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NATO-CCMS PILOT STUDY

)ISASTER PREPAREDNESS FOR RESPONDING TO CHEMICAL ACCIDENTS"

CHAPTER 2

HEALTH HAZARD ASSESSMENT

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2 HEALTH HAZARD ASSESSMENT

2.1 INTRODUCTION

Increased use of toxic or flammable dangerous goods in recent years as a source of energy or chemical feedstock by industry has pointed out to the need for developing disaster preparedness plans by governments and industry in order to minimize damage to the public, workers and property in case of accidental releases of these dangerous goods from containment.

In an industrial emergency, normal plant operation and normal social life are disrupted as a result of fire, explosion or a release of hazardous materials. The effects may reach as far as the wide surroundings of the activity (off-site), or they may be limited to the plant site (on-site). In an on-site event, in general only employees of the factory are involved; an off-site emergency will also affect the residents in the vicinity of the plant.

The differences between on-site and off-site emergencies are mainly the magnitude of the accident and the division of responsibilities between the company management and the authorities. For the rest there are many similarities.

Mathematical modelling is an important tool used in the preparation of disaster preparedness plans. By examining possible release scenarios of dangerous goods, types of potential hazards are first identified in the initial stages of the planning exercise. Once the possible scenarios and their associated hazards are identified, then use of mathematical models make it possible to estimate the extent of potential damage for a given release. A knowledge of the extent of possible damage in turn can be used in determining the type and magnitude of the response effort that would be required to minimize the level of undesirable impact of the accident. Accurate mathematical models, which incorporate knowledge from previous experience and the essentials of basic physical laws, therefore form the cornerstone of disaster preparedness planning.

To obtain an impression of the nature and magnitude of a specific emergency, the following steps have to be carried out:

a) identification of the nature of the unwanted event (type of accident and dangerous materials involved);

b) determination of the nature and magnitude of the physical phenomena ("calculation of physical effects"); and

c) determination of damage caused by the physical phenomena, taking into account the population involved ("consequence calculations").

In addition, the corresponding probabilities (unwanted event probability, effect probability and consequence probability) may be determined. This is especially suitable when carrying out a full safety study as supporting material for, e.g., land use planning. Also when preparing for disaster response in a specific region, it is important to get an estimate of the potential risks (i.e., both probabilities and hazards) in that area.

The magnitude of the consequences together with the overall probability is a measure for the "risk" of the activity. In case of emergency management, however, the use of probabilities is somewhat different from a safety study. Therefore we will use the term "hazard" instead of "risk", which implies that probabilities may have been used in identifying the potential emergencies but that the hazard assessment is limited to effect and consequence calculations.

Table 2-1 summarizes the different risk analysis techniques that may be used in each of the phases of the disaster management cycle.

TABLE 2-1

Application of Risk Analysis Techniques in Disaster Management

PHASE	RISK ANALYSIS TECHNIQUE
Prevention	Identification of unwanted events (HAZOP, FMEA) and potentially risk posing activities.
Preparedness	Risk analysis of installations/activities; identification of potential emergencies and their size; determination of required emergency response organization and equipment.
Response	Decision support by effect and consequence calculations (resulting in damage area, number of casualties, total and per health effect category); evaluation of countermeasure strategies; determination of required input and logistics of operational services, location of medical support, hospitals, etc.
Recovery	Evaluation of the activity's (inherent) safety, preparedness to this specific emergency, effectiveness and efficiency of response; feedback to former phases.

In this section, first the types of hazards of most interest in disaster preparedness planning will be reviewed. Then the mathematical models used in effect and consequence calculation will be discussed.

2.1.1 Hazards Associated with Releases of Dangerous Goods

In general, dangerous goods are contained in storage or process vessels in liquid, gas or solid form. Releases could occur over land or water, from fixed facilities, or during transportation by trucks or rail on land, by ships or barges on water, or by pipelines.

Spills of dangerous goods which are in the form of **solids** are of significance from a disaster preparedness point of view, if the solid

- is an unstable material like an explosive, posing a potential blast (pressure) wave hazard,
- is flammable and the resulting combustion products could pose an acute toxicity and/or long-term (e.g. carcinogenic) health hazard, and
- is toxic or carcinogenic and soluble in water, and the spill is on water, thus causing a health hazard.

If the spilled dangerous good is in **liquid** form (storage temperature is below the boiling point of the substance at atmospheric pressure), a liquid pool would normally form and spread on the spill surface. This pool will pose

- a thermal radiation hazard, if the liquid is flammable and a pool fire occurs, the combustion products also potentially posing a short and long term health hazard; in case the fire is carried back to the

- events that result in **missile hazards** (tub rocketing), and
- events that result in a **gas cloud**, where the primary hazard to a receptor is by virtue of being physically within the cloud (toxic or carcinogenic clouds, including nuclear radiation, flash fires - note that the extent of the flammable region of a cloud is usually sufficient to define the extent of damage due to flash fires, the damage outside this region being rather minimal; these events are therefore classified in this group rather than within the "thermal radiation" group in anticipation of the ensuing modelling requirements for these hazards).

Models that can be used for estimating the extent of potential damage due to the above hazardous events will now be discussed. The first step in the modelling is estimation of source strengths of releases. Then, hazard models are used to estimate levels of hazard at receptor points of interest for a given type of accident. For example, a hazard model for a fire will give the radiation level as a function of distance from the fire location. An explosion model will give the degree of overpressure. An atmospheric dispersion model will give concentrations of the hazardous substance in air. The hazard levels estimated using such physical effect models can then be used in vulnerability models specific to a selected type of receptor to determine level of potential damage. For disaster preparedness planning, the type of receptor of most interest is human beings. A common way of determining level of impact is using the Probit approach.

These models will now be discussed in some detail.

2.2 PHYSICAL EFFECT MODELLING

2.2.1 Introduction

Models describing physical effects deal with phenomena like outflow, gas dispersion, evaporation from a liquid pool, etc. A release of a hazardous material is described by a source term model followed by the appropriate models describing the other phenomena.

2.2.2 Source Term Modelling

The strength of the source means the amount of the substance released. The release may be instantaneous or semi-continuous. In the case of instantaneous release the strength of the source is given in kg and in semi-continuous release the strength of the source depends on the outflow time (kg/s).

In order to find the strength of the source, it is first necessary to determine the physical state (solid, liquid or gas) of a substance in containment. The physical properties of the substance together with containment pressure and temperature determine the physical state.

2.2.2.1 Release from Containment

<u>Releases of Solids</u>

Estimation of how much a solid dangerous good could be spilled in case of an accident can be done by simple observation after an accident occurs, and by simply postulating a percentage during a planning exercise. If the material ignites, however, estimation of how much combustion products are being generated is not that straightforward. Depending on the spilled substance, chemical reactions, and their kinetics or information from past experience must be considered on a case by case basis (see below, section on combustion products).

- *Vapour outflow, liquid containment*

If the outflow point is located above the liquid level, vapour outflow will occur. In the case of a pressure-liquefied gas the liquid will start boiling as a result of the drop in pressure (flash-off). In the equilibrium situation, the pressure of the vapour which has formed in the storage tank is equal to the saturated vapour pressure. The necessary heat of evaporation will be drawn from the remaining liquid which thus cools down to its boiling point at atmospheric pressure (in an equilibrium situation).

The source strength of the releasing vapour is a function of the pressure in the storage system and after the temperature of the liquid has reached the boiling point at atmospheric pressure, it will become constant.

In the case of the outflow of vapour from a pressurized liquefied gas what is termed the Champagne effect may occur. Since the liquid starts to boil, drops may be carried along with the releasing vapour, resulting in a two-phase jet. The source strength is considerably increased by this Champagne effect.

In the event of the outflow of vapour from a refrigeration-liquefied gas, the source strength will be equal to the volume of liquid which evaporates per unit of time. Since the storage is cooled, this evaporation is zero. If the cooling shuts down, evaporation will occur as a result of the heat supplied from the surroundings.

- *Liquid outflow*

If the outflow point is located below the liquid level, liquid outflow will occur.

In the case of a pressure-liquefied gas, liquid outflow will result in a flash-off. The release will generally be so violent that the liquid jet will be broken into drops as a result of the intensity of the evaporation and form a two-phase jet. The drops formed will mix with air. The heat present in the entrained air will cause the drops to evaporate. If there is not much flash-off (the saturated vapour pressure is then not much higher than the atmospheric pressure) the remaining liquid which is cooled down to boiling point will start spreading on the ground and form a pool. Evaporation will also take place from this pool, resulting in a second semi-continuous vapour source (see below, "Evaporation").

In the case of the release of a non-boiling liquid the outflow is determined by the pressure above the liquid level (saturated vapour pressure) plus the hydrostatic pressure of the column of liquid. The releasing liquid will form a pool from which evaporation takes place (see below, "Evaporation").

- *Turbulent free jet*

When gas or vapour flows from a vessel and the Reynolds number under the release conditions is greater than about $2.5\ 10^4$ a turbulent free jet may occur. Apart from the fact that the Reynolds number must fulfil the conditions mentioned, the absence of obstacles in the jet is also a condition. Due to the direct mixing of air with the outflowing jet as a result of the "entrainment" of air in consequence of the high velocity, and turbulence occurring in the jet, a cloud will form in this case. This cloud may be toxic and/or explosive depending on the characteristic of the outflowing substance. If the turbulent free jet is ignited, we speak of a jet fire.

- *Two-Phase Releases*

Special emphasis has been given to two-phase discharges recently due to the complexity and importance of such releases in terms of disaster preparedness planning (Ianello et al.,1989). In that study, a computer program called RELEASE has been developed to handle such releases. Further experimental work is also being carried out to validate this model (Johnson, 1991).

- the partial vapour pressure of the liquid;
- the prevailing wind velocity; and
- the area of the pool.

Evaporative cooling and differential boil-off of various constituents of a spilled substance may be complicating factors in estimating gas source strength from liquid pools.

2.2.2.3 Generation of Toxic Combustion Products

Release of Stored Material

One of the hazards of an industrial fire is the release of toxic substances, which may be toxic products that are present in the plant or in storage, or toxic combustion products that are generated by the fire. Whether these materials are released and/or formed is dependent on the nature of the substances and on the circumstances during the fire.

The products in a storage in many cases are mixtures of the active substance and some inert material, called formulations. Formulations may be divided into two categories, namely solutions and mixtures of solids with some other solid inert material. In case of a solution, the solvent may be either flammable or not. In case of formulations with an inert material, the product may be either flammable or not.

A solution in a flammable solvent will burn easily, which means that the dissolved product will be more or less completely combusted, so in this case only toxic combustion products may be released. (Whether this will occur or not depends on the composition of the burning material.) If a solution of a solid material in water is involved in a fire, the water will evaporate; during this process, a concentrated solution is formed and finally the (solid) product remains behind. The solid will be burnt (partially or completely) or will disperse into the air. A mixture of a liquid product with water will generally evaporate as a whole, unless the boiling point of the liquid is very high, in which case a similar concentration process will occur as mentioned before. The evaporated product again will be more or less completely combusted.

Formation and Release of Toxic Combustion Products

Apart from the toxic products that may be released, under certain circumstances toxic combustion products may be formed. In the preparation on this research project, a literature survey was carried out for products released during fires of pesticides and hydrocarbons. The general picture emerging from this review is, that up to now relatively little data has been found about the generation of toxic combustion products, qualitatively as well as quantitatively. If any experimental data was available in the literature, the experimental conditions were very poorly described.

In the experiments, carried out within the framework of this research project, the generation of combustion products when burning four different pesticides has been studied. The pesticides are parathion, chlorfenvinphos, dichlobenil and three different 2,4-D-compounds.

Generation of toxic combustion products occurs when the products on fire contain other atoms than carbon, hydrogen or oxygen (so-called hetero-atoms). Hetero-atoms are for instance nitrogen, sulphur, and the halogens (chlorine, fluorine, iodine, bromine). This is the case for the pesticides mentioned above. The possible toxic combustion products are summarized in Table 2-3 (the compounds that are first mentioned are the ones formed most; in all cases carbon monoxide and hydrocarbons are formed).

The emission of PCDD/F is lower than 12 - 36 μg TEQ per kg pesticide. Only small quantities of NH_3, H_2S, Cl_2 and $COCl_2$ are formed.

Damage due to Release of Toxic Combustion Products

The consequences of the release of toxic combustion products may influence people in the surroundings of the fire (workers as well as residents) and the environment (waterways, ground water and soil). An important problem is environmental pollution via contaminated run-off fire fighting water. This route was the major cause of damage in the Sandoz case (1986).

CASE HISTORIES OF PESTICIDE FIRES

As an illustration of the hazard potential of fires in installations and buildings involving chemicals, descriptions of a few accidents that occurred during the last 15 years are presented. This is a purely random selection. Very large accidents like the Sandoz fire in Basel (Switzerland) have been left out on purpose, as these are often well-known and lots of material has already been published about this category of accidents.

In 1977 in Laytonsville (USA) a fire occurred in a garden centre, caused by short-circuiting. Due to the warm weather the fire fighters took of their protective gear. Only some time after the fire got started, the responders were informed that toxic chemicals like malathion and lindane were involved. 94 persons, including 76 fire fighters and 7 police men needed medical treatment. The area was evacuated and after 5 days the groundwater turned out to be contaminated with sevin, kelthane and metasytox.

In 1981, in a chemical pesticide plant in Groningen (Netherlands) a fire broke out in a mixer containing 2000 kg of a variety of chemicals (chlorine, chalk, thalonyl and maneb). Ignition may have been caused by an overheated mixing shaft. During the fire a dense cloud was formed, but measurements indicated that there was no immediate danger to the residents in the surroundings. At 100 m downwind the sulphur dioxide concentration was measured to be 4 ppm.

In 1987 a fire occurred in an agricultural chemical' warehouse in Minot (USA). Over 60 different types of pesticides, herbicides and other agricultural chemicals were stored, the most dangerous ones being malathion, parathion and lindane. A dense smoke cloud drifted over the town, causing the evacuation of 10,000 residents. The cloud travelled more than 80 kilometres. It was decided to hold the fire under control but to let it burn out in order to limit the quantity of contaminated fire-fighting water. One fire fighter required hospital treatment because of poisoning by chlorinated pesticides, 34 other people were sent to the hospital with a variety of symptoms. About 53 m^3 runoff water was collected in a plastic-lined temporary lagoon at the site. Some runoff water contaminated a nearby stream. Local authorities dammed it about 1600 m downstream from the warehouse. Creek water samples showed a concentration of 324 ppm 2,4-D. Samples from the soil of the warehouse premises indicated high concentrations of herbicides.

In 1984 a fire occurred in a warehouse in Sheffield (UK). The fire started in a furniture depository. The polyurethane upholstery intensified the initial fire. The fire fighters were hampered by lack of access for fire appliances to the warehouse because of railway tracks inside the building. The fire spread in roof voids to several sections of the warehouse. The asbest roof coating was ignited, contributing to the fire spread. The roof of the uits where chemicals were stored collapsed completely. The asbest fall-out affected the public as far as

- the model applies only to open terrain; allowance is made, however, for the roughness of the terrain. The influence of trees, houses, etc. on the dispersion can be determined by means of the roughness length.

2.2.3.2 Heavy Gas Dispersion Model

If the gas has a higher density than air (because of a high molecular weight or marked cooling), it will tend to spread in a radial direction because of gravity. This results in a "gas pool" of a particular height and diameter. As a result of this, in contrast to a neutral gas, the gas released may spread against the direction of the wind.

2.2.4 Models for the Calculation of Heat Load and Pressure Waves

If a flammable gas or liquid is released, damage resulting from heat radiation or explosion may occur if the released liquid or gas cloud is ignited. Models for the effects in the event of immediate ignition (jet fire, pool fire and BLEVE) and the ignition of a gas cloud will be discussed in succession. These models calculate the heat radiation or peak overpressure as a function of the distance from the jet fire, BLEVE, the ignited pool or gas cloud.

2.2.4.1 Jet Fire

If a releasing gas forms a cloud with concentrations between the lower and upper explosion limit (turbulent free jet) and ignition takes place, a jet fire occurs. Also when a liquefied flammable gas flows out a jet fire can form.

Empirical models exist with which the length of a jet fire and the thermal load for the surrounding area can be calculated (TNO, 1983). An ellipse is assumed for the shape of a jet fire. The volume of the jet fire is proportional to the outflow.

In order to the calculate the thermal load, the jet flame is simulated by a point source in the centre of the flame. This centre is taken as being half a flame-length from the point of outflow.

2.2.4.2 Model for a Pool Fire

The heat load on objects outside a burning pool of liquid can be calculated with a heat radiation model (e.g., TNO, 1979). This model uses an average radiation intensity which is dependent on the liquid. Account is also taken of the diameter-to-height ratio of the fire, which depends on the burning liquid. In addition, the heat load is also influenced by the following factors:

- distance from the fire;
- the relative humidity of the air (water vapour has a relatively high heat-absorbing capacity); and
- the orientation (horizontal/vertical) of the object irradiated with respect to the fire.

In the determination of the human probit equations, the intraspecies differences are accounted for. Animal toxicity data are obtained in relatively homogeneous populations, whereas the variation in the human population exposed during an accident can be enormous. To account for the larger response spread, the slope of the probit equation has been set to 1. This means that the LC95 relates to the LC05 at 27; this value is conservative but still realistic, when compared to the empirical value of 12, determined by Hattis with human volunteers.

In the so-called "Green Book" (TNO, 1990), the determination of probit equations that are applicable for humans is given as a two-step process: calculating a human LC50, followed by calculation of the probit constants.

In the first step, and extrapolation factor is used that takes into account the differences between animals and humans. For local irritants, these are the respiratory volume and lung surface; these properties can be empirically related to body weight. Furthermore, differences between animals and humans in breathing pathway (nose or nose-and-mouth), in susceptibility of the lung tissue and in the influence of lung damage to the organism as a whole were brought together in a safety factor, as well as behaviourial differences that may influence the respiratory frequency and thus the total respiratory minute volume.

For systemic agents, oxygen consumption is taken as the measure for toxic load, which is also assumed to be related to the respiratory volume. In this case, the safety factor reflects the differences in pharmacokinetics and -dynamics (and the lack of knowledge on this subject). Behaviourial differences are evaluated in the same way as with local irritants.

In calculating the human LC50, the safety factors are multiplied by a factor 2 if toxicity data for more than one species were available. This means that a larger amount of information is credited for by a less conservative approach.

In the second step, to account for the spreading in the human population that is larger than in experimental animal populations, the slope of the probit equation is set equal to 1. This limits the applicability of the probit functions to responses below 50%, which however is not a very serious limitation in accident evaluation. In reality, if concentrations exceed the LC50, the situation is most severe, and rescue activities will be at the highest possible level. It is not very likely that an LC80 will be considered ~~must~~ more dangerous than an LC60.

The Green Book probit approach is based on LC50 values, because these data are available in relatively large numbers and they have the highest accuracy. The extrapolation factor in the calculation of the human LC50 accounts for the intraspecies differences (between animals and humans). Application of safety factors is common practice in risk evaluation for food stuffs when establishing no effect levels: then, however, safety factors are often of the order of magnitude of 100-1000.

The assumption of a probit slope of 1 accounts for the intraspecies differences (within the human population). Because the actual spreading in susceptibility of the population is not known, such a conservative approach is favourable. Furthermore, the uncertainties in the probit functions are greatest in the upper and lower ends of the function.

The determination of probit functions as described here is a first step towards reliable vulnerability models. The Green Book methodology is applicable for toxic materials for which only few toxicity data are available. The probit functions apply for lethality; with today's knowledge, establishing well defined probit equations for other health effects is not feasible.

countermeasures have to be taken. This requires the ability to make a quick balance of the pros and cons of different response strategies. Many decision makers become rather hesitant when they are faced with such a situation, either leaving the decision to their employees or even completely failing to take a decision.

To help decision makers in their difficult job, so called "decision support systems" (DSS) have been developed. A DSS offers support in making a decision. That means that the DSS does NOT replace the decision maker: the person him/herself is the one who is finally responsible for the decision. In making the decision, aspects may be taken into account that are not incorporated into the DSS, such as social or political motives. These aspects are often hard to quantify, and it is up to the decision maker to give them proper consideration.

Often it is thought that a DSS is an automated system (i.e. some piece of computer software). This, however, is not necessarily the case. Handbooks, written procedures, maps, protocols and other paper material can provide very useful decision support. The only reason that automated systems have been (and are being) developed, is that they increase the accessibility to large databases and that a computer can rapidly perform calculations.

However, there are some disadvantages to automated systems:
- Databases need maintenance; especially geographical and demographical information will change rapidly in time. Databases containing properties of chemical substances may be subject to changes, especially for those chemicals that are not very well known. For many chemicals, toxicity data are lacking, or only rough estimates are available. If these data become available or are improved, the database has to be adjusted.
- The effect and consequence models are continuously being refined, which means that from time to time new versions become available, giving more accurate results. A DSS user may want to incorporate these newly developed models into the system.
- To use a DSS requires training; most decision support systems are too complicated to use them for the first time in an emergency situation with one eye on the computer screen and the other on the manual. This means that there must be at least one person (and preferrably more) who is really familiar with the system.
- The final and maybe most important disadvantage of a computerized DSS is, that although everybody knows that it is "only" a computer, the DSS is seen as an oracle speaking the ultimate and utter truth. The results of a DSS are mere estimates, indicating the possible dimensions of the hazard area and the order of magnitude of the number of casualties.

In spite of all this, we may say that in many cases a computerized DSS has big advantages. Large stocks of information are rapidly accessible, huge amounts of data can be processed quickly and the results are displayed in an orderly fashion, be it alphanumerically or graphically. In an emergency situation many people have to be informed; the computer may establish connections automatically (via telephone or fax), and will call everybody on the list without forgetting a single person... Hard copy messages may be generated and distributed promptly to those needing them. Provided the requirements in terms of (personnel) time and money are met, a computerized DSS will greatly enhance the performance of the emergency management organization.

2.4.2 Components of a decision support system

Let us now turn to the elements that may be present in a decision support system.

* Registration of accident information.
The first emergency response activity is to establish an "accident diagnosis". This means that the relevant information has to be reported and registered (location and time of the accident, chemicals involved, casualties, injured, weather, etc.).

list without forgetting a single person... Manpower otherwise involved in this (often tedious) job can now be used in other activities.

Another function of an automated DSS is generating hard copy messages, containing text, chemical property information and maps of the hazard area, and distributing them promptly to those needing them. This ensures that complicated information is spread quickly and without errors.

Finally, a decision support system may present a list of alternative countermeasures, with the best choice on top and the worst possibility at the end of the list. Ranking of countermeasures may be achieved by simply comparing the expected numbers of victims, but there are also more advanced techniques available. One of these is Multi-Attribute Utility Analysis, which will be discussed in more detail in section 2.4.5.

2.4.3 Examples and short description of non-automated DSS

There is a great variety of non-computerized decision support instruments. Nearly every alarm post or emergency response service will have them available: registration forms, handbooks of all kinds (chemical and physical data, toxicological information such as RTECS or "Dangerous Properties of Industrial Materials" by N. Irving Sax, CHRIS, etc.), military or other maps, descriptions of procedures to be followed, report protocols, and so on.

A special non-automated decision support tool that is used in the Netherlands are the so called "Hazard Contours" (* CHECK ENGLISH NAME!! *), indicating the concentration or the consequence distances for a specific release. The hazards have been categorized, and the user must answer a limited number of questions before arriving at a certain Hazard Contour. The Contours are printed on transparencies that may be used as an overlay on a map of the accident area.

2.4.4 Examples and short description of automated DSS

In the last few years, many computerized decision support systems have been developed, with varying features and for different hardware configurations. Some examples of commercially available systems are:

- SAFER (Systematic Approach For Emergency Response), developed by SAFER Emergency Systems, which is now part of the Du Pont Company; it runs on a microcomputer, and contains a Lagrangian trajectory dispersion model including complex terrain and dense gas dispersion; dosage can be calculated, but numbers of victims are not given; automatic connections with relevant authorities/persons.

- MIDAS (Meteorological Information and Dispersion Assessment System), developed by Pickard, Lowe and Garrick, Inc.; there are three versions regarding the hardware, varying from a PC to a large minicomputer (Tektronics); dispersion is modelled by a Gaussian straight line plume model, a Gaussian variable trajectory plume model or a Lagrangian particle tracking model (including dense gas dispersion); final results: concentration contours;
(NOTE: the MIDAS system must not be confused with MHIDAS, a databank containing information on major hazards, which is an activity of the British Health and Safety Executive (HSE) in conjunction with the Safety and Reliabiity Directorate (SRD)).

- CHARM (Complex Hazardous Air Release Model), developed by the Radian Corporation; it runs on an IBM-PC and contains a specially designed dispersion model; concentration contours; listing of relevant contacts.

their own, and even derive new rules from the information that has been entered into the system. However, this type of systems has not yet been made available for application in emergency response.

Decision Logic Principles

The purpose of introducing countermeasures after an industrial accident is to limit the health risk for individuals, e.g., by reducing the exposure to toxic materials. However, the consequences of taking countermeasures are not limited to the reduction of exposures. There will be other consequences, some beneficial, some harmful, and it is necessary to take account of all these consequences when formulating decisions on countermeasures

Principles have been developed for the introduction of countermeasures which recognise this need to take account of all beneficial and harmful consequences. The first principle states that no countermeasure should be introduced unless it produces more good than harm, i.e., the introduction of the countermeasure should be justified. The second principle states that the countermeasure should be introduced in a manner which maximises the net benefit. This is known as optimization, and is complementary to the principle of justification

Multi-Attribute Value/Utility Technique (MAVT)

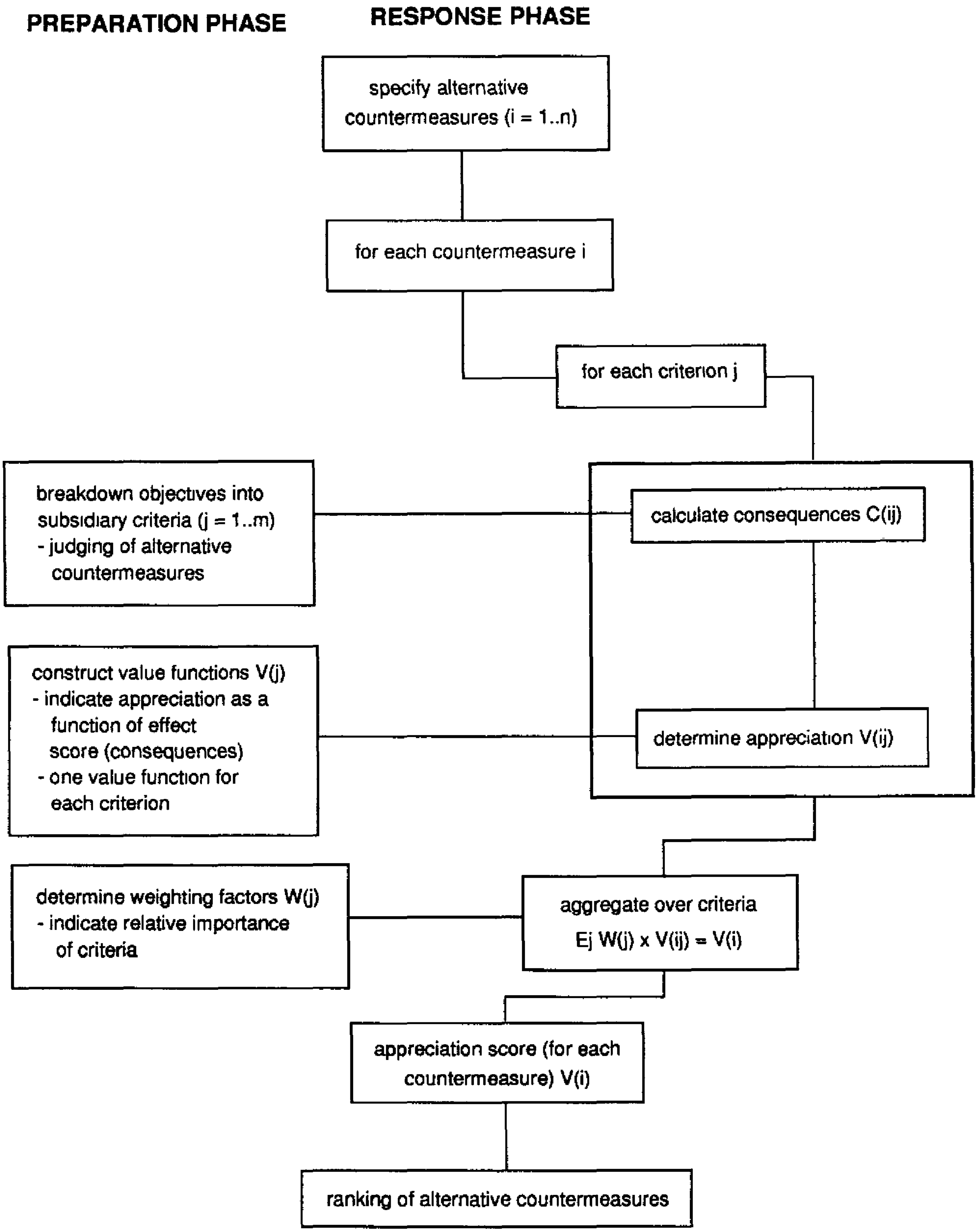
The formulation of a countermeasure strategy, following an emergency, will be based on a number of quantitative and qualitative considerations. Ordering the countermeasures is a multi-dimensional decision problem for which there exist several well known decision techniques, such as Multi-Attribute Value/Utility Technique (MAVT).

MAVT is a proven method for evaluating alternatives in decision situations involving multiple objectives. The technique is recommended by several recognised organisations (e.g., the International Commission on Radiological Protection). The main advantages of the method are:
- the clear structure of its decision logic,
- the relative simplicity of the mathematics,
- the explicit trade-offs between attributes, and
- the explicit specification of relative preference for outcomes of different alternatives.

Decision analysis in general, and MAVT in particular, attacks complex problems by reducing them into smaller, manageable components. The decision process can be subdivided into the following steps:
- identification of alternatives;
- identification of an overall objective and the definition of the derived attributes on which it can be measured;
- evaluation of alternatives for each of the attributes;
_ valuation of consequences;
- determination of the relative importance of attributes;
- overall evaluation and ranking of the alternatives;
- exploration of the sensitivity of the ranking.

Structuring the Decision Problem

The decision-make has to specify the alternatives (countermeasures). In theory, there may be a very wide range of countermeasures, but in reality practical or political constraints limit this range significantly. Generally, it is helpful to limit the number of countermeasures considered; often it is most profitable to specify a few of them which bound the possible range, and then, by repetition, to refine the options which appear most promising.


PREPARATION PHASE
RESPONSE PHASE
specify alternative countermeasures (i = 1..n)
for each countermeasure i
for each criterion j
breakdown objectives into subsidiary criteria (j = 1..m)
- judging of alternative countermeasures
calculate consequences C(ij)
construct value functions V(j)
- indicate appreciation as a function of effect score (consequences)
- one value function for each criterion
determine appreciation V(ij)
determine weighting factors W(j)
- indicate relative importance of criteria
aggregate over criteria
Ej W(j) x V(ij) = V(i)
appreciation score (for each countermeasure) V(i)
ranking of alternative countermeasures

2.6 Health Plan Development

2.6.1 Definition

The definition of a health plan depends on the point of view. Somebody who is in charge of the health care in emergency situations will tend to see the health service as the most important part of the emergency management organization. A fire chief or police commander, on the other hand, will stress the contributions of their respective organizations. Most important, however, is that those who are involved in an emergency are properly rescued and taken care of. This is the one and only job that is to be done after an accident, and it is the responsibility of the emergency management organization as a whole, not just of one of the individual organizations.

Therefore, the integrated emergency management concept should be adopted. This means that the organizations involved have to be working together in all phases of the emergency management cycle: in prevention, preparation, response and recovery. Since we have seen an excellent example of this concept in Louisville, Kentucky, I need not go into more detail about it. One of the main features of such a concept is to be highlighted: integrated emergency management is not a static situation but a continuous process. It needs ongoing development and continuous exercise, not only because of changing situations, new data and materials becoming available and personnel replacement but also to keep everyone involved alert.

2.6.2 Contents of a health plan

What should a health plan look like, that is to say, which elements should it contain at the very least?

First of all, in a health plan attention should be paid to identifying the potentially hazardous situations. This can either be done in a fairly simple way, by brainstorming with a number of local "experts" who are familiar with the situation in a community or in a region, or by using more advanced techniques such as a risk analysis, especially when complicated industrial installations are present. In such a case, it may be worthwhile to calculate the possible consequences of a hypothetical accident (e.g. a fire or a toxic gas escape). In performing these calculations, the effect and consequence models discussed in this chapter have to be used. If there is the need for setting priorities, also attention may be given to the probabilities involved.

For the health service part, it is important to get an impression of the maximum number of casualties that might occur in order to judge whether the capacity of the local medical services (ambulances, hospitals) are sufficient. In this phase, attention must be given to the cooperation with services and hospitals in neighbouring regions.

If really hazardous situations are identified, it may be decided to impose risk reducing measures such as installing safety devices, process changes or even a complete plant shut down.

Another result of the identification phase is that a proper estimate can be made of the response capacity that is required. A material maintenance plan is essential. Also, the organizational picture for the most important accident situations should be drawn up, and the people involved should be exercised on a regular basis. This is what is called "preparedness": knowing the needs and keeping the personnel and material in good shape.

In an operational situation, a health plan should provide information on those responsible for the different tasks to be performed. Furthermore, a decision support system, be it a paper version or an automated system, may be of a great help in determining the optimal countermeasure strategy. By calculating the expected numbers of casualties (again by using the effect and consequence models presented in this

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