3.5 Combination Accidents

In a combination accident one event leads to another, which itself can cause more damage.

It is not possible to list all the conceivable combinations. Even actions taken in response to an accident can have serious consequences. The fire in the Sandoz plant in Switzerland (1986) is an example of this water used to extinguish the fire contaminated the whole Rhine. You must use your imagination to think of potential knock-on effects when doing hazard analysis, as well as in emergency response situations. Knowledge of local conditions and reports of incidents are necessary to the creation of an inventory of places in which hazards can cause combination accidents.

Some selected examples of combination events from recent years are given below:

Hearne, Texas, USA 1972

On 14 May, 1972, crude oil sprayed out from a pipeline into the air, showering the surrounding countryside with oil. The oil flowed along a stream beneath a railway and a highway. The crude oil was ignited by an unknown source. The resulting explosion and fire killed one man and seriously burned two other people. An intense fire several hundred feet high and about 200 feet long burned on the surface of the oil, along the stream and on the railway, road and stock-pond, and scorched the whole area.

Beek, the Netherlands, 1975

In the early morning of 7 November 1975 the startup was under way of Naphta Cracker II, on the 100 000 ton per annum ethylene plant at Beek
An escape of vapour was observed near the depropanizer. Shortly after, the cloud ignited and there was a massive unconfined vapour cloud explosion. The explosion killed 14 people and injured 104 inside the factory and 3 outside it. It caused extensive damage and started numerous fires It also caused fire to break out in the pipeline system and six tanks ranging in capacity from 1.500 to 6 000 m3 within a common dike burnt out

Baton Rouge, Louisiana, USA, 1976

On 10 December 1976 some 100 tons of chlorine escaped from a storage tank at a chemical factory in Baton Rouge. The plant had been shut down for maintenance. During the start-up an explosion occured. The force of the explosion was sufficient to dislodge the chlorine tank from its foundation The tank fell and was punctured, allowing chlorine to escape. The explosion was attributed to the presence of natural gas in the inert gas purge system of the plant The release continued for about 6 hours. The gas was carried about 1 kilometer by the wind The local population was evacuated and there were no fatalities

Westwego Louisiana, USA, 1977

On December 1977 a series of explosions took place in the silos of a large grain elevator at Westwego, Louisina There were 45 silos involved, containing corn, wheat and soya beans. Thirty-five people were killed Most of these were in an office building which was crushed when a 250-feet concrete tower fell on it The value of the silos was estimated at the time to be 100 million USD

Restaurant explosion, Stockholm, Sweden 1981

A violent explosion caused great structural damage to a building housing a restaurant in central Stockholm. Fortunately no one was injured, since the restaurant was empty at the time, as was the road outside. A fire broke out on the fourth floor and spread to other parts of the building. Ruptured gas pipes increased the risk of the fire spreading.

Heavy rain, Italy, July 1987

At least 25 people were killed in Italy as a result of landslides and flooding following torrential rain In the same month 22 people died when they were buried in mud on a campsite in the village of Le Grand-Bornand in the French Alps

Dangerous goods accident, Borås, Sweden 1987

A railway tanker containing concentrated hydrochloric acid began to leak at a chemical factory. A large white cloud spread over a shopping centre and residential areas. About one thousand people had to be locked into the shopping centre. 6 - 8 cubic metres of acid escaped. It was the fourth accident at the factory. Each accident had been followed by criticism of the local authorities, which allowed the factory to be built as late as in 1979.

Fighter plane crash, West Germany, 1988

A West German fighter plane was a matter of seconds from crashing into a nuclear power station

Flooding, West Germany, 1988

Flooding caused environmentally harmful waste to escape, contaminating ground water in the surrounding area

3.6 Selected Examples of Accidents in Various Countries, 1970-1989

Sources: OECD statistics, Swiss Reinsurance Company.

Year	Place	Cause	Product	Deaths(d)/inj(i) /evacuated (e)
1970	Osaka, Japan	Explosion	Gas	92 d
1973	Fort Wayne,USA	Rail accident	Vinyl-chloride	0 d 0i 4.500e
	Market Tree, "	" "	LPG	0 d 0i 2.500e
	Greensburg, "	" "	Chlorine	0 d 0i 2.500e
1974	Flixborough, UK	Explosion	Cyclo-hexane	23 d 104i 3 000e
	Decatur, USA	Rail accident	Isobutane	7 d 152-
1975	Beek, Holland	Explosion	Ethylene	14 d 107i -
	Heimstetten, Germany	Warehouse	Nitrogen	0d 0i 10.000e
1976	Houston, USA	Silo explosion	Wheat	7 d 0i 10.000e
	Lapua Finland	Explosion	Explosives	43 d - -
	Seveso, Italy	Leakage	Dioxin	0 d 193i 730e
1978	Los Alfaques, Spain	Road accident	Propylene	216 d 200i-
1979	Bremen,Germany	Mill explosion	Flour	14 d 27i
	Mississauga, Canada	Rail accident	Chlorine/ Butane	0 d 0i 200.000 e
1980	Mandir Asad, India	Industrial accident	Explosives	50 d - -
	Barking, USA	Industrial fire	Cyanide/Sodium	0 d 12i
1981	Tocaoa, Venezuela	Explosion	Oil	145 d 1 000i
1984	Sao Paulo, Brazil	Pipeline explosion	Petrol	508 d - -
	Bhopal, India	Leakage	MIC	>2.500 d 10 000 i > 300.000 e

	San Juanico, Mexico	Explosion BLEVE	LPG	600 d 7.000i
1986	Chernobyl, USSR	Nuclear accident		direct 31d 500 i >112.000 e
	Basel, Switz.	Warehouse fire		caused severe environmental damage to Rhine
1987	Harbin, P R of ChinA	Explosion in a flax factory		49 d
	Djakarta, Indonesia	Fire in textile factory		30 d
	Pampa, USA	Explosion in a chemical plant		31 d severe damage
	London, U K	Fire in underground station		30 d
1988	Paris, France	Train collision in a railway station		59 d
	North Sea	Piper-Alpha platform		166 d
1989	Near Ufa, USSR	Gas leaking out of pipe-line explode because of sparks from two trains		645d
	Pasadena, USA	Gas cloud explosion in a petrochemical plant		23 d - -
	Alaska. USA	EXXON Valdez lost about 40 million litres of crude oil		cost at least 2 bn. US $

3.7 Other Risk Analysis Methods

This annex will give brief information about some of the risk analysis methods used by industry and others. It could be of interest to know about some of these methods, if and when you would like to go beyond the scope of this Handbook, to go more deeply into the problems and to do more detailed hazard analysis

A number of methods for identifying and evaluating hazards are outlined below The first methods give an overview and are suitable for a locality risk analysis Those following are more analytical and systematic They are more suitable for the detailed analysis of high risk installations carried out within industry However it is useful for those involved in work at a local authority level to know about these methods. The information provided by industry on risks associated with technical systems may well be based on one of these more advanced methods

The need for reliability in industrial processes means that equipment is often complicated. Hazard analysis is intended to create a better understanding of the interplay between various systems and how a complicated course of events with a high degree of human error can lead to a serious accident. The results of such a detailed analysis can be used when:

- deciding where to locate hazardous operations
- deciding on investments in equipment to prevent accidents or limit their consequences
- designing processing equipment and control systems
- dimensioning safety systems such as safety valves, sprinklers, containment walls etc
- creating operational and maintenance routines
- writing safety documents for an establishment

Analysis methods are much the same when identifying and characterizing risk sources, whether they involve fires and explosions or chemical leakages. Estimations of probability can also be made using the same methods. However, different methods must be used when considering consequences (see "Consequence Analysis" below).

3.7.1 Overview methods

3.7.1.1 Checklists (comparative analysis)

Checklists are most often used in comparative analysis to identify known hazards and to check that recognized standards are being followed.

Large and complex systems require detailed checklists which are adapted to the type of process in question Such checklists often include specific requirements for the technical make up of the equipment and for suitable operating procedures

The result of the analysis is a list of notes on whether a number of specifications are being met

There are more general checklists for an overview of the risks in a system as a whole They contain questions on the characteristics of chemicals being handled, hazardous processes the effects of external factors such as power and water supply failures.

together with the state of emergency equipment etc. This kind of checklist is often used in "Rough Analysis" and "What If? Analysis".

3.7.1.2 "Rough Analysis"

Rough analysis or "preliminary risk analysis" is used to identify risk sources without going into technical detail Often the aim is to get a rough picture of which systems are a serious risk. A more detailed method could then be used for the high-risk systems A rough analysis is used at an early stage when planning a new industrial project

The result of a rough analysis is a list of risk sources and a very approximate evaluation of the probability of an accident occurring. together with an estimation of the consequences.

The analysis requires information on the characteristics of chemicals being processed, the quantities, the type of equipment and routines being used, etc, together with details on the installation's location and surroundings

The method is suitable for a community risk analysis

3.7.1.3 "What If? analysis"

This method is used to identify risk sources by asking what the effect would be of a number of unexpected events and finding out which of these would have serious consequences. The method is often used in industry to look into the risks associated with changes in equipment and operational routines.

The analysis results in a table of possible accidents and their consequences together with proposals on measures to reduce risk if this is thought necessary.

"What If? analysis" requires a better knowledge of the processes and operational routines at an installation than a rough analysis does. It is therefore often carried out by interviewing those responsible for the operation and maintenance of an installation Possible problems and mistakes are outlined in a questionaire A suitable technical description of the installation is required as a basis for the analysis (including plans and process/instrument diagrams where necessary).

The method is logical and gives valuable information without too much work. as long as there is a good descriptive basis and the aims are clearly defined. It is suitable as a more detailed follow-up to a rough analysis at specially hazardous installations. As such it can be a useful tool in a community risk analysis

3.7.2 More detailed methods

3.7.2.1 Relative ranking (Dow and Mond index)

Index methods are used to identify risk sources and to classify different sections of installations for processing chemicals according to fire and explosion risk Detailed manuals are used to work out various risk and bonus factors from information on what is processed, equipment, control and safety systems, etc These numerical factors are then used to work out indices for fire and explosion risks as well as "total" risk These judgements are based on comparison with data from previous accidents The risk category shows whether preventive measures should be considered. By working out indices for various parts of an installation, an objective comparison of risks can be obtained

The method is more demanding than those given above, the analysis techniques taking some effort to learn. There is a computer program for the method, developed by Dow and Mond.

3.7.2.2 Risk and reliability analysis (HazOp)

This is a much more detailed and analytical method than those mentioned earlier It is used to identify risk factors and potential operational problems, as well as working out the course of an accident or break in production. The analysis leads to a basic understanding of the importance of certain critical components and the effects of human error in operation and maintenance, as well as producing a list of hazards and points that could lead to breaks in production A detailed technical background is needed for the analysis. The work is based on diagrams of process and instrument systems, a number of key words being used to focus attention on potential deviations from normal conditions

Risk and reliability analysis is of use within industry It is only justifiable as part of a community analysis of very complex systems where an accident would have serious consequences. Few municipal facilities would require such a detailed analysis

3.7 3 Operator and competence analysis

Faults in a system usually occur as a result of mistakes by operators or malfunctions of components. There are two similar analysis methods; one focusing on the consequences of human error, the other on technical malfunctions. Both methods are suitable for a limited analysis of particular systems or tasks. They are not relevant during the initial stages of a community risk analysis.

3.7.3.1 Human reliability analysis

The method is used for one particular aspect of operation or maintenance. The operator's responses to various situations are documented in a logical order The effect of these responses being applied too late or not applied at all is considered in the discussion that follows Mistakes with potentially serious consequences are noted.

A detailed knowledge of the system in question is required for this analysis, together with an understanding of routines and the decision making process Experience shows that mistaken interpretations of dangerous situations and the failure to act in the best way are common causes of accidents. It is therefore important to see if equipment is set up and routines laid down so that human error can be avoided where possible and its consequences limited should it occur. The effects of human error should be considered in many more fields - at present most interest is shown by the chemical industry.

3.7.3.2 Malfunction, effect and consequence analysis

The method leads to a table of components, their functions, their potential malfunctions and the consequences of these malfunctions The method concentrates on components but can also be used to predict the effects of human error. The work is based on a list of components, a description of the system and its function (P & I diagram) and experiences of malfunctions The method is systematic and suitable for use in many technical systems The method is not able to give much information when a system is so complicated that a certain malfunction can only cause an accident if a number of other mistakes or malfunctions occur In these cases it is necessary to use a tree diagram.

3.7.4 Tree methods

These methods are based on tree diagrams systematically displaying a number of events which are dependent on each other. Detailed descriptions of processes and equipment are required The methods are very time consuming and the results are difficult to interpret They are therefore limited to a particular part of a system (an exception to this is risk analysis at nuclear power stations). Computer programs do exist to support the construction and interpretation of tree diagrams

3.7.4.1 Fault Tree analysis

This is used to identify combinations of mistakes and mechanical faults that can lead to certain kinds of damage The "top event" is the starting point for the analysis. The probability of the top event can be worked out from the conditions causing it to occur which are displayed in the level of the tree immediately below. Those events are in turn caused by events at a lower level. You follow the conditions back down the tree to arrive at the initial "base" event. The method produces a fault tree and a table which outlines the combination of base events which is necessary and sufficient for a top event to occur

3.7.4.2 Event Tree analysis

This is used to identify and evaluate initial events which can lead to damage, by illustrating the connections that exist between various stages in an accident Initial events could be malfunctions in components, human error or external factors such as landslides or lightning.

The analysis begins with a given event and then goes on to look at its consequences and the conditions that must prevail for the event to go further. (Fault tree analysis goes in the opposite direction, starting with a given top event and then looking at its causes).

3.7.4.3 Cause and effect analysis

This is a combination of the two methods described above You begin with an intermediate event and look at what effects it could produce, then go back to consider what would be required to cause the intermediate event. The graph is similar to a tree with roots constituting potential initial events. The roots come together to form a trunk constituting the intermediate event The trunk branches out into a number of possible final events, some of which may be undesirable

3.7.4.4 Consequence analysis

The methods outlined above are attempts at identifying risk sources. They illustrate how various factors affect the probability of an accident by constituting an initial event or leading the process towards a dangerous conclusion. Consequence analysis looks at the damage that an accident would cause.

Consequence analysis of processes involving dangerous chemicals should show:

- how large could be the leakage as the result of certain kinds of damage to a particular system
- how a substance should disperse (concentrations and exposure times)
- what could be damaged in the area affected by a leakage
- the damage to be expected to life, property and the environment

The majority of leakages involve only a small part of the total amount of the chemical being handled. They occur from leaking pumps, pipe junctions etc Breaks in pipelines can lead to larger leakages. If highly dangerous chemicals are being transported, it is usual to divide a pipeline into a number of sections and install pressure gauges and automatic valves, limiting the size of a potential release. It is rare to have a large leakage of chemicals even in transport accidents

The physical properties of a chemical, together with its temperature and pressure, affect the size of a leakage. Condensed gases stored under pressure can cause sudden, large-scale leakages By being mixed with air (flushing) the chemical can be provided with energy, speeding up evaporation A leakage from below the surface of the liquid leads to a much greater release than if the leakage is located above the surface High pressures and temperatures can cause a liquid with a high boiling point to escape with such power that it becomes finely divided and boils or evaporates to a great extent.

The dispersal of a chemical leakage depends on the form of the substance (gas,liquid, solid, powder) and the conditions at the site of the leakage. Gases, mists and powders will be spread by the wind Diffusion and turbulence will cause the concentrations to decrease as the chemical disperses

Deposits on buildings, vegetation and the ground will also reduce concentrations in the air Solid particles and water soluble gases are also extracted from air by rain or water sprays

Computer programs have been developed to enable dispersal predictions to be made, based on models taking into account the chemical's properties, meteorological condition and the surroundings A release near ground level with low winds and temperature inversion leads to the highest concentration in air Reactive substances can sometimes break down while airborne, affecting the dispersal

Leakages on the ground are affected by its geological constitution and its affinity for certain chemicals. Liquids can pass through sand and marraine, quickly reaching the water table. With clays it is a much slower process. Layers of soil that are acidic have a tendency to bind alkaline metal ions. Humus-rich layers can bind organic substances such as oils

Lakes and rivers are affected directly by a leakage or contaminated indirectly via ground run-off or ground water. Dispersal in water depends on whether the substance floats, sinks or dissolves. The substance can disappear from the water system by dissolving, evaporating or breaking down. Many substances such as metal salts and highly chlorinated hydrocarbons are stable and insoluble. They can cause serious long-term problems by accumulating in the food chain.

Poisonous gases such as chlorine, sulphur dioxide, ammonia and vinyl chloride are transported in large quantities as compressed gases It is above all in this form that large-scale leakages can occur, spreading very quickly and exposing plants and animals to dangerous doses of toxins. However the accidents in Seveso and Bhopal, together with the Sandoz fire at Basel show that, in unfortunate circumstances, other poisonous substances can be formed and lead to serious accidents.

There are some computer programs on the market which could be useful when evaluating hazards, e g CAMEO from the US, IRIS, SEA BELL from the Netherlands, RISKAT from the UK and RISK from Sweden. Some details about CAMEO (Computer-Aided Mangement of Emergency Operations) are given here, since it is regularly demonstrated in APELL Seminar/Workshops and the US Environmental Protection Agency is in the process of producing a version for use in other countries in the context of UNEP's APELL programme

CAMEO is a software program which assists local planners in managing information about chemicals in the community and in conducting a hazards analysis. CAMEO uses the methodology described in "Technical Guidance for Hazards Analysis" (published in 1987 by the US EPA, FEMA and DOT) This methodology is in three parts: hazard analysis; vulnerability analysis (identifying the geographical area at risk); and risk analysis (estimating the likelihood of an accident and the severity of its consequences)

The method can be quickly applied to all known hazards in a community - using credible worst case assumptions about quantity stored, toxicity, weather conditions, topography and atmospheric stability - to identify which hazards pose the greatest risk to the community. Planners then gather more detailed information about the risk object and use more realistic assumptions to develop scenarios that can be used for planning, exercising the plan and training responders. The 'Technical Guidance' includes tables and charts, so that it can be used by community planners without resort to the computer software

CAMEO includes an extensive database for over 3,000 chemicals. It allows planners to store information about facilities and transportation routes as well as individual hazards (including facility and community maps) and to draw vulnerable zones which identify threatened objects around each hazard. The air modelling program in CAMEO allows planners to develop detailed scenarios, taking into account local weather, storage conditions of the chemical and various release scenarios

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Technical Guidance for Hazards Analysis
Both Washington DC, USA, 1987 - contact Title III Hotline, (1- 800) 535 0202. Enquiries about the CAMEO program should be directed to, US EPA, CAMEO Program, 401 M St. SW, Washington DC 20460, USA

UNEP INDUSTRY AND ENVIRONMENT PROGRAMME ACTIVITY CENTRE

About UNEP - IE/PAC

The Industry and Environment Programme Activity Centre (IE/PAC) (previously the Industry and Environment Office - IEO) was established by UNEP in 1975 to bring industry and government together to promote environmentally sound industrial development. The IE/PAC is located in Paris Its goals are · (1) to encourage the incorporation of environmental criteria in industrial development plans, (2) to facilitate the implementation of procedures and principles for the protection of the environment, (3) to promote the use of safe and "clean" technologies and, (4) to stimulate the exchange of information and experience throughout the world. IE/PAC provides access to practical information and develops co-operative on-site action and information exchange backed by regular follow-up and assessement. To promote the transfer of information and the sharing of knowledge and experience, IE/PAC has developed three complementary tools technical reviews and guidelines, "Industry and Environment" review. and a technical query-response service. In keeping with its emphasis on technical co-operation, IE/PAC facilitates technology transfer and the implementation of practices to safeguard the environment through.
- promoting awareness and interaction; - training activities, - and diagnostic studies

Some recent UNEP - IE/PAC publications

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