
cyclohexanone	0	0	0	0	0	propene	0	0	0	0	0
1,2-dichloroethylene	0	0	1	1	3	*n*-propyl alcohol	0	0	1	1	3
dimethylamine	0	0	0	0	0	propylene oxide	0	0	1	1	3
dimethyl sulfate	0	0	0	0	0	sodium hydroxide	0	0	0	0	0
dinitrotoluene	0	0	0	0	0	styrene	0	0	1	1	3
epichlorohydrin	0	0	0	0	0	sulfur dioxide	0	0	0	0	0
ethyl alcohol	0	0	1	1	3	sulfuric acid	0	0	0	0	0
ethyl chloride	0	0	1	1	3	toluene	1	1	1	1	15
ethylene	0	0	0	0	0	toluene-2,4-diisocyanate	0	0	0	0	0
ethylene dichlororide	0	1	1	1	7	*p*-toluidine	0	0	1	1	3
ethylene glycol	0	0	0	0	0	1,1,1-trichloroethane	0	1	1	1	7
ethylene oxide	0	0	1	1	3	trichloroethylene	0	0	1	1	3
fluorine	0	0	0	0	0	trimethylamine	0	0	0	0	0
formaldehyde	0	0	0	0	0	trinitrotoluene	0	0	0	0	0
formic acid	0	0	0	0	0	vinyl chloride	0	0	1	1	3
gasoline	0	0	0	1	1	xylene	0	0	1	1	3

DZ—dizzy, HD—headache, CM—coma, CV—convulsion, NA—nausea.
Values: 0—not observable, 1—observable. The codes have been transformed from their binary forms.

Table 8
Secondary coding for effects on the digestive system (Code 7)

Chemical name	AB	VO	NA	CD7	Chemical name	AB	VO	NA	CD7
acetaldehyde	0	1	1	3	hydrochloric acid	0	0	0	0
acetic acid	0	0	0	0	hydrogen chloride	0	0	0	0
acetone	0	0	0	0	hydrogen cyanide	0	1	1	3
acrylamide	0	0	0	0	hydrogen fluoride	0	0	0	0
acrylonitrile	0	1	1	3	hydrogen sulfide	0	0	0	0
allyl chloride	0	0	0	0	Iodine	0	0	0	0
ammonia	0	0	0	0	LPG	0	0	0	0
aniline	0	0	0	0	methyl acrylate	0	0	0	0
arsine	1	1	1	7	methyl alcohol	0	0	0	0
barium	0	1	1	3	methylamine	0	0	0	0
benzene	0	0	0	0	methyl bromide	0	1	1	3
biphenyl	1	0	1	5	methyl chloride	0	0	0	0
bromine	0	0	1	1	methylene chloride	0	0	0	0
n-butyl alcohol	1	1	1	7	methyl methacrylate	0	0	0	0
carbon disulfide	0	1	1	3	naphthalene	0	1	1	3
carbon monoxide	0	0	0	0	nitric acid	0	0	0	0
carbon tetrachloride	0	0	0	0	nitrobenzene	0	0	0	0
catechol	0	0	0	0	nitrogen dioxide	0	0	0	0
chlorine	0	1	1	3	oxalic acid	0	0	0	0
chlorobenzene	0	0	0	0	phenol	0	0	0	0
chloroform	0	0	0	0	*p*-phenylenediamine	0	1	1	3
hexavalent chromium	0	0	0	0	phosgene	0	1	1	3
crude oil	0	0	0	0	phosphoric acid	0	0	0	0
cyanides	0	1	1	3	phosphorus trichloride	0	0	0	0
cyclohexanone	0	0	0	0	propene	0	0	0	0
1,2-dichloroethylene	0	0	0	0	*n*-propyl alcohol	0	0	0	0
dimethylamine	0	0	0	0	propylene oxide	0	1	1	3
dimethyl sulfate	0	0	0	0	sodium hydroxide	0	0	0	0
dinitrotoluene	0	1	1	3	styrene	0	1	1	3
epichlorohydrin	0	1	1	3	sulfur dioxide	0	0	0	0
ethyl alcohol	0	0	0	0	sulfuric acid	0	0	0	0
ethyl chloride	0	0	0	0	toluene	0	1	1	3
ethylene	0	0	0	0	toluene-2,4-diisocyanate	1	1	1	7
ethylene dichlororide	0	1	1	3	*p*-toluidine	0	0	0	0
ethylene glycol	0	0	0	0	1,1,1-trichloroethane	0	0	0	0
ethylene oxide	0	1	1	3	trichloroethylene	0	0	0	0
fluorine	0	0	0	0	trimethylamine	0	0	0	0
formaldehyde	0	1	1	3	trinitrotoluene	0	0	0	0
formic acid	0	0	0	0	vinyl chloride	0	0	1	1
gasoline	0	0	0	0	xylene	0	0	0	0

NA—nausea, VO—vomiting, AB—abdominal pain.
Values: 0—not observable, 1—observable. The codes have been transformed from their binary forms.

cloud. It was hot and humid, 27°C, relative humidity 82%, and almost calm. The surface temperature was 26°C so that the air was in a stable condition. The nearby structures were all one or two story country buildings. People slept with their door open to get some cool feeling. The release lasted nearly 10 min. Because of the meteorological conditions, the hazard persisted for 30 min. It was estimated later that the areas of intoxication were: severe, $2500\,m^2$; moderate, $20\,000\,m^2$; and light, $220\,000\,m^2$. People in the neighborhood were in a deep sleep. When the release started, the driver and the technician were so frightened that they could only break into shouting: ''hurry, escape, toxic gas out!'', then ran away. The combustion was incomplete, so that most of the liquid evaporated to form a toxic cloud which dispersed slowly. The toxic cloud was about 5–6 m high, headed first to the southeast, then turned to the opposite direction after several minutes. The awakened people were under threat. After several minutes, many of them knew there was a release of toxic gas. Within the first hour, 130 severely intoxicated patients were rescued and taken to hospital. However, the name of the chemical was only identified two hours later, after the town police officers had rushed to the truck and found the shipping paper. There are lessons to be learned from the accident. If the name of the chemical could have been known earlier, more appropriate response measures would have been taken and the number of casualties would have been reduced. For example, a number of the patients sustained severe skin burns because the rescue team did not know the chemical hurt the skin and kept the patients in their contaminated clothing.

The clinical manifestations of two severe intoxication cases are provided. (1) A young man, 29, awakened by the suffocating feeling caused by several minutes' intake of the toxic vapor, managed to get himself to the hospital. He was found to have a body temperature of 37.4°C, respiration $20\,min^{-1}$, pulse $96\,min^{-1}$, blood pressure 17/10 kPa. He exhibited violent coughing, dyspnea, stridor, lacrimation, photophobia, irritating feeling of mouth and lips, palpitation, depressed consciousness, burns on bare skin, and corneal hyperemia. Wheezing, pneumonisis, pulmonary edema, cardiac arrhythmia and myocarditis were found three days later. (2) A boy, 15, breathed in the toxic vapor during sleep, experienced tachypnea and upper airway obstruction, then fell into a coma. After being rescued and taken to hospital, he was found to have body temperature 39°C, respiration $38\,min^{-1}$, pulse $124\,min^{-1}$, blood pressure 16/11 kPa, burns on bare skin, hyperemia and edema on eyelids, corneal and mouth membranes, and râles in his airway. Pneumonisis and pulmonary edema, cardiac arrhythmia and myocarditis were diagnosed 24 h later.

In this incident, except for crying ''toxic gas out'', the driver failed to provide any other information. We therefore expect the possible on-scene reports would come successively like the following:

1. Truck incident; tank leakage; gas; fire; cloud; pungent odor; injury and fatalities.
2. Intoxication; irritating on skin; obvious effects on eyes and respiratory tract.
3. Non-cryogenic liquefied gas; cloud dispersion along the surface, nearly 5–6 m thick; casualties with burns on the mouth and bare skin; violent coughing, dyspnea, obstruction in upper airway, asphyxia; eye irritation, lacrimation, corneal damage; unconsciousness, coma.
4. Pneumonisis and pulmonary edema, cardiac arrhythmia and myocarditis.

Within the module, this information is transformed into the codes. It is noted that there are sub-codes in each designated code. For example, for code 1, CD1 = 3310 and 3320. Since there was a fire, the chemical should be coded as flammable. However, this does not mean the chemical is without danger of explosion. Explosion usually happens under confined conditions. In this case, it means the screening should allow the sub-code FL $\geq$ 1. Another example is code 2, CD2 = 3100. This refers to the sub-code OD = 0, non-specific or not reported. The screening for code 2 allows the sub-code OD $\geq$ 0. On the other hand, there are three chemicals that satisfy code 3, CD3 = 57 in Table 3. Comparing these remaining chemicals with the screening by the three codes, the result comes out as methylamine. No more screening is needed.

Take a closer look into this procedure. The reasons for such a quick identification can be found as follows: the chemical was found to be flammable, and casualties were examined with severe intoxication, mainly on the skin, eyes, and respiratory tract, resulting in respiratory asphyxia. In particular, among the 80 chemicals remaining after primary screening, there are only a few chemicals listed as severe skin, eye and respiratory irritants. However, if the pressure valve had not broken but had merely leaked, the chemical would have been released much more slowly. There might not have been a fire. People could still have become intoxicated and felt irritation on skin, eye and throat, even breaking into lacrimation and coughing, but no asphyxia. Identification would also be possible, but more steps would be needed for the screening process.

6. Conclusion

Chemical identification is an important step in emergency management and consequence analysis for hazardous chemical incidents. This study proposes a scheme for identification which allows all possible information to be taken into account, especially the emergency clinical manifestations. To allow successive and interactive operation, two orders of codes are suggested for both the information items and the chemicals. Consequence analysis modelers are often unfamiliar with medical diagnostics. Therefore, more careful study is needed to improve the coding systems. This includes investigation of existing databases of the properties and health effects of hazardous chemicals, especially analysis of all available records of chemical incidents. There are over 1000 known hazardous chemicals. No matter how good a screening procedure is designed, it is still essential to require preliminary screening, which we call 'administrative'. For this reason, although this scheme can in principle be applied anywhere, the application of a completed scheme will be restricted to a prescribed area. As described in the paper, because of the uncertainty characteristics of incidents, the experience and intuition of the first responder always plays an important role. Nonetheless, the present scheme provides a better chance for him to act correctly.

References

[1] R.T. Luckritz, A.L. Schneider, Decision making in hazardous materials transportation, J. Hazard. Mater. 14 (1980) 129–143.

[2] Ooms, G. and Tennekes, H. (Eds.), *Atmospheric Dispersion of Heavy Gases and Small Particles*, Springer-Verlag, Berlin, 1984.

[3] Technica, Ltd, *Techniques for Assessing Industrial Hazards: A Manual*, World Bank Technical Paper No. 55, 1988.

[4] P.K. Raj, J.A. Morris, Computerized spill hazard evaluation models, J. Hazard. Mater. 25 (1990) 77–92.
[5] S.R. Hanna, D.G. Strimaitis, J.C. Chang, Evaluation of fourteen hazardous gas models with ammonia and hydrogen fluoride field data, J. Hazard. Mater. 26 (1991) 127–158.
[6] W.Y. Lin, P. Biswas, EMERG: an expert system to develop emergency responses to hazardous material spills, Hazardous Waste and Hazardous Mater. 8 (1991) 263–274.
[7] USEPA, *Guidance on the Application of Refined Dispersion Models to Hazardous/Toxic Air Pollutant Releases*, EPA-454/R-93-002, 1993.
[8] P.W.M. Brighton, A.J. Byrne, R.P. Cleaver, P. Courtiade, B. Crabol, R.D. Fitzpatrick, A. Girard, S.J. Jones, V.L. Homme, A. Mercer, D. Nedelka, C. Proux, D.M. Webber, Comparison of heavy gas dispersion models for instantaneous releases, J. Hazard. Mater. 36 (1994) 193–208.
[9] E.L. Quarantelli, Disaster planning for transportation accidents involving hazardous materials, J. Hazard. Mater. 27 (1991) 49–60.
[10] M.J. DiBartolomeis, G.V. Alexeeff, A.M. Fan, R.J. Jackson, Regulatory approach to assessing health risks of toxic chemical releases following transportation accidents, J. Hazard. Mater. 39 (1994) 193–210.
[11] P.V. Rao, P.K. Raj, Expert system interface to hazard prediction model, J. Hazard. Mater. 25 (1990) 93–106.
[12] P. Heino, A. Poucet, J. Suokas, Computer tools for hazard identification, modelling and analysis, J. Hazard. Mater. 29 (1992) 445–463.
[13] Bowen, J.B., *Emergency Management of Hazardous Materials Incidents*, NFPA, 1995, Chap. 2.
[14] TRB–NRC, *Special Report: Hazardous materials Shipment Information for Emergency Response*, National Academy Press, 1993.
[15] Hughes, J.P. and Letz, G., Some clinical manifestations of occupational chemical exposure seen in emergency medical exposure situations, in: *Proctor and Hughes' Chemical Hazards of the Workplace*, 3rd edn, Hathaway, G.J., Proctor, N.H., Hughes, J.P. and Fishman, M.L. (Eds.), Van Nostrand Reinhold, 1991, pp. 9–25.