NOMENCLATURE FOR HAZARD AND RISK ASSESSMENT IN THE PROCESS INDUSTRIES

Prepared by a Working Party of the Engineering Practice Committee of the Institution of Chemical Engineers

HAZARD AND RISK

Unlike many of the terms defined later, the words HAZARD and RISK have the following characteristics:

(a) The are words in common use.
(b) In their ordinary dictionary meaning they are synonyms.
(c) There has been and to some extent still is, sharp controversy as to the meaning to be assigned to them.
(d) They are terms of a very fundamental character which are to be found, either singly or in compound with other words, in virtually every text on the subject.

In consequence of this, it was decided to devote a more extensive and detailed narrative to these words and some of their derived expressions.

Though a decade ago it was common for one author to use “hazard” where another would use “risk” and vice versa, it seems true that in the United Kingdom there is a growing consensus as to the general sense in which the terms are to be used. This has arisen, at least in part, because authoritative bodies have seen the need in writing official or otherwise influential reports to include a glossary of the meanings of the terms used in the reports though without necessarily seeking to impose these meanings on others. Of special significance here has been the publication by the Royal Society of its Study Group Report on “Risk Assessment” in which it has defined both “hazard” and “risk”. It is our intention in defining these terms in this glossary to ensure that the definitions provided should not be inconsistent with the definition given in the Royal Society’s Study Group Report. However, these were phrased in general terms and we have seen it appropriate to use definitions, which are more specific to the field in question.

The first term we shall define is “hazard”:-

HAZARD	A physical situation with a potential for human injury, damage to property, damage to the environment or some combination of these.

As so defined hazards not only include process plant and associated materials, but also major structures, flying aircraft, and materials which release ionising radiation. However, it is intended that this glossary should cover only the process industries and therefore the hazards discussed are CHEMICAL HAZARDS, which may in turn be defined more narrowly as follows:

CHEMICAL HAZARD	A hazard involving chemicals or processes, which may realise its potential through, agencies such as fire, explosion, toxic or corrosive effects.

Wherever the word hazard is used below, it has the meaning of chemical hazard as so defined.

The term MAJOR HAZARD has been used in the United Kingdom for more than a decade; it was used in 1067 in the Annual Report of the Chief Inspector of Factories and in 1972 in the Robens Report. In addition, various documents have proposed definitions based on the quantity of materials stored on a given site. These include DoE Circular No. 1/72 and the 1st and 2nd Reports of the Advisory Committee on Major Hazards. Perhaps, it should be noted that subsequent legislation, namely the Notification of Installations Handling Hazardous Substances (NIHHS) Regulations 1983, and the draft Control of Industrial Major Accident Hazard (CIMAH) Regulations, which were derived from the earlier sources, do not use the term major hazard. The term may be defined as follows:

MAJOR HAZARD	An imprecise term for a large scale chemical hazard, especially one which may be realised through an acute event. Or, a popular term for an installation, which has on its premises, a quantity of a dangerous substance which exceeds the amount prescribed by the above references.

A term of recent origin is MAJOR ACCIDENT HAZARD. This term occurs in the title of the EEC Directive of 24th June 1982 and is synonymous with major hazard.

A substance constitutes a hazard by virtue of its intrinsic chemical properties or of its temperature and pressure, or some combination of these. For example, air and water may pose a hazard if compressed and heated, but neither would be classed as a HAZARDOUS SUBSTANCE, as their chemical properties alone do not constitute a hazard. The term hazardous substance may be defined generally as follows:-

HAZARDOUS SUBSTANCE	A substance which by virtue of its chemical properties constitutes a hazard.

In the context of the NIHHS Regulations the term hazardous substance has a more specific meaning, applying only to those substances listed in the regulations or meeting specified indicative criteria. Similarly, the term DANGEROUS SUBSTANCE has a specific meaning under the CIMAH regulations it is recommended that this term is used only with this specific meaning the CIMAH regulations. It is recommended that this term is used only with this specific meaning and that if a general term is required hazardous substance should be used.

DANGEROUS SUBSTANCE	A specific term defined in the CIMAH Regulations referring to listed substances and others meeting given criteria.

In assessing the threat posed by a hazard, the principal factors are the likelihood that it may be realised, and the likelihood and extent of the consequences, i.e. damage to people, property or the environment, in the event of its realisation. The term which expresses likelihood in the present context is risk. Little controversy surrounds this point; the controversy around the use of “risk” is whether it may also be used to mean other quite different things. For example, whether it should also have the meaning attributed to “hazard” as defined above or a combination of the meaning of “hazard” with the meaning of likelihood. This practice of giving a number of meanings to “risk” is common where meanings are commercial rather than scientific and where their meaning has to be deduced from the context. The Working Party recommends that the word “risk” should only be used to mean the likelihood of some specified undesired event. This would avoid the public confusion, which arises when an installation is described using one meaning, as “high risk”, and using another as “low risk”; it will encourage people to consider the “risk of something happening:

RISK	The likelihood of a specified undesired event occurring within a specified period or in specified circumstances. It may be either a frequency (the number of specified event occurring in unit time) or a probability (the probability of a specified event following a prior event), depending on the circumstances.

When considering the risk of harm to populations exposed to hazards, it is helpful to consider two derivatives to risk. In cases where the potential is large, many factors dictate the severity, which might be realised, and there is a wide spectrum of possible harmful outcomes with associated likelihood's. This is known as the SOCIETAL RISK. In this case, the undesired event in our definition of risk is an accident, which can affect a group of people. This is usually quantified as an F-N curve.

Individuals amongst the population who could be affected by such an accident will not usually be exposed equally. This distribution of the risk is illustrated by considering the likelihood of particular individuals being affected, known as the INDIVIDUAL RISK. In this case, the undesired event in our definition of risk is harm to a specific individual (or person living at a particular location). Individual risk can, of course, be used in the limiting case where only one individual could be affected in an accident.

SOCIETAL RISK	The relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards.
INDIVIDUAL RISK	The frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards.

The usefulness and limitations of some of the above concepts can be illustrated by an example. One might assume that 10 tonnes of a toxic material poses a greater threat than 1 tonne. However, whether any quantity actually poses a hazard depends upon the circumstances under which it is held. In the case of bulk storage, the larger quantity evidently has more potential for causing harm since, where released rapidly under the same conditions, harmful concentrations would extend to a greater distance. Although the larger quantity, in this case, could be said to pose a greater hazard, the magnitude of the effects resulting from an actual release depends on many other factors. There may be no people within this range of harmful effects and therefore no risk of injury. If there are people present, the number affected may vary depending on the wind direction, weather conditions and other factors as well as the quantity released.

The likelihood of various sizes of detrimental effects to a population has been defined as the societal risk. The maximum number of people that could be harmed in an accident and the associated probability of occurrence is part of this concept. This maximum possible number affected in any one accident will usually be less than the total number of people who are within the range of possible harmful effects. Societal risk tells one nothing about its geographical distribution. People in the prevailing downwind direction from the storage would be more likely to be affected than those in the opposite direction. This will be reflected in the level of individual risk at such locations.

CONSEQUENCES

The process industries handle many hazardous substances, which provide the potential for accidents leading to adverse consequences for people, property or the environment. There are three main categories of undesired events: explosions, fires and toxic or corrosive releases.
Hazardous substances can cause adverse consequences under one or more of these categories.

Explosions

Description of Effects

The term EXPLOSION is not a scientific one and it is used frequently in common parlance to describe incidents where there is just a loud noise. The Working Party recommends, however, that its use be confined to describing incidents where there is a rapid release of energy, which causes a significant BLAST WAVE capable of causing damage.

In a chemical explosion, the gases, which form as a result of chemical reactions, expand rapidly due to a sudden increase in temperature, thereby increasing the pressure relative to the surrounding atmosphere (medium). A similar expansion can occur in a physical explosion when a gas under pressure is released suddenly into the atmosphere. These expansions initiate a blast wave, which travels outwards, at first with a velocity comparable with that of the expanding gases. A blast wave consists of an initial positive pressure phase followed by a negative pressure phase. Where the pressure pulse formed by a blast wave creates a sharp discontinuity then this is usually termed a SHOCKWAVE.

The damage, which arises from an explosion, may be caused either by the effect of the blast wave or by damage caused by MISSILES. Part of the energy liberated in an explosion may be imparted to fragments or whole systems in the form of kinetic energy. These fragments, or missiles, may be projected outwards some considerable distance from the centre of an explosion.

EXPLOSION	A release of energy, which causes a pressure discontinuity or blast wave.
BLAST WAVE	A pressure pulse formed by an explosion.
SHOCK WAVE	A pressure pulse formed by an explosion in which a sharp discontinuity in pressure is created as the wave travels through a fluid medium at greater than sonic velocity.
MISSILES	Fragments or whole systems, which are projected by a release of energy.

Types of Explosions

If the explosion is caused by a chemical reaction then there are two basic terms, which are used to describe the mechanism or type of explosion; namely a DEFLAGRATION or DETONATION.

A deflagration occurs when the reaction front advances at less than sonic velocity into the unrelated material. For a rapid deflagration of a flammable vapour-air mixture, the flame front moves at a velocity of a few tens to several hundred metres per second. A deflagration may have varying degrees of violence ranging from cases with negligible blast damage effects (cf flash fire) to cases in which a distinct blast wave with potential for serious damage is present. The conditions cannot be specified as yet, under which the flame front may accelerate sufficiently to create a deflagration with significant blast damage effects rather than a flash fire. A detonation, on the other hand, is where the chemical reaction is extremely rapid and the reaction front advances into the unrelated material at greater than sonic velocity.

In the case of explosions of vapour or gas clouds, a number of terms are used to describe the circumstances of an explosion. The principal two are CONFINED EXPLOSION which describes an explosion of flammable vapour-air mixture inside a closed system (e.g. vessel or building) and UNCONFINED VAPOUR CLOUD EXPLOSION (often shortened to UVCE), which relates to an explosion of a flammable vapour-air mixture in the open air. The latter term is very widely used, but is imprecise, as, in practice, an UVCE will nearly always be partially confined due to the presence of buildings, structures, trees, etc. It is included in this listing due to its widespread use, but the term VAPOUR CLOUD EXPLOSION is preferred.

There are many other terms used which fall into the category of describing the characteristics of an explosion. Most of these are self-explanatory, e.g. dust explosion, mist or aerosol explosion. The term dense phase explosion relates to an explosion caused by the chemical reaction of a solid or liquid material, such as TNT (trinitrotoluene).

A blast wave may be created by other means than evolution of gases from a chemical reaction. For example, the term PRESSURE BURST relates to the rupture of a pressurised system and subsequent formation of a blast wave. Similarly, when a material rapidly changes its state a blast wave may be formed. For example the sudden release of pressure and subsequent flashing of a liquefied gas may contribute to the blast wave created by the pressure burst. Where the change of state is as a result of a significant temperature difference between two or more substances as they come into contact, then the term RAPID PHASE TRANSITION is used usually to describe this event, which may produce a blast wave; for example, the instantaneous vaporisation of water to steam on contact with molten metal. In the case of these explosions, there is no combustion process, only a release of physical, rather than chemical, energy.

The term BLEVE (Boiling Liquid Expanding Vapour Explosion) is similar to the extent that the limited blast involved arises only from physical energy. The acronym BLEVE is now used widely and is abused. It was introduced originally in the USA to describe a specific sequence of events commencing with the sudden rupture due to fire impingement, of a vessel/system under pressure containing liquefied flammable gas. The release of energy from the pressure burst and the flashing of the liquid to vapour (flash fraction) creates material. However, immediate ignition of the expanding fuel-air mixture leads to intense combustion creating a fireball, which rises away from the ground due to buoyancy. This is the principal hazard, together with the missile effects of the ruptured containment system. In times, attempts have been made to widen the usage of the term BLEVE to include any sudden failure of a system containing any liquefied gas under pressure. It if felt that to avoid confusion, the name BLEVE should be avoided wherever possible and term such as pressure burst, flashing and fireball should be used to describe the particular scenario. If the term BLEVE is to be used then it is recommended that it should only be used in its original sense as described above.

DEFLAGRATION	The chemical reaction of a substance in which the reaction front advances into the unrelated substance at less than sonic velocity. Where a blast wave is produced which has the potential to cause damage, the term explosive deflagration is usually used.
DETONATION	An explosion caused by the extremely rapid chemical reaction of a substance in which the reaction front advances into the unrelated substance at greater than sonic velocity.
CONFINED EXPLOSION	An explosion of a fuel-oxidant mixture inside a closed system (e.g. vessel or building).
VAPOUR CLOUD EXPLOSION (VCE)	The preferred term for an explosion in the open air of a cloud made up of a mixture of a flammable vapour or gas with air.
UNCONFINED VAPOUR CLOUD EXPLOSION (UVCE)	Defined as for VCE above and is an imprecise term.

PRESSURE BURST	The rupture of a system under pressure, resulting in the formation of a blast wave and missiles, which may have the potential to cause damage.
RAPID PHASE TRANSITION	The rapid change of state of a substance, which may produce a blast wave and missiles.
BLEVE	Used to describe the sudden rupture of a vessel/system containing liquefied flammable gas under pressure due to fire impingement. The pressure burst and the flashing of the liquid to vapour creates a blast wave and potential missile damage, and immediate ignition of the expanding fuel-air mixture leads to intense combustion creating a fireball.

Common Technical Terms used in quantifying the Effects

There are numerous detailed technical terms relating to quantifying the effects of explosions. Below are terms which are used frequently and for which definitions are provided.

OVERPRESSURE	For a pressure pulse (blast wave), the pressure developed above atmospheric pressure at any stage or location is called the overpressure. Overpressure is sometimes used to describe exposure of equipment to pressures in excess of the design pressure, but the term over pressurisation is preferred for this purpose.
PEAK POSITIVE OVERPRESSURE	The maximum overpressure generated is called the peak positive overpressure.
DURATION	The time taken for the pressure pulse to decline to zero is known as the positive phase duration, usually shortened to duration.
SIDE-ON OVERPRESSURE	If a pressure-sensitive device which offered no obstruction to the passage of the blast wave was placed in its path (i.e. one which was facing sideways in relation to its advance), the device would record side-on overpressure.
REFLECTED OVERPRESSURE	If a “rigid” object was perpendicular to the advance of the blast wave (i.e. facing), the object would reflect and diffract the wave. Due to this reflection, the object will experience an effective overpressure of at least twice the side-on overpressure.
EPICENTRE	The ground location beneath the inferred centre of a vapour cloud explosion.
EXPLOSION EFFICIENCY	The ratio of the energy in the blast wave to the energy theoretically available from the heat of combustion, usually expressed as a percentage.

TNT EQUIVALENT	The amount of TNT (trinitrotoluene) which would produce the same damage effects as those of the explosion under consideration. For non-dense phase explosions the equivalence has meaning only at a considerable distance where the nature of the blast wave arising is comparable with that of TNT.

Fires

When a material burns, THERMAL RADIATION is emitted. This form of heat transfer other than by conduction or convection can cause harm or damage to people and objects. The amount and rate of energy emission depends upon a number of factors, the first of which is the type of FIRE. A POOL FIRE may result from the ignition of flammable vapour from a spill of liquid which has collected on the ground or in a container. The linear rate of evaporation of liquid from a pool fire is usually termed the BURING RATE. This term is also used to describe the mass-burning rate of other types of fires. If the ignition takes place when material is emerging from the release point under pressure, a JET FLAME can be produced. If, however, the release produces a cloud of gas which is then ignited, the FLAME FRONT usually moves through the cloud in a FLASH FIRE, ultimately consuming at least those portions of the cloud in which the concentration is above or below the LOWER and UPPER FLAMMABLE LIMITS respectively. Portions of the cloud which are at concentrations above the upper flammable limit will not burn until further diluted with air. The lower and upper flammable limits are not constant and depend upon a number of factors. On occasions, a cloud fire can induce sufficient buoyancy to rise in the air, burning as a FIREBALL.

An adequate supply of oxygen is necessary to sustain combustion of the material and therefore a fire will draw air into the combustion zone. In the case of extremely large fires (over several kilometres square) caused by large scale wartime bombing this in-rush of air reached hurricane force. This phenomenon is known as a FIRE STORM. However, the relevance of fire storms to chemical plant hazards is very doubtful.

For each type of fire, the radiation emitted depends, among other things, on how fast the burning material is consumed. Calculations of the rate of energy received at a target are based on the behaviour of black body radiators. The extent to which the source approaches the emissive power of a black body at the same temperature is known as the EMISSIVITY. This can be used to predict the SURFACE FLUX of a flame. To estimate the proportion of this flux received at any specified “target”, it is necessary to know the VIEW FACTOR, which depends on the special configuration of source and target and the TRANSMISSIVITY of the intervening medium which allow for the attenuation of radiation passing through that medium. The ABSORPTIVITY of the target material determines what fraction of the incident energy will go towards raising the target’s temperature.

Fire, in the sense discussed above, refers, to the combustion of materials in air. However, there are reactions in which air is not involved but which produce similar hazards; e.g. the burning of military propellants or the burning of iron in a chlorine atmosphere. No attempt has been made to produce definitions for such specialised areas.

Safety measures associated with fire fall into two broad categories. FIRE PREVENTION measures are those intended to reduce the likelihood of a fire occurring. FIRE PROTECTION measures are those which seek to minimise the extent of damage from fire should it occur. Fire protection systems may detect, extinguish, contain, or allow persons or property to tolerate a fire.

THERMAL RADIATION	The propagation of energy in the infra-red region of the electromagnetic spectrum.
FIRE	A process of combustion characterised by heat or smoke or flame of any combination of these.
BURNING RATE	The linear rate of evaporation of material from a liquid pool during a fire, or the mass rate of combustion of a gas or solid. The context in which the term is used should be specified.
JET FLAME	The combustion of material emerging with significant momentum from an orifice.
FLAME FRONT	The boundary between the burning and unburnt portions of a flammable vapour and air mixture, or other combusting system.
FLASH FIRE	The combustion of a flammable vapour and air mixture in which flame passes through that mixture at less than sonic velocity, such that negligible damaging overpressure is generated.
LOWER FLAMMABLE LIMIT (LFL)	That concentration in air of a flammable material below which combustion will not propagate.
UPPER FLAMMABLE LIMIT (UFL)	That concentration in air of a flammable material above which combustion will not propagate.
FIREBALL	A fire, burning sufficiently rapidly for the burning mass to rise into the air as a cloud or ball.
FIRE STORM	An extremely large area fire resulting in a tremendous in-rush of air which may reach hurricane force.
EMISSIVITY	The ratio of the radiation emitted by any surface or substance to that emitted by a black body at the same temperature.
SURFACE FLUX	The radiant power emanating from unit area of a flame or other source.
VIEW FACTOR	The solid angle subtended by the source at the target, as a proportion of the solid angle of a hemisphere.
TRANSMISSIVITY	The fraction of incident thermal radiation passing unabsorbed through a path of unit length of a medium.
ABSORPTIVITY	The ratio of the radiant energy absorbed by any surface or substance, to that absorbed under the same conditions by a black body.
FIRE PREVENTION	Measures taken to prevent outbreaks of fire at a given location.

FIRE PROTECTION	Design features, systems or equipment which are intended to reduce the damage from a fire at a given location.

Toxic Substances

Everyone is exposed to a great variety of chemical substances in the normal course of their life, both at work and away from work. Most of these substances do not present a hazard under normal circumstances, but have the potential for being injurious at some sufficiently high concentration and level of EXPOSURE. TOXIC substances, or POISONS, are those materials which can have an injurious effect when introduced into, or absorbed by, a living organism. In this same context, CORROSIVE materials are included because they may damage or destroy living tissues. The terms ACUTE and CHRONIC are used frequently in connection with both toxic exposure and toxic effects. Although used in their normal sense, care is necessary in the use of these terms. Acute implies short duration, while chronic implies a prolonged or recurrent nature. Short-term accidental exposures would therefore be termed acute while daily exposures to background concentrations in the workplace would be termed chronic. To avoid confusion, it is recommended that the terms acute and chronic should not be used to infer high and low concentrations of toxic materials. Their meaning should be restricted to describe time rather than severity, in line with the medical profession in their description of disease.

Some effects do not arise immediately after exposure and are termed “delayed” or “latent”. These terms are obviously relative and confusion can arise between exposure to a CARCINOGEN where the induction period before the appearance of harm (if it does arise) may be many years and exposure to toxic agents where a person may appear to survive a lethal exposure only to die after a day or two.

For some substances, a very small quantity may cause considerable harm whereas for others, a much larger quantity may be required to cause a harmful effect. It is this relative power of a toxic material to cause harm that is termed TOXICITY. It is important to distinguish toxic and corrosive materials from those, which are purely narcotic or IRRITANT. The latter may cause pain and discomfort through immediate or prolonged contact with the skin, but they do not themselves harm or destroy living tissue. Similarly, narcotic substances dull the senses and impair reactions without necessarily causing permanent damage.

Materials, which are not toxic, irritant or corrosive, may still endanger life if present in high enough concentrations in the atmosphere by reducing the oxygen content and thus may lead to ASPHYXIATION.

Two types of occupational exposure limit are now in use; CONTROL LIMITS, which should not normally be exceeded, and RECOMMENDED LIMITS, which are considered to represent good practice. For each type of limit, two types of exposure are considered. The LONG TERM EXPOSURE LIMIT is concerned with reducing the risk from total intake, day after day, over long periods. The SHORT TERM EXPOSURE LIMIT is aimed primarily at avoiding acute effects from brief exposures or peaks in exposure. Both long and short term exposure limits are expressed as time weighted average concentrations, the long term exposure limit is normally averaged over eight hour periods and the short term exposure limit over a ten minute period. Some of the short term exposure limits were formerly expressed as ceiling values which should not be exceeded even instantaneously, but this could not be monitored in practice since all samples need to be taken over a finite period. Ten minutes is considered to be the shortest practical time over which most personal samples can be taken at the levels of the exposure limits due to the limitations of available sampling and analytical techniques. Presently, control limits are only specified for a small number of hazardous substances. It should be noted that further action to reduce exposure below the limits may be necessary to fulfil legal requirements, particularly in the case of substances for which there is no apparent threshold below which adverse effects do not occur. The limits should not be used as an index of relative hazard to toxicity and do not represent a sharp dividing line between "safe" and "dangerous" concentrations.

Until recently the term Threshold Limit Value (TLV) has been used to describe exposure limits. TLV's have traditionally been quoted in three forms. The TIME WEIGHTED AVERAGE (TLV-TWA) has been used to cover long term effects, the SHORT TERM EXPOSURE LIMIT (TLV-STEL) has been used to cover acute effects from a few minutes exposure, and the term CEILING (TLV-C) has been used to cover situations where even the briefest of exposure is likely to cause harm. Many attempts have been made to categorise toxic materials according to the health hazards that may result from single high-level exposures. The majority of these "classifications" are based on the LETHAL DOSE administered, or LETHAL CONCENTRATION inhaled over a period of 4 hours, that results in the death of 50 per cent of a test group within 14 days. This is the concept of the terms LD50 and LC50 respectively. Percentage other than 50 may be quoted. It should be noted that the term LC50 is often used loosely for exposure durations of other than four hours in which case the exposure period should be stated.

A further concept in categorising actual health hazards is that of conditions which are IMMEDIATELY DANGEROUS TO LIFE OR HEALTH (IDLH). This term originated in the USA and was developed with reference to escape from highly toxic atmospheres. It can be confusing since the definition also refers to conditions, which could have cumulative or delayed effects on health.

EXPOSURE	Amount of a toxic substance to which an individual is exposed. This may represent the amount ingested, absorbed or inhaled or it may refer to the integral of concentration with time in the immediate environment. Where ambiguity may arise the basis used to define the exposure should be specified.
DOSE	Used as a synonym with exposure
TOXIC	The property of substances which, when introduced into or absorbed by a living organism, destroy life or injure health.
POISON	Common term for a toxic substance
CORROSIVE	In the context of toxic substances a corrosive substance is one, which may, on contact with living tissues, destroy them.
ACUTE	Immediate, short-term. Relating to exposure: conditions, which develop rapidly and may cause harm within a short time. Relating to effects: effects, which appear promptly after exposure.
CHRONIC	Persistent, prolonged and repeated. Relating to exposure: frequent, or repeated, or continuous exposure to substances. Relating to effects: when physiological effects appear slowly and persist for a longer period or with frequent recurrences.
CARCINOGEN	A substance, which produces cancer.
TOXICITY	The relative power of a toxic material to cause harm.

IRRITANT	A non-corrosive material which may, through immediate prolonged or repeated contact with the skin or mucous membrane, cause pain, discomfort or minor injury. Such reactions may appear as a precursor to more serious injury.
ASPHYXIATION	Endangering life by causing a deficiency of oxygen.
CONTROL LIMIT	An occupational exposure limit, which should not normally be exceeded.
RECOMMENDED LIMIT	An occupational exposure limit which is considered to represent good practice and a realistic criterion for the control of exposure, plant design, engineering controls and the selection and use of personal protective equipment.
LONG TERM EXPOSURE LIMIT	A time weighted average concentration, usually average over 8 hours, which is appropriate for protecting against the effects of long term exposure.
SHORT TERM EXPOSURE LIMIT	A time weighted average concentration, usually average over 10 minutes, aimed at avoiding acute effects.
THRESHOLD LIMIT VALUE-TIME-WEIGHTED AVERAGE (TLA-TWA)	The time-weighted average concentration for a normal eight hour work day or 40-hour work week to which nearly all workers may be exposed, day after day, without adverse effect. (to be superseded by the term “Control Limit”.)
THRESHOLD LIMIT VALUE-SHORT-TERM EXPOSURE LIMIT (TLV-STEL)	The maximum concentration to which workers can be exposed for a period of up to 15 minutes continuously without suffering from (1) intolerable irritation, (2) chronic or irreversible tissue change, or (3) narcosis of sufficient degree to increase accident proneness, impair self-rescue or materially reduce work efficiently; provided that the daily TLV-TWA also is not exceeded.
THRESHOLD LIMIT VALUE-CEILING (TLV-C)	The concentration, which should not be exceeded even instantaneously.
LETHAL DOSE (LD)	The quantity of material administered orally or by skin absorption which results in the death of 50% of the test group within a 14-day observation period.
LETHAL CONCENTRATION (LC)	The concentration of airborne material, the four-hour inhalation of which results in the death of 50% of test group within a 14-day observation period.
IMMEDIATELY DANGEROUS TO LIFE OR HEALTH (IDLH)	Conditions such that an acute exposure will lead to acute or chronic effects.

RELEASES AND DSPERIONS

Mechanisms of Releases

The potential of many hazardous substances to cause harm can only be realised via a RELEASE of energy or of the substance to the surrounding environment. This can arise from failure of the CONTAINMENT SYSTEM designed to hold the substance in a safe condition. Releases fall in a spectrum from deliberate and controlled discharges necessary for the operation of a process to inadvertent and uncontrolled escapes. The possible effects of all such releases should be considered, but it is particularly important to identify initiating events, which may cause inadvertent containment failure leading to an uncontrolled release.

Initiating events fall into two general categories, those internal and those external to a system. Internal causes may be subdivided broadly as those arising from departures from design conditions during operation (e.g. overheating); failure of equipment operating within design conditions (e.g. due to defective or incorrect materials of construction) or from human error in operation. External causes can be similarly subdivided; examples being failure from mechanical damage, “natural hazards”, external corrosion, and domino effects (i.e. events arising at one plant affecting another).

Releases from containment systems range from slow discharge through a small “pinhole” failure to rapid discharge resulting from a major break. Various mechanisms, such as fatigue, creep, or stress corrosion, may cause cracks or defects to grow, possibly leading to a through-wall failure and therefore a release. If the effect exceeds certain critical proportions, which depend on a number of factors, a propagating FRACTURE may rapidly result in a major failure. For example, perforation of an underground pipeline could result from a third party activity, such as digging with a pneumatic drill. Such PUNCTURES may lead to a propagating fracture under certain conditions. The type of fracture may be described as brittle or ductile. A complete failure of pipework resulting in discharge from two open ends of pipe is often described as a GUILLOTINE failure, a term which is usually used in the description of hypothetical failure cases.

A sudden and severe failure of equipment, possibly with division into a few or many pieces and resulting in a rapid release of the contents, is often referred to as a CATASTROPHIC FAILURE. However, a catastrophe, as such, is not necessarily the outcome in terms of damage, other than that suffered by the equipment itself. It is useful to have such a term to describe a variety of very serious equipment failures, but because of the subjective and possibly misleading interpretations which may be derived from the term “catastrophic” it is recommended that it is only used in conjunction with the term “failure” and with specific reference to the equipment concerned. Another term encountered is “disruptive”, which also implies breaking open of equipment, and which is often used synonymously in this context.

RELEASE	The discharge of energy or of a hazardous substance from its containment system.
CONTAINMENT SYSTEM	The process and storage equipment in which a hazardous substance is kept.
FRACTURE	The breaking open of a containment system by the propagation of a crack.

PUNCTURE	A perforation or hole in a containment system as a result of impact.
GUILLOTINE	Complete severance of piping.
CATASTROPHIC FAILURE (of containment)	The sudden opening up of a specified part of a containment system resulting in a rapid loss of contents.

Behaviour of Releases

The type of release depends on the manner in which the containment system fails, the physical properties of the material involved and the storage conditions. Some initiating events lead to such a rapid release of inventory that they are termed INSTANTANEOUS RELEASES. Other produce discharge over a prolonged period and are termed CONTINUOUS RELEASES. Quantification of the rate of release is achieved using fluid mechanics principles applied to single or two phase flow.

Gas held under pressure as liquids form an important category of hazardous substances. On depressurisation a proportion of such materials vaporise with a resulting decrease in temperature. This can result in two phases flow in the leak path, for example, if a liquid off-take pipe is severed at a point some distance away from a vessel. This is known as FLASHING FLOW. In many cases the driving pressure is sufficiently high for this flow to become choked and so the substance is still under pressure on release to the atmosphere, where further flashing occurs. Once depressurisation to atmospheric pressure is complete the temperature of the material will have fallen to its normal boiling point. The proportion which would be vaporized if the entire depressurisation were carried out adiabatically, is known as the FLASH FRACTION. It provides an estimate of the maximum proportion of a superheated liquid emission which promptly vaporises on release to the atmosphere. Rapid depressurisation is a violent process and such a pressure burst may be hazardous in its own right and much of the remaining liquid fraction may be atomised. MOMENTUM TURBULENCE will entrain the surrounding fluid and a proportion of these droplets may “rain-out” and subsequently vaporise. Heat transfer between the surrounding medium – usually the atmosphere – and the suspended liquid droplets may also lead to further vaporisation. These factors tend to increase the vapour fraction beyond the theoretical flash fraction.

Pools, formed by spills of materials, which are normally liquids at atmospheric temperature and pressure, evaporate by atmospheric convention and solar heating. Pools, formed by gases, which are liquefied by low temperature, vaporise, also taking heat from their surroundings, in this case mainly from the sub-medium. The rate of these processes is characterised by the REGRESSION RATE of the liquid pool. This rate is enhanced significantly if the vapour is flammable and is ignited, in which case the term linear burning rate is usually used.

The quantity of released material made airborne, its form, composition, and temperature, can therefore depend on many factors. The description of the release required as input to consequence models, particularly dispersion calculations, is known as the SOURCE TERM.

INSTANTANEOUS RELEASE	The escape of a specified quantity of a hazardous substance over a short time span typically a few seconds.
CONTINUOUS RELEASE	The escape of a hazardous substance at a flow rate, which is sustained

	for a prolonged period.
FLASHING FLOW	Two phase flow in the leak path of a release of super-heated liquid.
FLASH FRACTION	The fraction of a superheated liquid that will vaporise under adiabatic conditions on depressurisation to atmospheric pressure.
MOMENTUM TURBULENCE	Turbulence induced by the speed with which the material is injected into the surrounding fluid.
REGRESSION RATE	The rate of decrease in depth of a liquid pool.
SOURCE TERM	The quantitative description of a release required as input to a consequence model, i.e. quantity or rate, concentration, temperature, density, etc.

Dispersion

When a hazardous substance is released it may explode or burn at the point of release, or it may travel away from the source. During such travel it becomes progressively diluted with the surrounding fluid. This is the process of DISPERSION. A GAS or vapour may mix with air and form a GAS CLOUD, which drifts downwind; a liquid may fix with water and disperse along any currents present.

If dispersion proceeds for a long enough time the concentration of hazardous substance will fall below that required to cause harm. For a flammable substance, the concentration will eventually fall below the lower flammable limit; for a toxic substance, the level will fall below the threshold of significant toxicity. The progress of dispersion to such levels may be estimated quantitatively using a dispersion model which predicts PEAK or mean CONCENTRATION at a point of interest, or ISOPLETHS showing the extent of the effects of a gas cloud. Great care is necessary in interpreting the results of model calculations, particularly with the definition of peak or mean concentration. Dispersion is a stochastic phenomenon, since it is determined by turbulence. In principle, concentration should be defined in statistical terms, taking specific account of frequency and duration of sampling, number of samples, volume of samples, duration of event. In practice, for toxic substances a time-averaged mean concentration or integrated dose is used, so statistical details are neglected. For flammable substances, real difficulties can arise, since the “instantaneous” concentration determines whether ignition is possible.

The dispersion behaviour of a gas cloud is determined by its intrinsic properties as well as local external conditions. Differences arise between DENSE, NEUTRAL DENSITY and BUOYANT GAS CLOUDS. A dense gas cloud may be formed from a DENSE GAS or because it is associated with a cold vapour release. Such gas clouds, which may also be called heavy or non-buoyant, tend to slump towards the ground in the early stages of dispersions. A buoyant gas cloud, often associated with combustion, tends to rise. A neutral density gas cloud has the same density as the atmosphere so it follows the turbulence pattern of the atmosphere. This is known as PASSIVE DISPERSION. The external conditions affecting dispersion include WIND SPEED, SURFACE ROUGHNESS and the stability of the atmospheric boundary layer, which is characterised by WEATHER CATEGORY.

A gas cloud may behave as a discrete PUFF from a brief (instantaneous) release, or a PLUME may form during a continuous release. The time-averaged shape of a plume is a cigar-Shape downwind, but an instantaneous picture may show a complex shape. Time-averaged plume dimensions are usually of most interest for toxic materials, but instantaneous dimensions are of interest for flammables (see below).

DISPERSION	The process of dilution of a hazardous substance by the surrounding fluid.
GAS	Adequately understood and used in common parlance. "Vapour" is sometimes used instead, particularly for the evaporation of a spill of liquid.
GAS CLOUD	The mass of gas/air mixture within a particular envelope of concentration mix.
PEAK CONCENTRATION	The highest concentration predicted at a point by a dispersion model.
ISOPLETH	A surface joining points of equal concentration, i.e. A three-dimensional "contour", in a gas cloud.
DENSE GAS CLOUD	A gas cloud which is heavier than the surrounding air immediately after the release process, because either the gas is a dense gas, or the mixture has a temperature sufficiently below ambient.
NEUTRAL DENSITY GAS CLOUD	A gas cloud, which has a density equal to that of the surrounding air.
BUOYANT GAS CLOUD	A gas cloud, which is lighter than the surrounding air.
DENSE GAS	A gas whose density exceeds that of air at the same temperature.
PASSIVE DISPERSION	A dispersion process depending only on atmospheric conditions in which the properties of the dispersing material do not affect the local turbulence.
WIND SPEED	The mean speed of the air past a stationary point at a specified height, e.g. 10m.
SURFACE ROUGHNESS	A measure related to that component of the turbulence of the atmosphere which is aided by the departure of the ground profile from perfect smoothness.
WEATHER CATEGORY	A measure related to that component of the intrinsic turbulence of the atmosphere, which is specifically determined by thermal stability.
PUFF	The gas cloud resulting from an instantaneous release.
PLUME	The gas cloud resulting from a continuous release.

ASSESSMENT TECHNIQUES

General Terminology

LOSS PREVENTION is a general term used to describe a range of activities carried out in order to minimise any form of accidental loss, such as damage to people, property or the environment or purely financial loss due to plant outage. It includes the various techniques and approaches that have been developed for the assessment and control of risk. Some terms are used to describe the general objective of an activity, others are more specific and imply use of a particular technique. The extent and detail of an assessment depends on the particular problem, but the main stages are: -

(a) Identification of undesired events.
(b) Analysis of the mechanisms by which undesired events could occur.
(c) Consideration of the extent of any harmful effects.
(d) Consideration of the likelihood of the undesired events and the likelihood of specific detrimental outcomes. Likelihood may be expressed as probability or frequency.
(e) Judgements about the significance of the identified hazards and estimated risks.
(f) Making and implementing decisions on courses of action, including ways of reducing the likelihood or consequences of undesired events.

Various combinations of terms such as “hazard”, “risk” and “safety” with “analysis”, “assessment” and “evaluation” are in use to describe all or part of these activities, often loosely being used as synonyms. The term HAZARD ANALYSIS has become established and is now widely used to describe the systematic approach to hazard identification of stages (a) and (b) above followed by, where the severity of the hazards concerned justify it, the subsequent consideration of likelihood and consequences involved in stages (c) and (d). This consideration usually involves quantitative estimation to a greater or lesser degree. Where it does, that part of the process is sometimes referred to as risk analysis. Use of the term risk necessarily implies consideration of the likelihood of events and outcomes and, to this extent; the Working Party considers the term Probabilistic Risk Analysis to be tautologous. An advantage of using the terms hazard or safety to describe such studies is that discriminating can be made between publications on diverse subject matters, such as financial decision making and chemical plant safety, which give different meanings to the term risk.

The Royal Society Study Group use the term risk estimation for stages (a) to (d), risk evaluation for stage (e) and risk management for stage (f), giving a general definition for the term RISK ASSESSMENT which covers stages (a) to (e) in this context. These terms do not encompass the very common situation where none or only some of the aspects are treated quantitatively and therefore the risk is not explicitly estimated. Because there are a number of factors, which influence the degree to, which the consideration of likelihood and consequences merit, or allow, quantitative estimation, the Working Party have found it useful to draw only a limited distinction between hazard analysis and risk analysis. The definition adopted for hazard analysis includes the identification stages (a) and (b) and the subsequent stages (c) and (d) so far as they are relevant in a particular case. It is recommended that the term risk should only be used, in describing a study or assessment, where an estimate of likelihood is involved. The use of the terrm assessment rather than analysis implies taking judgements about significance rather than analysis implies taking judgements about significance rather than estimation alone and so a definition for risk assessment covering stages (a) to (e) has been adopted.

The term HAZARD SURVEY is used to describe the application of loss prevention techniques in the assessment of the hazards from an installation and the means of controlling them. The scope of a hazard survey depends on the hazards and other features of the particular installation. It necessarily involves a consideration of possible accidents, and may include a risk assessment. It includes consideration of all features important to safety, i.e. design, management, operation, maintenance, protective equipment, emergency procedures and training. By identification and examination of the critical features, it should consider whether any justifiable improvements to reduce risk can be introduced.

However, even when this whole process is complete, it is very rare that the risk can be reduced to zero. The remaining element of assessed risk is known as the RESIDUAL RISK and it is usually this, which is compared with the chosen criteria.

The presentation of a justification for the safety of an installation, based for example on a hazard survey, is known as a SAFETY CASE. This term is used in connection with the Control of Industrial Major Accident Hazards Regulations and will therefore have a quasi-legal use for the particular type of installation concerned. Similarly, safety evaluation is used to describe the analysis of risk required by the Pipelines Inspectorate.

It is important to ensure that the standard of all features vital to safety are monitored and updated. The SAFETY AUDIT is a review process carried out with this objective. Features of the process and design, management policy and attitudes, training, operating procedures, emergency plans, personnel protection, accident reporting and so on, may be examined by appropriately qualified personnel, usually including safety professionals independent of production management, to disclose strengths and weaknesses and recommend necessary actions.

LOSS PREVENTION	A systematic approach to preventing accidents or minimising their effects. The activities may be associated with financial loss or safety issues and will often include many of the techniques defined in this report.
HAZARD ANALYSIS	The identification of undesired events that lead to the materialisation of a hazard, the analysis of the mechanisms by which these undesired events could occur and usually the estimation of the extent, magnitude and likelihood of any harmful effects.
RISK ASSESSMENT	The quantitative evaluation of the likelihood of undesired events and the likelihood of harm or damage being caused together with the value judgements made concerning the significance of the results.
HAZARD SURVEY	The total effort involved in an assessment of the hazards from an installation and their means of control.
RESIDUAL RISK	Is the remaining risk after all proposed improvements to the facility under study have been made?
SAFETY CASE	The presentation of a justification for the safety of an installation. (N.B. use in connection with CIMAH Regulations).
SAFETY AUDIT	A critical examination of all, or part, of a total operating system with relevance to safety.

Hazard Identification Methods

There are two categories of hazard identification techniques: fundamental and comparative methods. Fundamental methods are based on a systematic consideration of deviations from the design intent. The most powerful method is a form of hazard study, which uses GUIDEWORDS applied to process stages or functions. FAILURE MODE AND EFFECTS ANALYSIS (FMEA) is the other widely used fundamental method. A primary objective of these techniques is to identify the INITIATING EVENTS, which may lead to dangerous situations.

Hazard studies may be carried out at various stages as a design evolves. Early in a project, a limited study may be carried out to identify the most serious hazards, which may require consideration of fundamental design changes. Such a study will often be accompanied by some preliminary risk assessment. Later studies will be more detailed, with the objective of discovering all significant hazardous situations. They may also identify operability problems, which may lead to lost production. This involves application of guidewords on a line-by-line basis to plant diagrams and procedures and is known as a HAZARD AND OPERABILITY (HAZOP) STUDY. Hazard and Operability Studies can be applied to existing plants – in particular when modifications are being considered – but are most effective when carried out at a design stage where a wide range of possible actions still exist. The guidewords used must be relevant to the stage of the design and must be sufficiently comprehensive to be capable of identifying the hazards involved. A general set of guidewords with a broad range of application has been published by I.Chem.E. Many specialist lists have also been developed for particular applications. Experience has shown that this technique is most effective when carried out by a team of designers, operators, safety advisors independent of the design functions and other specialists as appropriate, at a series of study meetings. The outcome of a study meeting is a list of actions to be pursued outside the meetings, e.g. design changes for consideration, cases identified for more detailed study and analytical quantification and items which will require further consideration at a later state in the design.

Failure Mode and Effects Analysis (FMEA) involves consideration of the possible outcomes from all known failure modes or deviations within a system, identifying which lead to undesirable situations. There is no formal method but results are usually summarised in tables. FMEA is most useful where there are a limited number of failure modes known to be of interest. When, within this process, the chance of failures and the seriousness of their consequences are ranked to identify the most critical features, the process is known as Failure Modes Effects and Criticality Analysis (FMECA).

Hazard identification procedures also provide information on the mechanisms by which the identified hazards can be produced and as such, the distinction between these techniques and the complementary analytical techniques described Section 6.3, which can also be used for hazard identification, is somewhat artificial. The main difference is that the hazard identification techniques do not provide a framework for setting down mechanisms, while the analytical techniques must start from an event, which has been identified by some method.

Comparative methods use CHECKLISTS based on in-house or industry wide experience and may derive from Codes of Practice or fundamental studies on similar plants. This may be adequate where the plant design is relatively standard and sufficient experience exists for the principal hazards to be well known. HAZARD INDICES provide identification via checklists, although they also provide a preliminary ranking order for the degree of hazard. The best known and most widely used are the Dow Fire and Explosion Index and the Mond Index.

GUIDEWORDS	A list of words applied to system items or functions in a hazard study to identify undesired deviations.
FAILURE MODE AND EFFECTS ANALYSIS	A process for hazard identification where all known failure modes of components or features of a system are considered in turn and undesired outcomes are noted.
INITIATING EVENT	A postulated occurrence capable of leading to the realisation of a hazard
HAZARD AND OPERABILITY (HAZOP) STUDY	A study carried out by application of guidewords to identify all deviations from design intent with undesirable effects for safety or operability.
CHECKLIST	A method of hazard identification by comparison with experience in the form of a list of failure modes and hazardous situations.
HAZARD INDICES	A checklist method of hazard identification, which provides a comparative ranking of the degree of hazard posed by particular design conditions.

Analytical Techniques

The main technique for analysis of the mechanisms, or failure logic, leading to hazardous events is the use of LOGIC DIAGRAMS. They can be classified as "top down" or "bottom up" depending upon whether they trace outcomes back to causes or follow causes through to possible outcomes. They provide a powerful method of displaying qualitative information, but also provide a model for quantification. The main techniques, although there are other variations, are FAULT TREE ANALYSIS, EVENT TREE ANALYSIS, and CAUSE-CONSEQUENCE ANALYSIS.

Fault Tree Analysis works back from an undesired event, known as the TOP EVENT, to the sub-events which are immediate precursors of the top event, then to the precursors of those sub-events and so on. Combinations of events are illustrated by GATES, which, when the logical combination of the input conditions is satisfied, produce a specified output which is propagated. A fault tree models system states but can only show sequences of events with difficulty. There is a considerable amount of terminology specific to fault trees for which the reader should refer to a specialised text.

Event Tree Analysis follows a cause through to the possible outcomes, branching at each point where there is more than one possible result from the precursor event, until the final outcomes of interest are reached. The outcomes are conditional on the occurrence of the precursor events and so event sequences and time dependence can be readily displayed.

Cause-Consequence Analysis also follows through cause to events, but allows for the use of gates to show logical combinations of events or stages while retaining the ability to show sequences and therefore time delays. Although potentially very useful where these factors are important it is necessarily more complicated than fault tree and event tree analysis and is not used widely.

LOGIC DIAGRAM	A representation of the logical combination or sequence of events leading to or from a specified state.

FAULT TREE ANALYSIS	A method for representing the logical combinations of various system stages, which lead to a particular outcome (top event).
EVENT TREE ANALYSIS	A method for illustrating the intermediate and final outcomes, which may arise after the occurrence of a selected initial event.
CAUSE-CONSEQUENCE ANALYSIS	A method for illustrating the possible outcomes arising from the logical combination of selected input events or states.
TOP EVENT	The selected outcome whose possible causes are analysed in a fault tree.
GATE	A symbol in a logic diagram which specifies the logical combination of inputs required for an output to be propagated

Quantification of Event Frequency

The likelihood of an event occurring is normally expressed as a FREQUENCY of occurrence over a time period of interest (usually a year). This can be related to the number of occurrences over a sufficiently long period or a PROBABILITY that the event will occur within a shorter period, e.g. a plant lifetime or a year.

An event frequency may be estimated by the following methods: -

(a) Direct use of statistical data on the occurrence of similar events, requiring the number of events that have occurred and the total amount of experience to be known. This is sometimes called the historical approach.
(b) Synthesis from the frequencies and probabilities of sub-events, e.g. component failures, by quantification of logic diagrams.
(c) A combination of the above approaches.

Availability of relevant data is often an important factor in selecting the approach to be adopted. The mathematical model for quantification of event mechanisms, which include logic combinations, is derived by use of Boolean algebra. The quantification process usually involves application of RELIABILITY engineering techniques. There is a wide range of terms specific to this field for which references should be made to an appropriate source.

If there are protective systems, which provide safeguards against particular hazardous events, the frequency of the hazardous events depends on the frequency of DEMANDS on the protective system and the probability of the protective system being in a failed state on demand. The average probability for a protective system being unavailable is known as the FRACTIONAL DEAD TIME. This utilises knowledge of the distribution of the failures, the test interval and repair times to obtain the fraction of time for which the system is unavailable for any reason.

FAILURE MODES are often classified as fail-to-danger or fail-safe. In protective systems a FAIL-TO-DANGER FAULT would make the protective action less likely in the event of a demand while a FAIL-SAFE FAULT would usually result in spurious operation of the protective system, often causing an unnecessary shutdown. These terms can cause difficulties and it is often clearer to use more specific terms such as “fail to closed position” “fail to open circuit”, etc. Failures may also be referred to as revealed or unrevealed, depending on whether their effects are immediately apparent. Fail-to-danger faults in passive protection systems are likely to be unrevealed in normal operation.

Where high reliability of engineered safely features is required, consideration may need to be given to building in REDUNDANCY and DIVERSITY. The analysis of failure probability for these types of systems must give attention to the possibility of failures of more than one component of system due to the same cause. Power failure or external events such as lightning or earthquake are examples of such COMMON CAUSE FAILURES. Where this causes different items to fail in the same manner, the resultant failures are known as COMMON MODE FAILURES. This commonality is only of interest if it results in items being in a failed state at the same time.

FREQUENCY	The number of occurrences per unit of time.
PROBABILITY	A number in a scale from 0 to 1, which expresses the likelihood that one event, will succeed another.
RELIABILITY	The probability that an item is able to perform a required function under stated conditions for a stated period of time or for a stated demand.
DEMAND	A condition, which requires a protective system to operate.
FRACTIONAL DEAD TIME	The mean fraction of time in which a component or system is unable to operate on demand.
FAILURE MODE	The manner in which a component fails.
FAIL-TO-DANGER FAULT*	A fault, which moves a plant towards a dangerous condition or limits the ability of a protective system to respond to a dangerous condition.
FAIL-SAFE FAULT*	A fault, which results in no deterioration of safety.
REDUNDANCY	The performance of the same function by a number of identical but independent means.
DIVERSITY	The performance of the same function by a number of independent and different means.
COMMON CAUSE FAILURE	The failure of more than one component, item or system due to the same cause.
COMMON MODE FAILURE	The failure of components in the same manner.

Quantification of Event Consequences

There are three stages in the quantification of the possible consequences of a hazardous event. The first stage requires a model for the attenuation of the damage causing effect (e.g. toxic concentration, explosion overpressure of thermal radiation) over time and distance. The second stage utilises knowledge of the critical levels of exposure (e.g. a dose-effect relationship) to obtain a relationship between degree of damage and distance, often known as the HAZARD RANGE. This may be a maximum distance for a particular level of damage (e.g. fatal injury) or may be a relationship between distance and probability or degree of damage or injury. VULNERABILITY MODEL is a term used to describe the mathematical models adopted to combine these two stages of the quantification of event consequences.

There may be different outcomes from a hazardous event depending on the prevailing circumstances. In the third stage of consequence quantification, the results of the vulnerability model are applied to the particular case under consideration (e.g. plant layout, personnel or population distribution) with probabilities allocated to variable factors such as wind direction, weather conditions and occupancy. The result is a relationship between probability (conditional on the occurrence of the hazardous event) and the extent of detriment, usually expressed as the number of people suffering a specified degree of harm. The product of the vent frequencies and the conditional probabilities gives the frequency at which numbers of people would be harmed by the event. Summation of the frequencies for particular numbers of people over all events gives the overall relationship between the number of people affected and the frequency, i.e. the societal risk. This is often expressed as an F-N CURVE showing the cumulative frequency at which N or more people are affected. This presentation is adopted, as it is not particularly useful to state the chance of killing exactly 10 people rather than 9 or 11. Besides giving a misleading impression of the accuracy of such a calculation, it is actually the chance of all accidents larger than certain sizes, which is usually of interest.

The frequency, at which an individual at a particular location would be harmed by an event, is obtained from the product of the event frequency and the conditional probability for the specified degree of harm at that location.

Where more than one event has the potential to harm the individual, the individual risk is obtained by summation over all such events.

HAZARD RANGE	The relationship between distance from the source of hazard and detriment.
VULNERABILITY MODEL	The mathematical models applied in the estimation of hazard range.
F-N CURVE	A plot showing, for a specified hazard, the frequency of all events causing a situated degree of harm to N or more people, against N.

CRITERIA

In assessing the performance of any plant, works, site or industry, it is essential that we have a measure against which to judge its adequacy. This general term for such a measure is CRITERION (plural CRITERIA).

Criteria may be used either in the predictive mode, that is to assess the need for action against some predicted risk, or in the historical mode to assess actual recorded performance. They are generally quantitative statements expressed as the frequency of a specified undesired event. In setting criteria, it is essential that the units chosen are consistent with available techniques for prediction or measurement, and that the chosen value is within the limits of credible use of those techniques, otherwise no valid comparison can be made.

In the field of hazard and risk assessment, criteria are set as standards of safety performance, which may be used to indicate situations where expenditure or procedural changes are necessary. An organisation may set criteria for itself or be guided by some external body.

Criteria based on risk alone can only provide general guidelines. The accuracy of assessments is generally only to order of magnitude precision and so criteria cannot be applied rigidly. The law in the UK requires adoption of “reasonably practicable” measures to prevent accidents, which means implementing such measures unless the reduction in risk is insignificant in relation to the sacrifice necessary to achieve it. Although this can involve emotive issues, implicitly or explicitly putting a value on human life and suffering, cost-benefit aspects are an important element in taking decisions. However, it is useful to set risk targets for designers in order to encourage development of economical ways of limiting risk. Several ways of including these concepts in risk criteria have been proposed. One approach involves setting a limiting risk criterion, which must be achieved; costs, risk and benefits are considered only once this target has been met. A second, insignificant level of risk may also be set as a very stringent target beyond which further reduction in risk would be unlikely to be justifiable. This type of compound risk criterion is known as a TWO BOUNDARY CRITERION.

The most common criteria used in hazard and risk assessment are those associated with fatal accidents. These can relate to major incidents where multiple fatalities could occur or to those incidents where the possible consequences are limited. In the case of multiple fatalities, these are often expressed as SOCIETAL RISK CRITERIA to give an indication of the impact on the local population of a catastrophic event. Because of the difficulty of accurately predicting the number of fatalities n any particular event, it is sometimes convenient to consider MAJOR INCIDENT CRITERIA instead. In this case, a number of categories of incident are defined with a range of consequences in each category. The categories are chosen to be consistent with the discriminating power of the assessment technique. Frequency criteria can then be ascribed to each category.

INDIVIDUAL RISK CRITERIA are used where it is necessary to consider the distribution of risk. Individual risk criteria may either be expressed as peak values to indicate where the risk is concentrated on one or a very few individuals or as average values where the risk is shared fairly evenly amongst the exposed population. Both peak and average values have their advantages; AVERAGE INDIVIDUAL RISKS can be compared directly with statistics for other man-made and natural risk to achieve a good perspective on the size of the problem, while PEAK INDIVIDUAL RISKS will indicate situations where a small sector of the local population carries a disproportionate amount of the total risk.

An example of such a criterion is the FATAL ACCIDENT RATE (FAR), which is usually used in assessing risk to an exposed workforce rather than to a population outside a works. FAR is sometimes applied in the predictive mode to risk faced by an individual in a particular job. In this case, it is defined as the predicted number of fatal accidents per 10 hours of exposure to the hazards involved in that job. (10 hours is approximately equal to the working lifetime of a thousand people).

Only rarely will any one of these criteria convey the whole picture alone and a thorough assessment will usually examine the situation against a number of them.

Terms, which have been widely used in the past, are acceptable risk and criterion of acceptability. At first sight, these seem attractive concepts because they suggest an absolute level of performance which if achieved would be acceptable and therefore would avoid much emotional debate. However the word “acceptable” immediately begs the question “acceptable to whom?” and the debate in this area is no less emotional. The true value of quantitative assessment and criteria is not in trying to prove that a given situation is acceptable, but in improving decision taking by helping to put problems in perspective. Acceptability is a much wider issue involving not just the quantitative assessment and criteria, but also the PERCEIVED RISK as seen by those concerned. Perceived risk is the phenomenon of an individual interpreting the magnitude of a risk against the background of his own understanding. This background may be the result of extrapolation of his own experience or may be influenced by “popular belief” as expressed in the media or by other interested parties. Thus the perceived risk may either exceed or fall short of the result of a quantitative assessment. Perceived risk cannot be predicted and is often linked only loosely to measures taken to reduce the true risk. It will generally be influenced most directly by education or propaganda.

Thus acceptability is most unlikely to be determined specifically by hazard and risk assessment and it is therefore strongly recommended that terms in the field of criteria which use the word “acceptable” should be avoided.

CRITERON	Is a standard of performance with which assessed performance may be compared?
TWO BOUNDARY CRITERION	Is a compound criterion with a lower standard, which must be achieved, and an upper standard as an ultimate goal.
SOCIETAL RISK CRITERIA	Criteria relating to the likelihood of a number of people suffering a specified level of harm in a given population from the realisation of specified hazards.
MAJOR INCIDENT CRITERION	Criterion (expressed as a frequency) for incidents falling within a defined category or consequences.
INDIVIDUAL RISK CRITERIA	Criteria relating to the likelihood with which an individual may be expected to sustain a given level of harm from the realisation of specified hazards.
AVERAGE INDIVIDUAL RISK	Is the average chance of an individual in a defined population sustaining a given level of harm from incidents, which are considered to be limited to that population.
PEAK INDIVIDUAL RISK	Is the highest individual risk for any person in the exposed population
FATAL ACCIDENT RATE (FAR)	(previously known as FAFR) is the number of deaths that have occurred or are predicted to occur in a defined group, in a given environment, during 10 hours of total exposure.
PERCEIVED RISK	Is that risk though by an individual or group to be presenting in a given situation.