Health and
Safety
Commission

Advisory Committee on Major Hazards

Second report

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Health & Safety Commission

Advisory Committee on Major Hazards

SECOND REPORT

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Preface

As explained in the Foreword, the Advisory Committee on Major Hazards was set up by the Health and Safety Commission towards the end of 1974 to consider the safety problems associated with large-scale industrial premises conducting potentially hazardous operations.

In their first report, published by the Commission in September 1976, the committee recommended that regulations should be introduced requiring persons having control of certain types of installations to send details of their activities to the Health and Safety Executive. Public response to this concept of a notification scheme was generally favourable and in June 1978 a Consultative Document on Hazardous Installations (Notification and Survey) Regulations was issued by the Commission. The replies to this document are being considered by the Health and Safety Executive. The publication of this second report is intended to maintain public discussion of the philosophy behind the committee's thinking as well as their specific recommendations.

The Commission welcomes the report as making a further important contribution to current thinking about the safety of hazardous industrial operations in this country.

The report is very much in the nature of a discussion document and as the Commission is anxious to continue the general informed debate on major hazard problems, the views of bodies and individuals primarily concerned will be welcome.

Any comments should be sent in writing to Mr H E Lewis, Health and Safety Executive, 25 Chapel Street, London, NW1 5DT, to reach him not later than the end of February 1980.

W SIMPSON
Chairman, Health and Safety Commission

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3 Limitation of exposure and interaction Chairman: Professor J L M Morrison
4 Planning controls Chairman: J M Miller
5 Research Chairman: Professor J F Richardson

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M J Turner Hazardous Installation Policy Branch, Health & Safety Executive (Groups 2 & 5)

Foreword

The committee was appointed by the Health and Safety Commission at the end of **1974** ***"To identify types of installations (excluding nuclear installations) which have the potential to present major hazards to employees or to the public or the environment and to advise on measures of control, appropriate to the nature and degree of hazard, over the establishment, siting, layout, design, operation, maintenance and development of such installations as well as over all development, both industrial and non-industrial, in the vicinity of such installations."***

In our first report, published in September **1976**[1], the Chairman of the Commission invited interested bodies and individuals to send in their comments so that these could be fed back into discussions at the formative stage. We thank all those who did respond. The comments received, including those from CBI and TUC, have helped clarify our thinking, particularly in the preparation of this second report.

Meetings were arranged between the committee and some of the bodies with a particular interest in major hazards to discuss comments. These included the British Chemical Engineering Contractors Association; the Chemical Industries Association; the Council of Engineering Institutions; the Royal Town Planning Institute; the British Insurance Association; the Institute of Petroleum and the Institution of Gas Engineers.

Our first report stressed the importance of research into the problems presented by major hazards and, in view of the need to keep abreast of worldwide developments in this area, we decided in October **1977** to set up a fifth working group specially for this purpose.

The work of the five groups forms the basis of this second report which deals with historical information on major hazards, including explosion hazards; siting and structure of control buildings and protection of workpeople; planning; legal controls and a possible licensing scheme; research and future work. The report also outlines the thinking behind the notification scheme currently the subject of the consultative document on Hazardous Installations (Notification and Survey) Regulations **1978** issued by the Commission[2]. This detailed account of our work will, we hope, act as a catalyst in encouraging a general informed debate on major hazard problems.

Throughout our deliberations we have been conscious of the recommendations of the Court of Inquiry into the Flixborough disaster and have taken account of them in this report; consequently, we have not set aside a particular chapter for specific comment.

Type of major hazards

The committee has examined historical evidence to assess the frequency, causes and consequences of major incidents in the UK and overseas. Those resulting in deaths involving toxic gases, extremely toxic materials, flammable liquids and gases, and unstable and highly reactive materials are listed in table form, along with such details as: source of leakage; nature of incidents; materials involved; quantity of material and numbers of deaths. This evidence, the committee concludes, shows no more than that tonne-for-tonne conventional explosives, ammonium nitrate, flammable gases, chlorine, and possibly phosgene, seem about equally hazardous, with ammonia appearing to be less dangerous.

However, the mortality indices calculated from this evidence should be used as no more than a framework of reference and the relative levels for notification must remain a judgement that is reasonable and generally acceptable.

Consideration of the behaviour of large clouds of flammable vapours mixed with air shows that such mixtures can give rise to effects which at a distance are difficult to distinguish from the detonation of high explosives. Despite the efforts devoted to studying such clouds, the information available is far from complete or conclusive and will remain so for many years.

The factors which determine the size of a vapour cloud explosion and its destructive effect at any given location are examined. These include: quantity of material and TNT equivalent; fraction likely to flash off to form a cloud; composition of cloud; extent of drift; pressure and duration of blast. Guidance is given on the likely strengths, duration and range of blasts which will be useful in the consideration of the design of buildings on major hazard sites. Values have been calculated for these parameters using knowledge of the behaviour of structures subjected to known degrees of blast from high explosives, notably TNT.

Protection of people and control buildings

The elements of managerial control and categories of

1 Experience of major accidents and problems in evaluation of major hazards

The criteria for the assessment of major hazards is discussed by firstly examining historical experience and then by considering the techniques of theoretical prediction. The consequences and frequency of world-wide incidents involving toxic gases and substances, vapour cloud explosions and fires, and highly reactive and unstable substances are examined. Although the quantitative information derived from those occurrences provides no more than a framework of reference, the historical data in general supports the levels at which inventories should become notifiable. The complementary role of the techniques of theoretical prediction is emphasized.

1 In our first report, at para 48, we set out an interim list of substances and processes which we thought should be made notifiable. Much of this Chapter is concerned with a review of that list, and Chapter 2 then describes the action taken by the Health and Safety Commission in arranging for draft regulations to be prepared on the basis of the list. We have first studied the historical evidence of certain major incidents in order to ascertain the number of casualties in relation to the quantities of hazardous substances involved, to see if there is any common ground for the various catergories of hazard and to what extent this could assist us in assessing whether the inventories proposed for notification purposes were of the right order because the list, although based upon considerable experience drawn both from the Health and Safety Executive and ourselves, was prepared pragmatically. We describe the results of this review in paras 3-21 below. It would have been perhaps too much to expect that our analysis of historical data would have precisely matched the levels which we proposed for notification in our first report. However, we believe that the historical data in general support the levels set out for notification.

2 This review has borne out the statement made in our first report that the ultimate potential of an incident is seldom realised, and that the number of casualties and extent of damage depend on the interaction of a whole range of factors. Hence a study of past events cannot be relied upon on its own, as a means of predicting what will happen in certain circumstances and we therefore go on in paras 22-26 to outline some of the problems involved in evaluating hazards. We have not dealt extensively in this report with predictive techniques but we are aware that this important and developing subject is being studied by experts in this field and we believe it is worthy of deeper consideration.

3 In order to assess the frequency, causes and consequences of major incidents, we have studied summaries and reports of recorded events that have occurred in the UK and overseas, in particular those which involved:

(i) Toxic gases which, following release in tonnage quantities, were lethal or harmful for considerable distances from the point of release.

(ii) Extremely toxic material which, following release and dispersion in kilogramme quantities, was lethal or harmful for considerable distances from the point of release.

(iii) Flammable liquids or gases which, following release in tonnage quantities, formed a large flammable cloud, which in turn burnt or exploded.

(iv) Unstable or highly reactive materials which have exploded.

We have restricted ourselves to studying the number of fatalities, because injuries are less easily quantified.

4 In our analysis we needed, however, to be cautious because we found that available information on major incidents was frequently unreliable. It has to be remembered that such information is often based on reports from people who could well have been in considerable danger, who may have been subject to shock and who did not fully understand the technical implications of what they were witnessing; all factors which are likely to add to the well-known fallibility of eye-witness accounts. Also we have noted that the data quoted in the original reporting by the news media have a great persistence and can override more authoritative data arrived at later by official inquiries or by technically competent investigators. We, in this report, quote what we think is the most reliable information available, and in our tables of selected incidents we give the quantities and number of fatalities only when we consider these are known with a reasonable degree of certainty.

5 In considering the historical evidence we have

Table A Releases of chlorine

Location	*Date*	*Area/site*	*Source of leakage*	*Quantity released (tonnes)*	*Number of fatalities*
1 Baton Rouge Louisiana	10 12 76	Factory	Storage tank	90	0
2 Rauma Finland	5 11 47	Factory	Storage tank	30	19
3 Cornwall Ontario	30 12 62	Urban/Rural	Rail tanker	28	0
4 Griffith Indiana	13 3 35	—	Rail tanker	27	0
5 La Barre Louisiana	31 1 61	—	Rail tanker	27	1
6 St Auban France	13 12 26	Factory	Storage tank	24	19
7 Syracuse New York	10 5 29	Factory	Storage tank	24	1
8 Zarnesti Rumania	24 12 39	Factory	Storage tank	24	60
9 Wyandotte Michigan	1917	Urban	Storage tank	17	1
10 Chicago Illinois	4 2 47	Urban	Rail tanker	16	0
11 Niagara Falls New York	8 2 34	Factory	Rail tanker	15	1
12 Walsum West Germany	4 4 52	Factory	Storage tank	15	7
13 Brandtsville Pennsylvania	28 4 63	Rural	Rail tanker	8	0
14 Mjodolen Norway	26 1 40	Factory	Rail tanker	7	3
15 Freeport Texas	1949	Factory	Pipeline	4	0
16 Lake Charles Louisiana	10 3 56	Factory	Connecting pipework	3	0
17 Johnsonburg Pennsylvania	12 11 36	Factory	Rail tanker	2	0
18 Mobile Alabama	12 7 64	Factory	Pipeline	Unknown	1

$$\text{Mean mortality index} = \frac{\text{Total number fatalities}}{\text{Total amount lost}}$$

based on incident Nos 1-17 in Table

$$= \frac{112}{361}$$

$$= 0.3$$

made use of the study carried out by one of our members Mr V C Marshall[3]. The tables and mortality indices published in that reference have been subjected to intense critical scrutiny and revision by ourselves and our Secretariat before arriving at the figures quoted in the report. In the course of studying these tables and other incidents we also have calculated 'mortality indices' i.e. the number of fatalities per tonne of material released, because we see this as a possible way of comparing various categories of hazard. The information we can draw on is limited and applies only to those materials produced in the largest tonnage quantities. There is insufficient historical experience for many of the substances named on our list.

6 The major proportion of tonnage toxic releases recorded refer to chlorine. There are a number of reasons for this, not least the fact that chlorine has been produced and used on a significant scale since the beginning of the century.† Table A lists

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† The highest death toll from chlorine in recorded history appears to be that which arose not from its use in an industrial context but from the use of the gas as a weapon of war against unprotected troops at Ypres in April 1915. Some 168 tonnes of chlorine were released over a period of about 5 minutes along a 7 kilometre front in circumstances deliberately chosen to maximise the toll of human life. If the most extreme estimate of 5000 fatalities is to be believed, and there is reason to think that it may be an over-estimate, the mortality index did not exceed 30 fatalities per tonne. The fatalities represented some 20% of the allied troops in the battle zone at the time.

Table B Releases of ammonia

Location	*Date*	*Area/site*	*Source of leakage*	*Quantity released (tonnes)*	*Number of fatalities*
Floral Arkansas	5 6 71	Rural	Pipeline	600	0
Enid Oklahoma	7 5 76	Urban	Pipeline	500	0
Conway Kansas	6 12 73	Rural	Pipeline	277	0
Landskrona Sweden	16 1 76	Port	Ship-storage connection	180	2
Blair Nebraska	16 11 70	Rural	Storage tank	160	0
Crete Nebraska	18 2 69	Urban	Rail tanker	90	9
Belle West Virginia	21 1 70	Urban	Rail tanker	75	0
Texas City Texas	3 9 75	Urban	Pipeline	50	0
Potchefstroom S Africa	13 7 73	Urban	Storage tank	38	18†
Houston Texas	11 5 76	Urban	Road tanker	19	6
Lievin France	21 8 68	Urban	Road tanker	19	6

$$\text{Mean mortality index} = \frac{\text{Total number fatalities}}{\text{Total amount lost}} = \frac{41}{2008} = 0.02$$

† Without this incident the mean mortality index = 0.01

significant accidental releases of chlorine. Some of these releases resulted from hydrogen, generated by the same electrolytic process that produced the chlorine, finding its way into the chlorine storage where it reacted explosively.

7 It seems likely, that in recent years operational practices to say nothing of engineering techniques and even mitigatory measures intended to reduce fatalities in the event of a major release to atmosphere have considerably improved. The table shows that in the case of storage tanks the worst incidents occurred thirty or more years ago and this in spite of the great increase in the scale of production of chlorine since the end of the Second World War. Further information on chlorine incidents provided by the Chlorine Product Group[4] of the Chemical Industries Association, and shown in Fig 1 bears this out.

8 Most of the other recorded toxic releases of significance relate to ammonia, a gas which has also been produced and used in large quantities for over half a century. Major rapid releases are listed in Table B which shows a lower mean mortality index for ammonia than for chlorine which in our view is to be expected and is consistent with its lower toxicity. However, information on the behaviour of ammonia released from both refrigerated and pressurised systems is needed, and we are glad to record that further research is being undertaken.

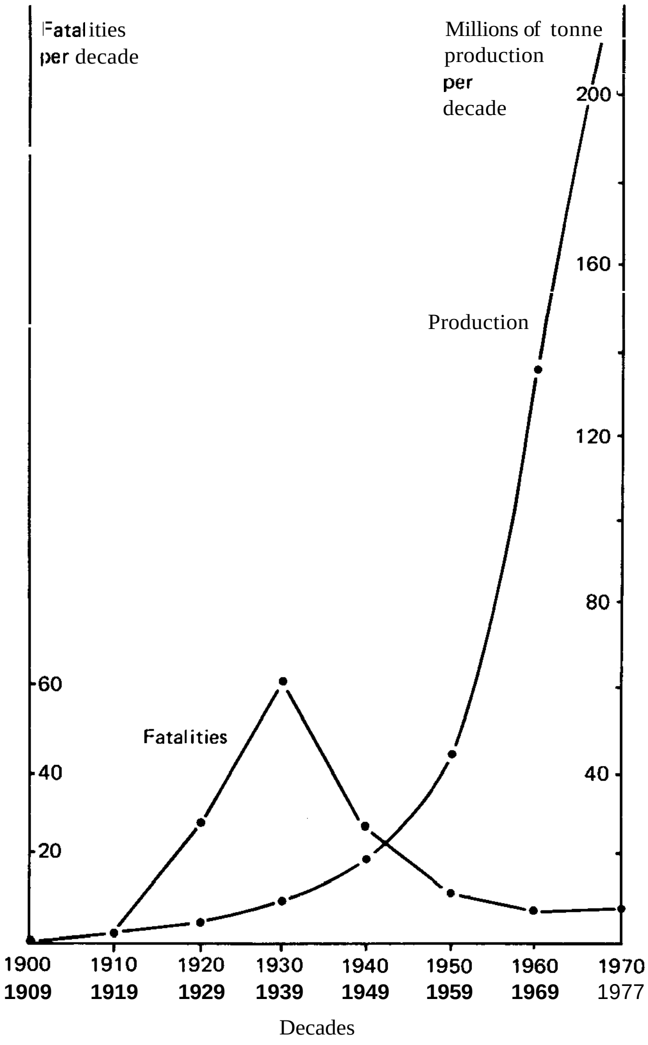

Fig 1 World production and known fatalities from incidents involving liquid chlorine. Source: Chemical Industries Association, Chlorine Product Group.

9 We have found only one industrially recorded incident involving phosgene and it occurred in Hamburg in May 1928, when 10 tonnes were released from a store and ten people were killed.

10 There are substances which are more toxic than those mentioned above, and a small number can be lethal to man even in microgramme doses. A most serious incident of this nature was the accidental release of TCDD (2,3,7,8 — tetrachloro-dibenzo-p-dioxin) at Seveso in Italy in 1976. Here, this highly toxic substance was not part of the normal chemical process but was produced as an accidental by-product in an uncontrolled exothermic reaction. Reports have indicated that kilogramme quantities were released and the nature of the incident led to dispersal of the substance over a large area. No immediate fatalities were reported. This incident however underlines the difficulties associated with setting criteria for the limits above which substances should require special notification and control. While TCDD is no longer produced in the UK under normal operating conditions, nor, we understand, is it likely to be produced in any significant quantity under abnormal conditions, we regard as essential the inclusion of a further category in the proposed regulations for notification and hazard surveys (see Chapter 2) to include substances which might be described as violently toxic.

11 Vapour cloud explosions and fires are always spectacular. We would like to believe that as a consequence, most of the incidents which have occurred in other countries have been recorded, but unfortunately we cannot be certain that this is so. In 1972 Strehlow[5] collated and analysed incidents known to him and drew attention to the increasing danger from the deflagration* of unconfined vapour clouds. Surveying the events of the previous 42 years, he listed no fewer than 108 incidents which had occurred, mainly in the USA but also in Germany and Holland and which had, in total, cost 386 lives and 173 million dollars. His data appear to show that the frequency of incidents was increasing at a significant rate; from about four in one decade to a rate of over 60 per decade as can be seen from Fig 2. At that time no such major catastrophes had occurred in the UK. In March 1977 J A Davenport presented an updated resume of vapour clouds to the American Institute of Chemical Engineers[6] where he listed 22 incidents occurring in the five years from 1972 to 1976.

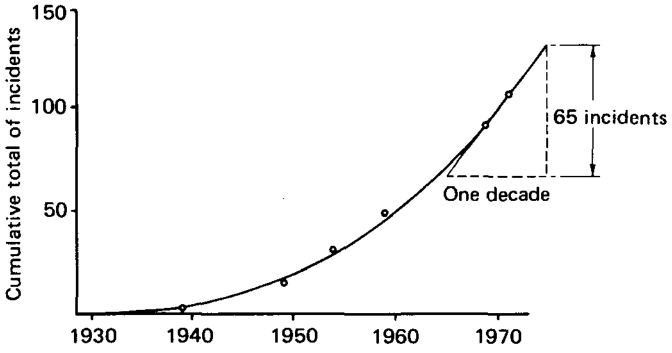

Fig 2 Data from Strehlow

12 Our investigations have shown that there has been a greater number of releases of flammable than of toxic materials. The consequences range from harmless dispersion to fire or explosion which in some cases has been of considerable magnitude. The events that follow a release are governed by many factors and, while those which determine whether an explosion will occur are at present not well defined, it appears that, in broad terms, and perhaps not surprisingly, the smaller the quantity of flammable vapour and the less it is confined, the lower the likelihood of an explosion.

13 The character and effects of vapour cloud explosions are discussed in detail in Chapter 5. For the moment, it is sufficient to note the data in Table C, which gives examples of incidents that have occurred with flammable materials, to provide an indication of what can happen, However, in drawing any conclusion from the list, it should be borne in mind that it is selective. The table includes some relatively well known incidents which have significance for some particular reason - usually because of the number of fatalities, the quantity of material released or the explosive effect. We have excluded incidents where ignigtion did not occur.

Table C Sudden releases of flammable gases or vapour

						Quantity of material lost (Tonnes)			
Location	*Date*	*Area/site*	*Source of leakage*	*Nature of incident*	*Material involved*	*Total*	*Before ignition*	*Time to ignition (minutes)*	*Number of fatalities*
1 Austin Texas	22 2 73	rural	pipeline	fire	NGL	530	80 - 100	10 - 12	6
2 Climax Texas	29 6 74	rural	rail tanker	explosion	vinyl chloride	more than 100	100	short	0
3 Decatur Illinois	19 7 74	urban	rail tanker	explosion and fires	isobutane	not known	69	10	7
4 Port Hudson Missouri	9 12 70	rural	pipeline	explosion	propane	360	60	24	0
5 East St Louis Illinois	22 1 72	urban	rail tanker	explosion	propylene/ propane	more than 56	56 max	1	0

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* See Glossary

Table C (continued)

Location	Date	Area/site	Source of leakage	Nature of incident	Material involved	Quantity of material lost (Tonnes)		Time to ignition (minutes)	Number of fatalities
						Total	Before ignition		
6 Pernis Holland	20 1 68	factory	storage tank	explosion	mixed hydrocarbons	more than 50	more than 50	8	2
7 Flixborough UK	1 6 74	factory	chemical reactor	explosion	cyclohexane	more than 40	40	less than 1	28
8 Ludwigshafen Germany	28 7 48	factory	rail tanker	explosion	demethyl ether	30	30	not known	207
9 Meldrim Georgia	28 6 59	rural	rail tanker	fire	LPG	36	18	short	23
10 New Berlin New York	25 7 62	urban	road tanker	fire	LPG	13	13	not known	10
11 Los Angeles California	18 1 43	rural	road tanker	fire	butane	8	8	not known	5
12 Beek Holland	7 11 75	refinery	reactor	explosion	propylene fraction	5.5	5.5	2	14
13 Longview Texas	25 2 71	factory	½" diameter pipeline	explosion	ethylene	'tonnes'	0.5	not known	4
14 Cleveland Ohio†	20 10 44	urban	bulk storage	fires and explosions	LNG	more than 2000	not known	short	128-136
15 Hearne Texas	14 5 72	rural	pipeline	explosion and fire	crude oil	1000	not known	270	1
16 Devers Texas	12 5 75	rural	pipeline	explosion	NGL	800	not known	7	4
17 Lake Charles Louisiana	8 8 67	refinery	storage sphere connection	explosion	isobutane	40	not known	not known	7
18 San Carlos Spain‡	11 7 78	holiday camp	road tanker	fire	propylene	22?	not known	short	more than 150
19 Natchitoches Louisiana	4 3 65	urban	pipeline	explosion	natural gas (methane)	not known	not known	17	21
20 Amsterdam Holland	10 8 71	factory	—	explosion	butadiene	not known	not known	more than 45	8
21 Antwerp Belgium	10 2 75	factory	compressor pipe	explosion	ethylene	not known	not known	4	6
22 Umm Said Qatar	3 4 77	refinery	storage tank	explosion and fires	NGL	not known	not known	not known	6
23 Petal City Mississippi	25 8 74	storage-plant	underground storage cavern	explosions	butane (LPG)	several thousands	not known	not known	0
24 Plaquemine Louisiana	3 5 63	factory	reactor	explosion	ethane-ethylene mixture	not known	not known	0.5	0

Mean mortality index (based on incidents when the amount released before ignition can be estimated ie Nos 1-13 in table)

$$= \frac{\text{total number of fatalities}}{\text{total amount lost before ignition}} = \frac{306}{530} \simeq 0.6$$

Mean mortality index (based on incidents when the total amount released can be estimated, ie Nos 1-12 & 14-18)

$$= \frac{\text{total no of fatalities}}{\text{total amount released}} = \frac{599}{5090} \simeq 0.1$$

Confined and unconfined explosions have not been differentiated here because we had insufficient information to do so.

This table is in two parts; items 1-13 are listed in order of magnitude of the quantity of material lost before ignition. This information is not given for items 14-24 which are therefore listed in order of magnitude of the total quantity of material lost.

†Because of conflicting official reports the exact number of fatalities is uncertain; we have identified their probable range.

‡Based on unofficial press reports

The table has a preponderance of incidents which involved road or rail tankers. This may reflect the fact that such incidents are probably subject to more rigorous and accurate reporting, particularly in the USA by the National Transportation Safety Board. They have been included to indicate the possible effects of the release of flammable materials although the circumstances of release are not of direct relevance to the work of this committee.

14 Incidents where large flammable clouds did not explode but instead burned with great intensity have been described by Marshall[7]. Such clouds may start to burn around their envelopes and 'lift off' to form fireballs*, which are dangerous in the extreme. When formed of hydrocarbons, they are luminous and radiate sufficient heat to cause fatal burns to bystanders, and to ignite wood and paper; for example, they have been known to set fire to the interior of office blocks. As fireballs rise they produce mushroom clouds, in the stalks of which are formed violent upward convection currents which suck up and ignite debris, and scatter burning brands over a wide area. Such an occurrence can clearly cause damage far beyond the normal safety distance of what are termed conventional fires. This hazard has not been adequately investigated. We recommend that there be further examination of such occurrences.

15 Table C also shows that cross-country pipelines carrying gas or liquefied gases at high pressures contain enough material to produce a significant vapour cloud in the case of fracture. A very extensive network of pipelines has been in operation in the USA for several decades and major releases have occurred. One of the most notable examples was in 1970, in Missouri, near Port Hudson, when a pipeline built in 1931 split open for approximately 2 metres along a welded joint; a considerable quantity (some 60 tonnes) of propane was released into open country and eventually ignited to give one of the largest known vapour cloud explosions; however no-one was killed. The total length of pipelines in use in the UK is considerably less than in the USA and is primarily for natural gas transmission and distribution. Most of the pipelines have been installed during the last fifteen years, although some of the petrol and oil lines were installed before or during the Second World War. While there have been failures on UK pipelines systems, none has led to a serious incident. One of our working groups currently engaged in investigating pipeline hazards has concluded that certain pipelines can pose a potential threat to people and property in the vicinity, and discussion on the specific requirements for the inclusion of pipelines in the proposed notification scheme is well advanced.

16 Another potential source of an explosive release of energy is a range of substances which are highly reactive or unstable when subjected to pressure, temperature, mechanical force or when mixed with other reactive material. Such substances include acetylene, ammonium nitrate, sodium chlorate, nitrocellulose compounds, peroxides, both organic and inorganic, and certain organic oxides such as ethylene oxide. Some of these have been produced industrially on a significant scale since the beginning of the century and continue to be necessary for many manufacturing processes, in some cases specifically on account of their highly reactive properties. Of these substances ammonium nitrate has been the cause of some disastrous explosions, although in more recent times such events have become a rare occurrance, due, we believe, to the introduction of stricter controls and the use of carefully considered methods of manufacture and storage. This continuing improvement in safety is characteristic of the matters we have considered and we refer to it later in this chapter in connection with the need for predictive techniques. An indication of the catastrophic result of the realisation of the potential hazard from such a material is demonstrated by three serious incidents which occurred with ammonium nitrate in the first half of this century and by two more recent incidents with ethylene oxide, as shown in Table D.

17 It may not be justifiable directly to compare the reactive substances mentioned above with conventional explosive as the former may be used in situations where they are rendered less reactive by e.g. dilution or the addition of an inhibitor. However it is our view that such a comparison is worthwhile and accordingly we have examined the analysis of 162 accidental explosions given in Reference[3] which was based upon References [8] and [9]. This information has been summarised here in Table E and plotted in a convenient form in Fig 3 to give an indication of the variation of the effects with increasing size of incident.

Table D Serious incidents involving reactive substance

Location	*Date*	*Area/site*	*Circumstances*	*Material involved*	*Tonnes*	*Number of fatalities*
Oppau Germany	21 9 21		Store exploded	Ammonium Nitrate	4000	561
Texas City Texas	16/18 4 47	Docks	Two ships blew up	Ammonium Nitrate	About 4000	550
Brest France	28 4 47	Docks	Ship blew up	Ammonium Nitrate	2500	21
Doe Run New York	17 5 62	Factory	Storage tank blew up, aerial explosions followed	Ethylene Oxide	35	1
Antwerp Belgium	4 6 64	Factory	Reflux vessel blew up, aerial explosion followed	Ethylene Oxide	1	4

Mean mortality index Ammonium Nitrate $= \frac{1132}{10500} = 0.1$

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* See Glossary

18 In Chapter **2** we discuss the notifiable level for materials being held under pressure in situations in which there is considerable potential for destruction. We have not been able to adduce any historical evidence for this particular threat, but it is our view that where there is a level of potential energy in such systems, which if released could cause widespread damage, a major hazard exists. Thus, as there is always the possibility, however remote, that the pressure vessel or associated plant could burst, it is necessary that these installations are not excluded from the scheme for notification and hazard survey.

19 We cannot leave this subject without some mention of the hazard of dust explosions although we have not as yet studied the problem in depth. Even when the experience in mines has been excluded dust explosions, infrequent though they may be in this country, have resulted in a number of fatalities. For example, in **1911** there were two incidents in which there were a total of forty five fatalities and in **1930** one incident in which eleven people were killed. Since

Table E Mortality indices for different classes of incident

Class range of class (lb)	*2 Total quantity exploded in class (tonnes)*	*3 Total number of incidents in class*	*4 Total deaths in class*	*5 Mean quantity of explosive per incident in class (tonnes)*	*6 Mortality index (fatalities per tonne)*
10 – 31.6 – 100 – 316	0.437	5†	17	0.086	38.90
316 – 1,000	5.76	17	41	0.338	7.12
1,000 – 3,160	26.86	28	140	0.95	5.21
3,160 – 10,000	90.29	33	119	2.73	1.31
10,000 – 31,600	281	29	504	9.68	1.79
31,600 – 100,000	546	23	694	23.77	1.27
100,000 – 316,000	821	10	82	82.1	0.10
316,000 – 1,000,000	2722	11	970	247	0.36
1,000,000 – 3,160,000 – 10,000,000	11796	6	3242	1966	0.275

Mean quantities of explosive per incident (column 5) are obtained by dividing the figure in column 2 by the figure in column 3, and mortality indices (column 6) are obtained by dividing the figure in column 4 by the figure in column 2. In Fig. 3 the figures in columns 5 and 6 are plotted against each other.

†The paucity of data in the lower range is, in our view, due to a considerable under-reporting of such incidents, and since the incidents causing fatalities are more likely to be reported, the mortality index in this range is most likely to be an over-estimate.

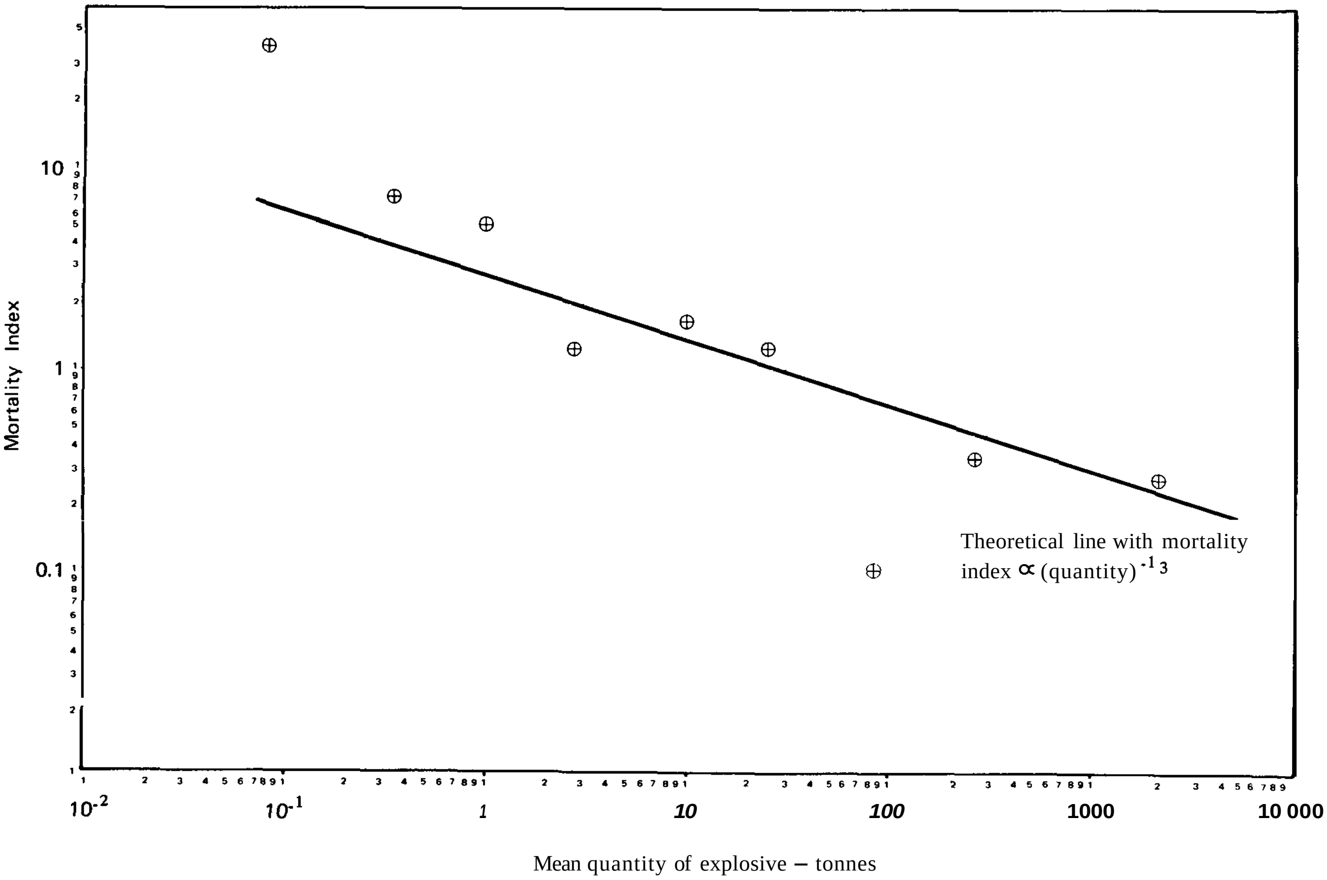

Fig 3 Variation of mortality index with size of incident for explosives (from table E)

1941 there have been a number of explosions in this country four of which resulted in a total of eighteen fatalities. Similar explosions have occurred overseas. For example, in 1919 at a starch/corn plant at Cedar Rapids, USA, forty three persons were killed, and in 1942, at a similar plant in Peking, Illinios, USA, forty two persons were killed. More recently in December 1977, thirty five people died in an explosion in West Wego and another seventeen died in an explosion in New Orleans.

Such dust explosions have usually, but not exclusively, taken place in premises processing grain into animal or human foodstuffs. The fatalities are usually the result of the collapse of buildings or structures, and to this extent the effects are localised. Materials which present a risk of a dust explosion are, however, to be found in a wide range of industries. It is generally considered that the potential hazard exists in the circumstances of the production of sugar, starch and flour where large quantities of flammable dusts are processed in tall or multi-storied structures of heavy construction.

Premises in which large quantities of aluminium or magnesium powder are processed are a matter of particular concern, as these materials have in the past produced explosions of exceptional severity. For example, two incidents in the USA, one in 1917, and the other in 1929, each resulted in eight fatalities. Thus, while the incidents involving dusts or powders usually have effects which could be termed local, and are therefore excluded from the notification scheme in the proposed regulations for the present, we propose to look at this topic more closely in the future.†

20 In paragraph 5 attention was drawn to the possible use of the mean mortality index of various substances as a measure of their degree of hazard. Because the data are limited and their deviation is wide, considerable caution must be exercised; the figures must be regarded as very approximate and should not be taken out of context. Variations in the circumstances of release give rise to a widely differing number of fatalities. For instance, in the case of chlorine, Table A shows that the highest value arose from the Zarnesti incident, where 60 people were killed by the release of 24 tonnes in a factory, while at Baton Rogue there were no fatalities from a 90-tonne release which by chance was carried by wind across the wide Mississippi[10]. Similarly, in the case of flammables, Table C shows that about 22 tonnes of propylene released by mischance near a holiday camp at San Carlos caused the death of over 150 persons by fire, whereas although 70 tonnes of propane released at Port Hudson caused an explosion, no-one was killed. Thus the mortality index from individual incidents in themselves varies too much to be very helpful, and even the mean from all the available reliable information is too dependent on individual incidents to be regarded as accurate. From the tables it can be seen that, tonne for tonne and at the levels of inventory* of interest to us and bearing in mind the accuracy of the data, conventional explosives, ammonium nitrate, flammable gases, chlorine (and if we can take note of the one recorded incident, phosgene) seem about equally hazardous, and ammonia appears to be much less dangerous. This seems about as far as the analysis should take us. The mortality indices should be used as no more than a framework of reference, and the relative levels for notification must remain a judgement that is reasonable and generally acceptable, based upon consideration of the properties, effects, use of and experience with the various materials. On this basis we accordingly see no reason to change the previously recommended levels particularly bearing in mind that these are intended to serve as a means for bringing the proposed notification controls into play.

21 In considering historical experience such as that outlined in the preceding paragraphs, one must take many other factors into account. We have already called attention to some of these in para 4. In addition, for example, there is no doubt that there is a bias which arises from failure to record publicly small incidents, especially where fatalities have not occurred. This is evidenced in Table E where there is a paucity of data for small explosions. From the point of view of the study of major hazards, which is concerned with large releases, this difficulty may not be very serious. There are serious problems also in drawing conclusions from history in times of rapid change. Mankind normally learns from disasters and this learning process makes it less likely that any given combination of disastrous circumstances will be repeated. The operation of this factor tends to make the lessons of history too pessimistic; mitigatory measures taken as a result of the study of experience, such as the provision of personal protection, more effective evacuation of the population at risk, better emergency services and general advances in medicine which reduce the risk of death from injury will all tend to reduce the number of fatalities. On the other hand the introduction of novel processes and the growth of scale of existing processes create new problems for which historical analysis may have few or inadequate answers.

22 As anticipated in para 2, having arrived at a list of notifiable activities we now consider some of the problems involved in evaluation of hazards at sites where these activities are being carried on. We recognised that realisation of the hazard depends on many considerations. Assessing the potential hazard in any specific situation requires the application of historical experience, suitably adjusted to take account of all relevant factors and circumstances for the site in question. It is sometimes possible to make direct use of information relating to a previous accident in assessing the possible consequences of a postulated release of energy or toxic or flammable material, but it is often necessary to consider different cir-

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† *See* Chapter 9

* *See* Glossary

cumstances of wind, weather, population distribution, and so on. Theoretical approaches designed to indicate the possible consequences of various types of accidents must take account of such factors as the properties of the material, the design and construction of the system, the nature of the process, the local population density, relevant climatic data and topography, and at the same time pay due regard to assumptions that are reasonable and are founded on reliable and realistic data. The fact that the potential of a particular hazard has not been realised may be significant but it does not mean that such an event could not or will not happen.

23 These problems require a theoretical approach which embodies imagination of high quality to foresee situations that are without direct historical precedent but are, nevertheless, not beyond the bounds of credibility. The models used to evaluate hazards are generally consistent with historical experience when applied to events which involve the energy within a high-pressure system, conventional explosives, heat radiation from catastrophic fires, or the formation of a toxic or flammable cloud of the same density as air. Difficulties arise when any vapours released are appreciably lighter or heavier than air because assumptions have to be made in the absence of reliable data and proven theories of cloud behaviour.

24 The spectrum of possible assumptions in hazard evaluation can lead to a range of predicted casualties often varying by orders of magnitude. A combination of assumptions such as the release of a large quantity of a hazardous substance in weather conditions which will allow it to affect a very densely populated area with no scope for escape from the hazard produces predictions of very large numbers of casualties. A combination of all the worst possible circumstances would however be very rare, and thus the possibility of a large-scale disaster is very remote. This is at least consistent with the limited historical experience. In contrast one can also use a combination of assumptions which have a combined probability which broadly accords with current expectations based on historical experience.

25 Additional factors may affect greatly the number of casualties. These could include on-site emergency action by the plant operators to protect themselves from the effects of the release, as well as arrangements to limit the inventory lost, and to alert other people at risk. A slow rate of release and certain wind and weather conditions coupled with a low population density downwind of the point of release particularly within the first kilometre or so could all reduce the number of casualties. Moreover if people in the path of the cloud become aware of it by sight or smell and if the concentration is not too high, they might be able to move away from the cloud or to protect themselves before they are overcome. As we discuss below, there is some evidence to support the formulation of a scaling law (i.e. a law which relates anticipated fatalities to the quantity of agent involved) for explosives, and it may be that with sufficient data such a law could be deduced for toxic releases. This is a field for further theoretical and experimental work.

26 In the case of vapour cloud or other explosions the lethal blast wave travels outwards at high speed, and people caught in its path have no time to protect themselves from any physical damage that may occur. Explosion waves attenuate fairly rapidly, and their decay can be estimated with some accuracy. Provided the size and nature of the explosion can be predicted then reference to historical data will allow explosives experts to make predictions of the type and scale of damage which will result. The rapidity with which explosions occur simplifies the problem of theoretical prediction by virtually eliminating the evacuation factor which plays a major role in the study of toxic releases. If it be assumed that the probability of fatal injury in an explosion is a function of the level of overpressure*, Hopkinson's Scaling Law would lead to the conclusion that number of fatalities (F) would for a given situation be a function of $(M^{1/3})^2$; ie $M^{2/3}$ where M is the mass of the explosive. If then, the mortality index I_M is defined as $\frac{E}{M}$, it would be expected that I_M would be a function of $M^{-1/3}$.

The above relationships are derived from the assumption that the distance at which a given effect is produced varies as the cube root of mass M, and the number of persons involved varies as the square of that distance. From the analysis of the effects of **162** accidental explosions mentioned previously, and plotted on Fig 3, it appears that the exponent from the best fit line is close to the theoretical value of $-1/3$. Prediction of the size of a vapour cloud explosion is difficult, but given that one can assume the rate of release of flammable vapour and the conditions of formation of the vapour cloud, then estimates of the type and scale of the consequences can again be made. In general terms, and put to practical use as we have attempted to do in Chapters **5** and **6,** we believe we have found that such predictive calculations of damage and casualties can agree reasonably well with the pattern obtained from actual incidents.

27 We may perhaps summarise our conclusions from this Chapter by saying that we believe that there is considerable value in the historical approach in that it provides quantitative information on actual occurrences and that the figures so derived, in spite of their many shortcomings, provide at least some bases for estimating the levels at which inventories should become notifiable. We believe also that techniques of prediction have an indispensable role to play both in allowing us to reach a greater understanding of the historical record and in enabling us to foresee situations for which historical evidence is lacking or insufficient. Such techniques, to be valid, however, must always lead to results in specific cases which accord with the generality of historical experience of major incidents.

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* See Glossary

2 Notifiable inventories and proposed regulations

This chapter seeks to justify the level of inventory of the specific substances contained in Schedule 1 of the proposed regulations and of situations in which there is the possibility of considerable potential for destruction due to materials being held under pressure. It explains how the committee has refined and developed its earlier thoughts in the context of the survey, assessment, and appraisal of various categories of installation.

28 In August 1977, the Health and Safety Commission announced the preparation of regulations which would require the notification, hazard survey and, in some cases, detailed assessment of existing and proposed premises and installations having,or likely to have prescribed quantities of hazardous substances or prescribed processes. The regulations would be made and enforced by the use of powers contained in the Health and Safety at Work etc Act 1974 - a matter which we return to in Chapter 3. The prescribed quantities for notification purposes would be based on the criteria set out in our first report at para 48. In June 1978 the Commission published a consultative document containing the proposed regulations and guidance notes on hazard surveys and we await with interest the comments from those consulted. In this chapter we seek to explain how the preliminary thoughts in our first report were refined and developed into recommendations to the Commission.

29 We had been criticised in comments on our first report for taking a pragmatic approach to the problem of deciding the level of inventory which would constitute a 'notifiable level'. Pragmatism means to us 'treating the facts of history in their connection with each other as cause and effect and with reference to their practical lessons'. There may have been alternatives to the pragmatic approach but we believe that they were unlikely to ease the problems of identifying potential major hazards.

30 The proposal which was subjected to the most severe criticism was the concept of 'chlorine equivalent'. Ironically, such criticism, in effect, supported the argument for the pragmatic approach and in consequence, we translated the basic criteria into a list of the more important substances and processes (see para 35). In doing so, we modified certain notifiable quantities but did not attempt precise matching because of known approximations indicated in the previous chapter. Indeed, 15 tonnes of flammable vapour is not directly equivalent to 5 tonnes of explosives. The former could produce a 'soft' explosion whereas the latter will produce a 'hard' explosion but in reality their potential to do harm is of a similar order of magnitude.

31 We took account of the numerous comments and representations made as a result of the publication of our first report. We were pleased to find that much common ground existed both outside and within government circles as to what should be notifiable and as to what the notifiable level should be. Indeed there was a remarkable measure of agreement between our new list and the list used by HSE and local planning authorities for the existing consultation arrangements decribed in Chapter 5 of our first report. The latter list was based on the experience and intuition of HM Factory Inspectorate and was first brought into use in 1972.

32 Our new list is not exhaustive: for example, there are numerous substances which are more toxic than chlorine but most of them are not kept, as far as we know, in sufficient quantities to justify our listing them. In deciding the notifiable levels for various toxic substances, we had to consider, for each substance, its general toxicity, its physical properties, and its vapour pressure, and to agree a quantity which in our judgement and in the experience of the Health and Safety Executive, is equivalent in its effect to 10 tonnes of chlorine. An entirely different class of toxic substances demanded attention, particularly after the escape of TCDD from Seveso in 1976 which is described in Chapter 1. In the case of flammable materials, we set different notifiable levels for gases. The different quantities arise from variations in behaviour on release. In the case of gases the full inventory could be immediately available for cloud formation whereas in the case of liquids, despite the 'champagne effect' which occurs on release of pressure, it is unlikely that all the inventory would be immediately available for cloud formation.

33 Where any substance is kept under pressure, there is always the possibility however remote, that the pressure vessel or systems will burst and scatter itself and its contents. In the case of a catastrophic failure

of a vessel under high presssure the energy is divided mainly between the kinetic energy of the fragments and the energy of the shock wave. The damage caused by the shock wave from a rupturing vessel can be estimated approximately by assuming that it is the same as that caused by detonation of such amount of TNT as will release the same energy. The procedure is practicable in view of the extensive literature of the effect of explosives on structures. Assuming that the contained substances are inert, the actual range of the effects of a catastrophic failure depends primarily on the size of the vessel and the pressure at the time of the failure. The factor suggested by the High Pressure Technology Association in their High Pressure Safety Code is 1 kg TNT = 4.5×10^6 J which is in pressure volume terms, approximately equivalent to $45\ m^3$ bars. Consequently it is possible to select with sufficient accuracy for our purposes, the vessel size and pressure levels which in their own right may be potentially very hazardous.

34 We well appreciate that theoretically even 1 tonne of any of the listed substances, if released in confined and crowded circumstances , could lead to a substantial number of fatalities, but suggest that such possibilities are best dealt with in accordance with current practice and by enforcement of current safety legislation. We would not want to see valuable and limited resources diverted from the examination and control of hazards which inherently pose an even higher level of threat to safety. We concluded that the scale of the quantities in our list is of the right order and that any future changes in the list would be by the way of refinement. Indeed, we believe the net to be fine enough to catch all major hazard installations.

35 At the request of HSC we modified the proposals in our first report and the revised list we subsequently presented is as follows:

INVENTORIES REQUIRING NOTIFICATION

Group 1 ***Toxic substances***

phosgene	2 tonnes
Chlorine	10 tonnes
Acrylonitrile	20 tonnes
Hydrogen cyanide	20 tonnes
Carbon disulphide	20 tonnes
Sulphur dioxide	20 tonnes
Bromine	40 tonnes
Ammonia	100 tonnes

Group 2 ***Substances of extreme toxicity***

Toxic liquids or gases likely to be lethal to man in quantities of less than one milligramme	100 grammes
Toxic solids likely to be lethal to man in quantities of less than one milligramme other than those which are and which will be maintained at ambient temperature and atmospheric pressure.	100 grammes

Group 3 ***Highly reactive substances***

Hydrogen	2 tonnes
Ethylene oxide	5 tonnes
Propylene oxide	5 tonnes
Organic peroxides	5 tonnes
Nitrocellulose compounds	50 tonnes
Ammonium nitrate	500 tonnes
Sodium chlorate	500 tonnes
Liquid oxygen	1000 tonnes

Group 4 ***Other substances and processes***

Flammable gases not specified in any other group.	15 tonnes
Flammable liquids above their boiling point (at 1 bar pressure) and under pressure greater than 1.34 bar including flammable gases dissolved under pressure but not mentioned in any other cateogory.	20 tonnes
Liquefied petroleum gases such as commercial propane and commercial butane and any mixture thereof.	30 tonnes
Liquefied flammable gases under refrigeration which have a boiling point below 0°C at 1 bar pressure and are not included in Groups 1-3.	50 tonnes
Flammable liquids of flash point less than 21°C not included in Groups 1-3.	10000 tonnes
Compound fertilisers	500 tonnes
Plastic foam	500 tonnes

36 We also recommended in our first report that notification should be required for installations with a large inventory of stored pressure energy, typically process operations at 100 bars or above using gas phase reaction. On reflection we considered that a pressure of 100 bars above atmospheric was too high and we subsequently suggested that notification should be required for any process using plant at a pressure greater than 50 bars when the product of the volume of the pressure system in cubic metres and the pressure in bars exceeds 10 000.

37 After further deliberations in the committee we recommend consistent with the arguments of para 33 above, that the proposed regulations should cover all pressure systems having a gas or vapour phase except for steam boilers for which we consider adequate controls already exist. When calculating the pressure energy for notification etc., the volume occupied by any liquid should be ignored.

38 We did not overlook the fact that the use of a list of this nature can give rise to some anomalies. In our suggested scheme we recommended that the quantity of a substance for which notification is required should be the total amount of materials that is stored and/or is in process within the boundaries of an installation. Thus, adjoining installations in separate ownership each having, say 9 tonnes of chlorine would not be notifiable. This omission was intentional: in our view there is not a strong case for the aggregation of hazardous substances if completely separate control is involved. Historical experience indicates that events leading to the simultaneous release of separate inventories are remote. This may not be so for connected vessels, but we believe that cases where there is connection between stored inventories under separate ownership/control will be rare.

39 Similar considerations apply to undetakings which have, under one control, a number of hazardous substances all in quantities below the notifiable level. Again the likelihood of an event which would lead to a simultaneous release of several toxic and/or flammable categories from separate vessels appears to be remote because of the separation distances normally adopted and the absence of direct pipe connections between the vessels. Although a combination of hazardous categories might be brought together in a process vessel, the total must be a fraction of that in store.

Notification regulations

40 We recommended that the proposed regulations should require a person, who at any one time keeps, manufactures, processes or uses a notifiable quantity of hazardous substance in any place, to supply information about the undertaking.

We suggested:

(1) name and address of person making the notification;

(2) address and postal code of the place to be notified, or ordnance survey grid reference;

(3) approximate area of the installation or place covered by the notification;

(4) a general description of the activities carried on e.g. oil refinery, water treatment works, fertiliser store, research station;

(5) for the notifiable substances or processes — a list of those which are kept or are expected to be kept in excess of the notifiable levels, and the estimated maximum quantities for each or generated by or contained in each such process.

41 The above information was, for the sake of simplicity, intentionally limited but it would be sufficient to enable a crude appreciation of the hazard potential to be made. The Health and Safety Executive will want to examine and analyse the information, and their analysis will give us a better indication of the range and scale of hazards which we have to consider.

42 We understand that the adoption of this notification scheme could lead to several thousand notifications, perhaps as many as five thousand. The majority of these will not require any special surveillance, and HSE examination of the notification will identify those which will continue to receive normal surveillance by virtue of the enforcement of the Health and Safety at Work etc Act 1974.

Hazard surveys

43 In our first report we recommended that following notification the operating organisation should carry out in selected cases a hazard survey. The objectives of this survey are:

(1) To provide information and data on the nature and scale of the hazards involved.

(2) To identify the more critical features of the hazardous undertaking and of the systems used to control the hazards.

(3) To cause the operating organisation to review the events which could lead to loss of containment of the most hazardous inventories and the consequences of such loss.

44 We envisage that the key information and conclusions will be distilled by the operating organisation and that the resulting report will be submitted to HSE. This will enable HSE to allocate its resources for surveillance more effectively. It will also give the Executive a better understanding of the undertaking and of its possible threat to public safety for purposes of advising local planning authorities about developments involving, affecting or affected by the undertaking. Furthermore, both the Executive and this committee would acquire a better appreciation of the type and number of installations which may require detailed assessment.

45 We originally envisaged that all notifiable installations, whether existing or proposed, would be the subject of a hazard survey. Because there are only a limited number of trained people available, in industry to carry out surveys and in HSE to appraise them, the Commission advised us that the proposed notification regulations should contain criteria which would identify 'priority sites' which would then be statutorily required to produce a hazard survey. The Commission invited us to consider how these criteria should be arrived at and we discussed various alternative methods. We understand that multiplication by a factor of 10 of the quantities now set out in our list (see para 35) appears likely to produce a not unmanageable number of sites in the first instance. We therefore suggested the use of this factor but stressed that we believe it should serve as no more than an interim first step based on practical considerations and should in no way represent a refined technique for selecting sites with the greatest hazard. The unsatisfactory feature of a factor of this scale is that it gives undue and spurious weight to inventory at the expense of other factors such as the nature of the threat that such inventories pose and the population at risk. We therefore urged the Commission that the regulations should be prepared in a form which would facilitate amendment of the criteria at appropriate intervals.

46 Although this limitation on hazard surveys originally arose from the scarcity of resources we see some advantage in working down from what are obviously the largest installations. We envisage that in due course it will be found appropriate to require hazard surveys for notifiable installations other than those which exceed the notification inventories by a factor of 10, but not necessarily for all notifiable installations.

47 The hazard survey should be carried out, bearing in mind the objectives listed in para 43. In the field of major hazards it is necessary to consider in particular relatively rare but potentially catastrophic events. The hazard survey should deal, therefore, with these hazards as well as with those which are considered more likely. In this context large inventories of hazardous material are particularly important.

48 The hazard survey should state the ways in which, under fault conditions, the hazardous material might escape from containment, the quantity and rate of release of the material, the effects which the escape might have, the probability of its occurring and the precautions taken to prevent it. Thus, for example the possiblility of the loss of the total inventory from a vessel must be considered, but, depending on the circumstances, it may be acceptable to state reasons why a large release may be disregarded. Such reasons might be factors relating to physical possibility such as lack of energy for dispersion of the material, or to measures such as **bunding** or to factors relating to probability of the release such as pressure vessel integrity.

49 The hazard survey should not be a once for all exercise and further surveys should be required. We have recommended that a further survey be carried out when the basis of the last survey is likely to become invalid because of changes in the substances or processes or inventories, the additional survey being completed before the changes are made; also in every case at an appropriate fixed interval. The draft regulations in the consultative document reflect these recommendations. The document also contains draft guidance on the preparation of hazard surveys.

Detailed assessment

50 We said in our first report (para 31) that in some cases the company's hazard survey might have to be followed by a more detailed assessment if HSE called for it, particularly at those installations appearing to present the highest risk or involving novel or rapidly changing technologies. The hazard survey should help to pinpoint these, as well as those features which are or will be most critical.

51 Our proposals for detailed assessment which have been incorporated into the consultative document, include amongst other features:

(1) Management systems and staffing arrangements by which any hazard is controlled.

(2) Safety systems and procedures for the control of any hazard.

(3) Qualifications, experience and training of staff concerned.

(4) Design and operating documentation.

(5) Design and operation of containment and pressure systems.

(6) Protection of personnel from the effects of loss of containment.

(7) Emergency plans.

(8) Reporting of and learning from incidents.

52 Detailed assessments are likely to be very costly both in terms of the expert resources that they require and the time that they take. It is not our wish, nor do we expect, that such assessments will be required indiscriminately or in large numbers. Although it is too early to be sure, we suspect that where a detailed assessment is required this will often be for just one or two aspects of the undertaking or of the particular installation. More might be required if it were decided that the premises should be controlled by inductive regulations or licensing, but we discuss that prospect in the next chapter.

3 Legal controls

Those installations which pose the greatest threat to safety have been identified, and consideration has been given to what additional controls may be required to evoke from those who operate such installations, their evidence that the process does not present an unacceptably high level of risk. The committee considers the possibility of further controls by regulation or 'licensing' and, at Appendix 1 sets out in detail an overt form of an outline scheme for 'licensing'. The committee proposes, however, to keep an open mind and to hold further discussions when the initial response to the proposed notification regulations has been evaluated.

53 In our first report, we mentioned various forms of additional legislative control which might be applied to a limited number of installations. Our overall concern is to ensure that whatever further legislative procedures are considered, they should be aimed at ensuring that the decision making processes, whether initially at the design stage, or during the course of production, or — in extreme cases — in the face of imminent disaster, are primarily influenced by considerations of safety. Whenever management or workers are presented with choices where a fundamental element in making a decision may be a safety consideration, it is our aim to ensure that they favour caution. To say this is not to overlook the excellent safety record of much of modern industry using new and often complex processes which is due to the fact that decisions are made with proper regard to safety. Nevertheless management and workers are obviously concerned with maintaining production, and may sometimes feel tempted under pressure to take a chance rather than to play it safe.

54 It would perhaps be foolish, however, to assume that all the things that go wrong are due to someone taking a chance in favour of production rather than of safety. Far more serious may be the wrong decisions which are made in ignorance. Proper decision making requires adequate competence to understand the implications of the various choices which lie open. In some cases, ignorance may be very subtle. A designer may, for instance, need to know what level of uncertainty is acceptable in going from a pilot stage to full-scale production. The manager of a plant faced with a reaction that is behaving in an unusual manner may well be in a situation that is entirely novel for him. He may be ignorant of the significance of the changes which are taking place.

55 It can be seen that any proposals for intervention which will infuence decision making in these circumstances, and which go beyond the general duties already laid upon management by the Health and Safety at Work etc Act 1974, are not easily envisaged, since they must take account not only of unwise decisions, but perhaps more often of decisions based on ignorance or incompetence. Ideally, then, any new regulations should provide a mechanism to ensure that the unwise think again, that the ignorant seek knowledge, and that the incompetent are never in control. But how can this be achieved? The answer to that question is and has been fundamental to all our deliberations.

56 Perhaps we should report here that in response to our first report, where we clearly envisaged that some form of further legal intervention additional to the HSW Act would emerge, it has been strongly put to us that no such further action is needed. The argument, so it seems, is that the best run companies have fine safety records and that this comes about by the ordinary commercial pressures on competent management. It is concluded that no company will willingly lay waste to its own assets, and that the financial penalties of destroying its plant* together with the actions for damages which would probably follow, are a greater deterrent to mismanagement than any legal intervention could be.

57 We would not contest that the best run companies achieve high standards of safety, but we believe this is because they have to a great degree systematised the procedures necessary to keep their plants both safe and productive. We believe that they have set themselves high standards of competence for their key staff, and at the same time they have instituted procedures which will make manifest to themselves that all is going well. They have learned that tests and checks which in 99 cases out of 100 prove to be unnecessary, will only be continued if the production system is such as to ensure that they must continue to be made. Above all, they have achieved

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***** ***See*** **Glossary**

what is perhaps best described as technical discipline in all that they do.

58 We believe that the best practices must be followed by all companies and that we have reached a state of technological development where it is not sufficient in areas of high risk for employers merely to demonstrate to themselves that all is well. They should now be required to demonstrate to the community as a whole that their plants are properly designed, well constructed and safely operated. Another argument put to us for taking no further action is that any attempt to intervene in the affairs of these hazardous plants will inevitably lead to a growth of a 'vast army' of civil servants to operate the scheme. We are only too conscious that such a development would be undesirable, but, as we said in our first report, it would also be impossible because of the comparative scarcity of manpower of the right skills. Indeed, this comparative shortage of skills is one of the factors which we have had to consider in framing our proposals.

59 Our first report has also evoked the suggestion that further legislative intervention in this field would result in levels of risk being imposed on workers and the public to which they had not agreed, and they would have had no say in determining how safe a particular plant, in which they work, or which is situated near to their homes, is to be made. We do not believe that any proposals for further intervention would in any way touch on the question of what level of risk is acceptable. We made it clear in our first report that this was an area where public debate was desirable, and we suggested that there might well be circumstances in which the level of risk judged to be acceptable was a political decision.

60 We do not think that improved safety in relation to the plants and processes with which we have been asked to deal, will emerge automatically from public debate, and a statutory framework for further intervention may be needed. But it should be clear from our first report that we consider that any further statutory provisions should be cast in the mould of the Robens proposals by evoking from those who operate hazardous plants further evidence that the process is safely controlled.

Control by regulations

61 There are two main avenues by which this objective may be achieved. We note that the Health and Safety at Work Act empowers the Secretary of State for Employment to make regulations (at the request of or in consultation with the Health and Safety Commission) on some thirty different subjects which are set out in Schedule 3 of the 1974 Act. The range of subjects is without doubt sufficient to provide for more specific legal control of all aspects of hazards. Such regulations would, it is to be expected, be supplemented by codes of practice approved by the Health and Safety Commission, and by notes of guidance prepared by the Health and Safety Executive. It should therefore be technically possible to produce regulations which would demand certain procedures to be undertaken by all plant operators. Not to comply with these requirements would naturally involve the enforcement procedures of the Health and Safety at Work etc Act 1974.

62 There are however certain drawbacks to the introduction of specific controls on these lines. The need to escape from a system of detailed rules enforced by an ever increasing army of government inspectors illuminates much of the Robens Report. The key to what the Robens Committee thought was needed is to be found at paragraph 28 of their report when they declared 'the primary responsibility for doing something about the present levels of occupational accidents and disease lies with those who create the risks and those who work with them.' The Health and Safety at Work Act 1974 has given clear legislative form to this concept in the early sections of the Act which impose general duties on employers and has extended it, as Robens intended, to embrace the safety of the public as well — a matter of vital concern to us. The proposed notification and hazard survey regulations follow this concept.

63 We think that the overall intention of any such regulations should be to require a company to identify the problems of its own situation, to decide the standards, systems and priorities which should apply, and, when required, to show the HSE the conclusions it has come to and the solutions to the problems which it proposes. Inductive regulations of this kind would have many attractions. In particular there is no need to limit in advance the range of installations to which they might be applied. The existing enforcement procedures by improvement and prohibition notices would automatically apply and they could be made to affect existing installations without difficulty. It might be possible for such regulations to require the operating organisation to show for example, that for each prescribed stage of the process, it had taken such steps as were necessary to ensure the safety of the process, and that procedures which were essential to safe operation were under control of personnel whose competence in terms of relevant experience and qualifications had been formally assessed. Regulations would have to follow (even if simplified) a recognised pattern and would not in themselves provide for individual variations to suit special circumstances. There could be a degree of flexibility where such regulations followed the pattern, for instance of boiler legislation and required a competent person to report on certain aspects of the plant, but it would not be possible to escape from the overall framework which characterises regulations of this type.

64 To sum up legislation in this field could be conceived in terms of the general duties imposed by the HSW Act, supplemented by regulations made under the Act to a pattern which is already familiar in relation to the risks in other areas of occupational health and safety, but we do have reservations as to its effectiveness with regard to potentially high hazard plants.

Control by licensing

65 The alternative is to proceed to a form of control which can be broadly described as licensing. We think that the issue of licences appears to engender a degree of public confidence in the control of hazards, because of the assumption that the installation will be thoroughly checked before the official body is prepared to issue a licence. Moreover, compliance is not assumed until the licence is issued, whereas in the case of regulations compliance is assumed until the contrary is established. Given the allocation of the same enforcement resources, at some stage it is necessary to consider which particular form of legal control is likely to be most effective.

66 Contemplation of a licensing scheme cannot take place in isolation and we have been conscious of the various problems which present themselves when the subject of further intervention is investigated. Indeed, we have been forced to ask ourselves some fundamental questions as to the purpose and effectiveness of legal constraints on technological developments and the success or otherwise which can be expected to attend the adoption of any further form of control. In our first report we expressed the view that this mechanism might well have to be evoked in the case of a small number of plants which presented the highest level of risk. Licensing, we pointed out, has been in a great variety of applications such as explosives, nuclear energy, petroleum spirit storage and manufacture of drugs. We also said that a licensing scheme might license plants or it might license the people in control of plants, or even a combination of both. Our main concern in the consideration of licensing schemes is that we should not weaken the responsibility of the employer for safety, since in the long run there can be no substitute for the employer's awareness of his own responsibilities, and we believe that proposals for further legislative intervention should enhance rather than detract from those responsibilities.

67 The many licensing schemes which we have examined differ from one another in the degree of intervention which they allow the enforcement authority to exercise. Where the risk is minimal or where a licence is no more than a revenue raising exercise there may be virtually no intervention at all. At the other end of the scale a licence can become the framework for controlling all operations connected with the activity in question. In the latter case the concept emerges that all activities carried on within the framework of the licence are deemed to be safe. This we believe tends to weaken individual responsibility and initiative. The very comprehensiveness of the concept demands that the framework should anticipate every eventuality, and it must therefore descend to detail, with all the complexities which the operation of such a scheme would demand.

68 We think that strongly interventionist licensing schemes have inbuilt drawbacks that make them unattractive, certainly in this stage of our thinking, in relation to the areas with which we have been concerned. They tend for instance, to transfer responsibility from the operator to the licensing authority to an extent which we regard as undesirable. Not only does this breach the Robens philosophy which we endorse, but it tends to make those charged with issuing licences somewhat conservative in their approach. This may affect not only process changes which are desirable for commercial reasons but also changes which might have long-term implications for improved safety. Anyone whose duty it is to issue a licence is not likely to be a willing innovator. Indeed, it is undesirable that he should be such and the very nature of his duties will tend to make him discourage innovation in others.

69 In the long term we believe this could be bad for the health and prosperity of the industries concerned and we would prefer the adoption of a system of control which would not slow down innovation and development, but would nevertheless ensure that development for commercial reasons would invariably attract a complementary development for safety reasons. This will not happen unless the control arrangements are flexible enough to encompass both developments.

70 Strongly interventionist schemes present other difficulties too. If detailed rules and procedures are to become essential ingredients of the grant of a licence, then those who draw up the rules and outline the procedure cannot be less skilled than those who are to be expected to abide by them or carry them out. If they are less skilled, then the resultant sense of frustration which will be evoked in industry will bring the whole operation into contempt.

71 Certainly at present we see no obvious surplus of such skilled manpower on the scale necessary to service schemes of this kind in the industries with which we are dealing. The public would be unlikely to approve of a large growth in the number of civil servants needed to carry out new tasks and they can in any case as we have already said only be drawn from industry itself. The result would be to denude industry of precisely those people most needed to guide it on the right lines.

72 It is these considerations which have made us decide not to advocate licensing schemes of the kind we have described. In all our proposals we have been concerned that those whose skill is vital not only to commercial prosperity but to the safety of major plants should remain in industry where their vital expertise can be fully exploited. We have said previously that the crucial factor in all our considerations is the need to ensure that proper regard to safety is shown at all levels of decision-making across the whole range from drawing board to actual production. Safety must be involved in all the strategies to be employed in research, design, construction, maintenance and operation. Indeed any legislative intervention should seek to influence the very ethos of the industry it purports to control.

73 Such thoughts take us back to the main theme of our first report and the proposals for surveys which we have expanded in Chapter **2.** We are dealing with a wide spectrum of hazards which fall within the broad categories we have set down. At one end are the large number of companies who will have to comply with our notification scheme. Of these there will be a smaller number who will have to submit hazard surveys to the enforcing authority. There will then be an even smaller number of installations which we described in our first report as the true 'major hazards'. We should be in a position to consider whether more specific control measures will be needed for these potentially high hazard plants when we see how the proposed regulations are working.

74 We do not think that plant of the highest hazard should be regulated in a way which is radically different from that appropriate for plants of lower hazard. We think that the mechanism for ensuring safety should not differ in kind but only in the degree of particularization and formality which should apply to the various levels of hazard.

75 If a further degree of regulation is ultimately proved to be necessary for these plants, we think that the concept of the employer having to demonstrate to the enforcing authority the steps taken to ensure the safety of the operation or process engaged in, may have notable advantages. In the first place it would keep responsibility within the industry, since employers would have to show that they continued to operate the plant safely according to their own arrangements. We believe that as a result safety would become interwoven with all decision about the management of the plant.

76 Secondly, responsibility of this kind would be 'dynamic' since (as in the case of the general duties under the Health and Safety at Work Act itself) the employer's responsibility would be open-ended, and he would have to update his safety procedures to match the developments in the process. It would be no defence to say that the rules had been complied with since it would be the employer's duty to make sure that the rules which he had made remained relevant and adequate to meet the hazards involved.

77 Nevertheless, at this stage we strongly believe that whatever is proposed for further intervention should follow the same pattern that we have set for all other plants. Although we might wish to propose a greater degree of particularization and documentation, it would not depart from the principles which we have invoked in our other proposals which may be described in short as 'supervised self-regulation'.

78 It would be quite wrong to suppose this would be a 'soft option' as regards those plants of the highest hazard. In order to dispel any suggestion to that effect, Appendix 1 is an outline of the type of scheme we have in mind which has taken up a great deal of the efforts of one of our sub-groups to prepare. It should be immediately obvious from this Appendix that a scheme on these lines would require a high level of discipline and detailed control, but the discipline would be generated by the companies concerned and the control exercised by their managements and not imposed from outside. We have prepared this Appendix in the form of an outline scheme for licensing but it should be clearly borne in mind that in this context 'licence' might be interpreted as 'approval' or 'authorisation' or a 'certificate to proceed'. Some document would clearly have to be issued to an employer which would give him the right to go ahead but we believe this should be of the simplest form perhaps no more than a statement of 'no objection', since the supporting documentation would have to be provided by the employer along the lines that we suggest in the Appendix and not by the enforcing authority.

79 Proposals to adopt some form of more stringent arrangement for plants of the highest hazard might raise many difficult points of detail. It would be necessary, for instance, to consider how the arrangements should be made to apply and what legal problems would be involved. For example would all current regulations still apply? On the face of it we see no reason why controls such as a Fire Certificate (Special Premises) Regulations **1976** should not co-exist with a licensing scheme along the lines we envisage. We would have to consider whether such proposals should apply to existing as well as new plants. Above all, it would be necessary to generate criteria for deciding what level of hazard should attract special consideration beyond that which we have already proposed. We have not pursued these matters in the report as they are subjects for the future.

4 The relationship of planning to major hazards

The committee holds firmly to the view that the location of hazardous development should always be a matter for planning authorities. Planning controls do not however apply to some variations in industrial processes which may introduce or increase the degree of hazard at existing installations. In this chapter the committee investigates the way in which the planning system can be applied to the siting of new notifiable undertakings, to the introduction or intensification of notifiable acitivites at existing installations and to the control of development in the areas surrounding notifiable installations. It is recognised that the implications of restrictive planning controls may involve local authorities in having to meet claims for compensation, and the proposal is made that the Secretary of State for the Environment should review the extent of his powers to make compensation payments in certain circumstances. Finally in this chapter the practical issues involved in consideration of siting problems are set out.

80 In our first report we reviewed in general terms the application of the planning system to the siting of new notifiable undertakings: to the introduction or intensification of notifiable activities at existing installations, and to the control of development in the areas surrounding notifiable installations. We stressed then that the siting of developments should remain a matter for planning authorities to determine, since the safety implications, however important, could not be divorced from other planning considerations. This view was received with mixed reactions: some respondents felt that because local planning authorities were not necessarily competent to judge technical safety issues, all decisions about potentially hazardous developments should be taken by central government. However, this appears to us to give insufficient recognition to the fact that local authorities are well placed to take proper account of the full range of local factors, including safety issues, which are relevant to a planning decision.

81 We emphasized in our first report that absolute safety was impossible to achieve and that some weighing up of advantage and benefit against risk was inevitable. There are occasions where the advantage and benefit of allowing a hazardous development to be introduced into a particular location are sufficient to override the risk. Developments involving the initial introduction of a potential hazard or a significant increase in existing potential hazard are frequently viewed by the local community as a threat to their interests - which of course include their safety. They naturally expect their locally elected representatives to look after those interests. Even when planning applications are called in for decision by the Secretary of State, the planning procedures ensure that the views of the local planning authority are still taken into account. Thus the planning system does give members of the local community the opportunity to make their views known, irrespective of whether the decision is taken by the Secretary of State or at local level.

Scope of planning control

82 Planning control will only apply to the introduction of, or increase in the quantity of hazardous substances, if the construction or alteration of buildings and/or plant or a material change in the use of land are involved at the same time. We still hold firmly to the view that the location of hazardous development should always be a planning matter, but that the subsequent containment and control of a hazard, once there, is more appropriately and effectively dealt with under health and safety at work legislation. Planning conditions are not well suited to controlling day to day management and the detailed operation of activities. Planning conditions should be related to the proposed development itself, reasonable in themselves, and enforceable and no attempt should be made to impose conditions which are rightly the concern of HSE.

The planning system

83 Planning legislation provides that permission should be obtained for the 'development' of land. 'Development' is defined in the Town and Country

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† The term 'notifiable' throughout this chapter relates to the notification to the **HSE** of certain types of installations having significant quantities of hazardous substances under the proposed Hazardous Installations (Notification and Survey) Regulations 1978[2] recommended by the ACMH in the first report (1976).

Planning Act 1971[†] as 'the carrying out of building, engineering, mining or other operations, in, on, over or under land or the making of any material change in the use of land'[‡].

84 This definition of development is so wide that a vast range of activities would require express planning permission but for the grant of general permissions contained in successive General Development Orders (currently the Town and Country Planning General Development Order, 1977): these general permissions allow limited additions, extensions or replacements to be made to existing developments. Certain changes in use are permitted by the Town and Country Planning (Use Classes) Order, 1972. Some of these permitted developments and certain changes in use might involve the introduction or intensification of hazards which could be very significant in terms of the safety of the community. We recognise that a planning system cannot be all-embracing and that some limitations must be introduced if planning controls are to be kept to a practicable level; but we believe that the initial introduction of hazards should always be subject to some form of control - but not necessarily planning control.

85 The way in which the planning system can be used for the control of hazards varies with the circumstances and type of development, and it is necessary to consider three separate situations:

1 the introduction of potential hazard as part of the development of 'green field' sites;

2 the first introduction of potential hazard to existing installations;

3 the intensification of hazard at existing installations.

We also have to consider the problems arising from proposed and existing uses of land in the vicinity of hazardous undertakings.

86 In all these situations it is important that any safety implications are recognised by the local authority at an early stage and that technical guidance as appropriate is available. Where major developments are concerned, the prospective developer normally holds informal discussions with the local planning authority and HSE before submitting a formal application for planning permission. Such discussions provide an opportunity for consideration of the safety implications from the outset. However, several of the responses to our first report mentioned difficulties encountered by planning authorities in identifying applications that could involve or be affected by hazardous activities. The statutory notification scheme referred to in Chapter 2 will provide a means of reducing this problem.

87 Planning authorities themselves can help to reduce the possibility of notifiable hazards being inadvertently overlooked by the adoption of the question about hazardous activities set out in the model forms of application for planning permission. All that need be provided at the outline stage is a brief description of the development and a plan outlining the site, but the planning authority can, if they consider it necessary, require further information about the development beyond that set out in the application form. We consider that it would also be useful in this context, and render the statutory notification scheme even more effective, if developers were required to inform the local (planning) authority that a notification had been sent to the HSE and we recommend this accordingly.

Initial introduction of hazards to 'green field' sites

88 Provided the hazard implications are fully recognised, following implementation of the recommendation in paragraph 87, the introduction of hazards as part of the initial development of a 'green field' site will be adequately controlled, because the developer requires planning permission either for the material change of use or for the construction work involved. Permission for some developments is sought on a two stage basis - 'outline' first and 'detail' later. An outline permission, once granted, is in all senses a planning permission. The only matters not dealt with (termed 'reserved matters') might include those relating to siting, design, external appearance of the buildings, landscaping of the site, and the means of access thereto. All or most of these might not have been supplied with the initial application, but would be submitted for approval subsequently. In considering an application for approval of details, the planning authority can only deal with reserved matters; they cannot impose any new restriction on the development other than that relating to the reserved matters. It is therefore essential that any restrictions or conditions which they wish to attach to the use of the land should be imposed when the outline permission is granted. The combined effects of the steps discussed in paragraphs 86 and 87 for providing better information to local authorities should in due course provide a means of ensuring that the introduction of hazards to new developments or to major redevelopments will from the outset be recognised and considered by the planning authority. However in furtherance of this aim, we also recommend that local planning authorities should impose a standard condition prohibiting without specific consent the introduction of notifiable hazards at a later date on all planning permissions of an industrial nature.

[†] **In this chapter all references are to the Acts and Statutory Instruments which are applicable in England and Wales. The relevant Scottish Acts and Statutory Instruments, while separate, are for practical purposes identical and the views expressed by us apply of course to Scotland as to England and Wales.**

[‡] **Chapter 1 mentions that the committee is considering to what extent pipelines are to be subject to the proposed Hazardous Installations (Notification and Survey) Regulations. It should be noted that except for local pipelines (those under 10 miles in length) there are separate planning procedural arrangements for the processing of pipeline proposals and these differ according to the nature of the particular development.**

Initial introduction of hazards to existing installations

89 During the past forty years and with increasing frequency, significant hazards have been introduced into existing installations particularly as a consequence of the pressure to improve efficiency and to take advantage of advancing technology. Many of these installations were constructed before planning controls existed. We have already noted that the introduction of a hazard unaccompanied by development does not require planning permission, although in some cases where the Explosives Act 1875 or the Petroleum (Consolidation) Act 1928 and its Orders apply, a licence will be required. Even in cases where additional plant or building operations are involved, the occupier might be able to avail himself of one or more of the general permissions referred to in paragraph 84.

90 Thus, in practice, planning permission is needed when it is proposed to construct additional plant or buildings beyond the permitted limits of the General Development Order or when planning conditions requiring further applications to be made have already been imposed in the past - which will not often be the case. Authorities when granting permission for industry, warehousing or storage, have not always anticipated the possibility that a hazardous activity may one day be introduced there. Comments on our first report indicated that planning authorities were concerned at the lack of planning control in this area.

91 We are of the opinion that the introduction of a notifiable hazard at an existing installation, or a change of use, should be capable of control so as to provide the local community with an opportunity of deciding whether they are prepared to accept the introduction of that hazard. We have therefore reviewed the appropriate parts of the present system of development control with a view to identifying ways in which this could be achieved.

92 In theory it might appear that extending the definition of development in Section 22 of the Town and Country Planning Act 1971, quoted in paragraph 83, so as to include the initial introduction of a notifiable activity, and thereby making planning permission a prior requirement would provide a way. But this radical approach, although not beyond the realms of possibility in the longer term, will not provide a ready answer now. We are advised that there are considerable practical difficulties about securing amendment to the Act because the definition of development is in very broad terms and has been the subject of many judicial decisions and it may be difficult, if not impossible, to confine amendment of the definition to matters which are the concern of this committee. We have therefore examined alternative measures which may be more easily attainable.

93 One of the alternatives, put forward by some respondents to our first report, would be the creation of a new use class in the Use Classes Order. However such an addition would not provide effective control because the purpose of the Use Classes Order is to reduce the need to make planning applications by permitting certain changes in use without specific permission. The intention of these respondents would, in fact, be better achieved by the express omission of 'notifiable activities' from the Use Classes Order altogether. This would enable local planning authorites to require applications to be submitted in respect of the introduction of notifiable activities at existing installations.

94 We have also considered the extent of permitted development available to operators of existing industrial installations under Article 3 of the Town and Country Planning General Development Order 1977 especially through Class VIII of Schedule I which covers development for industrial purposes. Article 3 provides that the permission granted by the Order in respect of any class of development shall be defined by any limitation and be subject to any condition imposed in Schedule I in relation to that class. We therefore suggest that an appropriate limitation be inserted into Class VIII which would have the effect of excluding additions or replacements of plant or machinery or structure or erections of the nature of plant and machinery, or the extension or alteration of buildings, intended to be used for the purposes of a notifiable installation.

95 Another and alternative approach to these amendments to the Town and Country Planning subordinate legislation would be the institution of some form of additional control, entirely separate from planning legislation, to deal with the introduction of hazards at existing undertakings. For example, analogous controls are those exercised separately from planning legislation, e.g. licensing of explosives stores, liquor licensing and betting licences (licences are granted by the magistrates courts while planning permission for the buildings or change of use is given by the local planning authority). A control separate from planning legislation would be preferable to no control at all, but it appears to us to be a far less satisfactory solution since it might result in decisions being made without due regard to relevant land use planning considerations.

96 Of the courses mentioned in paragraphs 92 to 95 an alteration to the definition of development in the 1971 Act seems the most effective way, if it can be done. The suggested amendments to the Use Classes Order and the General Development Order discussed in paragraphs 93 and 94, however, would in practice provide a reasonable measure of additional control particularly after the notification regulations come into force. They would also be more easily implemented. We recommend that these changes should be made without prejudice to consideration of the proposal to amend Section 22 when such an opportunity occurs.

97 The effectiveness of any legislation ultimately

depends on its enforceability. It is not an offence to carry out development or make a material change of use without first obtaining planning permission, but an offence arises when an enforcement notice takes effect. The local planning authority have complete discretion to decide whether or not it is expedient to serve an enforcement notice. Thus in the final analysis the efffective enforcement and application of planning controls depends upon fairly easily detectable and outwardly visible breaches of control coming to the attention of the authority. This remains a problem as far as the local authority is concerned but the HSE hold and exercise a right of entry and can draw appropriate matters to the attention of the local planning authority. The results which we desire may be obtainable by other means including those powers operated by the HSE Inspectorates. As far as planning control itself is concerned, this state of affairs, in our view, reinforces the argument for making the recommendation, in paragraph 88, that planning authorities should consider the imposition of the recommended standard condition when granting planning permission for any type of industrial development, to prohibit any subsequent introduction of a notifiable activity.

Intensification of hazard at existing installations

98 The most common forms of hazard intensification involve increases in the quantity of hazardous substances stored or the introduction of a substance which is more hazardous than its predecessor. Some changes may increase the threat to the local community. Some changes will have no planning significance; others will require planning permission because of associated development. However in all situations the local community, through the decisions of its planning committee, should have had the opportunity of expressing a view on the principle of introducing, into its midst, a potentially hazardous activity. Provided therefore that the local authority has previously been given this opportunity, intensification of hazard, being a complex and technical matter on which the planning committee will lack expertise, could be more appropriately dealt with under health and safety legislation unless, of course, development is involved.

99 However it is essential that planning authorities are made aware of significant proposed hazard intensification to enable them to have regard to the new situation when proposals for development in the vicinity are under consideration. Accordingly we recommend that HSE should inform planning authorities of any intensification of existing hazards notified to them under the proposed regulations.

Proposed development in the vicinity of notifiable installations

100 Planning authorities will have to consider at the outset the need to restrict incompatible new development from encroaching too near to a notifiable installation and in this regard there are several precautionary steps open to an authority.

101 Firstly, it can enter into agreements with the owner or occupier of the land for the purpose of restricting the use of the land (Section 52 of the 1971 Act). Alternatively, the planning authority might be able to agree with the operator of the notifiable installation, or the prospective operator of a proposed notifiable installation not yet in operation (but they have no power to compel him to do so) that he should ensure control over the use of land surrounding his installation. Or again, the planning authority might be given an indemnity by the operator or prospective operator of the notifiable installation in the event of the local authority having to pay compensation or meet the cost of a purchase notice served on the planning authority under Section 180 of the 1971 Act as a result of any planning decision taken on safety grounds to the benefit of the installation. Whether or not the operator or prospective operator of the notifiable installation would see such an arrangement and the corresponding commitments as fair and satisfactory to him will clearly depend on the circumstances of the case.

102 One of the main objectives of planning controls is to ensure that incompatible land uses are kept apart. In our view any proposed development or redevelopment involving a significant increase in the population in the vicinity of a hazardous undertaking, must be carefully examined to see whether the nature and situation of the development renders it incompatible with its surroundings. We recognise that it is not easy to define "in the vicinity" as a precise distance because the areas potentially at risk from an installation vary considerably from case to case. Greater precision may be possible as knowledge of the consequences of loss of containment is built up through experience and research. In the meantime HSE may suggest precise distances in order to set up working arrangements with planning authorities, but the arrangements should be sufficiently flexible to enable planning authorities to seek advice whenever they feel in doubt.

Existing development in the vicinity of notifiable installations

103 The gradual build up of information about the location and nature of undertakings having notifiable hazards may well bring about reviews by some planning authorities of existing land uses which involve or are affected by such undertakings. Where changes in the undertakings are planned there may be an opportunity to reduce the hazard and the chances of its potential being realized. Planned redevelopments in the vicinity of the undertakings may present an opportunity to reduce the number of people at risk. Where there is no early prospect of redevelopment, the local planning authority is faced with the decision of either accepting the risk or making a discontinuance or a modification order.

Revocation, discontinuance and modification orders and compensation

104 Straightforward refusal of planning permission, because, for example, a proposed site for a new installation is too near to existing or other proposed developments with which it would be incompatible or for any other good reason, does not give rise to any claim for compensation. Likewise if in granting permission an authority imposes conditions, including conditions restricting the further extension of the installation which might otherwise be permitted under the GDO, or prevents changes in use which might otherwise be permitted under the Use Classes Order, again such conditions would not render the local planning authority liable to claims for compensation. But there is a right of appeal to the Secretary of State against conditions unacceptable to the applicant.

105 In some instances a refusal or conditional grant of planning permission might lead to a purchase notice being served on the planning authority by the prospective developer (Section 180 of the 1971 Act). This only arises in a very limited set of circumstances, namely where it can be shown that the land has become incapable of reasonably beneficial use. If the planning authority accept the purchase notice, or it is confirmed by the Secretary of State, the local authority will be obliged to buy the land. Again where following a direction under Article 4 of the GDO a planning application must be submitted in respect of development which would otherwise be permitted under the GDO (see paragraph 84 above), Section 165 of the 1971 Act provides for compensation to be paid on the extra cost incurred or on any loss in value or damage sustained which is directly attributable to the refusal of planning permission or conditions attached.

106 The grant of planning permission does not represent the last opportunity for a local planning authority to influence a development in its area. Following the grant of a planning permission, but before it has been implemented, the permission can be revoked for example as a result of a change of planning policies for an area or because of new information coming to light which was not available when permission was granted. Furthermore, in exceptional circumstances, the local planning authority may even consider it expedient to bring an existing use to an end or to secure some measure of control over it. Compensation is payable and the sums of money involved depend on the nature and scale of the development being restricted but they could be very substantial indeed.

107 We note in all these circumstances it is the local planning authority alone which is liable as a consequence of those decisions taken in the interest of public safety unless they have made other agreements with developers (see paragraph 101 above). We note also that the Secretary of State has, in certain situations only, discretion to make contributions to local authorities if compensation is payable. We consider that the circumstances in which such payments might be made should be identified; we believe that this might reveal a need to extend the discretionary powers given to the Secretary of State. We accordingly recommend that the Secretary of State should review the extent of his discretionary powers to make payments in certain circumstances.

Application of siting policies by planning authorities

108 Consideration of siting problems is far from an exact science; it is one where the best information available must be examined and a judgement formed. It always has to take account of the situation as it exists. We learn that HSE is frequently asked to comment on development proposals relating to an installation set up in a far from ideal location at a time when consultation arrangements did not exist. In these circumstances we are told that the HSE has to bear in mind to what extent the development proposals represent an improvement on the existing situation. The HSE is also frequently asked to comment on proposals to develop or to redevelop land in the neighbourhood of an existing hazardous undertaking where there may already be other land users which are closer and possibly incompatible. In these cases HSE tell us that it takes the view, which we fully endorse, that the existence of intervening development should not in any way affect the advice that it gives about the possible effects of that activity on proposed develoments which may appear to be less at risk than the existing ones. In other words the existing situation should never be regarded as providing grounds for failing to draw attention to the implications for development at a greater distance.

109 These fundamental difficulties may make it inevitable that any future siting policy can be expressed only in very general terms since so much depends upon the appraisal of the individual circumstances of each case. The overall objective should always be to reduce the number of people at risk, and in the case of people who unavoidably remain at risk, to reduce the likelihood and the extent of harm if loss of control or of containment occurs. As knowledge of the behaviour of hazardous activities grows and appraisal techniques are improved the expertise of HSE in this field will develop considerably.

5 Explosion hazards

In recent years increasing effort and resources have been devoted to searching for a better understanding of the formation, behaviour and explosion of vapour clouds. The committee reviews the evidence that they have been able to obtain and discusses the sources, characteristics and factors that affect the magnitude and destructive effect of vapour cloud explosions.

110 It was a major explosion at Flixborough which led to the setting up of our committee and it was to be expected that following our first report we should pursue this area of our enquiries in detail. One of our working groups, in particular, has studied the subject of unconfined vapour cloud explosions* in some depth, and has been greatly helped by close consultation with the Chemical Industries Association's Chemical Industry Safety and Health Council at several joint meetings, and by the willing cooperation of many other individuals and organisations. We recognise that for decades the hazards which arise from conventional explosives such as gunpowder, nitroglycerine, TNT, RDX, and the like, have been well understood. Consequently the manufacture and use of such materials have been strictly controlled by specific and detailed safety measures such as compartmentalisation of the individual stages of the process, mounding and barricading, minimising of inventories and severe limitation (or even elimination) of manning. In contrast the possibility that a large cloud of flammable vapour mixed with air could give rise to an explosion in the open was treated with considerable scepticism, until comparitively recent times. Today there is indisputable evidence that large clouds of flammable vapours mixed with air can give rise to effects which in some though not all respects are difficult to distinguish from the detonations* of high explosives.

111 In recent years increasing effort and resources have been devoted to searching for a better understanding of the formation, behaviour and explosion of vapour clouds and we have reviewed the evidence that we have been able to obtain. Our work has been assisted by a recent study of the problem by Marshall[11] but is must be said at the outset that the information is far from complete or conclusive, and will inevitably remain so for many years to come. Thus the conclusions and recommendations in this chapter are interim in nature.

112 In Chapter 1 we referred to Strehlow's[5] survey of vapour cloud incidents. In 1972, he listed no fewer than 108 incidents in the previous forty two years mainly in the USA but also in Germany and Holland: none had occurred in the UK. The alarming increase in the frequency of such incidents from four in one decade to a rate of over sixty per decade (largely due to the increase in the number of large plants) is illustrated in Fig 2. Since 1972 there have been disastrous vapour cloud explosions at Flixborough and at Beek in Holland. Detailed investigations were made in both cases and reports[12,13] have been published.

113 The clouds which have been generated in recent history have been by any standards very large indeed. That which formed at Flixborough was probably about 0.5×10^6 cu metres in volume. (By comparison St Paul's cathedral has an internal volume of about 0.2×10^6 cu metres.) In view of these magnitudes, it is hardly surprising to find that the destruction caused at Flixborough for example has been estimated[12] as comparable with that due to amounts of TNT in the range of 10 to 45 tonnes. These figures have been refined in more recent work[14] to 16± 2 tonnes.

Sources of unconfined vapour explosions

114 Flammable liquids stored in bulk at atmospheric temperature and pressure may, if containment is breached, give rise to fire, but are most unlikely to produce a large cloud of flammable vapour which on ignition would explode. Liquefied gases stored under refrigeration at atmospheric pressure have to be given much more serious consideration. If on loss of primary containment the cold liquid finds secondary containment in such a way that the rate of heat transmission from the surroundings is low, it is again unlikely that a large cloud of flammable vapour would be produced, and fire is the most likely danger. However if the cold liquid were to be released over a large area of land or a large expanse of relatively warm water it might, depending on the temperature difference, the properties of the cold liquid and the detailed nature of the surroundings, evaporate at such a rate that a large and dangerous cloud would form. The most serious danger of all, however, would arise from loss of containment of a flammable gas, or of a

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***See** Glossary

flammable vapour when stored under pressure in equilibrium with its liquid phase.

The magnitude of the explosion hazard

115 The estimation of the magnitude of a vapour cloud explosion and of its destructive effect at any particular location, depends upon a number of factors which are listed below:

(a) Inventory of flammable material
(b) Fraction likely to flash off to form vapour cloud
(c) Composition of ensuing cloud
(d) Dimensions of the cloud
(e) Extent of cloud drift
(f) Likelihood that cloud will give rise to explosion
(g) TNT equivalence* or other measure of blast effect
(h) Relationship of overpressure to distance from epicentre*
(i) Duration* of overpressure

Inventory of flammable material

116 In the case of a storage tank this may be obvious enough. A plant may, however, consist of semi-independent units, and a loss of containment from one may or may not lead to significant escape from others. It may be possible to provide isolating valve systems which must be designed to 'fail-safe'. In any given plant, therefore, it will be necessary to estimate the inventory in total, or for each unit or group of units which can in an emergency be isolated very rapidly and preferably by remote or automatic control.

Fraction likely to flash off to form vapour cloud

117 If the flammable material is a gas the answer may be obvious, but if it is in the form of a liquid in equilibrium with its vapour at elevated pressure it is far from obvious. The location of the opening will determine whether boiling liquid, or vapour with or without entrained liquid or froth are ejected. As soon as the material escapes to atmosphere the liquid will 'flash off' a quantity of vapour - 'the theoretical flash' - which can be calculated from such factors as the original pressure and the specific and latent heat of the material. It has been argued that the whole of the release should be assumed to be transformed into a cloud of vapour and, indeed, in one Japanese experiment's in which ethylene was deliberately released through a **25** cm bursting disc at the top of a vessel containing 718 kg at a pressure of 8.3 atm, **620** kg was ejected in the form of a **gaseous/liquid** mixture in **6.5** seconds. To avoid an explosion it was deliberately ignited at exit, so causing a huge expanse of flames about **100** m in length and a 'fireball' some 40 m in diameter.

118 The amount of the ejected liquid which will be entrained with the vapour and the size of the entrained droplets will depend on many other factors such as the physical properties of the liquid and the geometry of the opening. A small orifice would give fine droplets, but to produce a large vapour cloud a large opening is needed, and this would encourage the production of relatively large drops which might not remain in the cloud but could soon fall to the ground. It seems rational to suppose, however, that had ignition not been engineered, in the Japanese experiment quoted above, less than the **620** kg released might have mixed in the form of vapour with air to form a mixture in the explosive range.

Unless information is availabe which enables a more precise calculation to be made for a particular case, we suggest that the amount of spray in the cloud which takes part in the explosion can for most purposes be assumed to be equal to the theoretical flash; in other words, that the total effective mass of vapour in a cloud be estimated at twice the theoretical flash provided this does not exceed the total inventory.

Composition of ensuing cloud

119 It is impossible, in general terms, to predict the composition of the resulting cloud. It will depend on the position and totally unpredictable geometry of the opening which allows the material to escape, the condition, pressure and density of the material released, the atmospheric conditions at the time, and the influence of surrounding plant and buildings. The cloud will almost certainly be heterogeneous in composition with a centre core very rich in vapour, an outer layer lean in vapour and an intermediate zone where the composition lies within the explosive range. Because of poor mixing there will inevitably be localised pockets of varying composition throughout each of the zones. Initial ignition will produce turbulence that may make the cloud more homogeneous and more dangerous; temperature rises will widen the explosive range.

Dimensions of the cloud

120 Although any estimates of size and shape of the cloud are necessarily very tentative indeed, it is reasonable, if only to estimate its volume, to assume that its mean composition is stoichiometric. This volume can be expressed in cubic metres, or more vividly by quoting the diameter of an equivalent sphere, but seldom, if ever, will such clouds approximate to a spherical shape, and many of the clouds which are of concern will be formed from hydrocarbon vapour much denser than air. In these cases the cloud is likely to take such a shape as an oblate hemispheroid. If, for the sake of illustration, a ratio of cloud radius to cloud height of **5:1** is assumed (and there is some evidence that this is in reasonable accord

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***See** Glossary

with past experience)[†] a rough estimate can be made of the cloud radius R as

$$R = 30\sqrt[3]{M}$$

where R is in metres and M the mass of vapour in tonnes.[11] Perhaps the most important lesson to be derived from such crude calculations is the degree to which a vapour cloud explosion must differ from one at some imaginary 'point source'.

Extent of cloud drift

121 Clouds will drift with the wind. Pasquill's and other existing theoretical methods for predicting the dispersion of vapour do not seem to be completely valid when applied to heavy vapours, and, since the subject is of vital importance in relation to the dissemination of toxic gases appropriate experimental work has been put in hand[‡]. Experience indicates that the vapour clouds which are most likely to explode are those which have formed rapidly. Because the atmospheric conditions at the time are quite unpredictable, there is little option but to ignore the effect of drift except perhaps by placing sensitive parts of the plant, as far as possible, upwind of danger spots in relation to the prevailing wind direction.

122 In passing, it might be worth noting that the epicentre of the Flixborough explosion has been estimated to have been some 30 metres from the point of escape but that this displacement was not in the direction of the wind but was at right angles to it. The displacement may have arisen as the result of the velocity of the escaping cyclohexane or of the influence of buildings or plant in the vicinity (Fig 4).

Likelihood that cloud will give rise to explosion

123 The enormous difference between the effect of the extremely rapid burning of, say, a gun propellant such as cordite, which may take two or three milliseconds to reach maximum pressure, and the truly shattering effect of the detonation of a high explosive such as TNT, which occurs in microseconds, is well known. That in the combustion of confined gaseous mixtures there is a similar discontinuity is illustrated by 'pinking' or 'knocking' in a petrol engine, which if severe and allowed to persist will damage it, on occasion even shattering the pistons. It may seem improbable that any similar phenomenon could occur in an unconfined vapour cloud, but it is certainly possible to induce deliberately by using high explosive a true detonation in an unconfined mixture of ethylene oxide and air, so the possibility cannot immediately be ruled out. We know of only one accidental unconfined hydrocarbon explosion where responsible investigators have claimed that a detonation occurred; that at Port Hudson in 1970. According to Strehlow', "550,000 cu ft (STP) of propane gas" (about 31 tonnes) "leaked from a pipe before ignition occured, 13 minutes later.......The Port Hudson explosion is a proven example of an accidental vapour cloud detonation." According to Burgess and Zabetakis[16] in a much fuller report, the leakage consisted of "about 750 barrels of liquid propane" (say, 70 tonnes) during twenty four minutes before the explosion occurred, and in their introduction they state that "this explosion....... was unique in the investigators' experience in that it involved the detonation of a large unconfined cloud." In the body of the report, however, they say: "Judging from such damage" (which they illustrate) "and the abruptness of the illumination of the valley, we think the witnesses had the unusual experience of observing a gas detonation." Such evidence in our opinion does not amount to a justification of the statement in their introduction, still less to Strehlow's use of the word 'proven', and since no other single case is on record, and many deliberate attempts to detonate unconfined hydrocarbon/air clouds have failed, it would seem more justifiable to regard the occurrence of true detonation in an unconfined vapour cloud as so improbable as to be disregarded for design purposes.

124 That the combustion of vapour clouds may take the form of 'explosions' cannot, however, be doubted. True, in the case of relatively small clouds it is not always easy to distinguish between fire and explosion: ignition may be accompanied by a loud noise and people may be hurled to the ground without any other evidence of blast, such as shattered windows, appearing. In the case of large clouds, such as that at Flixborough, the resulting damage quite certainly has been due to a shock wave or 'overpressure' of considerable magnitude. Some of the most serious incidents which have occurred in the last half-century have been tabulated in Chapter 1, Table C. From this it is clear that for very large clouds, containing say, more than 15 to 20 tonnes of gas or vapour before ignition, the risk of explosion is so great that it would be foolhardy in the extreme to proceed on any assumption other than that in such cases an explosion will occur. Explosions have occurred with smaller amounts, but it must be remembered that many other similar recorded escapes have either not ignited or if ignited have not exploded, and very many more must have occurred without even being regarded as newsworthy. It would seem unreasonable to argue that every such release should be regarded as a major explosion hazard. It seems clear that, until further evidence becomes available either from deliberate experimentation or as the result of further accidental releases of a range of flammables, some sort of sensible compromise should be adopted. In our first

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[†] According to recently-published paper by Sadee et al[14] the mass of cyclohexane which escaped at Flixborough was of the order 40 tonnes, so our estimated radius of the hemispheroidal cloud would be 102 metres, and height 20 metres. From this same paper fig 4 has been reproduced, showing the authors' estimate (on the basis of the carbonization, melting, and soot formation observed after the disaster) of the plan boundary of the cloud. The deviation from a circular shape is of course very great - in view of the obstructions in the shape of buildings and the existence of a wind it could hardly be expected to be otherwise - but the minimum radius of their boundary is 70 metres, the maximum 175 metres, and the mean radius (i.e. $\sqrt{\text{area}/\pi}$) is 110 metres.

[‡] Chapter 8

report we suggested that if 15 tonnes of vapour could be released an installation should be regarded as offering a major explosion hazard, and we have not found cause to change our view.

TNT equivalence or other measure of blast effect

125 The question of the yield of an explosion in terms of blast effect is still largely unresolved. The complete combustion of a stoichiometric hydrocarbon/air cloud releases a total amount of energy equivalent to about ten times the explosive energy of a mass of TNT equal to the mass of hydrocarbon in the cloud, but the fraction of this energy manifest in blast effects is critically dependent on the rate of combustion in the cloud. It may be zero, as in a fire, or it may be as high as 0.3. It has been estimated that flame speeds of the order of 100 m/s are required before pronounced blast effects develop.

126 In a real situation, only a fraction of the release will be in the flammable portion of the cloud, as discussed in paragraph 119, and only this flammable portion of the cloud can contribute to an explosion (the lean portion will not burn; the rich portion will contribute to the ensuing fire). The blast energy resulting from the rapid burning of this flammable portion will depend on many factors such as the ignition source, the degree of containment of different parts of the flammable volume, turbulence generated by flow round obstacles and other factors that have been mentioned in the preceding paragraphs.

127 It is in no sense surprising to find that the fraction of combustion energy available in the material released from containment which appears as explosive energy varies between about 0.01 and 0.1. The majority of serious incidents which have occurred in the past have been in the lower end of this range. Surveys made in 1968[17] and again by two independent investigators in 1977[6,18] show that major vapour cloud explosions have in practice developed between 0.01 and 0.03 of available energy.

128 It is worthwhile to emphasize, in passing, that we cannot ever hope to reach an accurate answer even by deliberate experimentation: the variables are quite beyond control and impossible to assess in general terms. As accidents continue to happen throughout the world, it may be possible to reduce the range of uncertainty, but even this is more than doubtful. In our opinion, this is another aspect which requires a sensible compromise to be made in order to avoid taking extremely pessimistic values so giving rise to a design which covers unrealistically low probabilities of occurrance. We suggest that the explosive energy in a vapour cloud should be assumed to be 0.03 of the available energy. In pragmatic terms, this means that the TNT equivalent of a vapour cloud can be estimated at 0.3 tonnes of TNT for every tonne of vapour and spray which makes up the cloud.

129 When considering this figure, it must be borne in mind that since the distance at which a given amount of damage is caused by an explosion varies as the cube root of the quantity of explosive, it is of course relatively insensitive to variations in the calculation of the equivalent mass of TNT. For instance, even a doubling of the assumed efficiency of explosion would alter the predicted damage radius by only 26%.

Relationship of overpressure to distance from epicentre

130 The major advantage of using 'TNT equivalent' as a model lies in the considerable amount of data amassed on the effects of TNT explosions; data which are unclassified for security purposes and available for use. One such set of data, based on well-established information'' , and here summarised by plotting a graph of 'side - on peak overpressure'[†] versus 'scaled distance'[*], is shown in Fig 5, by the solid curve, labelled ''Basic curve for TNT''. From this curve, if the TNT equivalent of the explosion is known and if it may be assumed that an unconfined vapour cloud explosion gives the same relationship, it is easy to read off the overpressure at any distance from an assumed epicentre. There must, however, be enormous differences between the explosion of TNT and an unconfined vapour explosion. Apart from the difficulty of determining the effective epicentre, which is unlikely to coincide with the centre of the cloud but is more likely to be displaced away from the initiating ignition point, there is the obvious fact that the original cloud is very large in volume compared with the equivalent mass of TNT which can from this point of view be regarded as a point source. It will have been noticed that the curve in Fig 5 shows no upper limit of overpressure. The theoretical upper bound might however be expected to be related to that pressure which would be achieved if a mass of TNT after detonation could be confined under adiabatic conditions within its original boundaries. The resulting detonated mass would then produce a pressure of about half a million bar. In sharp contrast, the maximum pressure arising from confinement under adiabatic conditions within the initial volume of a vapour cloud would not be expected to exceed about 8 bar[19]. In consequence, it is hardly surprising to find that the vapour cloud explosion is relatively 'soft'[‡] in other words that the shattering effect, and the velocity of any missile which may be generated, are relatively small.

[†] We are here discussing a complicated situation involved in the passage of a shock wave over an obstacle. There is no universally accepted agreement of the descriptive terms which can be used. These can be found in the Glossary. It is however, worthwhile to add at this stage that if a shock wave strikes a surface perpendicular to it the pressure developed on the reflection at the surface will be very much higher - from 2, to in an extreme case, 8 times the 'side - on peak' overpressure. In the cases we have to consider the factor will be of the order 2.5 to 3.

[*] See Glossary

[*] At Flixborough, for instance, no crater was produced such as would have been caused by an explosion of TNT at ground level, nor was the plant at the cloud centre damaged nearly so severely as it would have been, had the quantity of TNT been exploded there which would have been required to cause the distant damage.

131 In both cases, the practical upper limit of overpressure will be some fraction of the theoretical maximum suggested, and it is not unreasonable to suppose, in view of the great difference in time scale, that the fraction would be much smaller in the case of the vapour cloud than in the case of high explosive. Indeed, although large-scale research would be required to determine the upper limit of overpressure due to an unconfined vapour cloud explosion, such data as exist suggest a value of 1 bar, and this we have accepted as our best estimate of the overpressure near the middle of the cloud. It seems rational to assume that this pressure will be somewhat less at the edges of the cloud, and we have taken the value of 0.7 bar as reasonable for this region. Since, as we argued in para 123, detonation is highly improbable, it would seem that construction of a building to withstand such pressures is a practical proposition.

Duration of overpressure

132 The peak value of the overpressure is not the only factor which determines the destructiveness of an explosion; duration is no less important, and the resulting impulse* probably more important than either. We know that in the case of the detonation of high explosives the blast wave* at a modest distance usually takes the form of an almost instantaneous pressure rise to the peak value, say P_1, followed by a steady decay to zero after time t_0 (and subsequently to a negative value, the total impulse $\int p\,dt$ being approximately zero). The value t_0 depends on the amount of explosive detonated, and varies at least from about 1 ms for a very small charge to about 50 ms for a large one and 250 ms for an extremely large one. We have no comparable reliable information about vapour cloud explosions. We have no reason even to assume that the shock waves will be very similar in form. Because of the difference in time scales which must exist, it is fairly certain that the duration will not be short: on the other hand, because of the magnitudes involved it is equally certain that the duration will not approach the uppermost figure. Indeed, the longest estimate of which we have knowledge is 75 ms, but this figure has been challenged. Until more information is available, we suggest that an estimate of 30 ms be accepted.

Vapour clouds and high explosives

133 In attempting to sum up the preceding discussion it must once again be emphasized that we have no direct knowledge of the precise nature of the blast wave produced by the explosion of a large unconfined vapour cloud. The reasons are obvious enough. Such explosions as have occurred by accident have, of course, been totally unexpected, and no monitoring equipment has ever recorded one of these events. On the other hand, the number of variables involved in a large unconfined vapour cloud explosion as outlined in the preceding paragraphs is such, and the cost of carrying out even one experiment so large, that it has not yet been found possible to outline an agreed experimental programme, far less to carry one out. We hope that this state of affairs may be ameliorated in the near future, but it will be many years before we can hope to have satisfactory answers to any but the easiest of the questions which can be posed. In the meantime, there is (from defence and home security sources) considerable knowledge of the behaviour of various types of structures subjected to known degrees of blast from high explosives, notably TNT. There is some knowledge of the behaviour of some similar types of structures accidentally subjected to unknown degrees of blast from estimated amounts of vapour mixed to estimated degrees with air. It is therefore possible to make some attempt to deduce the quantity of TNT which would have given this amount of damage at a considerable distance from the position at which it has been assumed to be detonated. When this quantity of TNT is related to our estimates of the amount of vapour in the cloud the factor of 0.1 to 1 previously discussed emerges (para 125) and we have given our reasons for accepting a factor of 0.3 as a sensible estimate when discussing the precautions and protection which should be provided at a considerable distance from the likely epicentre of any possible vapour cloud. In the consideration of the precautions and protection which should be provided at a lesser distance, the'equivalent TNT' model breaks down completely, and we have suggested from the scanty evidence available that the maximum side-on overpressure due to the explosion of a vapour cloud should be taken as 1 bar at the middle, falling to 0.7 bar at the boundary, and the corresponding 'duration' as 30 milliseconds. We have no knowledge about the effective centre of such an explosion. When these estimates are collated, an interesting and useful coincidence becomes evident, thus: assume that V tonnes of hydrocarbon vapour mix with air to give a mean stoichiometric mixture*. If the cloud is of a form postulated in para 120 it will have a radius of $30\sqrt[3]{V}$ **metres.** Its equivalent mass (para 125) will be $0.3V$ tonnes of TNT. Now the 'scaled distance' at which TNT causes an overpressure of 0.7 bar (Fig 5) can be read off as 40, so the actual distance at which the pressure is 0.7 bar will be $40\sqrt[3]{0.3V}$ or $27\sqrt[3]{V}$ **metres.** Thus the cloud radius and the radius at which the overpressure might be expected to fall to 0.7 bar are sensibly identical and it can be assumed that the charge of TNT might be detonated at any point within a small circle, of radius $R = 3\sqrt[3]{V}$ metres, from the centre of the hypothetical hemispheroidal cloud, which gives a semi-rational overpressure distribution, varying from 1 bar to 0.7 bar within the cloud, and outside it decaying in accordance with the well-established curve in Fig 5.

The result is illustrated in the lower of the dotted curves in that figure. Alternatively, if it be considered preferable to assume that the effective centre of the

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***See** Glossary

***See** Glossary

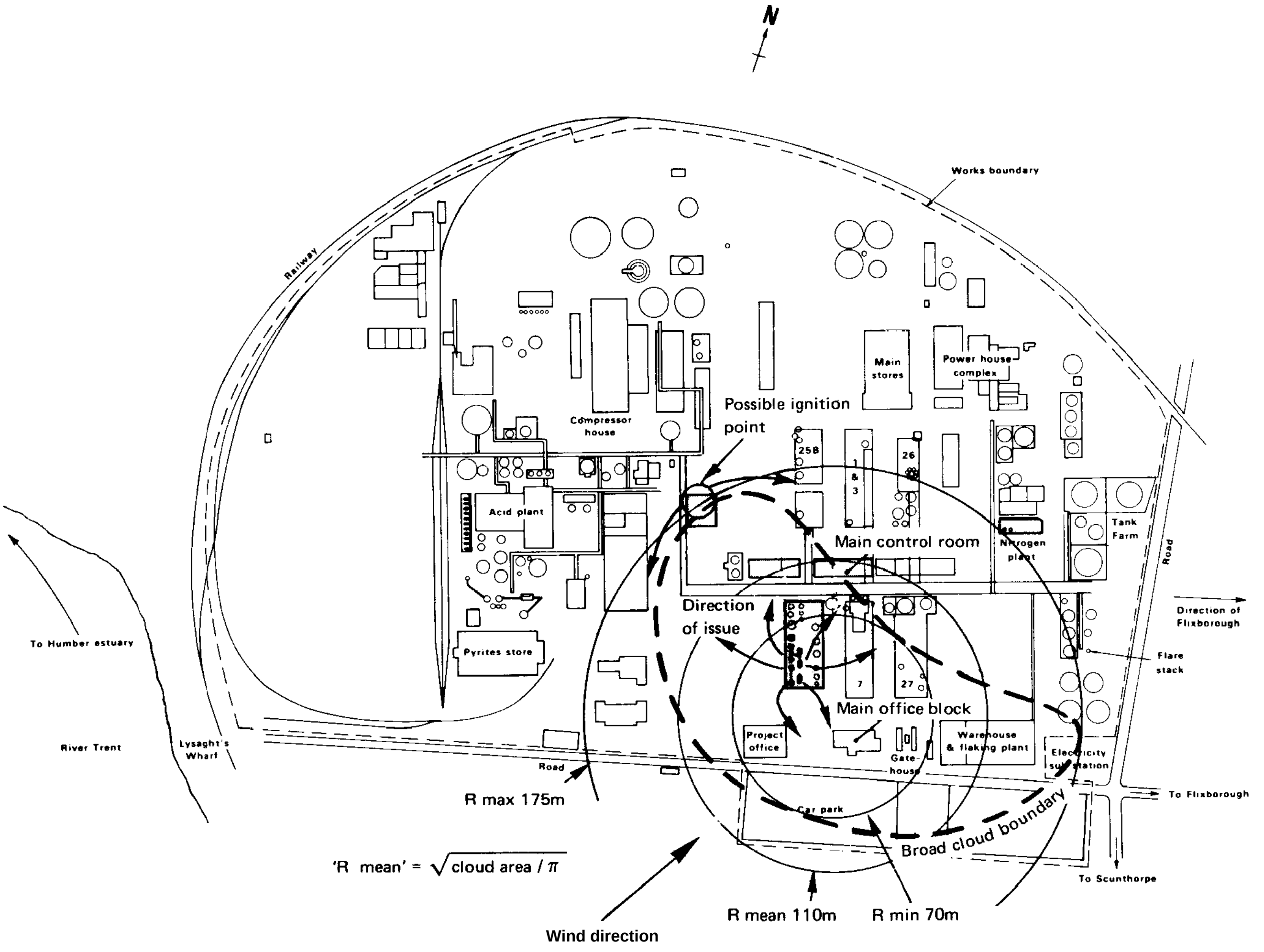

Fig 4 Simplified plan of Flixborough Works of NYPRO (UK) LTD

explosion coincides with the centre of the cloud, and if it be still desired to equate the distance at which the pressure equals 0.7 bar to the cloud radius, a slight modification can be made in the factor 0.3 accepted earlier as a sensible guess between 0.1 and 1, for the TNT equivalent. Calling this factor k, a simple relationship

$R = 30\sqrt[3]{V} = 40\sqrt[3]{kV}$ whence $k = (3/4)^3$ or 0.42 emerges. As stated earlier, such a change makes little difference in the overpressure/distance relationship: the result is illustrated in the upper of the dotted curves in Fig 5.

134 It should surely be clear that we have no thought of suggesting that either model is 'correct', but either offers an overpressure/distance curve without discontinuities upon which the rational design of buildings within the whole area may be based until more accurate data are available.

135 A most valuable paper by Sadee, Samuels and O'Brien[14] has been published, in which the characteristics of the Flixborough explosion are examined. In particular, the authors estimate that a total of 40 tonnes of cyclohexane escaped (of which 30 might have formed a cloud) and from a detailed examination of the damage caused they estimate the overpressure at distances varying from 98 to 2745 metres from the cloud centre. They conclude that this damage corresponds to that which would be expected from the detonation of 16± 2 tonnes of TNT at a height of 45± 24 metres†. Their overpressures, deduced from the damage, have been plotted in Fig 6 against the curve we have just suggested as reasonable. The cloud radius has been taken as $30\sqrt[3]{40}$ or 102 m and the TNT equivalence factor as 0.42, with the effective centre at the cloud centre. It is true that some of the actual damage is slightly in excess of our estimate -after all, this could well have been an instance when due to unusually effective entrainment or some similar cause the factor was unusually high - but when considering that the actual cloud 'radius' varied from 70 to 175 metres in a totally unpredictable manner, it is encouraging to find that the crude estimate corresponds so closely to actuality in this particular instance.

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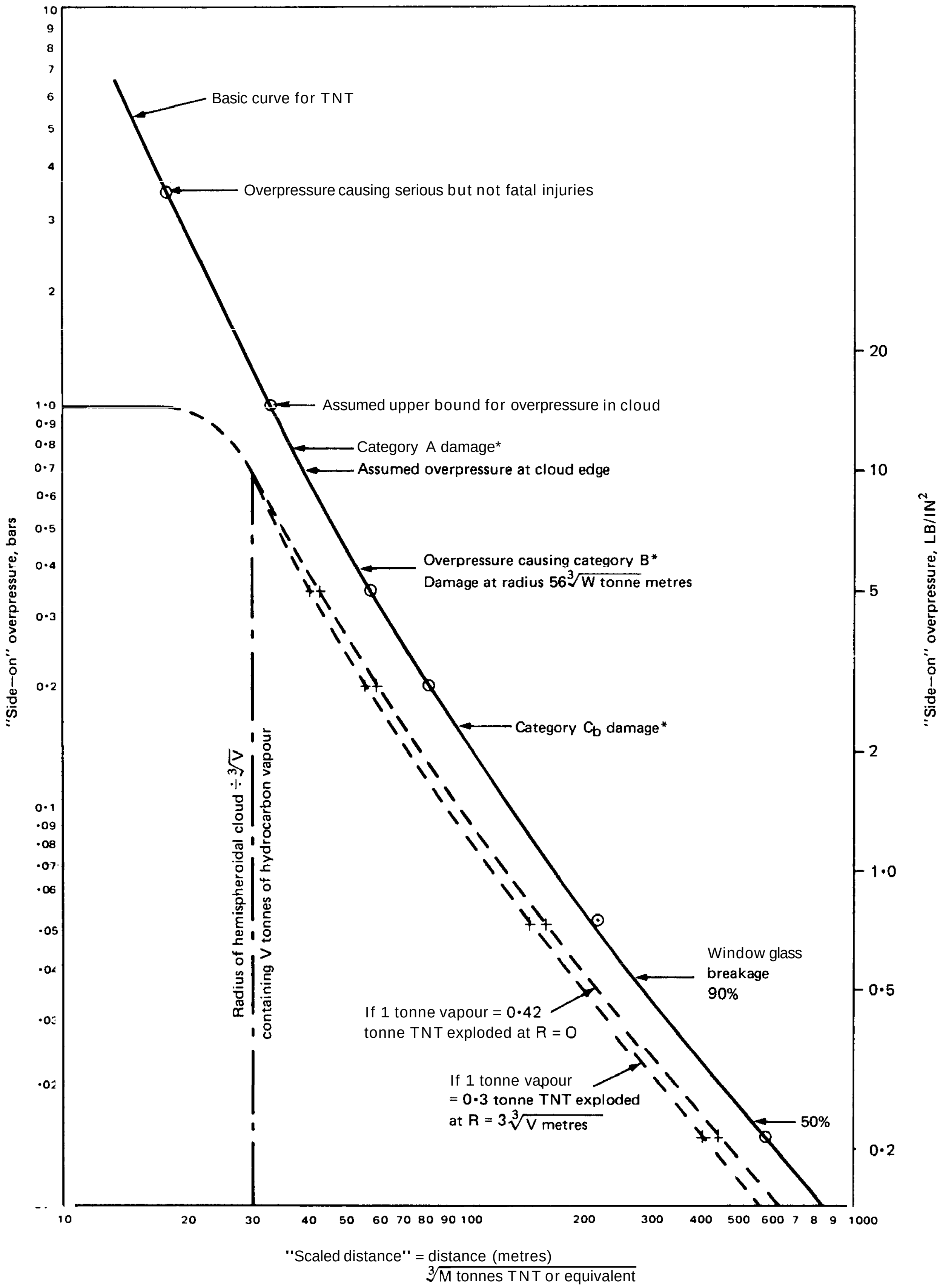
† We understand from the authors that this height is not to be taken literally but that it provides a convenient mathematical model which gives the best fit for the observed evidence.



* Damage categories as defined in chapter 6

Fig 5 Graph of 'side-on' peak overpressure versus 'scaled distances'

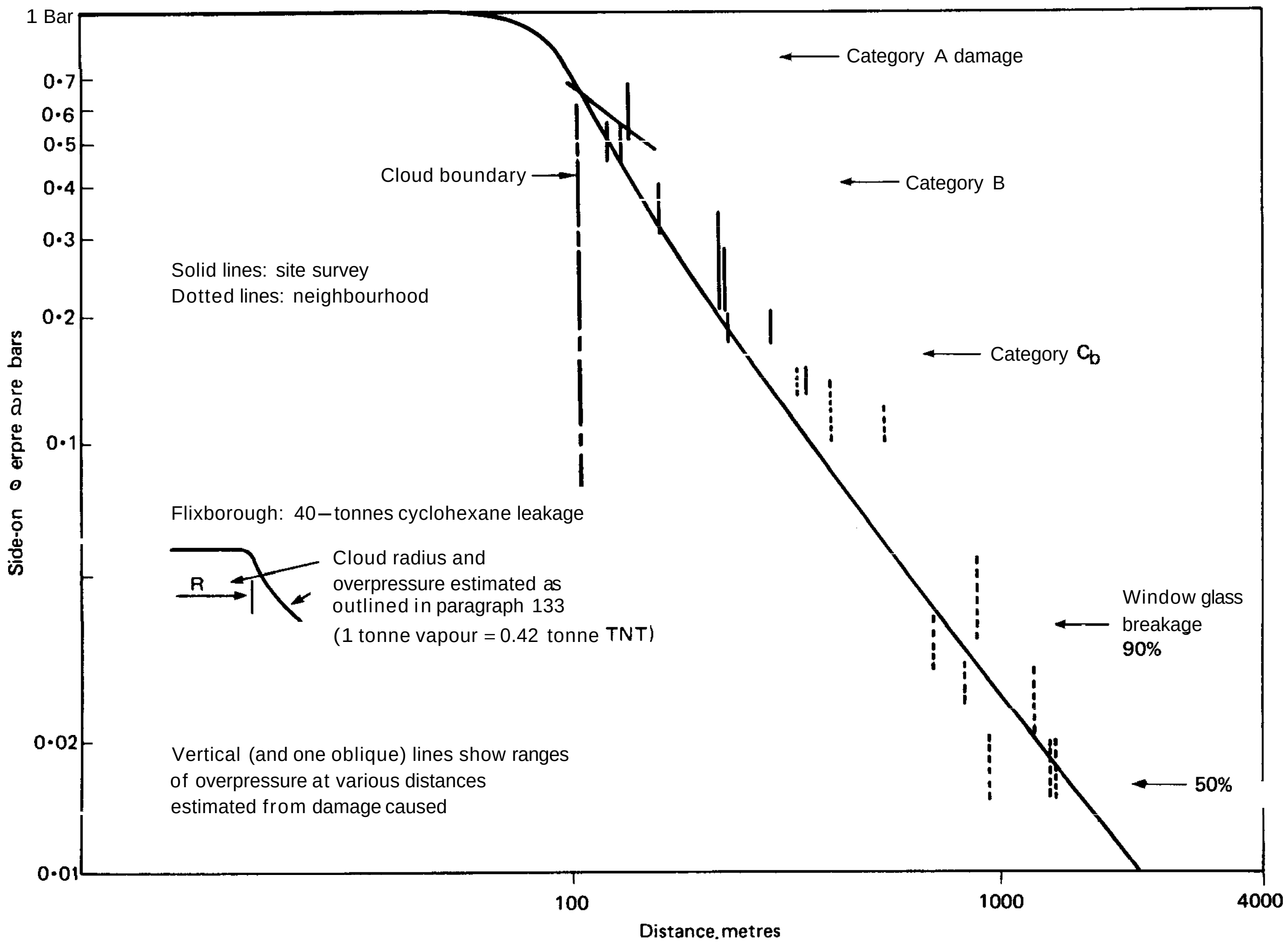


Fig 6 Sadee data

6 Buildings in the area of an explosion hazard

The overpressure experienced from an unconfined vapour cloud explosion will affect any personnel, plant or building in the whole area. The committee discusses which elements of management control can reasonably be removed from the most hazardous areas and considers the function, design criteria and siting of control buildings. The effects of unconfined vapour explosions on control buildings at Flixborough and Beek and the problem of flying glass are critically examined.

136 Two recent explosions have focused attention on the need to site and design buildings in the vicinity of major hazards in such a way as to escape destruction in the event of external explosion; in particular, at Flixborough in **1974,** where not only the control building for the caprolactam complex but even the main office building suffered total collapse; and the much smaller one at Beek, in Holland, which caused severe damage to the control building. Both cases gave rise to loss of life which, though serious, could have been much greater.

137 In this chapter we discuss which elements of managerial control can reasonably be removed from the most hazardous areas, and consider the siting and design of such buildings as from their nature and purpose cannot be so removed. In the preceding chapter we discussed the overpressure which may'be experienced at any distance from an unconfined vapour cloud explosion, and is therefore relevant to any personnel, plant, or building in the whole area. Attention will be concentrated first on the very special problem of the control building (or room, or house). It is special in that although from the aspects we have been discussing an obvious partial answer to the question "How far should any building housing people be from a conceivable vapour cloud?" would be "As far as possible", such a simplistic attitude is not valid in relation to a control building. The further a control building is from the centre of the plant the greater become the technical, operational, and economic difficulties of exercising effective control of the process and to site the building further away than it need be could result in reducing significantly the safety of the plant in day-to-day working, and therefore on balance increase the total risk to which men and plant were subjected. This is why this particular problem requires more careful study. It makes sense to start by considering the proper function of a control building.

The function of a control building

138 The normal function of a control building is to maintain conditions suitable for the functioning of the people and equipment it houses. It obviously does not follow that such a building will afford adequate protection against the extreme changes in environment which occur in the event of a disaster. Indeed, it is not always recognised that the sense of security engendered by being behind walls may well be spurious, and that if an explosion occurs the inhabitants of existing control buildings may be at greater risk than people caught in the open at the same distance from the explosion. On the other hand, given adequate design, it should be possible to make a control building a much safer place than the open air.

Separation of the various elements of 'control'

139 It may be useful to consider with some care the various elements which are often included in the concept of 'control', in order to distinguish those which, as argued in para **137,** really need to be near the centre of operations from others subject to no such need. For instance, to take the extreme case, it seems obvious enough that overall management control of an enterprise, at the highest level, need not be on the site at all. Site management control normally would be, but the buildings housing it should surely be as remote as reasonably possible from the sources of explosion or major fire and be adequately designed; yet at the explosions at Pernis, Flixborough, and **Ant**werp, serious damage (indeed complete destruction in one case) was sustained by main office buildings.

140 In hazardous situations every effort should be made to reduce, if not to eliminate, all but direct operational activities from buildings adjacent to the hazard.

141 Closer to the point of production come the control laboratory and instrumentation. 'On-line' analysis is a growing feature of process control and housing of the automatic analytical equipment close to the centre of production cannot reasonably be avoided. Where 'off-line' analysis is carried out by shift process operators its housing in a special part of the control building can probably be justified. Laboratory tests which demand skills, time, or attention beyond those which an operator can afford should be transferred to a laboratory more remote from the hazard area.

142 Finally, however, there comes the necessity to operate that nerve centre or plexus at which, primarily, input signals from the process generate output signals to control the process and at which data concerning these signals are logged. The signals are in large measure electronic or pneumatic, and the associated transducer may be a human operator, an automatic servomechanism, a computer, or some combination of these, but also and importantly the input signals include sight, sound, and smell. The need to receive, interpret and act on these signals means that human beings must be on the spot, must visit the plant, and must report or act.

143 It follows from all this that it is highly desirable to analyse very carefully the functions which really have to be performed in the control building proper and to eliminate provision for anything which is not essential. Separation of the accommodation for the various elements of control may indeed lead to some minor communication problems with a consequent small increase in running costs, but it will make possible a considerable reduction of manning and equipment in the most vulnerable areas and so reduce cost by restricting high-specification building to housing these essential elements and no other.

Criteria which determine the need for a strong control building

144 Ideally, every control building on sites where unconfined vapour cloud explosions are possible should be designed to withstand such explosions. There will, however, be many cases where the considerable problems arising from such a crude criterion would far exceed the likely benefit; perhaps because of adequate separation, small inventory at risk, or the extreme unlikelihood of serious explosion effects.

145 If adequate separation is possible, a conventional control building could be designed to give proper protection to the operators within it. In other cases, a decision will be needed as to whether a conventional, or a strongly designed, control building should be built, or even whether, in exceptional cases, existing control buildings should be strengthened. After extensive consultation with industry, we think it right that guidance should be given to those who make such decisions.

146 We have considered the possibility of listing specific types of new installation where strong control buildings would be necessary, but we are not satisfied that such a list would encompass all those plants which clearly need one unless it also included a great number of comparatively innocuous installations. We have therefore adopted the following approach to the problem of deciding what size of incident should be considered when designing an adequately strong control building.

147 As regards pressure vessels themselves, provided that it has been shown that the appropriate degree of strength is present and maintained by correct design, fabrication, testing, and inspection, it may be accepted that they will not fail; and under the same strict conditions the same acceptance may be extended to certain short, large-diameter, simple pipes.

148 For all other parts of an installation, the criteria would be the rate at which flammable material could escape and the total amount which could escape; and the following assumptions would be normally mandatory:

1 That there could be a failure of containment in the lines around each pressure vessel equivalent in area to the cross-section of the largest line.

2 That the contents of the pressure vessel emerge totally, unless the rate of emission is such that emergency action can be taken to stop the emission before the vessel empties. For each pressure vessel, or group of vessels, the details of the emergency action which will cause the flow to stop must be specified.

3 That vapour arising from liquid material which has been generated by adiabatic flash to atmospheric pressure will be accompanied by an equal mass of mist/aerosol, or the remaining inventory if that is a lesser quantity.

If the flammable airborne emission so caused is greater than **15** tonnes and adequate separation is not possible a strong control building will be needed.

149 Pressure storage facilities which are separate from the processing area can be treated less rigorously if it can be shown that the pipes leading to and from the storage vessel are well protected from external damage by traffic, cranes, and the like, and that an automatic flow-prevention valve close to the vessel will stop or adequately restrict the flow if the pipe beyond it is broken. With such safeguards, storage vessels remote from the process with a capacity of several hundred tonnes will not call for the provision of a strong control building.

Emergency control

150 Every hazardous site needs to have a room or suite of rooms which become the headquarters of the incident controller in the event of a disaster. Such room or rooms can be housed in the management control building but the overriding consideration is the need for emergency control to be at a location convenient to a main entrance to the site. We believe very forcibly that main emergency control ***must*** not be housed in a control building if this is sited in a hazardous area; and that the general considerations about siting and design which are discussed in this chapter apply with even greater force to emergency control buildings which ***must*** be of a construction capable of withstanding, without serious damage, any explosion which could occur on the site.

151 Discussion of the facilities which should be provided at emergency control is outside the scope of this chapter but it might be noted, in passing, that an emergency control room need not be sterilised for other uses when not required for emergency purposes. It could be used, for example, as a conference room.[20,21]

Siting of a control building

152 For the operational reasons discussed above, it must be accepted that a control building may have to be so sited that, in the event of a vapour cloud explosion, it will be subjected to a considerable shock wave: an estimate of its probable magnitude has been outlined in paragraph **115.** If calculations show that the probability that the building will be within the possible cloud is so remote as to be negligible, the shock wave can be regarded as a vertical wave moving horizontally towards it. Any wall of the building facing the shock will have to 'withstand' (as discussed below) the much higher reflected pressure, and the side walls and roof the travelling wave. Information is available[22,23,24] as to the design methods which could be adopted, and it would not seem to be unduly expensive or time-consuming to carry out a modest experimental programme to check these methods.

153 A more difficult situation would arise if it could not be shown that the control building would be outside any probable cloud. If it were known that in a vapour cloud explosion a genuine epicentre (as opposed to an epicentre postulated near the centre of the cloud for purposes of calculation) existed, and if the building could be shown to be outside a 45° cone under this epicentre, the preceding argument could be accepted as valid for the new situation, and a building designed to withstand a horizontally-travelling shock wave with peak overpressure of 1 bar and duration 30 ms could be regarded as totally acceptable. A typical design basis for a reinforced structure recently promulgated by a working party appointed by the Chemical Industries Association's Chemical Industry Safety and Health Council[24] to cope with the less stringent conditions of 0.7 bar with 20 ms duration has been critically and independently examined and the conclusion reached that provided certain reasonable further conditions are observed such a building would indeed 'withstand' the higher loading.

154 The fact must however be faced that in the case of a very serious accident involving the escape of a large amount of flammable vapour the cloud may be so big that the control building cannot be sited to be certainly beyond its confines; indeed it may be engulfed within it. It seems clear that in what would appear to be the worst case, that is, if the effective centre of the explosion were to be directly overhead and a full downward overpressure of the magnitude suggested were to be exerted on the roof of a building designed to withstand only the horizontally-travelling shock wave it would collapse. It does not, however, appear to be unduly difficult to design a building to withstand the full pressures within the cloud if these pressures have been correctly estimated in the preceding chapter. According to advice received from HSE such a building could be constructed in reinforced concrete or could equally well be of the steel portal frame type, either of which could give the ductility necessary to accommodate large deflections within the plastic range. Summing up, it would seem that we can by the use of pragmatism and common sense justify a few general conclusions.

In the first place, without indulging in the sort of hubris which preceded the 'Titanic' disaster, we can say that the sort of control buildings envisaged (see above, and para **157)** if not impregnable would be many times stronger and more resistant than those commonly erected in the past.

155 In the second place, a control building should if reasonably possible be sited to be outside the confines of any likely cloud. If excessive distance should be found to introduce worse risks of accident in everyday operation than those to be feared from the relatively remote possibility of a vapour cloud explosion, it still makes sense to site it as far as tolerable from the danger area, not only because this will reduce the overpressure it will have to withstand from a smaller explosion but also because in the case of a really major accident the probability that the building will be directly under the effective epicentre, assuming no cloud drift, will diminish the square of the distance from the point of escape, and the depth of the cloud cover which must be important in relation to the actual vertical overpressure produced, may reasonably be expected to fall off with distance. The danger of excessive vertical overpressure would therefore appear to vary inversely with roughly the cube of the distance from the effective centre.

The meaning of the word 'withstand'

156 From the point of view of the owners and operators of the installation, it is clearly highly desirable that the control building (along with all other plant, not to mention personnel, on the site) should emerge undamaged, or only trivially damaged, from any accident which occurs, and it should not be overlooked that a building which had been designed just to 'withstand' the worst accident calculated as reasonably possible might well emerge with little or no damage from a grave but lesser catastrophe. In these circumstances the savings which would result from what might be regarded as 'over-design' might well far outweigh the additional costs incurred. But that is not our concern here. We are concerned with the 'worst possible' accident envisaged in Chapter **5** and in relation to it the word 'withstand' is used in a very special sense. The control building may finish up very heavily damaged, with walls cracked and leaning and roof sagging but, as long as those inside are alive and well, and enough of the equipment remains serviceable to let other plant be shut down without allowing another disaster to follow, the building has in our sense 'withstood' the catastrophe.

Design of a control building

157 The detailed design of any building is, of course, wholly outside of the scope of this chapter but, in view of the size and type of the buildings which have in the past housed the control function on hazardous sites, a few general comments are considered appropriate: paragraphs **139-143** argues that the control building of the future will be a relatively compact structure housing only the vital elements; paragraph **156** clearly implies that it will not be a multi-storey brick building with picture windows. Indeed, for economic reasons, it will almost certainly take the form of a single-storey building of either heavily-reinforced monolithic concrete or of heavy steel frame construction. Needless to say, the design will be based not on the ability of the structure to withstand the imposed stresses elastically, but on its ability to absorb, by plastic deformation, the shock energy transmitted to it. The possibility that it should be so built as to be able to slide slightly on its foundations in the event of a major explosion has been considered but effectively discarded: such a movement would reduce the problem of providing a building of adequate strength but introduce difficulties of 'connection' which appear to be virtually insuperable. Windows, on balance, seem for the time being to be desirable, though on occasion they might be eliminated by the use of closed circuit television equipment; but they will be severely restricted in number and size, very firmly mounted, and, of course, designed to minimise the risk of injury from flying fragments of window material. Proprietary windows of adequate size are available which could withstand the overpressures we have been discussing. No heavy equipment should be mounted in the roof, and no adjacent structure which could fall on the control building should be permitted.

Existing installations

158 We do not propose, for the time being, to recommend that existing control rooms should either be re-built to this standard, or even, in general, to be up-rated by reinforcement. There probably are, however a number of control rooms where the risk is much higher than is the general case, and we believe that the hazard surveys which we have proposed will help to identify those control rooms which should not be allowed to operate beyond a certain period (to be determined) without some reduction in risk to persons within them. When considering the technical obsolescence of an installation, the design of the control building should be one of the more important factors to be taken into account.

Other buildings in a hazardous area

159 Although the control building is a special case, it is obvious enough from the disasters which have occurred in the past that other buildings over a very large area, and their occupants, can be put at serious risk by a major vapour cloud explosion. If the arguments in the preceding chapter, culminating in the curves shown in Fig 5 and substantiated by the Sadee data[14] illustrated in Fig **6**, are accepted as valid, we have enough information about the whole region to guide designers and planners in their work.

160 Summarising very briefly information which required careful study in the original documents may be said that bomb damage up to and including the **1939/45** war has been classified with regard to its effect on 'dwelling houses' in a number of groups, of which the following are the most relevant.

Damage classification	*Description*
A	Almost complete demolition
B	So severe as to necessitate demolition
Cb	House unhabitable but not totally irreparable
Glass damage	Expressed as percentage of windows broken

161 The overpressures arising from the explosion of TNT which would be expected to give rise to each of these types of damage have been indicated in Fig **5**. There seems to be no real reason to doubt that comparable overpressures arising from the explosion of a vapour cloud would cause similar results.

162 It must however be repeated that these classifications were determined from the damage inflicted on 'dwelling houses' and their windows: industrial buildings on the site will normally be of quite different construction and their safety should be considered from first principles in the light of the overpressures they might have to withstand. Needless to say, we recommend that new buildings be designed on a conservative basis to withstand pressures not less than those indicated by the dotted curves in Fig **5**.

The problem of flying glass

163 When a large explosion occurs, be it because of enemy action or of industrial accident, windows are invariably broken over a very large area, and flying glass can cause serious injuries. Considerable public anxiety exists, and the dangers cannot be ignored. We have therefore given serious attention to this problem.

164 Obviously, a rational approach would be to consider in detail the fatalities and lesser casualties caused by previous vapour cloud explosions, or by comparable explosions of TNT, but the facts seem not have been recorded in sufficient detail to be very helpful. If we consider the most recent cases, we find that at Beek a total of **2508** cases of damage outside the factory was reported, consisting almost entirely of broken window panes: one woman was injured by glass. At Flixborough a total of **6539** windows outside the factory were broken in an area in which there were **4153** houses together with shops and factories.

Six people outside the factory boundary were injured with sufficient severity to cause them to be detained in hospital. A total of forty eight people were treated in hospital, of whom only six were injured at their homes. Clearly the information available is quite insufficient, but it would seem that the danger may be exaggerated in the public mind. Though it is positively known that some of those injured were injured by flying glass, it is not known how many. The figures of six and forty eight represent therefore the upper bounds of glass injuries but the true numbers are believed to be much less.

165 An alternative approach would be to carry out experimental work on the size and velocity of glass fragments from windows broken in this way. Exactly appropriate work does not seem to have been undertaken in this country, but what at first sight seems to be very relevant work has been carried out under the auspices of the Gas Council, and their reports are of course much more scientifically detailed than are reports of damage from war-time accidental explosions. If when we take as reasonably typical of 'dwelling houses' a window in 24 oz glass 1 square metre in area subjected to pressure caused by an explosion inside a room, Harris et al[27] find that the peak pressure to break it varies from about 0.03 to 0.05 bar. Smaller windows, or windows made from thicker or better glass, withstand considerably higher pressures. Figure 5 shows that an overpressure of 0.038 bar would be expected to break 90% of dwelling house windows. We have to make allowances for too many different factors such as the reflected pressure, the age of the glass, the quality of the fixing and so on, to say more than that we are clearly discussing the same order of magnitude. The paper quoted records in many cases the fragment velocity from the broken windows. It is true that the lowest pressure used in these experiments seem to have been 0.04 bar, but the fragment velocity varied astonishingly little, and was of the order of 40 mls or 90 mph, which must be regarded as quite intolerable. A moment's thought, however, shows that these experiments are likely to exaggerate very greatly the dangers we have to consider. In the case of these internal confined explosions, the pressure builds up relatively slowly (ie a few milliseconds) to a maximum value at or near which the window presumably breaks. At the moment of breaking, therefore, every element of the glass is being subjected to the peak value of the pressure, which will certainly not fall to zero instantaneously. Moreover, the gases escaping past the fragments must exert on them a considerable drag force. An elementary calculation suffices to show that if the pressure remains high for even a small fraction of a second, such fragment velocities are inevitable. In our case the exact opposite is true.

166 To take first the case of dwelling houses in the far field, it is a matter of common knowledge that broken windows have frequently simply fallen outwards during the negative phase of the shock wave, no doubt at least in part because the inward fixing is normally much the stronger. Moving inwards towards the explosion, it seems rational to suggest that when we reach a region in which 50% of the windows break due to the applied positive impulse, and consequently 50% of the windows do not break but recover elastically without even cracking, the average fragment velocity will be very low indeed, since at the instant of breakage the pressure must have fallen almost to zero. This (see Fig 5) would occur at a peak overpressure of about 0.016 bar.

167 Fortunately there has been some important work carried out in the USA which has been brought to our attention by Mr W G High, a member of the Chemical Industries Association working party. Experimental windows nominally %" (3mm) and ¼"(6mm) thick were mounted at various distances from large masses of TNT, so that overpressures about 0.3, 0.5, and 0.6 lb/in^2 (0.02, 0.035 and 0.04 bar) with a duration of 250 milliseconds were applied to them, and the relationship between fragment mass and velocity determined. In separate experiments the probabilities that such fragments would penetrate bare skin, or clothed skin, or 1 cm of soft tissue, were determined. Only a single fragment (out of 90) from the thicker windows broken at the highest pressure was found to have a 10% probability of penetrating 1 cm: none from the thinner windows, where the mean fragment mass was much less. No other fragment had even a 1% probability of penetrating 1 cm. Whether, in view of the improbability of the catastrophic accident we are discussing and the improbability of a fragment of glass broken at these pressures doing any damage, a much higher overpressure should be regarded as permissible must for the moment remain an open question: for the time being there would seem to be ample justification for regarding the risk from an overpressure of 0.04 bar as tolerable.

168 On those sites to which the criteria in paragraph 144 apply, it may well be that buildings other than the control building can be in danger of being subjected to higher overpressures than 0.04 bar. It may be extremely difficult even to plan a new site without giving rise to such a situation. In these cases it is possible to give greatly improved protection to people inside the buildings by the application to the windows of a shatter-resistant protective film. Again, although the results would require to be checked to allow for the very different conditions, Harris et al[27] show that the film results in a dramatic reduction in fragment (or whole pane) velocity. Moreover, Home Office trials[28]. in some respects resembling much more closely the conditions we have to cope with, in that explosive impulses giving peak overpressures varying from 0.25 to 1.7 bar but with a duration of only 1 ms, were applied to various test panes and gave equally dramatic results.

Table F Case histories of effects of unconfined vapour explosions on control buildings

Item	Flixborough	*Beek*
Date and time	1/6/74 16.53hrs	7/11/75 9.50 hrs
Agent responsible	Cyclohexane	Propylene
Quantity released	40 tonnes[14]	5.5 tonnes
Time taken for release	45 seconds[29]	120 seconds
Approximate mean radius of cloud	102 metres[14] kidney shaped	50 metres Irregular shape
Radius of cloud (as calculated from formula in Chapter 5)	102-105 metres	50 metres
TNT equivalent of blast	16 ± 2 tonnes [14]	2.5 tonnes
Fatalities	28 (All inside factory)	14 (All inside factory)
Injuries	36 inside factory 53 outside factory	104 inside factory 3 outside factory
Description of control building	2 storeys plus mezzanine, concrete frame, brick panels[30]	2 storeys plus mezzanine, concrete frame, concrete panels
Approximate dimensions	Height (max) 10 metres Width (max) 13 metres Length (max) 43 metres[30]	Height 11.5 metres Width 17.0 metres Length 35.0 metres
Damage sustained	Total collapse with pipe bridge on top	Severe blast and fire damage without collapse
Fate of process records	Total destruction	Almost total destruction
Approximate distance of building from presumed epicentre	90 metres	40 metres
Scaled distance* of building from presumed epicentre based on Fig 6	26 (Based on 40 tonnes vapour)	22 (Based on 5.5 tonnes vapour)
Deduced overpressure at control building	0.7 bar (from TNT model)	0.2 - 0.3 bar (general, from damage) 1.0 bar (local, from damage)

* See Glossary

Figures are taken from official reports except where indicated by reference or otherwise qualified.

7 Minimisation of exposure to hazards of people on site

Full consideration of the safety of personnel who are employed at, or may be allowed access to, the site must from the earliest planning and design stages of an installation run parallel with the consideration of plant and buildings. The committee establishes categories of people and of hazard areas in relation to risk and discusses the siting and construction of buildings within the site boundaries and the appropriate limitations of access. The essential features of a formalised arrangement of procedures and permits in designated areas is set out.

169 Although major hazard installations may be designed, constructed, maintained and operated to the highest standards, the remanent possibility of an incident which could lead to a serious explosion, toxic release, or cataclysmic fire demands that attention be given to personnel who are employed at, or may be allowed access to, the site. This is important, not only to minimise the risk to those persons, but also because some of them will be those needed to take action to limit and control the immediate effects of an incident. Full consideration of the safety of these people must, from the earliest planning and design stages, run parallel with the consideration of plant and buildings, and in particular, critieria should be set for the limitation of access to those areas which are acknowledged to be the most dangerous and which we will refer to as 'designated areas'. Although the numbers allowed in such areas should clearly be kept low, because those involved will be exposed not only to major catastrophes but also to minor incidents which have only local effects, it should be recognised that even in these designated areas there is an optimum number, commensurate with the safe and efficient operation of the plant, and that this number will vary from time to time with the operational conditions.

170 It must be accepted at the outset that absolute safety cannot be attained for those who work in a hazardous environment, but it is obviously desirable to reduce the risk for each individual to a minimum, and in pursuing this objective it is helpful to group the people concerned into some four categories. Firstly, there are those who have to be permanently located in a designated area, e.g. plant operators; secondly, those who when they do visit such an area, spend much of the working day there but only as part of their year's work, e.g. maintenance staff; thirdly, those who have reason to visit the area fairly often for short periods, e.g. technical staff, and lastly, those who need to spend relatively little or no time in the area, e.g. office staff. There must also be a system concerned with the dividing up of the whole works site on a common sense basis into areas corresponding to the degree of hazard. These will be the designated areas which, in the context of this chapter, will be those areas, in which at the time of a specified disaster anyone in the open would be liable to serious injury or death. At the other end of the scale there should be areas in which there would be no injuries of any consequence to anyone in the open. In between are those areas where there may be injuries or even a slight possibility of death to those in the open depending on the particular circumstances of the incident.

171 We think that the establishment of categories of people and areas should be sufficient to guide a competent and safety conscious management into certain lines of thinking. Naturally these considerations must be weighed with the other technical, commercial and employee considerations in order to achieve a proper view of action to be taken, but the following paragraphs concentrate exclusively on safety matters and develop various points in detail.

172 It is self-evident that the number of people permanently located within a designated area should be the minimum necessary for the proper operation of the area itself. This must take account not only of normal perturbations but also the emergency manpower requirements as laid down in the emergency operating procedures. The numbers are not necessarily the same on day work as shift work as the latter is, to some extent, dependent on the activities of certain day employees, e.g. the operating day supervisor, permanently allocated day engineering craft workers and day cleaning arrangements, all operations which can require the full time presence of certain employees.

173 Thus there will be a number of people whose presence in the vicinity of a designated area is absolutely necessary and it may be self-defeating to deem that some of these employees should not be permanently housed within the area when in practice it is essential that they spend nearly all their working time

there. However, the relevant word is 'essential' and should not be used when 'convenient' is more appropriate. On the other hand there may be staff such as technologists and other professionals, plant administrative assistants, operator training officers, maintenance supervisors and schedule planners, who are required to be in the designated area for only part of their time. Such people need not, and should not, be housed in the area and their access there should be controlled. Therefore it is our view that even if the buildings in which people are located are of a blast resistant character, as outlined in Chapter **6,** no-one should be permanently housed in, or indeed have access to, a designated area unless it can be clearly demonstrated that there is a good reason for that person to be there.

174 It is obvious that the maximum number of people should be permanently located in situations where they should be subject to minimum harm in the event of a disaster. The kind of people who fall into this category of location are those who have virtually no reason ever to visit a designated area (certain administrative staff) and those who have reason to visit periodically such an area for short times **(technol**olgists, draughtsmen, materials delivery staff, etc).

175 It is customary and normally administratively convenient to have an office block at the site which as a minimum houses the general management and support services such as finance and personnel departments. In some circumstances it may also house several other functions such as some of the technical support services, training departments, materials administration, laboratory, catering arrangements.

176 The design of such buildings is normally related to conventional office standards rather than to explosion resistance or prevention of ingress of toxic gases. Clearly if it is built far enough away from potential explosions or gas escapes, there is no need to depart from conventional office standards and equally clearly from a major hazard point of view the higher the proportion of the staff who are located there, the better. However, distance is not the only criterion, and it may not be possible to locate the office at a far enough distance, but if the design is suitable to offset the effect of building closer to a designated area there is no reason why this philosophy should not be acceptable.

177 There is no definitive answer as to how much risk someone located in the site office can be expected to run. While anyone in a designated area may be seriously at risk in the event of a serious incident it is doubtful if anyone in the office block considers that this should be a serious possibility.

178 It is unrealistic to suppose that site office block employees can be insulated from the hazards of the business so that they run no greater risk than those employed in a conventional office remote from the site. In a major incident, the possibility of some injury could be expected, although it is unreasonable to suggest that people in or near those buildings would be liable to death or serious injury through building collapse or severe glass fragmentation. Accordingly, people working in such offices should be housed in a building of design and location which would give them a level of protection that does not put them seriously at risk.

179 From the point of view of permanent location there remains a fairly large section of the workforce who are excluded from the designated areas, whom it is impractical to locate in a relatively remote side office block. These are employees such as those in the engineering workshops and associated materials stores, technical staff who work out of an office but who need to be in frequent contact with the plant areas. It is in the case of these kinds of employees that there is the biggest conflict between location for operational efficiency and location for safety in the event of an explosion or toxic release. It is our view that at worst their work base should be so located and protected that they would not expect to be seriously hurt. While this problem has similarities with which we dealt in the previous chapter, it is not the same problem and we believe it requires further study.

180 There are times when an operator recognises a period of increased hazard, as for example during plant start-up. On some plants it is essential to monitor additional functions during this period if the operation is to be carried out safely, and this means that there must be additional personnel in the hazard area. Nevertheless, because it is a period of increased hazard the rules governing admittance to the area must be tightened to exclude rigidly those people whose presence is not essential. In this way, during periods of increased hazard, the number of people brought specially into the area may often be exceeded by the number who may be temporarily excluded.

181 Similarly, circumstances arise in which there is no increase in the hazard from the plant but there is a need to bring into the vicinity of a hazard, substantial numbers of extra people above the normal operating complement. This may arise for example when installing new equipment in a designated area. Alternatively, a new plant may be destined for construction on an immediately adjacent vacant plot. Either of these situations would be accompanied by extra safeguarding to avoid interaction between the operating plant in a designated area and the new constructon. This safeguarding almost always involves additional controls on work procedures, permits and limitations of access to operating areas. Frequently it also involves physical barriers and the phasing of activities to minimise the possibility of an incident. However there are also times when the building of a new plant may be seen as quite inconsistent with continued normal operation of plant in a designated area which may therefore involve the temporary de-rating of the plant. In extreme cases this could even extend to complete shutdown for a substantial period of time.

182 It follows that the movement of people and equipment towards or into certain areas and the carrying out of associated activities must be covered by formal procedures such as permits to work.

183 There should be no conflict between safety and getting a job done but it is futile to expect that procedures and permit systems will work consistently and effectively unless they are rational, formalised, rigorously implemented and properly audited and the reasons for them clearly understood.

184 The detailed mechanics of the procedures and permits can only be determined within the overall organisational arrangements and practices of the company concerned but there are several features which we regard as essential:

(a) There must be an organisational mechanism for considering and determining how many extra people there can be in a designated area in defined circumstances.

(b) There must be a written permit arrangement before equipment can be brought into a designated area and before anyone can work on equipment in the area. This permit arrangement must cover as a minimum the nature of the job, who is doing it, the time the permit is valid, the precautions to be taken with special reference to gas testing, hot work, proximity of people.

(c) There must be a procedural arrangement for knowing who is working in a designated area at any point in time.

(d) There must be a written procedural arrangement which clarifies the levels of authority for technical approval of the work to be undertaken, and the organisational arrangements for advising, consulting, recording and auditing of the work to ensure the full involvement and commitment of all staff.

The final link in the chain, having determined that as few people as possible are exposed to a potentially serious incident is the emergency arrangement for dealing with an incident when danger is imminent and people are exposed.

185 This requires a formalised set of emergency procedures particularly the warning and evacuation arrangements for those in a designated area. To some extent these are dependent on the entry arrangements particularly if the designated area has its own perimeter fence (not to be confused with the site perimeter fence).

186 If one of the principal concerns is the release of toxic materials then clearly one of the principal ways of limiting exposure from a post-incident point of view is rapid evacuation of these not involved in the operations of the plant into an area unlikely to be enveloped in the toxic material.

8 Research

In recognition of the important role attached to research in assessing the factors which contribute to the realisation of a major hazard, the committee set up a fifth working group to study the subject. This chapter outlines their deliberations. The first task has been to evaluate the existing information available in the major hazard field in order that areas where further work is required can be identified. Particular attention has been paid to the problem of the dispersion of heavy gases and as a result of a recommendation made by the committee a series of trials has been completed. The results are discussed. The committee encourages increasing collaboration at international, governmental and industrial level.

187 It has become apparent to us that a considerable amount of theoretical and experimental work on various aspects of major hazards has been, and is being, carried out throughout the world. Nevertheless, there appears to be little co-ordination of the various programmes and there are many areas where there is considerable ignorance of the events which may arise following a failure in a plant handling hazardous materials. In particular we have felt it necessary to direct much of our attention towards the consideration of the behaviour of clouds of various substances in two broad categories; first those caused by the release into the atmosphere of a large quantity of flammable vapour in air which could burn or explode with results disastrous to persons or plant, and, secondly, those caused by the release of toxic gases in sufficient quantity to remain lethal at considerable distances from the point of escape.

188 We believe that research has an important role to play in assessing the factors which contribute to the realisation of the potential for a major calamity. In this respect, and in addition to the need for greater understanding of cloud behaviour, we regard methods for ensuring the integrity of the containment system and detection of leakage as important aspects where new knowledge and techniques are required. We also consider that there is much to be learned from a study of incidents and of near misses, and we believe that thought should be given to how experience can be pooled and disseminated to the benefit of all concerned

189 Thus in order that we may be properly advised on such matters, the fifth working group is closely collaborating with the other groups and with the Executive's own research organisation. The group is actively pursuing its main objectives which are firstly to indicate aspects relevant to the study, assessment and evaluation of major hazards which have been, or should be, subject to research; secondly to encourage research work in areas where there is thought to be a special need, and thirdly to facilitate the interchange of information between interested parties, both nationally and internationally.

190 The group agreed that its principal task must be an examination of the present state of information available in the major hazards area, including a survey of the research work. Their present aim is to identify areas where further work is required and make recommendations on how this should be sponsored and monitored.

191 It is immediately obvious that in the study of major hazards a multitude of disciplines interact and a full appreciation of the problems can be gained only by using highly specialised information and theory from several areas. Furthermore, because of the interdisciplinary nature of the problems, the relevant published material is widely dispersed in the literature with the result that it is necessary to seek material published in apparently unrelated contexts.

192 Notwithstanding these difficulties, which are common to the analysis of any complex problem, it is necessary to attempt to divide and categorise various aspects of the subject. For instance, the events leading up to an incident involving a vapour cloud may be considered in three separate stages, namely, release, dispersion and subsequent effects. Releases with which we are concerned will normally arise due to operator errors or following the fracture or failure of an item of plant and will involve the emission of large quantities of gas or vapour, possibly with associated liquid. The rate of emission will depend on the pressure and physical state of the material, upon the position, size and shape of the opening, and on those factors in the construction and layout of the plant which affect the flow of material towards the opening. Whereas there is plenty of information and adequate theory relating to the discharge of gases and vapours through orifices of simple shapes, the situation is completely different if the escaping material is a multiphase mixture and if

the geometry of the system is complex. Subsequent dispersion will be affected by such factors as the speed and direction of the discharge and the energy available to expel the material, by its density relative to that of atmospheric air, by atmospheric conditions and by topography — both the location of obstructions in the vicinity of the discharge and the nature of the surrounding landscape. The consequences of the subsequent fire, explosion or toxic effects will again depend upon many factors, including the degree of confinement, the location and nature of an ignition source, the toxicity of the substance and the population distribution. It should be noted that for a flammable material one is interested in concentrations measured in parts per hundred, whereas for toxic materials it is necessary to consider concentrations in parts per million.

193 Extensive information is available from meteorological studies on the dispersion of gases of approximately the same density as air, but much less is known of the behaviour of gases of lower or higher density. The most important low density gas which is handled in large quantity is natural gas (mainly methane), which upon escape is likely to disperse rapidly because of its buoyancy at ambient temperatures. High density gases, such as chlorine, propane, butane, and refrigerated or low temperature gas, however, may travel for considerable distances close to the ground and even when they have become diluted to such an extent that they are only about one per cent denser than the surrounding atmosphere, their dispersion characteristics may be significantly different from those of neutrally buoyant gases. It was for this reason that we recommended at an early stage that research be commissioned on the dispersion of heavy gases. In response to and following the publication of the first report, the Health and Safety Executive asked the Chemical Defence Establishment (CDE) to undertake a series of trials in which dense mixtures of vapour and air were to be released and their spread across the ground monitored. This programme of work has now been completed and the results will be published in the near future. A brief account of the work and of the preliminary conclusions reached, follows.

194 The objective of the trials was to release a series of tracer gases with a range of initial cloud densities, under various meteorological conditions, to obtain data on the dimensions and rate of movement of the cloud and on concentrations at different stages of its spread; these data were then to be analysed in terms of existing theoretical models or of any extensions to these theories which might be developed during the course of the work.

195 In practice a wide variety of conditions for initial release could occur. For example, the vapour might be generated from a pressurised liquid at a temperature above its boiling point at atmospheric pressure, or from a refrigerated liquid stored at its boiling point at atmospheric pressure. The vapour might be released as a jet of high momentum. In the field trials no attempt was made to simulate any of these particular source conditions. Instead the source was designed to release a preformed mixture of controlled initial density with zero initial momentum so as to examine the combined effects of gravity and of atmospheric dispersion.

196 In all the trials $40 m^3$ of dense vapour/air mixture was released from a collapsible-sided tent whose roof was held in position by vertical supports. The effect of the initial density of the cloud was studied by using a vapour of density 4.2 relative to air, mixed with air in various proportions. Shortly before release, orange coloured smoke was added to the dense mixture which was vigorously stirred and then left a few seconds to become quiescent. On operation of the release mechanism the tent collapsed to the ground in less than one second, leaving the smoke coloured mixture to disperse under the influence of gravitational forces and the wind.

197 Five trial sites of different slope and ground roughness were used during the series and in each case the trial site was marked out with surveying poles to give horizontal and vertical distance scales. The behaviour and progress of the cloud were monitored by using cine cameras arranged perpendicular to the main wind direction at ground level and overhead. Up to ten continuous vapour concentration monitors and up to one hundred and twenty dosage samplers were located downwind of the source. Standard meteorological measurements were taken during each trial.

198 In total forty trials were carried out, covering the following ranges of independent variables:

Initial density of mixture (relative to air)	**1.0 - 4.2**
Wind speed m/s	**0.5 - 5.9**
Pasquill atmospheric stability categories	B-G
Ground roughness (from atmospheric velocity profile measurements) mm	2 - 150
Slope	Level rising to 1 in 14 in the direction of the wind

For each trial, provided that all the instrumentation functioned satisfactorily, data were obtained of height, length and width of the cloud and of its movement across the trial site and of vapour concentration and dosage. Because of various instrumentation difficulties and such factors as late shifts in wind direction, a complete set of data was not obtained for each trial.

199 The report, which is in course of preparation for publication by the Health and Safety Executive, will give a qualitative description of the work and an analysis of the data; a film illustrating various features of dense vapour dispersion is being produced.

From a preliminary examination of the results it is seen that the influence of density on the dispersion process is considerable, particularly at low wind speeds, through the ground-hugging behaviour of dense clouds, their persistence in ground hollows and amongst long vegetation and in the greater degree of cross-wind spread compared with that for gas of neutral buoyancy. It seems likely, therefore, that a dense gas may be potentially more hazardous than a neutrally buoyant gas because dangerous concentrations can persist for a longer time.

200 The results are being interpreted in terms of a model in which it is assumed that gravity-dominated dispersion in the early stages gives way to turbulence-dominated effects later in the process. It is believed that the model may represent an over-simplification and that the transitional region is at present inadequately described. A more detailed modelling of the trial data is therefore being encouraged by HSE. As part of this study the trial data are being used in an international collaborative exercise to examine the validity of a number of existing theoretical models of dense vapour dispersion and the value of the data for this purpose has been stressed by a number of organisations.

201 The completed series of trials represents a useful step forward in obtaining a better understanding of dense vapour dispersion behaviour. Nevertheless, the quantity of dense mixture released, about 150 kg, is small relative to the quantity which may well be released in an industrial accident where, as pointed out in Chapter 1, many tonnes of hazardous vapours have been released in the past. For this reason it is considered desirable that there should be some validation of predictive models of dense vapour dispersion for larger sizes of initial release, and we are glad to learn that the Health and Safety Executive is investigating with the Chemical Defence Establishment, Porton, a feasibility study to examine the instrumentation and logistic requirements of larger scale trials. As part of this exercise, the Health and Safety Executive is engaged in technical discussions with other interested organisations to secure the maximum benefit from any trials which might be commissioned. Industrial contributions may be in the form of knowledge, money, materials, facilities and manpower and we can only encourage the development of such collaboration.

202 We are also pleased to note that, besides the particular involvement in the work on dispersion of heavy vapours, the Health and Safety Executive's own research establishments are committed to research programmes which are relevant to the committee's work, and in addition are holding discussions with industry on the possibilities of collaborative work. So far two particular problems have been identified for joint work and these relate to dispersion following a release of liquid ammonia and of chlorine respectively.

203 It is our view that in the major hazards field the collaboration in the planning of experiments and the dissemination of information is appropriate at all levels. Thus we are pleased to note that at governmental level collaboration is taking place through the Organisation for Economic Co-operation and Development, which has set up the International Group for Unstable Substances. While this group is mainly concerned with problems connected with the manufacture, storage and use of materials with unstable properties, including explosives, it has set up a working group to study the effects of vapour cloud explosions. The working group exists principally for the exchange of information on research activities carried out or sponsored by government laboratories. We are kept informed of their deliberations through the participation of HSE at the meetings which occur at approximately yearly intervals.

204 At the industrial level we are aware of the involvement of the Chemical Industries Association in major hazard topics, and we expect to maintain our close contacts with them on aspects of mutual interest. In particular we have been considering, as shown by our comments in Chapter 6, the design of control rooms, and have noted that the CIA have prepared a code of practice[24] on this topic. It is likely that continuing interest in the subject will highlight areas for further research. Furthermore we hope to continue discussions with the CIA's Chlorine Producers Sector Working Party which has world-wide affiliations and which is an important source of information on this substance including details of research that is being conducted in various parts of the world.

205 With regard to information exchange agreements, the Health and Safety Executive is a party to two which are of special interest. The first is with the US Coastguards in connection with the spillage of cryogenic hazardous materials on to water, and is related to the collaborative work mentioned above. The second concerns an information exchange between the Atomic Energy Authorities of France and the United Kingdom. While this agreement is orientated to the nuclear power industry, it will be concerned with aspects such as the effects of aircraft crashes, of seismic activity, and of external explosions on structures, some of which may be of interest with respect to our considerations.

206 Of great value to the committee is the experience of members of the Risk Appraisal Group of the Health and Safety Executive which meets regularly to give advice to local authorities who refer planning applications concerning developments at or near plants with a high hazard potential. We have asked the Executive to keep us informed of the nature of problems that are encountered to enable us to obtain a view of the various types of hazardous plant which are planned and to learn of those aspects which require further study in order that more reliable information may be available for advising the planning authorities of the risks involved in particular situations.

9 Forward look

There is inevitably a continuing need for a forum in which the problems that arise in the major hazard field can be discussed by people with the appropriate expertise. This chapter identifies areas in which the committee sees a need for further work.

207 At the completion of this second report on our deliberations it may perhaps be appropriate to take stock of the position we have reached in tackling the problems which we face in this field. We see this as being of particular interest to the Health and Safety Commission in their consideration of the future development of the various advisory committees which they have set up.

208 In the course of this report we have amplified the system we proposed in our first report for the control of potentially hazardous installations by describing how we drew attention to the activities which we saw as lying within our terms of reference, and how we arrived at the various levels proposed for a system of control. We have also dealt with specific aspects such as the categories of people and hazard areas in relation to risk, the siting and construction of buildings on site and limitations of access thereto. We do not however see the completion of our second report as marking the end of our deliberations and we therefore propose to indicate some of the areas in which we see a need for further work.

209 The development of the system of notifications and hazard surveys which will be introduced by the proposed Hazardous Installations (Notification and Survey) Regulations will lead to the building up of a comprehensive picture of hazardous activities in this country to which we attached particular importance in our first report. As that picture becomes clearer and we can see how these proposals are developing, we shall return to the subject of licensing and consider whether there is a need for the introduction of specific authorisations for installations falling within certain parameters. Indeed, the development and refinement of the notification and hazard survey scheme represents the foundation on which all our other work can be built.

210 Within that framework we see a number of more specific problems still requiring investigation. Some have been referred to in the course of this report, for example we are still discussing the extent to which pipelines should be brought within the notification system; as already mentioned in Chapter 1 we want to look at particular problems such as dust explosions and cataclysmic fires; and there may be some benefit in applying the overall approach which we have developed to the assessment of hazards in the transport of materials even though detailed regulations are being drawn up elsewhere.

211 One particularly important area is the development of a siting policy. We referred to this in our first report particularly from the point of view of being able to offer more specific guidance to planning authorities which might perhaps enable them to deal with certain categories of planning applications relating to potentially hazardous activities without reference to the Health and Safety Executive. The development of a siting policy is of course a complex and time consuming task. We understand that some preliminary thought is already being given to this within the Health and Safety Executive.

212 There will also be the ongoing need for monitoring research activities. This will already be apparent from Chapter **8.** We see our research sub-group as constituting a forum both for monitoring current research activities within as well as outside the direct control of HSE and for discussing future needs in the research field.

213 During the course of our enquiries and discussions we have noted that in some circumstances the various methods and processes that can be employed in the course of manufacture or storage of a given material differ significantly in their hazard potential. For example, the large scale storage of liquefied gases under refrigeration appears to be inherently safer than storage under pressure, though both methods are currently in use in different locations. Similarly we understand that the replacement plant at Flixborough employs a technology significantly safer than the previous one. Nevertheless care is needed to ensure that risk is not merely transferred elsewhere. However we believe that there may be much greater opportunity to use alternative processes than may be immediately obvious and we would strongly urge industry consciously to look for them and to develop them and we hope the HSE will encourage this kind of approach. There is a long history of successful substitution of materials in relation to toxic hazards exemplified by the use of safe abrasives in place of sand-blasting and the use of lead free glazes in the pottery industry.

214 We hope that our proposals for the stricter control of hazardous installations will contribute significantly to the reduction of hazard potential and will encourage industry to consider safety as a reason for choosing one path to an end product in preference to another even though the latter might appear to be initially more attractive.

215 We can envisage in the future, as a result of our proposals, a situation where a company might have to justify the use of a particularly hazardous process or material in preference to a safer one (see Appendix 1). Once the concept becomes widely accepted that technical feasibility is not the only criterion which must be considered in developing a new process then there is reason to hope that more resources will be diverted into finding safer processes and materials as well as more effective means of manufacture. A determined research effort to find safer processes in the long term might well have notable side advantages in reduced cost as a result of reduced problems of containment.

216 There remains therefore a considerable amount of work to be done in the major hazard field. Much of it is of a continuing nature and thus leads us to the conclusion that there is a case for some kind of permanent forum in which the problems that arise can be discussed by people with the appropriate expertise. The structure of that forum is not for us to decide. We would confine ourselves to pointing out that the original concept of a committee of experts who brought their individual experience to the deliberations of the committee has in our view worked well because it has enabled individual members to initiate ideas and generate discussion papers with a noticeable degree of momentum. We would hope that this momentum can be maintained.

10 Conclusions and recommendations

Notification and inventories

1 We have refined the criteria contained in our first report and have drawn up a revised list of substances and quantities requiring notification to the Health and Safety Executive. This generally confirms our original scale of quantities (para 34, 35).

2 The recommended details to be included in a notification are set out in para 40.

3 If completely separate control is involved, there is no strong case for the aggregation of hazardous substances in a notification requirement. Similarly, undertakings which have under one control a number of hazardous substances in quantities below the notifiable level, need not be notified (paras **38, 39)**.

4 The proposed Hazardous Installations (Notification and Survey) Regulations should include a 'violently toxic substances' category, (para 10) and installations containing materials under pressure should also be subject to notification (para 18).

5 Discussion on the specific requirements for the inclusion of pipelines in the proposed notification scheme is well advanced (para 15).

Assessment of hazard

6 Further investigation should be made into the causes, behaviour and consequences of fireballs and dust explosions (paras 14, 19).

7 We believe there is some evidence to support the formulation of a scaling law for explosives and it may be that with sufficient data such a law could be deduced for toxic releases. This seems to be a promising field for further theoretical and experimental work (para 25).

8 Data derived from a historical approach provide some bases for estimating the levels at which inventories should become notifiable. Techniques of prediction also have an indispensable role both in analysing the historical record, and in foreseeing situations for which historical evidence is lacking or is insufficient (para 27).

Hazard surveys

9 Persons in control of installations containing hazardous substances in quantities which exceed the notification inventories by a factor of 10 should be required to carry out a hazard survey.

This criterion should be regarded as an interim measure, and the regulations should be prepared in a form to facilitate amendment if required. In due course it will be appropriate to require hazard surveys for notifiable installations other than those which exceed the above criterion, but not necessarily for all notifiable installations (paras **45,46)**.

10 The survey should state the ways in which, under fault conditions, the hazardous material might escape from containment; the quantity and rate of release, the effects, the probability of occurrence, and the precautionary measures of prevention.

The survey should not be a once-for-all operation; further surveys should be carried out whenever significant changes invalidate the original survey; the additional survey being completed before the changes are made; also in every case at fixed intervals. In some cases, a more elaborate assessment may be called for by the Health and Safety Executive (paras 48, 50, 51).

Legal controls

11 In areas of high risk it is not sufficient for employers merely to demonstrate to themselves that all is well. They should be required to demonstrate to the community that their plants are properly designed, well constructed, and safely operated.

12 The committee has reservations about the effectiveness of a system of detailed regulations made under the 1974 HSW Act, with regard to potentially high hazard plants and feel that strongly interventionist licensing schemes have **inbuilt** drawbacks.

The concept of the employer having to demonstrate to the enforcing authority the steps taken to ensure the safety of the operation would keep responsibility within industry (paras 58, 68, 75).

13 A greater degree of particularization and documentation would not depart from the principle of 'supervised self-regulation' (para 77).

14 An outline of a possible scheme for licensing plant of the highest hazard is at Appendix 1.

Planning

15 The location of a 'hazardous' development should always be a planning matter, but the subsequent containment and control of a hazard is more appropriately and effectively dealt with under health and safety at work legislation (para 82).

16 Developers of proposed notifiable installations

should be required to inform the local planning authority that a notification under the (proposed) regulations has been sent to the HSE (para 87).

17 Local planning authorities should impose a standard condition, prohibiting without specific consent the introduction of notifiable hazards at a later date on all planning permissions of an industrial nature (para 88).
The introduction of a notifiable hazard at an existing installation, or a change of use, should be capable of planning control. An alteration to the definition of development in the 1971 Act would appear to be the most effective method (para 96).

18 Amendments to the Use Classes Order and the General Development Order would provide a reasonable measure of additional control, particularly if the notifications regulations come into force.
The committee recommends that these changes be made without prejudice to the proposal to amend Section 22 of the 1971 Act (para 96).

19 Hazard intensification is more appropriately dealt with under health and safety legislation, but the committee recommends that the HSE should inform planning authorities of any intensification of existing hazards notified to them under the proposed regulations (para 99).

20 Until greater precision is possible, general advice would be beneficial to. planning authorities to ensure that incompatible land uses are kept apart (para 102).

21 The extent of the discretionary powers of the Secretary of State for the Environment to make compensating contributions to local authorities, should be reviewed (para 107).

22 The committee endorses the view of the HSE that the existence of intervening development should not alter the advice that it gives about the possible effects of that activity on proposed developments which may appear to be less at risk than the existing ones (para 108).

Explosion hazards

23 The most significant factors affecting the magnitude and the nature of vapour cloud explosions include:

> the total effective mass of vapour and spray in the cloud; the volume, shape, and composition of the cloud.

The magnitude of the overpressure should be taken as 1 bar and 0.7 bar respectively at the middle and edge of the cloud and the duration of the overpressure can be taken as 30 ms until more information becomes available. The explosive effect in the far field can be taken for hydrocarbons as equivalent to 0.3 tonnes of TNT for every tonne of flammable material in the cloud. (paras 117, 118, 119, 120, 125, 131, 132).

24 We have not found cause to change our view that if 15 tonnes of vapour can be released, an installation should be regarded as offering a major explosion hazard (para 123).

Site safety

25 Site management buildings should be as remote as reasonably possible from potential sources of explosion or major fire, and be adequately designed. Every effort should be made to reduce, or eliminate, all but direct operational activities from buildings adjacent to the hazard.

If under specified conditions and assumptions, an airborne emission of flammable material exceeding 15 tonnes may occur, a strong control building will be needed and, if reasonably possible, it should be sited outside the confines of any likely vapour cloud (paras 139, 144, 154, 155).

26 Emergency control must be separately located, preferably near to a main entrance to a site, and the building must be so constructed as to be capable of withstanding any explosion which could occur on the site (para 150).

27 There must be a system to divide the site into areas of hazard degree, and criteria should be set for the limitation of access to those areas acknowledged to be the most dangerous.

No one should be permanently housed in, or have access to, a designated area unless there are good reasons for that person to be there.

Site office blocks should be located and so designed as to not put the occupiers at serious risk (paras 170, 173, 178, 179, 182).

Appendix 1 Model conditions for a possible licensing scheme for selected high hazard notifiable installations

The conditions outlined in this appendix have been written to give guidance as to the range and the scope of the requirements that might be required if a licensing system of control were adopted for major hazard installations with the highest hazard potential. As indicated in Chapter 3, the committee is not yet in a position to say if certain installations should be regulated in this way until more information is available, particularly from the proposed Hazardous Installations (Notification and Survey) Regulations. It is, however, clear that there is a gradation of hazard with size and complexity of plant, and as this is increased there should be a greater degree of control and surveillance by the organisation in control of such activities. Thus this appendix has a wider application than the possible requirements for a licensing system of control. It is recommended that any organisation operating a major hazard plant, particularly one at the highest level of hazard potential, should review and satisfy itself that it could demonstrate that the requirements given below are adequately met.

With regard to a possible licensing system it is recognised that a licence is the most stringent form of control under the major hazards arrangements and would be applied only to those notifiable installations which present the greatest hazard potential. The licence would be granted to the organisation which operates the installation and would be valid only for the specified location.

The approach adopted to licensing would be that foreshadowed by the Robens Committee and embodied in the Health and Safety at Work, etc Act 1974, namely that safety is the responsibility of the organisation which should demonstrate that it is taking appropriate measures to ensure effective control of the hazards.

The licensing procedure might be in two stages. At the first stage the organisation would provide the Health and Safety Executive with a statement of intent covering the nature of the proposed installation, the hazards and the features of the design and operation intended to control the hazards. At the second stage the organisation would provide HSE with design and operating information to show how the statement of intent is implemented.

The documentation required might be in two parts corresponding to these two stages and consist of:

Part 1

(a) The systems documentation.
(b) The preliminary design document.

Part 2

(a) The background documentation.
(b) The design document.
(c) The operating document.

The systems documentation, which is relevant to the licence conditions 1-9, would be concerned with the general systems which the organisation has set up to ensure safety and could be used in support of more than one licence application provided that it is up-to-date.

Details of the preliminary design document are given in licence condition 10.

The purpose of the preliminary design document would be to show the general nature of the installation and of any associated hazards. The onus would be on the organisation to draw attention at this stage to any special features which might have an important bearing on the granting of a licence.

The background documentation would be documentation on the implementation of licence conditions 1-9, in relation to the particular installation.

Details of the main design document and the main operating document are given in licence condition 10.

The main design document would be essentially a more up-to-date and detailed version of the preliminary design document, including additional details, such as materials of construction for the main plant items.

The main operating document, which incorporates the operating manual, would give details of the personnel structure for the operation of the installation.

A licence would be granted for a particular installation on a given site. The licence would not itself deal with questions of siting, but the issue of a licence is an indication that an installation meets certain standards and this is relevant to siting considerations.

The licensee would be required to inform HSE of significant changes which are proposed in any of the matters within the scope of the licence.

Conditions for a licence

The conditions for the issue of a licence are that the licensee shall demonstrate to the Health and Safety Executive that the design, construction, operation, maintenance and modification of his installation are or will be to a standard appropriate to the installation and in particular that the following features of his organisation are to such a standard:

1 The management system
2 The safety system
3 The responsible persons
4 The arrangements for the identification of hazards
5 The arrangements for the assessment of hazards
6 The arrangements for the design and operation of pressure systems
7 The arrangements for the minimisation of exposure of personnel
8 The arrangements for the administration of emergencies
9 The arrangements for reporting of and learning from incidents
10 The design and operating documentation.

Licence condition 1: the management system

The organisation should show that it has and supports a management system and staff structure which combine to ensure continuing effective control of the installation and its hazards.

The staff concerned include contractors and consultants. This aspect is considered further in licence condition 3.

The organisation should show the management structure, making clear the distinction between executive and advisory functions and should give a brief job description for each post.

The management system should give full support to the personnel who are responsible for the design and operation of the installation. Important elements include a suitable and well understood management structure; adequate human resources including coverage of absences, vacancies and emergency situations; recruitment, training and career planning; and effective communications.

The management system should in particular provide satisfactory arrangements in the areas which are the subject of licence conditions 2-9. There should be a comprehensive, formal and documented set of systems and procedures.

The management should define the objectives of its system of documentation in respect of immediate communication and of record-keeping and should specify the extent of the documentation required and the procedures for producing it.

The management system should provide for thorough initial and continuing training of personnel in their work generally and in safety in particular.

Full use should be made of appropriate standards and codes of practice. Where there are standards or codes which have statutory backing or which are commonly recognised within the UK as constituting sound practice, these should be applied as a minimum. Where there are no approved or accepted standards or codes the situation should be covered by the adoption of sound practice and the use of in-house codes.

The management system should include formal procedures for the control of modifications made to the plant or to the process, whether during design or during operation.

The management system should require the independent assessment of features which are critical to the safe operation of the installation. This independent check is essential for inspection of pressure systems and for reliability assessment of instrument trip systems. The guiding principle is that the feature is critical to safe operation of the installation. It is acceptable that the check be done by an in-house authority provided that this is genuinely independent of the interested party. Thus pressure system inspection, for example, must be done by an authority independent of the operating authority, as described by licence condition 6.

The management system should contain a variety of arrangements for the periodic audit both of the continuing appropriateness of systems and of the continuing effectiveness of their implementation.

Background

It is considered that in the case of major hazard installations the control of the plant and its hazards requires a considerable degree of formalisation of communications through written systems and procedures, standards and codes of practice. This is essentially to encourage, and where appropriate enforce, collective and personal discipline by the use of operating methods which have been carefully thought out and which contain an appropriate level of checks and counterchecks to obviate problems and reduce errors.

It is recognised that there is always the problem of over-administration through paper-work and what at times seems like 'going through the motions' without apparently contributing anything useful. However, it is considered that a careful review of incidents will, time and again, illustrate that there was a loss in discipline because appropriate procedures either did not exist or were not observed.

There should be an interlocking set of systems and procedures to ensure safety through sound engineering and management practices. There is no upper limit to the number of procedures which can be formalised, but there is nothing to be gained by deliberately trying to maximise the number. The optimum number is that which leaves no obvious gaps but avoids creating confusion by overlapping.

Many of the required procedures are implicit in the various licence conditions which follow. It is evident that key procedures include those for the identification of hazards, the assessment of hazards, the control of maintenance through permits-to-work, the control of modifications to process or plant, the inspection of equipment, the operation of the process (normal and emergency), the control of access, the conduct of safety audits, the reporting of incidents.

Self-auditing features should be built into the management system in the form of formal instructions for periodic checks on those parts of the system which may become degraded unnoticed. The operation of a permit-to-work system, for example, should be subjected to regular audit by some means such as an instruction, not merely an exhortation, to the plant manager to sample a proportion of permits each week.

Licence condition 2: the safety system

The organisation should show that within the management system there is a safety system which is appropriate to the level of hazard inherent in the installation.

The safety system should in particular provide for satisfactory arrangements in the areas of the safety organisation, safety objectives and assessment, safety consultative committees, and safety training.

The organisation should show that it has people competent to operate the safety system.

Background

Most of the aspects of the safety system mentioned are already legal requirements, but it is the object of this section to review their adequacy in relation to the major hazard installation.

A distinction can be drawn between the technological and human sides of safety. On a major hazard plant the technological features are obviously particularly important. The responsibility for these aspects rests primarily with the qualified technical staff in the design and operations areas. There should be no neglect, however, of the human side. On the contrary, on a major hazard plant it is more important than ever to run a 'tight ship' as far as safety is concerned.

The authority of the safety staff should be made clear, particularly in relation to the more technical aspects of the installation. Attention should be paid to the means of ensuring that the safety officers/advisors are effective and are seen to be so.

The safety objectives set for management and the assessment of the performance in meeting these objectives should be indicated. This may not be a simple matter of accident statistics. For major hazard installations there is an additional problem of avoiding rare but catastrophic events. This makes it important to monitor both the occurrence of 'near misses' and the degree of adherence to procedures and rules.

The programme of safety training provided for employees at all levels should be outlined.

Attention is also drawn to licence condition 9 which is concerned with the system of reporting of and learning from incidents.

Licence condition 3: the responsible persons

The organisation should nominate responsible persons who are in charge of the design and operation of the installation.

The term 'responsible person' has a specific meaning in the context and is explained below.

The organisation should show the management structure down to the lowest level of executive technical management, making clear the distinction between executive and advisory functions. There should be a job description for each post; the job descriptions for the posts held by responsible persons are particularly important.

The level of seniority held by the responsible person should normally be either the lowest or second lowest level of technical executive management.

It is envisaged that persons immediately senior to the responsible persons will themselves normally have been or be qualified to be a responsible person on major hazard installations, though not necessarily on those processes of which they are now in charge.

The organisation should show that a person nominated as a responsible person is qualified to hold the post by reasons of his academic qualifications, practical training and recent relevant experience.

On the operations side this experience should be experience in the operation of the actual process or of a similar process. Experience limited to design of the process or of similar processes and/or to operation of dissimilar processes is not acceptable. On the design side the experience should be in the design of similar processes.

Where the process incorporates features of considerable technical novelty as a result of which no person has first-hand experience of operation of relevant full-scale plant even greater regard must be paid to the level of competence of the individual and normally experience of pilot plant operation would be required.

Where the installation is to be designed in part or in whole by an outside contractor it is the responsibility of the organisation which will operate the installation to satisfy itself and to demonstrate to HSE that the design is to an appropriate standard. The minimum requirement is that there be a nominated responsible person in the operating company who has the duty of liaison with the contractor. Where practical it is also desirable to have nominated responsible persons in charge of design in the contracting company.

For convenience reference is made here only to design and operation. The organisation should enumerate all the project activities such as fabrication, construction, inspection, commissioning and satisfy itself and HSE that there are nominated responsible persons responsible for these activities.

It is emphasised that the ultimate responsibility for the safety of the installation lies with the organisation which operates it.

Background

The concepts of 'responsible' and 'authorised' persons occur in various management systems. Our usage of these words is that 'responsible' relates to a job, e.g. plant manager, and 'authorised' to a task, e.g. signing a permit-to-work.

We have considered various models for responsible persons. These include those in the Mines and Quarries Act, the Merchant Shipping Act, the Factories Act (radio-active substances), the Explosives Act, the Medicines Act.

We have also considered the arrangement whereby the Department of the Environment advised by the Institution of Civil Engineers recommends individuals for the design of reservoirs.

Competence to do a job must depend on the definition of the job and its relation to other jobs. We began, therefore, with a consideration of management structures and reviewed possible general models for a large and a small firm. It became apparent, however, that this was not a particularly helpful approach and it was not pursued. However, in a concrete situation we do consider the presentation of such a management structure and job descriptions desirable.

With regard to the level of seniority we started with the proposition that the responsible person should be at the lowest level of the executive technical management. However, this could give rise to problems in some areas. For example, it is necessary to train for succession and by definition trainees must be at a lower level. Such additional lower levels are not normal in existing practice, would be wasteful and would not offer job satisfaction. We therefore prefer to leave a degree of flexibility. But we do attach importance to ensuring that the responsibility is real rather than nominal and is at the lowest practicable level.

Thus we envisage that the responsible person on the operations side would usually be capable of 'stepping down' and carrying out the job at the next level down.

With regard to selection of responsible persons we consider academic qualifications, practical training and recent relevant experience are essential.

We think it is desirable that the person chosen should have the sort of broad scientific and technological education which a first degree in science or engineering usually gives. We consider that such a degree should normally be a necessary qualification. Exceptionally, however, people without a degree may be considered. We also attach importance to the ability of the person to recognise problems outside his sphere of competence and to his willingness to seek the advice of other experts.

We consider that although the Flixborough disaster has emphasized the importance of the integrity of the plant, there may be other major hazards where the integrity of the process is of at least equal importance. Thus, whilst it is probable that the responsible person will normally be an engineer there will be cases where he will be a scientist e.g. chemist.

We attach particular importance to the selection of responsible persons on the operations side.

We lay particular emphasis on recent relevant experience. There is obviously room for discussion as to the 'relevance' of experience or the 'similarity' of processes. It is up to the organisation to convince HSE on these points.

We stress, however, that we would not want this emphasis on recent relevant experience in any way to inhibit technological innovation or normal career development.

We accept that technological progress requires specialisation. The professional institutions already recognise this and are considering a register of persons considered competent to design and operate major hazard installations. We are maintaining contact, although, whilst welcoming their interest, we see a number of difficulties in this approach.

The requirement to nominate responsible persons should not be seen as detracting in any way from the necessity for a team effort by management to achieve high standards of safety in plants which have major hazards.

Licence condition 4: the arrangements for the identification of hazards

The organisation should show that is uses appropriate methods of hazard identification at all stages of the project.

The terms 'hazard identification' and 'safety audit' refer to mainly qualitative techniques which review the existence of a hazard.

The application of the techniques should be matched to the stages of the project, starting with coarse scale investigations and progressing to fine scale studies to discover detailed faults.

The management system should contain a formal requirement for the use of such methods, should specify the documentation required arising from this use and should monitor this use.

The organisation should show that it has people competent to implement these methods of hazard identification.

Background

The first objective of hazard identification is to reveal the substances or processes which have a hazard potential. The second objective is to identify all conceivable threats to the installation or its processes which might lead to loss of containment.

As technology has progressed identifying hazards has become in some ways more difficult. In particular, there are many hazards which are not revealed by traditional visual inspection. It has become necessary, therefore, to develop additional methods of hazard identification.

An illustrative list of methods is given in Table 1.

Since every human enterprise involves the possibility of error it follows that the soundness of the management of the potentially hazardous installation is the predominating factor and that the first essential in all cases is an audit of the management system as a whole.

It is recognised that there is a wide variety of methods of hazard identification in use in industry and that different techniques are applicable to different situations. There is no intention of imposing any particular method.

It is necessary that the use of these methods be a requirement of the management system, which also should specify the degree of recording and documentation required and should contain a mechanism for auditing the application of the techniques to ensure that they are used.

The people who have to implement these techniques must be competent to do so. HSE should be able to advise on opportunities for training in this area.

Hazard identification covers much the same ground as safety audits in the broadest sense. The Chemical Industries Association has published two guides entitled "Safety Audits: A Guide for the Chemical Industry" (1973) and "A Guide to Hazard and Operability Studies" (1977).

Licence condition 5: the arrangements for the assessment of hazards

The organisation should show that the hazards identified by the means described in the preceding section have been removed or that the associated risks have been reduced to a minimal level.

In this context 'minimal' means that the probability that an employee or member of the public will be killed or injured or that property will be damaged is at least as low as in good modern industrial practice.

The method of demonstrating that the risks are at a minimal level should be comprehensive and logical.

The method may consist of:

(a) the use of codes of practice generally recognised in the industry

(b) the use of special testing

(c) the use of calculations based on appropriate data.

In many cases it will be sufficient to show for all or at least some aspects of the hazard that a generally recognised and accepted code of practice is applicable and has been followed.

Where there is any aspect of the hazard, the risk of which cannot be reduced to a minimal level by following a recognised code of practice or by special testing, then, whenever meaningful, quantitative methods should be used to demonstrate that the risk has been reduced to a minimal level. These quantitative methods will normally consist of three steps:

(a) An estimate of the consequences to employees and the public

(b) An estimate of the frequencies with which hazardous situations will occur

(c) Comparison of (a) and (b) with the other risks to which people are normally exposed in order to show that the risk under consideration is relatively small

The management system should contain a formal requirement that such methods of hazard assessment shall be applied.

The organisation should show that it has access to people competent to implement these methods.

Background

Having identified hazards, as described in the previous sections, it is necessary to know that the associated risks have been reduced to a minimal level.

It is envisaged that the method of demonstrating the risks are at a minimal level will normally be based on a fault tree approach, but that a detailed development of all parts of the tree will not generally be required.

Sometimes it is possible to remove a hazard completely, for example, by replacing a flammable or toxic raw material by a non-flammable or non-toxic one.

More often, the hazard cannot be eliminated completely, though the risk can be reduced to any desired level by use of protective equipment. For example, the risk that a particular vessel will burst because of overpressure can be reduced by fitting a relief valve suitable for the duty, adequately sized and properly maintained. This does not eliminate the hazard completely as there is a small probability that the relief valve will fail to lift when required. Even if two relief valves are fitted, there is still a very small probability of coincident failure.

In many cases codes of practice provide generally recognised and accepted methods of reducing a hazard to a minimal level. For example, in the case just considered, it would normally be sufficient to show that the vessel is fitted with a relief valve, adequately sized and properly maintained, as relief valves have been generally recognised for many years as an accepted way of reducing to a minimal level the probability that a vessel will burst.

Similarly; if fracture of pipework has been identified as a hazard, it would be sufficient to show that the pipework has been designed and constructed and will be operated and maintained in accordance with a recognised and relevant code of practice.

Codes of practice should not be used outside their area of applicability. Codes of practice for pipework, for example, do not cover fracture by projectiles and if it is necessary to take the latter into account, a separate study is necessary.

Moreover, codes of practice imply acceptance of some level of probability of the hazard materialising. This level will be unacceptably high in relation to some major hazards.

In some cases it may be necessary to carry out special tests to quantify aspects of particular hazards.

Where there is no generally accepted code of practice and where the problem cannot be resolved by testing, but where it is reasonably practicable to show quantitatively that the risk has been reduced to a minimal level, this should be done. In some cases this cannot be done because of the lack of data or of a suitable model to describe the system. In these cases judgement will have to be used.

Examples of hazards which may not be covered by recognised codes of practice and which, if they produce major effects, would have to be individually assessed, are:

(a) Runaway reactions (e.g. decomposition and polymerisation reactions)

(b) Impact of moving objects (e.g. cranes, vehicles, missiles from explosions)

(c) Failure of instrumented protective systems

(d) Failure of services (e.g. electricity, water, compresed air)

These can be described as events leading to possible loss of containment.

The hazard quantification will normally consist of three stages in which probability and consequence must both be considered; sometimes it will be necessary to consider a number of possible outcomes differing in probability and consequence. An event which has the potential to kill many people may not cause great concern if the probability of it occurring is sufficiently small. We do not prohibit football matches because there is a small chance that an aeroplane may crash on the crowd. On the other hand we would not build a new football ground at the end of a busy runway.

(a) The first stage is the estimation of the probable consequences of the hazard. This may be based on past experience or it may be estimated from a theoretical study of the problem. The consequences may be expressed as the probability that an employee or a member of the public will be killed or injured or as the probability that extensive damage will be caused to the property of others, or both.

(b) The second stage is the estimation of the probability that the hazard will occur. Again this estimate may be based on past experience, or it may be synthesised from data on the failure rates of individual components or pieces of equipment.

In estimating the probability that the hazard will occur it is necessary to assume that certain standards are followed in the operation of the equipment, for example, that relief valves are tested regularly. If these standards are not followed the conclusions of the hazard quantification are no longer valid.

(c) The third stage is comparison of (a) and (b) with the other hazards to which people are exposed in order to ensure that the risk under consideration is minimal.

This implies the use of a criterion against which risks can be judged. It is not intended that any single criterion should cover all cases.

If it is not possible to carry out a complete study as indicated (i.e. stages (a), (b) and (c)), it may be possible to carry out a partial study and, if so, this should be done, as it helps to identify those aspects of the problem which have most effect on the probability and consequences.

Where a new feature is used in place of one of proven reliability then it should be shown that the new feature is at least as safe as, and preferably safer than, the original. For example, if an instrumented protective system is used in place of a relief valve it should be shown to fail no more often, and preferably less often, than a relief valve.

In other cases it may be appropriate to show that the risk to an employee is no greater than that for employees in the industry as a whole or to show that the risk to a member of the public is comparable with the other risks to which the public are exposed without their consent.

It may be noted that it is difficult to find examples of instances in which members of the public have been killed as a result of accidents on major hazard installations. In most cases, if the risk to employees is minimal, the risk to the public will also be minimal; although a lower level of risk is required, the public are usually further away.

It is necessary that the use of quantitative methods, whenever meaningful, should be a requirement of the management system. This should specify the recording and documentation required.

In some cases a detailed study may be required taking many days or even weeks, but in other cases relatively simple calculations may be sufficient.

The organisation should show that it has access to, and uses as necessary, people competent to assess hazards, but these people need not be in its full-time employment; they may be consultants.

Quantitative methods provide a means to assist management to choose those measures which are 'reasonably practicable' for providing a safe plant and system of work.

Licence condition 6: the arrangements for the design and operation of pressure systems

The organisation should show that it has a formal and well-understood management system for controlling and monitoring the design, fabrication, commissioning, operation, inspection and testing of pipework, vessels and other equipment together forming the constituents of a pressure system which may give rise to a serious hazard.

The term 'pressure system' refers to a linked series of equipment items operating at a pressure either above atmospheric or under vacuum, together with all the inter-connecting pipework. Such systems commonly form processing units, but the definition includes also storage and handling installations.

The management system of control should be in two parts, and should be effected through two recognised channels of authorisation, related to design and to operation.

The management design authority should identify and state the design parameters within which the pressure system is to operate and the conditions for which each component part of the pressure system shall be designed. It should also define the code under which the individual components shall be designed, or where no design code exists should cause sufficient work to be undertaken to satisfy themselves, either by experiment or by the use of specialist advisers, that the design is at least as safe under all foreseeable circumstances as the standard demanded by recognised codes.

The design authority should also define the standards to be used for the pressure system during the fabrication and construction stages. Whenever possible the standards specified should be those quoted in recognised codes applicable to the particular pressure system.

Management should ensure that an appropriate inspection system is operated during fabrication and construction work to check that the standards set by the management design authority are being met. This inspection system may be in the same management organisation as the design authority, or it may be appropriate to use one of the engineering insurance companies or other approved inspection agency. The inspection system should not be part of the operating authority. The design authority should also specify the written evidence required to demonstrate that the plant has been fabricated, constructed and proof-tested, in accordance with the design requirements. Copies of documentation forming this written evidence should be verified, preferably by the inspection agency before the pressure system enters service. Copies of all documentation relating to the design parameters and to the verification by the inspection system, should be retained by the design authority and should also be available on the works on which the pressure system is operated.

The operating authority should prepare a comprehensive set of instructions based on information issued by the design authority and upon an analysis of hazards involved. These instructions should set out clearly the way in which the pressure system shall be operated in both normal and abnormal circumstances, and the way in which the pressure system is to be protected from the effect of conditions more extreme than those permitted by the design authority. These instructions, which should be readily available to all those responsible for operation, inspection and repair of the pressure system, should set the limits within which the system is to be operated. Any variation in these limits outwith the parameters set by the design authority should be referred to the design authority or other independent qualified body for approval before fresh instructions are issued. Such submission and approval should be made in writing and copies retained in the works for future reference.

The operating authority is responsible for ensuring that any repairs and modifications are designed, fabricated and tested to a standard not less than that used by the design authority for the original system. The operating authority should have a system of documentation which controls the repair and modification procedures, so that modification to the pressure system cannot be made without written authority from an authorised person.

Thus instructions prepared by the operating authority should include formal procedures for identifying and making process modifications, for identifying and making plant modifications and for restarting the plant after discovery of a serious defect.

The operating authority should also provide and enforce the use of a code which ensures the continuing safety of the pressure system by a regular inspection of the equipment and the safety devices which are provided to protect that equipment. Such an inspection code should meet the following criteria. Firstly, that a register is held on each works in which each item of equipment is given a unique designation and an engineering description which adequately describes the design and fabrication details and also details of operating conditions, both normal and maximum. Secondly, that the code should specify the frequency of inspection for the various classes of equipment and should also specify rules concerning the selection and training of inspectors. There should also be rules by which inspection frequencies may be increased or reduced, decisions being based upon the result of inspection records which should be held in the register.

The code should specify rules which guarantee the independence of the inspecting system from the operating authority, either by appointing external inspection authorities, or by making satisfactory arrangements for the in-house inspection authority to be responsible to a senior member of the organisation who has the design authority within his charge.

The organisation should show that it has people competent to execute the control and monitoring functions described above in both the design authority and operating authority areas. It should also show that the inspection service is truly independent of the operating authority.

Background

The control of design and operation of pressure systems is a cardinal feature for ensuring safe operation of major hazard plants.

The separation of management control into the areas of a design authority and an operating authority has been made in order to bring out clearly the separate responsibilities of these two parts of the total organisation which designs, builds and operates a major hazard plant. The areas of authority interlock, and in small organisations there may be sharing of some specialist personnel. It is important, however, that the design concept and subsequent modifications to that concept should be controlled by an authority separate from the operating authority. In cases of contractor design the organisation will have to show that the contractor can carry out the duties of a design authority, particularly in the matter of documentation concerning the design parameters for the pressure system and the fabrication details, and in the provision of competent people for authorisation.

The use of a regular inspection is an essential feature of the safe continued operation of a pressure system. The register of equipment and inspection reports is the linchpin around which this inspection system is built. Decisions on the frequency of inspection and the nature of satisfactory inspection procedures should be taken by the inspecting authority with advice from the design authority. An essential feature of the integrity of the system is that the inspectors and their management are not under the technical control of the operating authority. In small organisations considerable use can be made of external inspection agencies and other specialist help. In large organisations such facilities are likely to be provided in-house. In those cases the organisaton should take particular care to show the independence of the inspection agency.

It is important that safety devices such as relief valves, non-return valves and vents are included in the register of pressure systems and are subject to the same type of inspection and testing arrangements as are specified for the pressure equipment. Details of testing and frequency of examination may well be different from arrangements made for pressure equipment, but the principle of inclusion in a register, together with test and inspection notes, is essential.

A system for registering and inspecting pressure vessels and other equipment and for the keeping of verification documentation which satisfies many of these criteria is described in BS 5500: (1976) ***Unfired fusion welded pressure vessels,*** in the Pressure Vessel Inspection Code and in the draft Piping Systems Inspection Code of the Institute of Petroleum.

Licence condition 7: the arrangements for minimisation of exposure of personnel

The organisation should show that it has assessed the hazards to personnel involved in the installation and that where necessary it has taken steps to reduce these hazards to a minimal level. In particular, measures should be taken to limit the number of people at any one time in areas of high hazard to a minimum consistent with safe and efficient operation and to afford protection to exposed personnel, who may include operating personnel, maintenance personnel, investigation teams, construction workers and visitors.

Background

This matter is fully dealt with in Chapter 7.

Licence condition 8: the arrangements for the administration of emergencies

The organisation should show that it has assessed the hazards involved in the installation in relation to major emergencies and has maintained emergency plans.

Emergency planning should include identification and assessment of possible major emergencies; nomination of persons responsible for administering an emergency; development of procedures for declaring, communicating and controlling the emergency and for evacuation; provision of buildings such as a control centre or refuge rooms and of equipment such as an alarm system; designation of works emergency teams and definition of duties of other workers; liaison with external services including police, fire and medical services; training and exercises for emergencies.

Background

A guide ***Recommended Procedures for handling Major Emergencies*** is published by the Chemical Industries Association (second edition, **1976),** This covers primarily the administration of emergencies within the works.

The guide also deals briefly with the planning of action, such as evacuation, which may be required outside the works. This is particularly important for certain major hazards. It should be emphasized in this connecton that for toxic gas hazards the value of the time bought by any distance separating the factory and the public may be wasted if there is no evacuation plan.

Licence condition 9: the arrangements for reporting of and learning from incidents

The organisation should show that it has prepared a schedule of signals to be recorded and that the relevant instuments are housed in such a way that an accident on the plant is unlikely to prevent recovery of the records.

The organisation should show that it has a system for the reporting of incidents which might endanger the installation or lead to loss of containment and that it uses the information obtained from this reporting system to learn how to reduce these hazards.

These requirements for the reporting of hazardous incidents are additional to the existing statutory requirements. They have two main objectives. One is to ensure the reporting within the company of the 'near-miss' type of incidents which often precede an accident. The other is to obtain data at national level on incidents related to serious hazards. HSE may request that certain types of incident be included.

Background

There already exist certain statutory requirements for the reporting of incidents. These include

The Petroleum (Consolidation) Act 1928
The Factories Act 1961
The Dangerous Occurrences (Notification) Regulations 1947

as well as those specific to explosives factories, mines and quarries, and nuclear installations.

These requirements are mainly concerned with accidents causing plant downtime, lost-time accidents and fatalities.

It is well known, however, that for every serious accident there are numerous incidents, including 'near-misses'. Since they are more numerous, these incidents offer greater scope for learning and improvement.

It is therefore proposed that the organisation should have its own reporting system covering the type of incident significant in relation to its particular hazards.

We have deliberately not specified the incidents which should be reported but we have in mind incidents relating to such matters as

Incidents involving serious operator error
Incidents involving trip system malfunction or disarming
Malfunctions of valves e.g. pressure relief, non-return
Leaks of flammable materials
Leaks of toxic materials
Leaks and fires at pumps
Fires and explosions in furnaces
Storage tank collapse

The important point is that the reporting system should be tailored to the needs of the organisation.

There may also be certain types of incident on which HSE wish to collect information nationally. In this case it may request their inclusion in the reporting scheme. Again we have not specified these incidents but an obvious one is the unconfined vapour cloud explosion.

These reporting requirements should be seen in relation to the fact that we have not recommended that all major hazard installations have a 'black box' recording instrument system. We consider that the arrangements proposed here are a more efficient way of learning both at company and national level.

The reporting system is intended primarily to assist the organisation to learn from incidents and it should show that is has formal arrangements to do this.

Licence condition 10: the design and operating documentation

The organisation should provide full documentation on the design and operation of the installation. The documentation required is as follows:

Part 1 Documentation

(For Part 1(a) ***The systems documentation*** see introductory section of this Appendix)

Part 1(b) Preliminary design document

This should contain:

(1) A brief description of the process and should include the nature of any chemical reaction involved and the various operations to which the material in process is subjected. In addition, any other exothermic reactions which may arise if operating conditions fall outside the design values, should be specified.

(2) A comprehensive description of the nature of the hazards in the materials handled (toxic, flammable, explosive materials), of the objectives to be achieved in order to limit these hazards and of the methods in plant design and operation necessary to achieve these objectives.

(3) A statement of any less hazardous process which could have been used and the reasons for selecting the particular process in question. This might include outstanding economic advantages, factors relating to the availability of raw materials, the avoidance of particularly difficult engineering operations or the necessity of making a product of a particular purity.

(4) A process flow sheet, indicating quantities, the temperatures and pressures of materials at each stage and the vessel inventories, and the flow-rates in each of the principal flowlines. The reasons why such pressures and temperatures must be used should be given. Mass and heat balance diagrams should be given where appropriate.

(5) A list of the ***main*** plant items, specifying the capacity, design pressure, temperature limits for

safe operation (upper and lower), and any special features of construction, together with the actual operating conditions. Details of services should be given.

(6) Details of the principal standards and codes to be used in the design.

(7) A statement of the inventory of all hazardous materials in process and of the steps taken to keep this at the lowest level consistent with safe and efficient operation.

(8) A statement of the method whereby the process will be controlled. Abnormal features, with particular reference to hazards, should be highlighted and references made to any special features, including trip systems.

(9) A list of all hazardous materials in bulk storage which may be endangered by a process incident and the steps to be taken to minimise the risk of their involvement.

(10) A statement of all materials and services needed to maintain safe operation of the plant and of the steps taken to ensure their continuous availability.

(11) A statement of any noxious effluents and their methods of treatment.

(12) A site layout showing the proposed plant and control room, and their position relative to other installations and buildings in the works, to loading bays at tanker terminals, to plants in neighbouring works and to the public area.

(13) A statement of the location and construction of the control room.

(14) The routeing for all vehicles needing access to the plant, whether for the supply of materials and removal of products, or for maintenance or emergency purposes.

(15) An account of the procedures for maintaining effective liaison between the company and any outside organisations involved in the design or construction of the plant.

(16) Details of actual experience of the company, or of availability of experience from external sources, in operation of pilot and production scale plants, for the same or a similar process.

(17) Manning levels on the plant.

(18) Proposals for dealing with emergency situations.

Part 2 Documentation

(For Part 2(a) ***The background documentation,*** see introductory section of this Appendix)

Part 2(b) The design document

This should contain:

(1) An updated and detailed statement of all materials submitted in the preliminary design document, including the process flowsheet, quantities and flowrates of all materials in process and storage areas, heat and material balances, instrument diagrams and plant layout diagrams.

(2) Details of all principal plant items, as in item 5 of Part 1(b), giving codes uses, materials of construction and any special features.

(3) Installation drawings and pipe layouts.

(4) Documentation on hazard assessments and reliability studies.

Part 2(c) The operating document

This should contain:

(1) A statement of the technical staff structure, including names of the responsible persons, together wth details of standby arrangements for absence such as sickness or holidays, and of call-in arrangements.

(2) A statement of the numbers of operating personnel and of their training with particular reference to emergency procedures.

(3) The operating manual

This should include details of the start-up, normal shutdown and emergency shutdown procedures.

Table 1 Some methods of hazard identification

Project stage	*Hazard identification method*
—	**Management and safety system audits**
All stages	**Checklists** **Feedback from workforce**
Research and development	**Screening and testing for** **Chemicals (toxicity, instability explosibility)** **Reactions (explosibility)** **Impurities** **Pilot plant**
Pre-design	**Hazard indices** **Insurance assessments** **Hazard studies (coarse scale)**
Design	**Process design checks** **Unit processes** **Unit operations** **Plant equipment** **Hazard and operability studies (fine scale)** **Failure modes and effects analysis** **Fault trees and event trees** **Hazard analysis** **Reliability assessments** **Operator task analysis and operating instructions**
Commissioning	**Checks against design, inspection, examination, testing** **Non-destructive testing, condition monitoring** **Plant safety audits** **Emergency planning**
Operation	**Inspection, testing** **Non-destructive testing, condition monitoring** **Plant safety audits**

Appendix 2 Glossary

This glossary does not aim to be a dictionary of technical terms. Firstly, the terms are restricted in number and secondly, it is not intended to define these for general use. We acknowledge that other meanings may be given to the terms in every-day speech, in other technical contexts or in industry. The purpose of the glossary is to give the meanings of certain terms as they are used in this report. It is in three sections: general; terms used in the chemical and process industries; and terms relating to explosions.

General

Hazard A physical situation with a potential for harm to life or limb.

Risk The probability that a hazard may be realised at any specified level in a given span of time; or
the probability that an individual may suffer a specified level of injury as the result of the realisation of a hazard in a given span of time.

At risk A significant probability of harm if a hazard be realised.

Terms used in the chemical and process industries

There are a number of related terms in use in the chemical petroleum and process industries which, in isolation, are difficult to define. This is because of the problems of delimiting the boundaries between some of them.

They may, however, be defined in relation to each other and here they are set out in a hierarchy of increasing size and complexity.

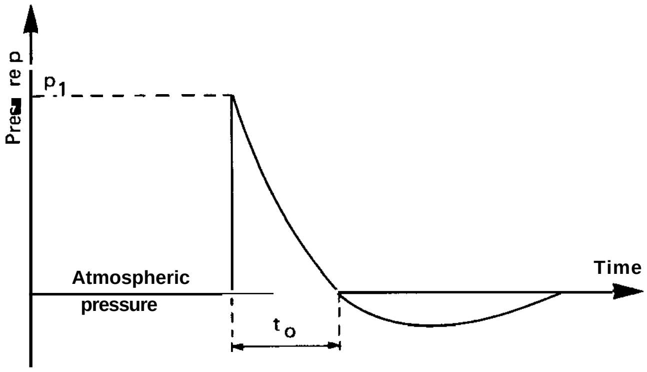
The committee recognises that their definitions may differ in their meaning from those used by a number of enterprises in the chemical and process industries. It does, however, believe that it is necessary for the committee to have an agreed terminology for use in its own publications and recommends that the Health and Safety Executive should adopt this in any regulations issued in connection with major hazards.

Inventory The quantity of a specified material or materials which an installation contains when all equipment is filled to its designed capacity.

Term	Definition	Examples
Equipment (or equipment item)	The basic items from which process units are assembled.	Pumps, valves, vessels, pipework, instruments.
Storage unit	A unit for storing particulate solids, liquids or gases or containers for such storage.	Silo. Compound for storing drums or bottled gas. Storage tank or storage sphere with associated facilities for charging and discharging.
Process unit	An assembly of equipment which performs a definable function in a process. Corresponds often with the concept of a 'unit operation'.	Distillation column with reboiler, condensers and instruments. Steam boiler with feed pumps, valves and instruments. Furnace.
Plant	An assembly of process units which produces a definable product or products.	Contact sulphuric acid plant. Ammonia synthesis plant Crude oil distillation plant.
Complex	A group of neighbouring plants on the same site.	
Site (or factory or works)	An area of land with a plant or plants with their associated buildings built on it and enclosed by a common security fence.	
Industrial complex	A group of neighbouring sites.	

Terms relating to explosions

Blast wave When an explosion occurs, the gases formed as the result of the reaction (whether from gaseous or non-gaseous reactants) are suddenly at high temperature and high pressure relative to the surrounding atmosphere. They therefore expand rapidly, driving before them the air they displace, and initiating a pressure pulse which travels outwards, at first with a velocity comparable with that of the expanding gases and afterwards more slowly, eventually degenerating into a sound wave. This pressure pulse is commonly described as a blast wave or shock wave. As it travels outwards its shape (i.e. the pressure/time relationship as it passes a particular point in space) changes. For the cases with which we are concerned in this report, however, it may be assumed that this pressure/time relationship is of the form shown in the figure overleaf a very sudden rise ('over' atmospheric pressure) to some value p, the peak positive overpressure, normally for brevity referred to simply as the overpressure, followed by a fairly steady decline to zero in time t_0, called the duration, and thereafter to a smaller negative value of longer duration. The area $\int pdt$ in the interval t_0 under this curve is called the positive impulse, or simply, for brevity, the impulse; the algebraic sum of the positive and negative impulses is usually very small, approximating to zero. Again for the cases with which we are concerned (though not for all) it may be assumed that the cause of damage is the positive over pressure phase.



Typical blast wave

If a pressure-sensitive device which offered no obstruction to the passage of the blast wave (or, roughly, one which was facing sideways in relation to its advance) were placed in its path, the device would record the changes described above. These overpressures are therefore variously described in the literature by the adjectives 'sideways-on', 'side-on', 'lateral', or (misleadingly, but presumably by analogy with the pressure base measured by the 'static' limb of a pitot tube) 'static'. In this report 'side-on' has been chosen as the most descriptive and least objectionable. If however a solid object of considerable size is exposed to the blast wave the effect on each face of the object will depend, ***inter alia,*** very much on its orientation. For instance, an isolated wall facing the wave will reflect and diffract it, and in so doing will experience a total thrust quite different from that which would be calculated by simply applying the pressure p to its frontal surface. In particular, a 'rigid' wall of a building facing the shock wave will experience due to the reflection an effective overpressure, usually called the ***reflected overpressure*** of between two and (for shocks of extremely high intensity) eight times the side-on overpressure; for the magnitudes with which we are chiefly concerned the factor may be estimated at two and a half.

Deflagration The chemical reaction of a material in which the reaction front advances into the unreacted material at less than sonic velocity.

Detonation The extremely rapid chemical reaction of a material in which the reaction front advances into the reacted material at greater than sonic velocity. The resultant blast wave is initially characterised by a very high peak pressure acting over a very short time. However, as the wave travels outwards from the source the pressure decays and the time constant increases, so that after travelling some distance the blast wave has characteristics and produces effects similar to those from a deflagration.

Duration See ***'Blast wave'***

Epicentre Originally used to denote the point on the earth's surface directly over the point of origin of an earthquake. The term has now come to mean also the inferred centre of an unconfined vapour cloud explosion (q.v.).

Explosion A rapid release of energy which causes a pressure discontinuity or shock wave, which then moves away from the source at a rate determined partly by the pressure differential and partly by the properties of the medium through which the shock wave is propagated. This pressure discontinuity and the subsequent shock wave are termed the blast wave.

A blast wave can be formed by a detonation or by a rapid deflagration, or merely by the sudden failure of a piece of equipment containing a potential energy source which is released at a high rate.

Thus an explosion and its associated blast wave can be produced by the detonation of TNT, or the rapid burning (deflagration) of a vapour cloud, or the disastrous failure of a pressure vessel containing a large volume of high pressure gas.

Fireball Is the phenomenon which may occur as the result of the deflagration (q.v.) of a vapour cloud which does not result in a blast wave.

The burning cloud may lift off the ground and form a mushroom cloud. Combustion rates are extremely high and may exceed 1 tonne per second.

Impulse See ***'Blast wave'***

Overpressure See ***'Blast wave'***

Scaled distance Is the quantity (Z) in Hopkinson's Scaling Law.

For any given explosive

$$Z = \frac{R}{\sqrt[3]{E}}$$

where R = Distance from centre of explosive source.
E = Energy of explosive

$$Z = \frac{R}{\sqrt[3]{M}}$$

Where M = Mass of explosive.

Overpressure is function of Z for a given explosive. (see Fig 5)

Stoichiometric mixture One in which the reactants are present in correct theoretical proportions for complete chemical reaction. In the case of a cloud of hydrocarbon mixed with air a stoichiometric mixture would contain just sufficient oxygen to burn the carbon in the compound to carbon dioxide and the hydrogen in the compound to water.

TNT equivalent A convenient way of expressing the size of a vapour cloud explosion by calculating the amount of TNT which when detonated at a particular point would cause damage equivalent to that caused by the exploding vapour cloud. The equivalence has

meaning only at a considerable distance as, for practical purposes, the vapour cloud, like TNT, can then be considered as a point source and the nature of the shock wave is comparable.

***Unconfined vapour cloud explosion* *An* explosion which results from the ignition, in the open air, of a cloud made up of a mixture of a flammable vapour or gas with air.**

***Vapour* Is a gas which can be liquefied by the application of pressure alone without reduction in temperature.**

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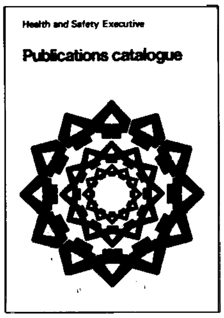
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