1.2.4.2 Pool Fire

The heat load on objects beyond a burning pool of liquid can be calculated with a heat radiation model (e.g., TNO, 1979; AIChE, 1989). The TNO model uses an average radiation intensity which is dependent on the liquid. The diameter-to-height ratio of the fire, which depends on the burning liquid is also considered. 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.

1.2.4.3 Models for a BLEVE and FIREBALL

BLEVE stands for Boiling Liquid Expanding Vapour Explosion. A BLEVE is a follow-up effect which occurs if the vapour side of a tank of pressure-liquefied gas is heated by a torch or a pool fire. As a direct result of the heating, the vapour pressure will rise and the material of the tank wall will weaken. The increased vapour pressure will cause the weakened tank wall to rupture. As a result of the expansion and flash-off, a pressure wave occurs. In the case of flammable gases, a fireball will also form. The effects of a BLEVE for a tank with a flammable liquid include:

1. Cracking of the tank, resulting in the formation of numerous fragments of the tank and resultant missile hazards. The distance the fragments are scattered becomes a function of their weight and the energy released; there are recorded instances in which tank fragments have been located up to 1.5 km from the explosion site.

2. Pressure wave effects resulting from the expansion of the vapour and the flash-off. The peak overpressure can be calculated using appropriate models (TNO, 1983; AIChE, 1989). It should also be noted that liquefied gases which are not flammable, can also cause BLEVEs, but not fireballs.

3. A fireball, which will grow, rise and burn out over a period of several tens of seconds. The thermal flux from such fires can be very intense due to high flame temperatures. The thermal load as a function of distance can be calculated again by using appropriate models (TNO, 1979; AIChE, 1989).

1.2.4.4 Ignition of a Gas Cloud

If a flammable gas is not directly ignited, the gas cloud will spread in the surrounding area and the drifting gas cloud will mix with air. As long as the gas concentration is between the lower and upper explosion limit, the gas cloud may be ignited.

The flammable content of a gas cloud is calculated by a three-dimensional integration of the concentration profiles which fall within the explosion limits. If the gas cloud ignites, there are two possibilities: (I) non-explosive combustion (flash fire), or (ii) vapour cloud explosion (very rapid combustion resulting in a significant pressure increase).

The heat radiation from a flash fire is usually quite insignificant outside the flammable cloud as the burning time is very short and temperature rise is limited. Models do exist for the calculation of the peak overpressure of a vapour cloud explosion which calculate the peak overpressure as a function of the distance from the centre of the gas cloud (TNO, 1979; AIChE, 1989). The peak overpressure can in turn be related to the degree of structural damage to buildings or chances of lung or eardrum damage in human receptors.

1.3 VULNERABILITY MODELS

Vulnerability models are used to determine the level of damage to specified receptors from exposure to heat or to toxic gases. In consequence analyses, a mathematical approach called "probit analysis" is often used (Finney, 1971). The probit approach assumes a normally distributed damage response within an exposed population to a specified hazard "load," such as a toxic load or thermal radiation load.

Empirical parameters characterizing the damage response distribution are determined using regression techniques, based on available data or using a method developed by TNO (TNO, 1990). A disadvantage of the probit approach is the sparsity of available information on probit parameters for different types of hazards and chemicals.

Most of the probit functions that are available now have been developed to describe mortality. However, recent research has demonstrated that the probit approach is also suited to describe other health effects, such as irritation of the respiratory system, lung impairment and damage to the central nervous system (TNO, 1993). This research is the first step in the development of a general methodology for the derivation of non-lethal toxicity data. To this end, the health effect categorization as developed by the American Institution of Chemical Engineers has been adopted. This categorization distinguishes between detectability (D1), discomfort (D2), disability (D3) and death/permanent incapacity (D4), in increasing order of severeness. Furthermore, a classification of chemical substances in 8 classes, based on the toxicological working mechanism, has been proposed. For chlorine and hydrogen cyanide, toxicity data for D1-D4 have been developed, based on the data that are now available in the literature.

1.4 DECISION SUPPORT AND REPORTING SYSTEMS

1.4.1 Introduction

In the first three sections of this chapter, attention was given to the models that are available to estimate the effects and consequences of a specific accident. In this section, the operational use of these models will be described. In order to ensure effective and efficient emergency response, those in charge of the emergency management must be provided with accurate and correct information about the nature and extent of the accident. Furthermore, the emergency management team must make decisions about the countermeasures to be implemented. The team must be able to conduct a quick balance of the various potential response strategies. Based on past experience it is evident that many decision makers become rather hesitant to act definitively when they are faced with a hazardous materials incident. They often either defer to their employees or, on occasion, fail to act at all.

"Decision support systems" (DSSs) have been designed to assist decision makers select and implement "reaction plans". The DSS does NOT replace the decision maker; that person is ultimately responsible for the decisions and their consequences. In making a decision, social and political considerations may alter the recommendations being generated by the DSS. Only the decision maker, and his or her superiors can integrate the system's recommendations and the political and social realities.

A DSS is generally an automated system in the form of computer software; however, handbooks, written procedures, maps, protocols and other paper material can provide very useful decision support. Automated systems have been (and are being) developed, because of the relative ease they provide in accessing large databases and in rapidly performing data analysis.

There are disadvantages to automated systems:

(1) Databases need maintenance and "up-dating" to reflect:

(a) changes in geographic (e.g., location and access to roads, new construction of factories), and demographic information (e.g., number of invalid/elderly and young children living near a particular potential hazardous incident site),

(b) better descriptions of the properties of chemical substances as they become available.

(2) Modifications and refinements to the hazard and vulnerability models need to be made. A DSS user may want to incorporate these newly developed models into their systems approach to the management of hazardous incidents.

(3) Most decision support systems are complicated and require advance training and simulated experience for their use to be optimized during an actual real-time incident. Therefore, personnel (preferably more than one) need to be trained on the use of the DSS and the maintenance of its hardware and software.

(4) Decision-makers must recognize that a DSS is "only" a computer model and cannot provide all answers, nor can it be assumed that the "answers" the DSS provides are always "correct" or "appropriate".

Despite these caveats, a computerized DSS has substantive advantages. A large body of information is rapidly accessible, great quantities of data can be processed quickly and the results displayed in an orderly manner (both in text and in images). In an emergency situation, communications become a critical element for coordinated planning, implementation, and information sharing. A computerized DSS, with pre-identified organizations/individuals (and their telephone and telecopier numbers), will minimize the failure to inform all appropriate personnel. Computers, with telecopier and/or printer capability, can rapidly generate and distribute hard copy messages. A computerized DSS will greatly enhance the performance of the emergency management organization, if it is adequately developed, maintained and supported between incidents.

1.4.2 Components of a Decision Support System

The components include:

(1) Registration of accident information.

The first emergency response activity should be the creation of an "accident diagnosis". The time and location of the incident must be disseminated immediately, followed by, as soon as possible, with a description of the hazardous incident (e.g., spill, fire, potential for explosion, etc.), a tentative identification of the chemical(s) or class of chemical(s) involved, an estimate of initial casualities (dead and injured), and exposed and "at risk" populations.

(2) Providing product/material information.

A DSS will contain the physical and chemical properties of a (large) number of hazardous substances. Often the end-user will initially focus on the practical information (e.g., appearance at room temperature - liquid, powder, crystal; liquid density - does the substance float on water?; reactivity to fire retardant substances; flammability; etc.) and only later utilize the data for model calculations including damage mitigation plans and procedures. Toxic properties need to be appreciated from the very inception of a response plan. These properties can be expressed either in qualitative (just a verbal description) or quantitative form (e.g., specific values of exposure threshold to specified damage levels or health effects).

(3) Providing geographic and demographic information.

Area maps provide a visual appreciation of the areas affected. Maps that provide topographical features and roadways will facilitate the transport of personnel and material to the area of the hazardous incident and victims and "at risk" individuals away from the affected area. Computer programs, either commercially available mapping programs, or custom-designed programs, exist. They can simultaneously display basic topographic information which may be combined with data on population density, transportation routes and special sites (e.g., industries, hospitals, schools, sport stadiums, etc.). In addition, a DSS may provide background information on the special sites (e.g., corporate and 'key contact' names and addresses, hazardous substances present, size and identities of work shifts, facility floor plans, etc.).

(4) Hazard level and damage calculations.

Dependent on the models that are incorporated into a DSS, hazard levels (source strength and spread of the chemical) and damage levels (health effects, material damage, environmental contamination) of an accident may be rapidly estimated. Most DSSs do not contain vulnerability or damage models; therefore, their "final" results are often hazard level (e.g., concentration, thermal radiation flux, over pressure) contours around the accident site (e.g., CAMEO - see below). In those systems that perform health effect calculations, population data are combined with the hazard level contours, and the hazard load is determined as a function of time; the level of damage which would result from this hazard load is often determined from probit calculations. Consequence calculations are expressed in terms of victims (casualties, injured) and areas of contamination.

(5) Evaluation of different countermeasure strategies.

Emergency response strategies are a function of the type and intensity of the hazardous accident. A common measure is to advise the population to find shelter; however, under certain circumstances evacuation may be a necessary alternative. A DSS may estimate the consequences of either strategy in terms of numbers of casualties and property damage. If the DSS indicates, for a particular chemical release, an increase in the number of casualties over time (e.g., a dense gas which slowly dissipates in a well defined cloud), then early evacuation may be the preferred decision rather than having the local population remain in buildings located close to the accident site. In such instances, early notification, using media (radio and television) and local emergency service providers may be a critical step in mitigating human casualties. For instance, if people have been sent indoors upon a toxic gas release, the protective effect of the building may disappear when the toxic fumes enter the air intake ports of the building's ventilation system.

(6) Providing operational information.

Effect or damage calculations may be useful in determining the best material supply and evacuation routes. A graphical display of the contour of a gas cloud, superimposed on a topographic or roadway map will immediately indicate those areas which are imminently threatened, and thus facilitate the identification of "safe" staging areas for the emergency response workers and evacuation routes for the "at risk" population.

(7) Performing automatic emergency response actions.

The more complicated the emergency situation, the greater the number of specialized services, and the larger the emergency response force required to rapidly control and mitigate the damages. Rapid, effective communication with large numbers of individuals requires a centralized communication system which can notify individuals and organizations about the nature of the hazardous incident, and the requirements that will be expected of a given responder or organization. Computers, pre-programmed to systematically call (and re-call if the parties cannot be reached) and provide standard messages, will facilitate the gathering of a well equipped response force. The manpower for such a task is minimized, and periodic hard-copy printouts will permit the response and coordinating teams to have real-time information on the location and availability of needed supplies and personnel.

(8) Alternative countermeasures - options for response, mitigation of damages and consequence management

A DSS can provide an hierarchical analysis of alternative countermeasures, listing the positive and negative consequences of each plan. The use of Multi-Attribute Utility Analysis (MAUA) for this purpose is discussed below.

1.4.3 Non-automated Decision Support Systems

Non-computerized decision support instruments are available, however, they need to be catalogued, readily accessible, and current. Specific examples include: registration forms, emergency procedures manuals, handbooks of chemical and physical property data, toxicological information (such as RTECS (1983); Sax (1984)), maps (topographic and roadway), and the telephone numbers of critical resource personnel and institutions (e.g., local and national toxicological centers, hospital trauma centers, the offices of key government personnel).

In the Netherlands, the so called "Hazard Contours" provides information on concentration or consequence distances for specific releases. The hazards have been categorized, and the user only has to answer a limited number of questions before being able to determine the "hazard contour". The contours are printed on transparencies and thus may be used as a map overlay of the accident area.

1.4.4 Automated (Computerized) Decision Support Systems

During the past several years, a number of computerized decision support systems have been developed which will operate on either desktop or portable computers.

1. Examples of commercially available products are:

    a. SAFER (Systematic Approach For Emergency Response), developed by SAFER Emergency Systems, a subsidiary of the Du Pont Company; it runs on a microcomputer, and contains a Lagrangian trajectory dispersion model including complex terrain and dense gas dispersion models; dosage exposure can be calculated, but rates of casualities, from exposure, are not provided; the system does permit automatic connections with relevant authorities/persons.

b. MIDAS (Meteorological Information and Dispersion Assessment System), developed by Pickard, Lowe and Garrick, Inc., can run on a microcomputer, and can produce concentration contours for gas releases including heavy gas releases; (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 Reliability Directorate (SRD)).

c. CHARM (Complex Hazardous Air Release Model), developed by the Radian Corporation; it runs on an IBM-PC. The system provides concentration contours and a listing of relevant contacts.

2. Examples of available government developed products are:

   a. CAMEO (Computer Aided Management of Emergency Operations), developed by the National Oceanic and Atmospheric Administration (NOAA) and the US Environmental Protection Agency (EPA); CAMEO has been developed for an Apple PC, but meanwhile also runs on IBM-compatible PC's; it contains the ALOHA dispersion model; the system is currently under use by a large number of emergency response organizations in the US, and it has been installed in regional offices of the Atmospheric Environment Service in Canada; its chemical database contains information for over 3300 commonly transported chemicals.

   b. IEMIS (Integrated Emergency Management Information System), developed by the US Federal Emergency Management Agency (FEMA); the IEMIS is a large system, originally developed as a part of the Radiological Emergency Preparedness Program; it consists of a complete database management system, hazard (dispersion, fire and explosion) and (radiological) consequence calculation models, graphical options and facilities for communication with other users/regions; runs on a VAX 11/750 minicomputer, serving 15 field workstations located in the Regional FEMA Offices.

   c. IRIMS (Ispra Risk Management Support System), developed by the EC Joint Research Centre at Ispra, Italy; the models are extracted from the risk analysis software package SAFETI, by Technica Ltd.; it has a Lagrangian dispersion model; runs on a Sun microcomputer;

   d. SEABEL has been developed by TNO (Netherlands), commissioned by the Dutch equivalent of the Coast Guard, Rijkswaterstaat; it is to be applied for emergencies at sea; it runs on an IBM-PC, and calculates concentration contours; the system contains an automatic contact module; at the moment it is being installed in the member states of the EC.

1.4.5 Decision logic

Decision support systems (DSS) generally will improve the selection and implementation of countermeasures after a chemical accident. However, in some instances, the increased information may complicate the decision-making process. Before any action can be taken, a decision must be made.

"Decision logic" is not the same as "an expert system" or "artificial intelligence". These three concepts are stages in a continuum of developments, ending in the "self-thinking machine". Decision logic is a formalized system of interpreting available data, using a collection of rules (which may or may not include calculations) leading to a ranking of alternative possibilities. In an expert system, knowledge of "experts" is stored and used in a logical sense, that is, through some decision logic). The words "artificial intelligence" indicate systems that are able to interpret data on their own, and even derive new rules from the information that has been entered into the system. However, this type of system has not yet been made available for application in emergency response.

1.4.5.1 Decision Logic Principles

The purpose of introducing countermeasures after an industrial accident is to limit the health risk for individuals and further limit damage to property by reducing the continued exposure to toxic materials. However, the consequences of countermeasures are not solely limited to the reduction of exposures. There will be other consequences, some beneficial, some harmful, and thus it is necessary to appreciate these consequences when formulating decisions on countermeasures. First, no countermeasure should be introduced unless it produces more good than harm - the countermeasure should be justified. Second, countermeasures should be introduced in a manner which maximises the net benefit - the countermeasure should be an optimal effort, based on a weighing of the alternatives.

1.4.5.2 Multi-Attribute Value/Utility Technique (MAVT)

The formulation of a countermeasure strategy, following an hazardous incident, often requires a multi-dimensional decision; one such technique, the Multi-Attribute Value/Utility Technique (MAVT) provides a means for quickly evaluating alternatives in decision situations involving multiple objectives. Its usefulness has been recognized by organizations such as the International Commission on Radiological Protection (ICRP). The main advantages of this method are:

a) the clear structure of its decision logic,
b) the relative simplicity of the mathematics,
c) the explicit trade-offs between attributes, and
d) 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:

a) identification of alternatives;
b) identification of an overall objective and the definition of the derived attributes or criteria on which it can be measured;
c) evaluation of alternatives for each of the attributes;
d) evaluation of consequences - what will be the cost of implementing or not implementing a given action;
e) determination of the relative importance of attributes;
f) overall evaluation and ranking of the alternatives;
g) exploration of the social and political sensitivity of the ranking.

1.4.5.3 Structuring the Decision Problem

The decision-maker has to identify and specify the alternatives or countermeasures. In theory, there may be a very wide range of countermeasures but in reality, practical or political constraints significantly limit this range. 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 review, refine the options which appear most promising.

"Objectively" structuring the decision problem results in the identification of:

a) the possible actions to limit adverse effects of the accident ("countermeasures");
b) the aspects against which they have to be judged ("criteria");
c) the resulting effects or "consequences".

1.4.5.4 Incorporation of Preferences and Priorities

The decision-maker must also systematically recognize "subjective" preferences and priorities in order to define the countermeasures. Thus, the consequences are transformed onto a linear dimension using value functions and weighting factors.

A value function is the relation between the consequences of the intervention and the degree of value or benefit of these consequences. The benefit is measured on a scale of 0 to 1 or 0 to 100. In general, value functions, for a given intervention, are determined in advance of an incident. Hypothetical consequences, for given interventions, are studied, discussed and assigned values or ranges of values.

Weighting factors are a numerical representation of the trade-offs between the valuation of different criteria. They are usually normalised to numbers between 0 and 1 and can be estimated by the decision-maker directly, or, when the decision-maker is not entirely certain, with the assistance of auxiliary methods.

The final result of decision analysis is the ranking of countermeasures, with the countermeasure having the highest score judged as "best", recognizing that there are no "perfect" solutions.

1.4.5.5 Sensitivity Analysis

The detailed characteristics of the final choice and of its close competitors can be studied more carefully using sensitivity analysis. It may leave the original analysis and conclusions unchanged or it may lead to further thought. Sensitivity analysis plays an important role in understanding the decision-making process and is a useful tool in testing the stability and solidity of the results. It is most useful to perform a sensitivity analysis with respect to the effect that (small) variations have on the weighting factors and thus, on the overall evaluation. It is also possible to explore the significance of uncertainties in the estimated consequences and judgements, in terms of the ranking of countermeasures. Such an analysis may indicate the types of additional information that may be useful in the decision-making process.

1.5 SAMPLING

After chemical accidents, it is important to obtain an estimate of the concentrations of hazardous gases near the site. If there is a flammable gas cloud that has not yet been ignited, it is essential to know the wind velocity and direction in order to minimize potentional ignition sources. If there is a toxic release, quantitative measurements of gas concentrations are valuable in determining rational relocation or evacuation plans for the surrounding community.

Sampling equipment exists for the continuous monitoring of both explosive and toxic gas mixtures. Portable equipment has the advantage of being able to assist in the tracking of the dispersion of the toxic material. There may be a tradeoff between a more sophisticated and sensitive stationary sampling device and a more mobile device; however, rapid availability of accurate information should be the requirement for any measuring system. While the limitations of hand operated systems are obvious, and the potential for errors in communicating the data are real, it is reasonable to use these systems until more complex (and hopefully, accurate) equipment becomes available.

Dräger gas detectors are an example of manually operated gas detector which can provide quantitative information. The gas detectors consist of a hand-operated bellows pump, equipped with a detector tube for the specific material to be detected. The Dräger detector functions as a dosage pump - as a gas sample is sucked through the detector tube, the sampled volume of air is measured. Dependent on the substance of interest, one or more strokes of the bellows are necessary to produce an adequate volume to measure a given concentration of agent; in some instances up to 200 strokes per measurement may be required. The concentrations that may be measured range from mg/m^3 to even a ppb-level (parts per billion).

At the other end of the spectrum of available ambient air sampling tools following a gas release is the German "Spurfuchs" ("trace-fox"), which is an expensive mobile unit equipped with advanced sensing equipment, thus providing the opportunity to repeatedly measure toxic concentrations at various points near the release location. The more accurate and reliable data that is available from more geographically disperate locations, the more refined and effective the decisions and interventions will become.

Sampling of contamination of soil and water resources including surface and groundwater are as important as sampling of the ambient air, especially from the perspective of cleanup decisions. Numerous techniques for these purposes exist; however, a discussion of these techniques is well beyond the scope of this report.

1.6 HEALTH PLAN DEVELOPMENT

1.6.1 Introduction

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, an 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. One of the main features of such a concept is that 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.

1.6.2 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 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 great help in determining the optimal countermeasure strategy. By calculating the expected numbers of casualties (again by using the consequence models presented in this chapter) and comparing the results of different tactics with respect to the accident development, the strategy resulting in the least number of victims may be chosen.

Furthermore, predictions of numbers of casualties may be very helpful in determining the required ambulance and hospital capacity.

A health plan should contain elements about the actions to be taken in the recovery phase. These will not only be concerned with the (after-)hospital care for the injured, but also with counselling of response personnel, and with social or psychological help for those who are not immediately involved but who have suffered indirectly from the events (for instance the relatives of the deceased). In the recovery phase conclusions will be drawn as to the performance of the emergency services as a whole. New plans may be developed, new material purchased and personnel (re-)educated and trained, and the emergency management cycle repeated.

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