Journal of Hazardous Materials, 3 (1979) 149—165 149
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AN ANALYSIS OF INCIDENTS INVOLVING MAJOR HAZARDS IN THE CHEMICAL INDUSTRY

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(Received February 14, 1979)

Summary

Some problems associated with assessing the safety performance of the Chemical Industry are discussed. Over 170 major incidents involving chemical plants world-wide have been collated and analysed for trends.

The number of major incidents and the total number of people killed by such events are rising exponentially. The trend to increased size and complexity of installations does not appear to have led to more severe incidents in terms of deaths, although the analysis has limitations. Financial costs of major incidents are increasing at a rate way ahead of inflation but there is no correlation between these costs and the number of fatalities arising from these incidents. All this, together with additional considerations identified, is considered ample justification for the special attention directed at the study of Major Hazard installations.

Introduction

Today, the British Chemical Industry is fourth largest in the Western World. In Europe it is second to Germany, with annual sales around £13,800 m. Table 1 lists volumes of production for some common materials in the U.K. [1].

The increase in demand for chemicals, coupled with economies of scale and advancement of technology e.g. in petrochemicals, particularly during the past two and a half decades, has resulted in an increase in the size of chemical and allied plants. Associated processes have been integrated forming chemical complexes on single sites. In 1967 and 1972 H.M. Factory Inspectorate expressed concern [2, 3] regarding the potential hazards associated with large industrial plants. Subsequently the Roben's report [4] referred to:

(a) "....the need to protect the public as well as workers from the very large scale hazards which sometimes accompany modern industrial operations."

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TABLE 1

Production figures of some common chemicals in the U.K.

Commodity	Production (million tons)
Ammonia	1.0*
Chlorine	1.0
Ethylene	1.2
Benzene	0.7
Propylene	0.7
Ethylene oxide	0.2*
Sulphuric acid	1.3
Hydrochloric acid	0.1

*1970 figures since 1976 figures not available.

(b) "....a number of locations in this country where high explosives or flammable substances are kept in such quantities that any failure of control — however remote the possibility — could create situations of disaster potential."

However it was the explosion at Nypro (UK) Ltd on June 1st 1974, the first major incident in the U.K., that provided the main impetus for the setting up of an Advisory Committee on Major Hazards. Their first report [5] was published in 1976 and in 1978 a Consultative Document was issued by the Health and Safety Commission [6]. Concern is essentially for those installations which could present a major threat to the safety of the workforce or the surrounding community from:

(i) catastrophic fires;

(ii) massive escape of volatile liquids or gases to form a large cloud of flammable vapour which may explode; or

(iii) massive release of toxic substances which could remain lethal for up to 20 miles from the point of escape (Great Britain, Health & Safety Commission, 1978).

The scale of operation, and the inventory and nature of the materials on site, are clearly important factors. Indeed it has been proposed [7] that the fatality rate in scaling up a process can be correlated by the expression, $F_R = KS^{0.5 \text{ to } 0.33}$, where F_R = fatality rate, K = a constant and S = stream capacity. The subject has recently received considerable attention in the literature; for example the present authors have discussed the definition and significance of Major Hazards [8] and reviewed their identification and control [9]. The recent report [10] on the investigation and assessment of the overall risks to health and safety arising from possible accidents at existing or proposed hazardous installations on Canvey Island, including the loading and unloading of dangerous substances (e.g. L.N.G., L.P.G., crude oil and ammonia) was a major contribution, costing in all about £400,000.

Understandably, concern has been expressed regarding the amount of effort devoted to such installations, since incidents involving them are fortunately rare in the U.K. and they cause fewer fatalities per year than the daily, less-spectacular accidents in the chemical or other industries. For example, Benson [11] suggests that "there could be a national cost which might be loss of overseas investment..." in the event of the government adopting an unbalanced approach and questions whether there is "any evidence that the consumer needs more protection from major chemical hazards than he has at the moment".

The present paper discusses the allocation of resources and assesses whether Major Hazards merit the attention they currently receive. In addition, reference is made to some problems associated with determining the safety performance of the Chemical Industry.

The problem

In allocating effort from finite resources to attempt to solve a variety of problems the quantity and rate (urgency) allotted to each should be determined by the magnitude of the problem. For Major Hazards this is a function of their number and the risk associated with each installation. This risk is determined by a combination of the *chance* of something going wrong coupled with the likely *consequences* of such a mishap. Since the latter component is socio-technical it is inevitable that any effort devoted to the problem of Major Hazards will be influenced not only by the "need" from a purely technical point of view, but also by social pressures, such as emotional and political implications. Such criteria, although important, should not be confused with the technical considerations.

Therefore care is required when statistics which purport to measure the risks associated with industry are used to justify technically the effort in studying Major Hazards. This can be illustrated by "over-3-day absences per thousand employees", a common yardstick for monitoring industrial safety performance. Besides being beset by under reporting, a limitation of this method surrounds the "severity threshold" [12]. This is the degree of injury above which a person goes absent from work; since this is strongly influenced by social and economic factors it is clearly an imperfect measure of true safety records.

Fatality statistics are considered more reliable than absence returns. Thus fatal accident frequency rates (FAFR) are believed to be a more accurate indication of the risk associated with a particular industry. Examples [13, 14] are given in Table 2. The FAFR is defined as the number of fatalities occurring in 10^8 working hours, sometimes expressed as deaths from industrial injury in a group of 1000 employees during their working life. Thus, like over-3-day absence statistics, FAFR figures neglect any effect of an industrial accident on the surrounding community, which is an essential consideration when assessing the problems of Major Hazards. Furthermore FAFRs do not include deaths resulting from acute events with chronic fatal outcomes.

TABLE 2

The FAFR for various occupations

Occupation	FAFR
Chemical industry	4
British industry (i.e. all premises covered by the Factories Act)	4
Clothing and footwear	0.15
Vehicles	1.3
Timber, furniture etc.	3
Metal manufacture, shipbuilding	7*
Agriculture	10
Fishing	35
Coal mining	12*
Railway shunters	45
Construction erectors	67
Staying at home (men 16—65)	1

*Latest values (T.A. Kletz, 1979).

Hence, in order to assess the safety record of "Major Hazards" more realistically, information on some 176 incidents worldwide with potential for multiple casualties was collected and analysed. The data were collated from four main sources [15—18] and summarised in Table 3, which is not intended as a comprehensive list of all incidents reported in the literature and press. The data were analysed for useful trends and to provide some indication as to whether the considerable effort devoted to a study of Major Hazards is warranted.

Analysis of major incidents

An analysis of the frequency of major incidents (i.e. with potential for multiple fatalities) in the U.K. is of limited value since the sample size is too small to be meaningful. All that can be concluded is that there were more incidents during the past decade than in the preceding 40 years.

An analysis of the frequency of major incidents world-wide, however, was more revealing and is illustrated by Fig.1. It may be argued that the exponential nature of the curve itself is ample justification for devoting resources to halt the rate at which such incidents occur, even though such a general trend could be expected simply from the growth of the industry.

Similarly, an exponential rise in the total number of fatalities from major incidents can be detected from Fig.2: the exponential trend for the period 1950—77 is emphasised by use of moving means (averaged over overlapping three-year periods) as shown in Fig.3. (Zero fatalities was assumed for incidents with unknown outcomes on the basis that multi-casualties are likely to receive

TABLE 3

Major incidents involving flammable and/or toxic material with potential for multiple fatalities

			Killed/injured			Cost (US$M)				
Year	Location	Description	Actual	Total for year	Mean fatalities/incident for year	Actual	Adjusted to 1976 values	Total for year	Mean per incident	Mean for fatality
1914	New Jersey, USA	Chlorine release (7 tons)	0/?	0/?	0	?	?			
1917	Michigan	Chlorine release (13.6 tons)	1/?	1/?	1	?	?			
1920	Niagara Falls	Chlorine release (0.07 tons)	3/7	3/7	3	?	?			
1921	England	Break up of dirigibles over Hull releasing hydrogen which ignited	1/?	1/?	1	?	?	—	—	—
1925	Oklahoma	Chlorine release (0.07 tons)	2/?	2/?	2					
1926	France	Chlorine release (25 tons)	40/?	40/?	40					
1928	New York	Chlorine release (2 tons)	0/0	10/?	5					
	Germany	Phosgene release (10 tons)	10/?							
1929	New York	Chlorine release (22.5 tons)	1/?	1/?	1					
1934	Niagara Falls	Chlorine release (14.5 tons)	0/?	0/?	0					
1935	Indiana	Chlorine release (27.3 tons)	0/?	0/?	0					
1936	Johnsonburg	Chlorine release (3 tons)	1/?	1/?	1					
1939	Roumania	Chlorine release (25 tons)	60/?	60/?	60					
1940	Norway	Chlorine release (8 tons)	3/?	3/?	3					
1943	Los Angeles, California	Escaped butane ignited	5/?	5/?	5	?	?	—	—	—
1944	Cleveland, Ohio	LNG escaped and caught fire	213/?	213/?	213	?	?	—	—	—
1945	New Jersey	Crude oil released and ignited	0/2	0/2	0	0.1	?	—	—	—
1947	Finland	Chlorine release (30 tons)	19/?	21/?	7					
	Illinois	Chlorine release (16 tons)	0/?							
	West Virginia	Chlorine release (0.07 tons)	2/?							
1948	Germany	Railcar of dimethyl ether ruptured alongside dimethyl aniline plant and ignited	245/ 2,500	245/ 2,500	245/ 2500	15	?	—	—	
1949	Texas	Chlorine release (5 tons)	0/?	0/?	0					
1950	U.K.	Chlorine release (0.5 tons)	0/?	0/?	0					
1951	Illinois	Butane escaped but failed to ignite	0/?	0/?	0	?	?	—	—	—
1952	Newark, USA	Unconfined propane vapour cloud explosion	?	7/?	35					
	Wilsum, Germany	Chorine release from storage tank (15 tons)	7			?	?			
1954	Tennessee	IPA and vinyl chloride escaped and ignited	?	1/?	0.25	0.25	0.68			
	West Virginia	Release of acrolein from ruptured tank car	0			2	5.4	6.97	2.3	
	Portland, Oregon	Escape of LPG from tank car valve	?			0.33	0.89			
	Canada	Chlorine escape (0.07 tons)	1/?							

TABLE 3 (continued)

Year	Location	Description	Killed/injured			Cost (US$M)				
			Actual	Total for year	Mean fatalities/incident for year	Actual	Adjusted to 1976 values	Total for year	Mean per incident	Mean for fatality
1955	California	Butane escaped from gasoline plant and ignited	?			0.4	1.0			
	Whiting, Indiana	Detonation in an ortho flow hydro reformer	2/30	2/30	1	16	40	41	20.5	20.5
1956	New York	Explosion of ethylene escape from polyethylene plant	?	?	0	?	?	—	—	—
	Lake Charles	Chlorine release (2.7 tons)	0/?							
1957	Quebec	Butane escape from exploding storage sphere	1/?	1/?	0.5	3.2	7.1	7.1	7.1	7.1
	U.K.	Chlorine release (2 tons)	0/?							
1958	Oklahoma	Ignition of propane at refinery	0/1			0.1	0.2			
	Niagara Falls	Detonation of railcar containing nitromethane	0/200	3/219	0.75	1	2.1	22.8	5.7	7.6
	Signal Hill, California	Ignition of vapours from frothing tank	2/18			9	19.4			
	Michigan	Butane tank ruptured and gas ignited	1/?			0.5	1.1			
1959	Georgia	LPG caught fire and exploded	23/?	23/?	23	?	?	—	—	—
1961	Texas	Escape of cyclohexane from oxidation process	1/0	1/0		0.7	1.5	1.5	1.5	1.5
	La Barre	Chlorine release (27.5 tons) from railcar	1/?		0.66	?	?			
	U.K.	Chlorine release (12 tons)	0/?							
1962	Kentucky	Ethylene oxide tank contaminated with ammonia causing explosion and ignition of cloud	1/9	11/26	3.7	8	16.6	17.0	8.5	1.5
	New York	LPG escaped from ruptured tank and exploded	10/17			0.2	0.4			
	Ontario	Chlorine release (27.5 tons)	0/?							
1963	Texas	Fire and explosion in polypropylene plant	?			6	7			
	Louisiana	Gas escaped from ethylene plant and exploded	0	0	0	3.9	8.0	15	7.5	—
	Brandtsville	Chlorine release (8 tons)	0/?							
1964	Nevada	Hydrogen vented and ignited	0			?	?			
	Texas	Escaping ethylene ignited by electrical switch gear	?	9/57	2.2	3	6	24	7.5	1.8
	Texas	Ethylene pipe exploded resulting in vapour cloud explosion	2/17			4	8			
	Massachusetts	Escaping vinyl chloride ignited explosively	7/40			5	10			
1965	Louisiana	Propane escape from ethylene process	0/12			3.2	6.4	20.2	6.7	—
	Louisiana	Ethyl chloride ignition	0	0/12	0	0.9	1.8			

TABLE 3 (continued)

Year	Location	Description	Killed/injured			Cost (US$M)				
			Actual	Total for year	Mean fatalities/incident for year	Actual	Adjusted to 1976 values	Total for year	Mean per incident	Mean per fatality
	Texas	Explosion of escaping vapour from polypropylene process	?			6	12			
1966	W. Germany	Ignition of escaped methane in ethylene process	3/83			4.8	9.4			
	Feyzin, France	Ignition of propane cloud escaped from ignition sphere	18/63	42/148	7	3.3(a)	6.5	23.1	5.8	0.7
	Louisiana	Ignition of butadiene	3/2			0.016	0.03			
	La Salle, Canada	Styrene in polymer plant exploded	11/?			3.7(b)	7.2			
	Pennsylvania, USA	Mixture of cumene, benzene and propane ignited	0			?	?			
	Italy	Chlorine release (7 tons)	7/0							
1967	Louisiana	Isobutane from alkylation unit escaped and ignited	7/?			35	65	65	33	9.3
	Texas	Ethylene cloud produced but failed to ignite	0			0	0			
	Newton, Alabama	Chlorine release (50 tons)	0/?							
	Santos, Brazil	Confined coal gas explosion causing widespread damage	0/300			?				
	New Jersey, USA	Explosion rocked four blocks of buildings	2/16			?				
	Argentina	Propane fire destroyed 400 houses	0/100	13/454	1.6	?				
	Antwerp	Fire involving vinyl chloride	4/33			?				
	New South Wales	Chlorine release causing evacuation of large area of town	0/5							
1968	Louisianna	Escape of vinyl chloride from VCM plant	0			0.83	1.48			
	Pernis, Holland	Explosion of vapours from frothing tank	2/75			28(c)	50	55.1	18.4	18.4
	Tamytown, Texas	Escape of C_3 hydrocarbons from IPA plant	1/2			2	3.6			
	Lievin France	Ammonia release (15 tons)	5/?			?	?			
	East Germany	Vinyl chloride release	24/?							
	Paris, France	Petrochemical plant explosion 400 people evacuated	?			?	?			
	Hull, U.K.	Confined vapour explosion involving acetic acid	2/13	34	3.8					
	Norway	Gas explosion	?							
	Alaska	LPG explosion	?/2							

TABLE 3 (continued)

Year	Location	Description	Killed/injured			Cost (US$M)				
			Actual	Total for year	Mean fatalities/incident for year	Actual	Adjusted to 1976 values	Total for year	Mean per incident	Mean for fatality
1969	Repesa, Spain	LPG leak ignited and burned for 6 days	0			$7.1^{(d)}$	12.1			
	England	Cyclohexane escape from oxidation plant ignited	2/23			?	?	18.1	9.0	9
	England	Naphtha and hydrogen escaped and ignited	?			3.5	6.0			
	Libya	LNG incident	0/12			?				
	Ohio	Chlorine release (1 ton)	1/?			?				
	Puerto La Cruz	Light hydrocarbon incident causing extensive damage to town	5/?			?				
	Long Beach, California	Lid of 600 gal tank ejected into suburban area	1/83			?				
	Escombreras	Petroleum explosion causing widespread damage and the evacuation of 5000 people	4/3	22/?	2.2	?				
	Crete, USA	Ammonia release 64 tons from rail tank cars	6/?			?				
	Basle, Switzerland	Nitro liquid explosion	3/28			?				
1970	Missouri	Propane cloud detonated equivalent to 70 tons TNT	0/1			?	?			
	Hull, England	Propane fire	2/?							
	Louisiana	Vinyl chloride escaped from VCM plant without ignition	0	7	0.7	0	0			
	New Jersey	Cloud of hydrogen/hydrocarbon escaping from reactor exploded	0/40			30	48	48	24	
	S. Philadelphia	Oil refinery blast	5/27			?				
	Surrey, England	Propane/butane exploded causing damage to residential property	?			?				
	St. Thomas Island	Natural gas explosion rocked virtually the entire island	0/25			?				
	Illinois	Propane escape from derailed rail tank car and destroyed part of town	0			?				
	Sweden	Chlorine release (2 tons)	0/?			?				
	Blair, Nebraska	Ammonia release from storage tank (145 tons)	0/?			?				
1971	Louisiana	Ethylene explosion	0/8			2.6	3.9			
	Texas	Ethylene explosion	3/7			8.8	13.1			
	Texas	Butadiene explosion	1/6			0.16	0.24	17.24	4.3	4.3
	Florida	Cyclohexane cloud escaped from oxidation plant without igniting	0			0	0			
	Emmerich	—	4/4							

TABLE 3 (continued)

Year	Location	Description	Killed/injured			Cost (US$M)				
			Actual	Total for year	Mean fatalities/incident for year	Actual	Adjusted to 1976 values	Total for year	Mean per incident	Mean for fatality
	Holland	Butadiene	8/21	16	2.3					
	Arkansas	Ammonia leaked (570 tons) killing livestock and fish and damaging 10,000 acres of forest	0/?							
1972	Illinois	LPG from crashed railcars ignited	0/230			7.5	10.8			
	Brazil	Explosion of butane cloud	38/75			8.4	12.1			
	Montana	Butane explosion	1/1			2.3	3.3			
	Delaware	Vinyl chloride escaped but failed to ignite	0			0	0	26.2	8.7	0.7
	Texas	Spilled crude oil ignited	1/2	65	8.1	?	?			
	West Virginia	Propane fire	21/20			?	?			
	Holland	Hydrogen explosion	4/4							
	East St. Louis	Propylene explosion resulting from rail car shunting accident	0/230							
1973	Austin, Texas	70 tons natural gas exploded	8/?			?	?			
	Japan	Ethylene explosion	1/4			10	22			
	Japan	1100 tons vinyl chloride exploded	1/23			?	?			
	New Jersey	Vapours from reactor exhaust ignited (methanol)	?/?			2.2	2.9	52.7	17.6	52.7
	Cologne	Explosion of 10 tons vinyl chloride	?			$21.4^{(e)}$	27.8			
	Gladbeck, Germany	Cumol incident causing evacuation of 1000 people	?			?	?			
	U.K.	Gas works explosion	4/24			?	?			
	France	LPG truck overturned	6/37							
	California	Vinyl chloride explosion causing widespread structural damage	0			?	?			
	New York	LPG explosion	40/?	78	5.5					
	S. Africa	38 tons of ammonia escaped	18/65							
	Falkirk W.G.	Fire ball of flammable liquid vapours destroyed distillery	?			?	?			
	Loos, Canada	Chlorine release (15.5 tons)	0							
	Kansas City	Ammonia release (210 tons)	0							
1974	Flixborough	Explosion of cyclohexane from oxidation plant	28/104			$70^{(f)}$	83			
	Florida	Propane explosion	0/0			1.	1.2			

TABLE 3 (continued)

Year	Location	Description	Killed/injured			Cost (US$M)				
			Actual	Total for year	Mean fatalities/incident for year	Actual	Adjusted to 1976 values	Total for year	Mean per incident	Mean for fatality
	Illinois	Isobutane explosion	7/356			18.4	21.7			
	Mississippi	Butane explosion	0/24			?	?			
	England	Ethylene explosion at polyethylene plant	0/2			?	?			
	Texas	Butadiene explosion	1/235			13.3	15.7	163.2	18	4.1
	Texas	Explosion of C_5 hydrocarbons from isoprene unit	2/10	55	3.6	16	19.2			
	Washington	Explosion of rail cars of monomethylamine nitrate	2/66			5	6			
	Texas	Vinyl chloride explosion (75 tons)	0/?			?	?			
	California	Explosion of trailer or organic peroxides	?			5	6			
	Rotterdam	Petroleum fire	?			6.1(g)	7.3			
	Louisiana	Propylene explosion	0			2.6	3.1			
	Czechoslovakia	Ethylene explosion	14/79			?	?			
	Roumania	Ethylene explosion	1/50			?	?			
	Nebraska	Chlorine escape, 500 evacuated	?			?	?			
1975	Belgium	Ethylene from polyethylene plant explosion	6/15			50	53			
	Beek, Holland	Propylene explosion	14/104			40(h)	42.8			
	Germany	Naphtha plus hydrogen exploded	0/4			1	1.1			
	California	Hydrogen explosion	0/2			2.75	2.91			
	Louisiana	Butadiene escaped without ignition	0			0	0			
	Louisiana	270 tons propane escaped but failed to ignite	0			0	0			
	Czechoslovakia	Explosion of light hydrocarbons	14/?			?	?			
	Holland	Ethylene explosion	4/35			?	?			
	France	Large confined vapour explosion	1/3	55	4.5	?	?	109.8	15.6	3.7
	S. Africa	Methane explosion	7/7			?	?			
	Philadelphia	Crude oil explosion	8/2			9	10			
	Essex, England	Electrolytor plant explosion	1/3			?	?			
1976	Texas	Ethylene explosion at alcohol plant	1/15			18	18			
	Texas	Natural gas leakage ignited	1/4			0.05	0.05	28	9.3	3.5
	Puerto Rico	C_5 hydrocarbons ignited	1/2	18	2.3	?	?			
	New Jersey	Propylene explosion	2/?			?	?			
	Lake Charles	Isobutane explosion	7/?			?	?			
	Baton Rouge	Chlorine release 10,000 evacuated	0							
	Norway	Flammable liquid escaping from ruptured pipe explosion	6/?			10	10			
	Seveso, Italy	Escape of TCDD resulting in evacuation of entire area.	0							

TABLE 3 (continued)

			Killed/injured			Cost (US$M)				
Year	Location	Description	Actual	Total for year	Mean fatalities/incident for year	Actual	Adjusted to 1976 values	Total for year	Mean per incident	Mean for fatality
1977	U.K.	Fire and explosion involving sodium chloride plant	?							
	Mexico	Ammonia escaped and leaked into sewer system	2/102							
	Quatar	LPG explosion damaging villages distant from source and closing airport	7/many	50	4.5			?	?	?
	Mexico	Vinyl chloride release	0/90							
	Taiwan	Vinyl chloride	6/10							
	Cassino, Italy	Propane/butane explosion	1/9							
	Jacksonville	LPG incident resulting in evacuation of 2000	?							
	Gela, Italy	Ethylene oxide explosion	1/2							
	India	Hydrogen explosion	0/20							
	Italy	Ethylene explosion	3/22							
	Columbia	Ammonia escape	30/22							

Notes

1. Zero fatalities were assumed for incidents of unknown outcomes (see text).
2. Only those incidents with costs quoted were used in computing "mean incident costs", since many of those incidents with unknown costs will have resulted in material damage.
3. Mean costs per fatality were computed from (2) by dividing the cost by the number of fatalities from those incidents for which costs were quoted.
4. Key: (a)based on FF 16 million and converted at rate 13.68 FF = 2.78 US $ (The Times 1966).
   (b)based on C $ 4 million and converted at rate 2.99 C $ = 2.78 US $ (The Times 1966).
   (c)based on £11 million and converted at rate £1 = 2.39 US £ (The Times 1968).
   (d)based on Pts 500 million and converted at rate 166.50 pts = 2.38 US $ (The Times 1969).
   (e)based on DM 50 million and converted at rate 5.85 DM = 2.50 US $ (The Times 1973).
   (f)based on £19 million and converted at rate £1 = 2.41 US $ (The Times 1974).
   (g)based on DFl 16 million and converted at rate 6.27 DFl = 2.41 US $ (The Times 1974).
   (h)based on £10 million and converted at rate £1 = 2.37 US $ (The Times 1975).

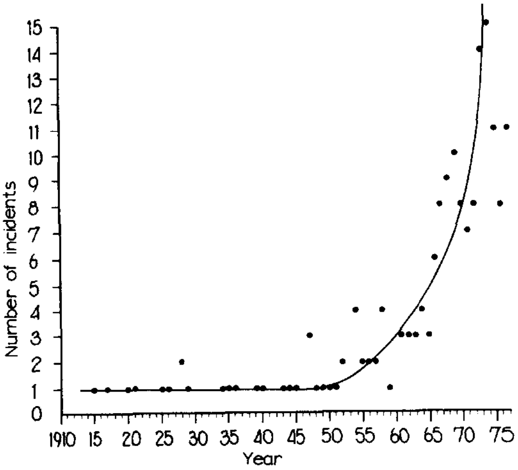
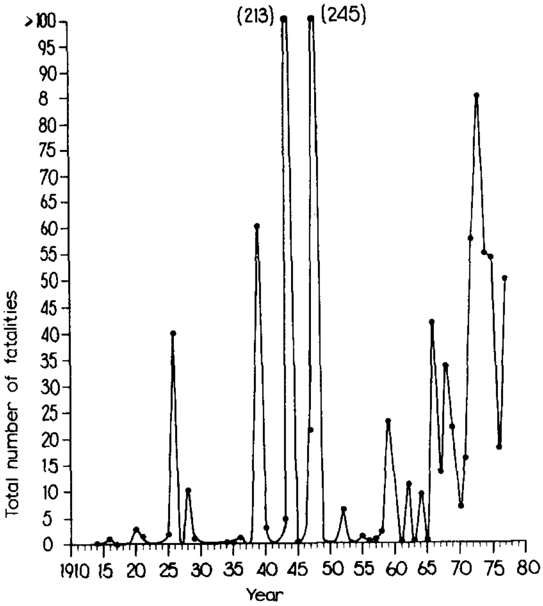


Fig. 1. Frequency of major incidents (i.e. with potential for multiple fatalities) worldwide.



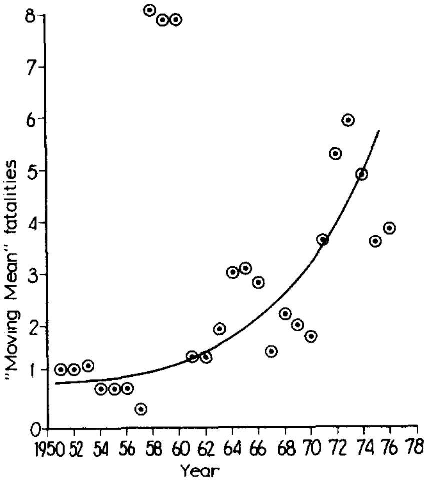
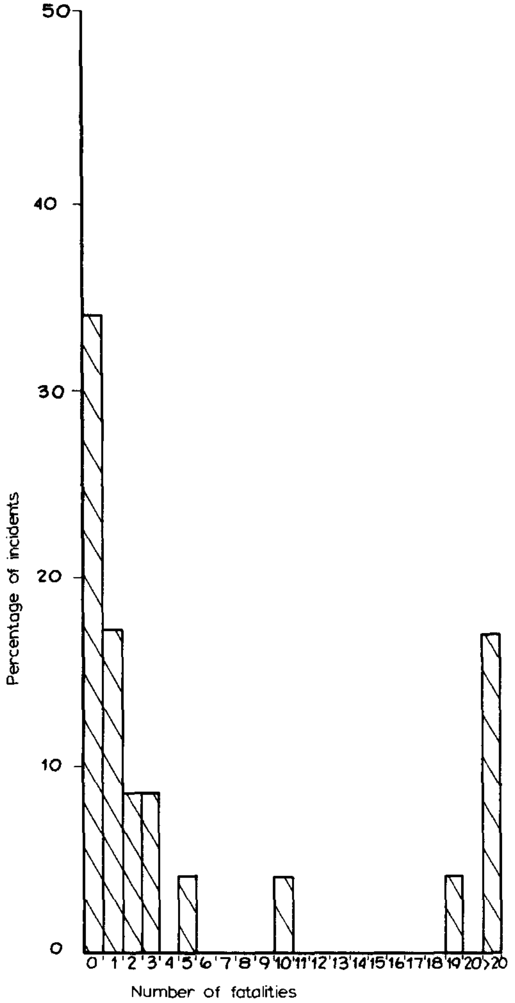


Fig. 2. Total number of fatalities from major incidents worldwide.

Fig. 3. Mean fatalities per year.

publicity.) It is not clear from these data alone, however, whether or not the rate of increase in fatalities is simply in line with the number of incidents or whether the trend to increased plant and site capacity has indeed increased the severity of incidents. If, as argued earlier, the significant changes in the industry with regard to the number, size and complexity of installations commenced in the 1950's (which also coincides with the upturn in the frequency of major incidents in Fig.1), then any effect of such changes on the outcome of incidents may be revealed by a comparison of data for incidents pre-1950 with those of more recent events. Accordingly, the histograms in Fig.4 were constructed. In-



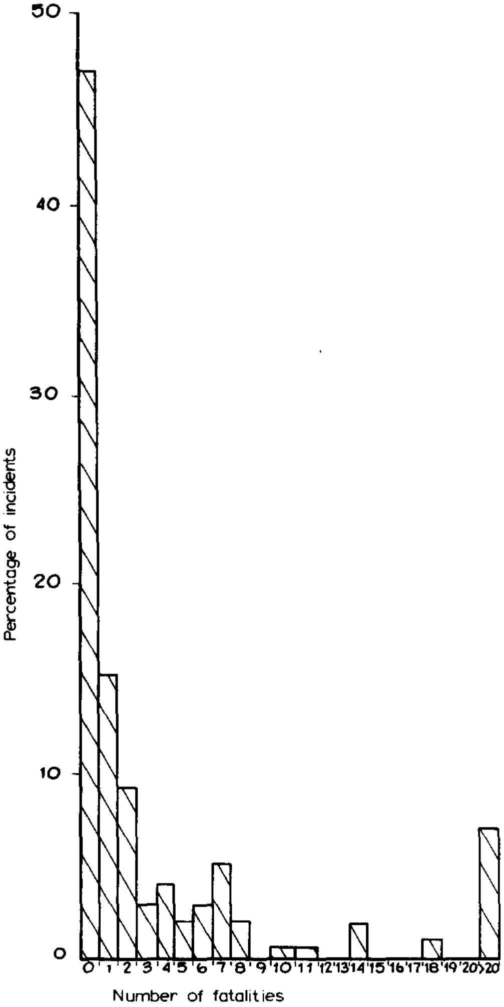


Fig.4(a). Pattern of major incidents prior to 1950.

Fig.4(b). Pattern of incidents since 1950.

terestingly, although a preliminary analysis suggested that the severity of incidents was increasing [8], visual inspection of the current data reveals little difference in the pattern of events for the two periods. If anything, the trend is to less severe disasters, although it is likely that this difference is not statistically significant. Thus pre-1950, 70% of all reported major incidents resulted in less than 5 fatalities while the corresponding figures for the period 1951—76 is 77%. Also, 17% of all incidents before 1950 resulted in 20 or more deaths whereas only 4% of incidents since then have caused 20 or more fatalities. The 2 most serious accidents before 1950 killed 213 and 245 in 1944 and 1948, respectively, while the worst two incidents since then in 1972 and 1973 resulted in 38 and 40 fatalities.

This cursory analysis does suggest that while present day large installations possess greater potential for harm, in reality this has not resulted in incidents of greater fatal consequences. Possibly, this is attributable to improvements in technology and more sophisticated design techniques. However a limitation of this approach for assessing the degree of hazard associated with major installations is the neglect of effects of incidents on the impairment of the health of the community by such disasters as that involving TCDD at Seveso [19]. For example, of the more than 100 incidents involving flammable/explosive vapours 13 involved vinyl chloride and of these at least 2 involved formation of a large unconfined vapour cloud without ignition. In these cases the cost was considered zero both in material and human terms, whereas, in addition to other toxic properties, vinyl chloride has potential to cause angiosarcoma in humans exposed to the vapour [20, 21], and it is uncertain whether the effect of this compound is time-dependent or whether a summation law holds [22]. In summary, the above mortality figures include those in which death occurred within a very short time-span of the incidents and fails to include casualties with deteriorated health leading to a reduced expectancy of life. Because of this limitation, the paucity of data in certain areas, and the unknown significance of improved reporting in recent years on the trend, a more detailed analysis of the data is not justified.

The financial costs of major incidents were also examined. Thus, Fig. 5 shows the change in average cost of incidents with time on which the mean cost per fatality is superimposed. All costs were normalised to 1976 values using data from Fig.6 to eliminate the main effects of inflation [15]. Only those events with quoted data on costs were used in calculating average costs per incident. Again by visual inspection an upward trend in the cost of major incidents is discernible, as might be expected from the trend to increased size and complexity of installations. The limited data suggest that the number of fatalities do not increase proportionally with material damage. Indeed, those incidents resulting in greatest financial loss are rarely the most costly in terms of lives i.e. there is no correlation between loss of life and material loss.

From the foregoing it is concluded that the special attention directed at affording additional protection to those working on Major Hazard sites is considerec

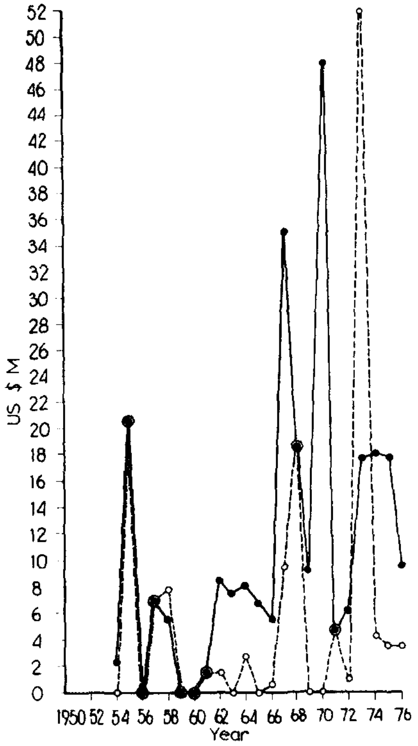


Fig. 5. Mean costs. (●) Mean cost per incident; (○) mean cost per fatality.

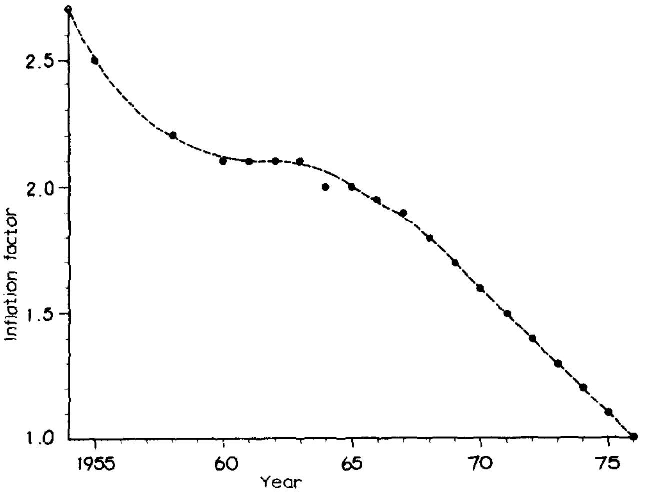


Fig. 6. Inflation factor.

justified on technical grounds because:

1. Incidents involving these installations although not increasing in severity are increasing exponentially in number.
2. The total number of fatalities arising from major incidents is increasing with the rising trend of incidents.
3. The cost of material damage caused by major incidents is substantial and rising ahead of inflation.

Further justification for expending additional effort on a study of Major Hazard installations comes from:

1. The greater size of the population potentially at risk from Major Hazards than exposed to the "normal" risks within industry. Thus, in considering the more frequent accidents leading to injury and loss of life in the industry, attention is directed solely at the workforce. However when considering Major Hazards the surrounding populace must also be considered and although the industry tends to be capital not labour-intensive and the total workforce per shift at a Major Hazard installation may be low, the neighbouring population density may be high.
2. The greater susceptibility of the community at large compared with the local workforce and the need for a lower level of acceptable risk [23]. Thus in the main the workforce is composed of healthy adult males trained in emergency procedures and, in the case of toxic hazards, provided with respiratory protection apparatus. Conversely, the community at large also contains children, the aged, the infirm, pregnant women and others more susceptible to impairment of health.
3. The disruption to the community as a whole, physically, mentally and economically as a result of single acute major events leading to multiple casualties and/or material damage, in contrast to the more frequent, less spectacular accidents in the industry. Both the emotional and the economic/social implications of loss of life, damage to dwellings, unemployment, lost production etc. must be quantified.
4. The need for a different method of control of Major Hazard installations [24]. With the increasing size and complexity of plants, and because of the relatively small number of major incidents, Gibson's view is that there has not been the time or the opportunity to learn from mistakes [25]. Hence data on the cause of previous incidents cannot be applied realistically to the protection of Major Hazard installations and the technique of "hazard analysis" is the approach currently adopted.
5. The causes of major incidents are in general foreseeable i.e. the chain of events are rarely, if ever, beyond existing knowledge of the technology involved. Therefore, with limited resources it is statistically justifiable in a non-labour intensive industry to devote effort to reducing the risk associated with Major Hazard Installations rather than to concentrate solely on those industrial accidents frequently resulting in fatalities.

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