CRITERIA FOR DECISIONS ON ACCEPTABILITY OF MAJOR FIRE AND EXPLOSION HAZARDS WITH PARTICULAR REFERENCE TO THE CHEMICAL AND FUEL INDUSTRIES.

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Guidance on the fire risks that may be expected (or endured) both by individuals and communities under threat may be obtained by examining statistical data on fatality fires, particularly those which have caused many deaths. Such data are presented for fatality fires which originate both in dwellings (D) and not in dwellings ($\bar{D}$); risk from the Chemical Industry is regarded as a contributor to the $\bar{D}$ risk. Both D and $\bar{D}$ relationships indicate an aversion factor against catastrophe. The literature of acceptability of risk is reviewed and comments are made on the relevance of Starr's concept of benefit for the risk agent. Principles of using the available data for assessing acceptability have been put forward; these lead to more stringent requirements for safety of a community under threat of catastrophic risk than would appear from suggestions that have been put forward so far.

INTRODUCTION

Fire, which in this paper will be taken to include explosion, is perhaps the commonest form of major hazard that exists in the Chemical Industry, particularly if the latter is seen as including the production and transport of liquid and gaseous fuel. In recent years there has been an emphasis in approaching the management of this hazard, and indeed others, in a rational way using quantitative criteria for decision making. There are two basic steps in this process. Firstly, it is necessary to decide how much safety there needs to be in a project, and secondly, it is necessary to design and manage the project so that it has the desired degree of safety. The second of these steps is mainly technical in nature and techniques are now being evolved to assist in the requisite design procedures: these include hazard surveys, fault tree analyses, operability studies, etc. However, the first step is perhaps more of a sociological and a political problem than a technical one. One logical way of approaching the problem of deciding how much safety is needed is to regard it as an extension of the design procedure and to find the method of working that gives rise to the minimum total cost of safety measures plus the expected loss from the residual hazard. This is not straightforward even if all losses were economic and expressible in monetary terms since aversion factors in consequential or process losses exert a significant influence. However, this approach becomes even more difficult if life loss and public reaction and anxiety are major factors.

RELATION OF THE CHEMICAL INDUSTRY WITH THE GENERAL FIRE SITUATION

As far as the introduction of major protection requirements into the Chemical Industry is concerned, life loss and public anxiety are indeed dominant factors.

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Even if a Flixborough - without fatalities - were to happen every year in the UK, the insurance for such an incident could be carried without too much impression on the industry as a whole. The major reason for the emphasis on extensive safety requirements for plant of this kind is the major life hazard and the anxiety that such hazard brings to the public. The approach of optimum cost is therefore of limited value and the situation is dominated by how much safety people ought to have, or how much freedom from threat they ought to feel.

This problem is a complex one and is subject to the influence of many factors. Concepts of acceptable and non-acceptable hazards and safety have emerged in this context. Even these very words cause controversy. It may be better to alter them to words such as "tolerable and intolerable" or even "endurable and unendurable".: this problem is of course not unique to the Chemical Industry nor to fire safety. However, the special position of fire does allow an approach to the matter. Fires causing deaths and destruction occur in almost every human activity and have occurred throughout recorded history. Although quantitative approaches to fire safety were first used directly in the Chemical Industry, this use is only a short head in front of their use in fire safety generally. Major questions such as, how much fire safety we should build into our furniture and clothes, our houses and hospitals, are continuing subjects of research since it is now becoming more and more accepted that the traditional method of learning fire safety by bitter experience is not good enough, particularly during a period of rapid technological development. The measurement of fire safety in general fire situations is more complex than in most process situations since there is a continuing interaction with people during the process of evacuation and response to fire. It does raise the point that in devising acceptability, tolerability, endurability criteria for the chemical industries, an attempt should be made to fit these into a logical system that covers fire risk situations generally.

In a way this may be a simplification rather than a complication since the amount of safety that exists in the community as a whole is perhaps open to more accurate measurement for fire and explosion safety than for many other forms of risk. This measure is obtained from the records of actual fires that have occurred up to the present time related to the population experiencing them. *The level of safety that this reveals has not occurred by chance.* It is the result of a continuing process of the interaction between the social and technical development of the environment on the one hand, and the legislative and regulatory process on the other, that has taken place over the centuries. Thus over the last few centuries conflagration in larger parts of cities has been virtually eliminated by an evolving design process of building construction and space separation. Extensive fires within buildings have been reduced by fire resistance and compartmentation and fires causing many deaths in buildings where people congregate have been curtailed by requirements for escape or refuge. By far the dominant factor, particularly in recent years, in developing these requirements has been related to life safety, and the major impulse towards legislative activity has been the occasional fire that has produced major life loss. As a result, regulations, particularly in buildings, are such as mainly to prevent multiple fatality disasters rather than individual deaths due to fire. In looking for criteria for acceptability of a residual fire risk in the Chemical Industry, they should in principle fit into the pattern of accepted fire risk generally. A major problem for the industry is the possibility of multiple fatality incidents; it is necessary therefore to consider the background of the pattern of experience of the community of fatal fires with particular reference to those which cause many deaths.

PATTERN OF MULTIPLE FATALITY FIRES

The completeness of statistics of fires varies in different countries. In the UK systematic statistics of all fires attended by the Local Authority fire brigades have been kept since 1947. In general, details of multiple fatality fires have not been reported on although with some effort this information could be unearthed. However, a certain amount of information is available in a report by Chandler (1) and this, together with details in the annual statistics themselves (2) allows a sufficiently detailed record for the purpose in hand to be obtained for the years 1963-73 which is summarised in Table 1. On the basis of this information it is possible to plot the annual expectation of fires with N or more fatalities per million UK inhabitants. This is shown in Fig. 1. It should be stated that these statistics do not include mine fires or most vessel fires since these are not attended by the fire brigade. About 10 per cent of single fatality fire deaths are also not included for the same reason. The full lines in A and B correspond to incidents in which fire or explosion was initiated in domestic premises (D) and non-domestic premises ($\bar{D}$) respectively.

It is clear from Fig. 1 that these distribution curves differ considerably. During the period under consideration there were no D fires which exceeded eight deaths, whereas there were nine $\bar{D}$ fires. The reason for this undoubtedly lies in the legislation that exists in the UK that extends back for centuries (3) that requires fire resistant partitions between houses and latterly between floors in blocks of flats. It is of interest to note that multiple family occupancy without this separation was a factor in the occurrence of multiple fatality fires (1). However, regulations of various kinds also cover precautions against $\bar{D}$ fires and curve B provides a measure of how effective these fires were - or perhaps were not - during the period concerned.

The circumstances of large fires in the UK are given in some detail in Table 2 which gives the location and type of property for fires with six or more deaths between 1960-1978. All the "6+" death fires that are represented in Fig. 1 are shown together with others occurring over the longer period. These details were mostly provided by the Home Office to whom the author is grateful but some were taken from ref. 1. Many of the fires are well known disasters and one thing which stands out is that by no means can the fire record that was experienced during the period be considered "acceptable". Thus the Liverpool Department Store fire was the main incentive for the Offices, Shops and Railway Premises Act. The club fire in 1961 was an incentive for the Fire Precautions Act 1971 and the first designation under this Act for hotels was much influenced by the spate of hotel fires that occurred in the early 1970's.

A closer examination of the $\bar{D}$ fires also reveals that in nearly every case those exposed to the risk and who suffered death, were obtaining a direct benefit from the activity that gave rise to the risk, i.e. by using the hotel, hospital, club, old people's home, etc., being employed on premises, or to fight the fire, or even just using the same building. Moreover, these premises in the main were also serving the local community. In only two cases did the risk come predominantly from an outside source and the people who died were probably getting no or marginal benefit from the activity that gave rise to the risk, these were (1) fire on the Manchester Ship Canal in 1970 that killed six people, and (2) the explosion at Clarkston Toll in 1972 that killed twenty-one; in the latter case one might argue that the community from which those who were killed came probably did benefit from the gas main from which the leak came. It is interesting that in both cases the reason for the incident was the flow of flammable liquid or gas out of containment into an area where it could endanger the public, i.e. the major type of fire risk that might be caused by the Chemical Industry. None of the reports of $\bar{D}$ fires with six or more casualties indicated a fire which started in one building and caused death in another. Indeed the author does not know of any occasion in the UK in recent years when this type of incident has occurred, although fatalities due to fires which have spread from one occupancy within a building to another do occur, particularly from a non-domestic occupancy on a ground floor to dwellings above.

EXTENSION OF DATA TO LARGER FATALITY NUMBERS

The full line BB represents UK data for 1963-73 for $\bar{D}$ fires. The largest number of fatalities in a single fire during that period was thirty-five. The data may be extended by taking account of very large fire disasters that have taken place outside the UK and the period 1963-73. The assumption needed here of course is that the basic exposure risk is similar and this limits extrapolation to fully developed countries in a generally temperate climate and not too far back in history. Thus the most fatal fire in the British Isles in the period 1949-78 was the Summerland fire at the Isle of Man in 1974 that killed fifty; only four fires in all rich countries similar to UK have killed a hundred or more people in the same period, the largest being the fire at L'innovation Department Store in Brussels in 1967. Finally the largest fire of the type covered by curve B reported for the last century in a fully developed country is the theatre fire in Chicago in 1903 that killed 602. Making due allowance for the increased exposure, these fires allow the extrapolation of B along the dashed line CC in Fig.1. Although the point at the 600 fatality incident fits very well, it is the most dubious because in general fire safety has improved over the last century, and hazard exposure will have changed significantly. Also, an explosion of ammunition in Halifax, Canada, was ignored because it occurred during war time (1917) and was probably associated with a ship fire (4). Nevertheless, the three curves in Fig. 1 with the extrapolation of B curve along the C curve to N = 1000 may be taken as representing the hazard of death by fire of various sizes to which people in the UK are exposed. Although mine fires are not included, an examination of the reports of the Chief Inspector of Mines and Quarries for the years 1967-73 indicates that they would only have a marginal effect on BB.

There are two points which may be made about the distribution curves in Fig. 1. Firstly, the curves are not far removed from straight lines that would represent Pareto distributions. Thus, with the A curve, the probability of N or more fatalities is approximately proportional to N^{-4} and the B curve to $N^{-2\cdot5 \text{ to } 1\cdot5}$. Secondly, the fact that these negative slopes are greater than unity even up to high values of N implies a strong traditional aversion factor against multiple fatality fires and fire catastrophes which should be taken into account when deciding on acceptability of a risk. In this respect the curve gives a different picture to that produced by the 1975 American Reactor Study in which up to a value of N of 100, the negative slope for fire and explosion appears as less than unity(5). In Fig. 1 the mean slope shown by the B-C curves from N = 1 to N = 100 is -2.

REVIEW OF CRITERIA FOR ACCEPTABILITY OF HAZARD

In the last few years there has been much discussion on the matter of acceptability of hazard and a number of possible approaches to the problem have appeared in the literature. While it is quite impossible in a short paper of this kind to review this matter in depth, it is important nevertheless that some of the main features and assumptions of the various views are highlighted. In this the author emphasises that the objective of this paper is limited to defining the acceptability criteria for fire hazard. The large majority of papers that have been published on this subject range over the whole of the death risk, including accidental deaths of various kinds and death due to occupational disease and general disease.

There is broad agreement (5,6,7,8,9) that statistical information of actual experience of the kind outlined in the previous section should be a major factor in guiding decision makers as to what might be acceptable. There are however two major objections to this procedure. The first by McGinty and Atherley (10) in that for many of the risk situations for which decisions need to be made, particularly where there is an occupational disease risk, it is not possible to provide information of the kind which is sufficiently accurate. Moreover, they declare that it is impossible to "compare risks of different types undertaken for different reasons in different social circumstances". These objections will apply only in a limited way if we concern ourselves only with fire risk.The second objection due to Green (11) is that it is not the actuality of the hazard as revealed by past experience that is the important factor in coming to a decision but the perception of it by the risk agents, i.e. the persons exposed to the risk, which may be determined by psychometric techniques. This perception might be influenced by knowledge of the hazard if the recipient had such knowledge, but not necessarily. The pursuit of this approach would require a great deal more information than we have at present about people's attitudes. Green is endeavouring to provide this by investigating the attitudes of groups of students, particularly architects, on this matter. The author thinks that limited experience of this kind may well be of value for everyday accidents in which most people are likely to have some direct personal or near personal experience, e.g. falls or death on roads. However, even if we extend experience of fire beyond death of a near person to personal injury, or the need to escape in an unconventional way, comparatively few people have experienced acute danger from a fire situation or the anxiety of living close to a major threat; in fact probably not more than one in thirty or forty of a random population. Moreover, the risk receivers tend to form a highly selected element of the population. For general fire risk they tend to be old people and young children and for catastrophic fire risk of the Chemical Industry, people who work there or live near the chemical plant. There is therefore some way to go before the data needed for such an approach is available.

Nevertheless, even amongst those who take objective fatality data and similar information as the basis for decision making, major differences are apparent on how one should use the data. Many factors in an ordinary environmental situation are seen as influencing the expectation of accidents and death. Rowe (5) details more than a dozen such factors, i.e. rich/poor, developing country; ordinary/catastrophic risk (Rowe suggests an incident that kills ten or more is a catastrophe); military/civilian incident; natural/man originated incident; immediate or delayed effect; controlled or uncontrolled risk; voluntary or involuntary risk agents; statistical or identifiable risk agents. From various statistical and other information available, he puts forward risk conversion factors for complementary pairs of factors as above, e.g. military/civilian, rich country/poor country. In the problem we are concerned with here, i.e. fire and explosion hazard in the UK, the relevant factors are rich country, civilian, man originated and immediate risk. In addition, the risk agent is partly identifiable, and according to definition rather than anything else, voluntary or involuntary. The risk is usually controllable and sometimes catastrophic.

The meaning of most of the above factors is straightforward. However, confusion does arise over the term "involuntary". There is little dispute that activities such as skiing, rock climbing and amateur boxing should be regarded as voluntary risk, but working for one's living in a risky job, or even living with a known risk in a house, is sometimes classed as a voluntary risk as well. Rowe's definitions appear to include these instances in the use of the word "voluntary". An examination of the various types of risk situations indicates that a risk activity is either undertaken in small packets of time or as a continuing and necessary feature of our existence. In the former case, risk is usually voluntary and may perhaps best be measured in terms of fatalities or injuries per hour (or 10^8 hours) of exposure, i.e. the Fatal Accident Frequency Rate (FAFR). The latter case includes such necessities as -

1. Finding a locality in which to live and being exposed there to natural and man-made hazards that may become manifest.
2. Finding a home or other building in which to live, work and enjoy various necessary services or leisure activities.
3. Finding a job, including the need to get to the place of employment most days in one's life.

The above may be classed as involuntary risks although they could be mitigated if desired by certain deliberate decisions on the part of the risk agent. These risks of course also include our continuing existence on this planet in competition with the ever present microbes and viruses and other biological mechanisms that have the capacity to do us harm. These involuntary hazards are best measured in fatalities or some other form of experience per year or even per expected life span.

It follows from the above that in most circumstances fire and explosion risk is basically an involuntary risk since it is a peripheral concomitant of one or more of the above basic necessities of life. For the most part the level of risk is established by traditional practice and legislative action although there is of course a varying capability of the individual to increase or diminish the level of the risk himself, even if only by choice of how he intends to live and what job to do. The major factor which probably influences the individual is the benefit that the risky activity brings to the risk agent and to others for whom he cares. The importance of benefit was brought out strongly by Starr (6) who indicated that there was a correlation between the benefit (B) of an activity and the accompanying measured risk of death (R) associated with it, in that R is approximately proportional to B^3 . This applies to both voluntary and involuntary risk situations although the risk for voluntary activity is about $10^{3 \text{ to } 4}$ greater than involuntary risk for a given known benefit. The benefit for voluntary risk was estimated on the basis of expenditure or income to the individual, although Starr appeared not to adopt this approach for involuntary risk.

Fig. 2 reproduces Starr's curve for involuntary risk. Benefit figures have been updated from 1968-1978 by multiplying by 3 based on the retail price index change (12) and converting to sterling by dividing by 2.25 (exchange rate 1979). Some points relevant to this discussion have been introduced. The risk of natural disasters is associated with what a person spends on a place to live, i.e. housing, and the risk due to fire in the home with what is spent by the individual on what could be a source of ignition or what might burn; the benefit associated with risk at work is the average wage. Figures expressing these benefits were obtained from the Annual Abstract of

Statistics and are relevant to 1977. Fig. 2 indicates that the involuntary risk benefit curve, as proposed by Starr, covers the range of involuntary risk outlined above. It would probably be more appropriate to make the curve asymptotic at very high benefits to the risk figure for disease (about 10^{-2}/py), rather than have it intersect the line at about £6,000 p.a: the high benefit may be regarded as associated with the act of living on Earth, which is usually more valuable than perhaps can be expressed by a benefit figure. At neutrality or zero benefit the curve would go to zero risk which is impossible; experience indicates a value of about 10^{-7}/py as being more appropriate.

In some recent pronouncements on this matter in the UK, benefit to the individual risk agent has hardly featured at all(13). The data in Fig. 2 illustrates that this neglect is a failing. Thus figures of present risk from the high benefit end of the involuntary risk curve have been quoted in a manner to allow them to be considered as fully relevant to the low benefit end (9). Moreover the practice of safety accounting that has arisen, particularly with regard to energy industries, appears to take no account of this matter; in particular, an employee who benefits greatly is regarded in the same terms as a neutral bystander who benefits marginally or who may suffer disbenefit. *An interesting approach to measuring benefit was put forward by Bowen (14) who* assesses the benefit for technologically advanced industry by calculating the extended life span to the average individual brought about by this advanced technology as opposed to the expected reduction in life span that may be caused by the risk. However, in using this approach to calculate maximum acceptable frequency of a major incident which could effect bystanders, the benefit of all technology was considered as relevant although in fact it is only a fraction of industrial technology that manifests such hazards.

Nevertheless, there is a fair consensus for the amount of risk which might be borne by individuals that benefit greatly from involuntary risk situations, particularly if their job is concerned with the risky activity. Thus a proposed total fatal accident frequency rate for workers in the Chemical Industry of $4x10^{-8}$/person hour (about 3.5/10 py) and $0.4/10^{8}$ph for any individual process item in the hazard (8) has not been vigorously disputed. McGinty (10) has strongly made the point that these levels should not be decided by the scientific community or even by decree laid down by a committee of experts and representatives, but should be influenced by local bargaining that includes those exposed to the risk. On the other hand, for hazard that the neutral public may be called upon to endure, and particularly catastrophic hazard, there is no clear consensus. Gibson suggests that a person outside the plant might be expected to bear a risk of .02 to .001 of those who work at the plant but is dubious about introducing a factor for catastrophe (8). The dams in Holland are built on the assumption that a disastrous flood might take place once in ten thousand years; this takes account of there being a substantial warning of a disaster and that only one in a thousand people exposed to hazard would be expected to die (15) The risk is therefore 10^{-7}/py. However, no particular mention is made of the fact that the dam is there entirely for the benefit of the people who are at risk and the likelihood of many deaths occurring in any incident has not been explicitly taken into account. Apparently similar criteria for a situation of exposure to people outside from a toxic risk in a chemical factory has been used (7) but the above caveats indicate that this is not entirely appropriate.

HSE publications (13,16) appear to be hovering towards a suggestion that a local catastrophe of once in ten thousand years might be not unacceptable even if it might kill one thousand people or more. Bowen came to the conclusion that once in one hundred thousand years was *reasonable* and the author (17) in advice given at the Public Inquiry for the Forth installations, suggested once in a million years, assuming that the catastrophe kills one tenth of the people in the area where it occurs. This was based fundamentally on the 10^{-7} p.y. criterion but also to some extent on tolerable exposure to catastrophic hazard.

Turning specifically to fire and explosion hazard from process and similar risks, I would now suggest that the criteria adopted should not be out of line with those which may need to be adopted for similar hazards in everyday life and should be guided by the type of information presented in Fig. 1 and Table 2. These express our present level of safety as developed through the centuries. We are approaching the stage of making deliberate decisions on maximum danger levels of fire for design within various hazardous situations, e.g. risks in hotels, hospitals or department stores. At the very least the author thinks we should not exceed the risk implicit in the contemporary experience data. He also suggests we observe the following principles:-

(1) There are two types of fire risk; individual risk and multiple fatality leading to catastrophic fire risks. The latter risk is experienced by an affected community and is an aspect of societal risk: the former risk is experienced by the individuals in the community. In view of the sharp cut off of domestic type (D) fatality fires at a value of N=10 (see curve A, Fig.1), a fire which produces ten or more deaths may well be regarded as a "catastrophe".

(2) No deliberate fire safety design should exert more than its fair share of risk. Moreover, since a large part of the regulations that give rise to present safety was prompted principally by fire disasters involving many deaths, no deliberate fire safety design should exert more than its fair share of catastrophic risk.

(3) Since fire safety is distributed more or less evenly throughout the nation, the catastrophic fire safety risk of any local project should be related to the community it serves or which it effects and should be in line with the degree of total fire safety that that particular community expects to enjoy.

(4) In deciding what should be a fair proportion of both individual and catastrophic risk that a specific project may impose on a community - or putting this another way, any person or community deliberating on what fraction of total fire risk might be tolerated from a given activity - then a major factor which they would be expected to bring into consideration would be the benefit that that activity brings to them. For example, with an old people's home for which there are certain inherent difficulties in fire safety management and escape design, experience has shown that there is a comparatively high risk of multiple death fires. A community may nevertheless decide to accept a high contribution to catastrophic fire risk from this source because of the extra comfort, safety and even perhaps paradoxically, extra individual fire safety, that these homes bring to the members of the community that use them. On the other hand, a gas tanker terminal which benefits an affected community marginally if at all, might reasonably be expected to reach a much higher standard of safety against inflicting a catastrophic fire incident on the community.

(5) If the nation as a whole decides it is necessary to impose either on individuals or on a local community a hazard higher than that which is fair, then some form of compensation is justified. This should be taken as an economic factor in making a decision on the risk. It is possible that guidance as to compensation might be obtained from Fig.2 although this does not cover catastrophic risk.

FOCUSSING FACTOR: EFFECT OF SIZE OF COMMUNITY ON ACCEPTABLE RISK

The above arguments suggest that what might be termed the focussing factor needs

needs to be taken into account in judging whether a risk should be acceptable in any given set of circumstances. There has been a tendency in discussing acceptability of risk to ignore this factor and to look at the risk as if it were affecting only the nation as a whole rather than a local group. If it is assumed that each individual and each community is entitled to the same amount of fire safety and this is implicit in suggested principle (3) above, then it is possible to use the curves BB and CC in Fig.1 to calculate the way community size affects the expectation of multiple death fires. This is shown in Table 3 as a function of the size of the population at risk and the number of people that might be killed in a fire. If used for design purposes this figure should be regarded as a maximum since the evidence indicates that many of the large death fires that gave rise to the figure were so repugnant to the nation as a whole that legislation to reduce the likelihood of occurrence of a similar incident was promulgated. Moreover, the figure must be regarded as representing total catastrophic fire safety; the current share of disaster risk attracted by activities that bring marginal or no benefit to the community at risk appear to occupy about one-twentieth to one-fortieth of this total hazard. This suggests that a single identifiable individual or catastrophic risk source that does not benefit the community should not contribute more than one twentieth of the total risk indicated in the table.

When approached in this way it is clear that the risk that it is suggested might be acceptable to a community is far less than almost all those that have been mooted so far. Thus a population of ten thousand represents a logarithmic mean size between the focussed area at risk in Aberdour and Dalgety Bay on the Forth, and Canvey Island on the Thames, who may be regarded as neutral communities with regard to the risk to which they are exposed. The above argument would indicate that the risk of a catastrophe involving one hundred or more deaths should not exceed about once in ten million years; far lower than values suggested as acceptable by the Canvey Island Report (15). Indeed the latter report indicates that even after all proposed developments have been put in hand, the changes of one thousand or more accidental deaths/ year exceeds 1/10,000, the major part being catastrophic fire risk. The table indicates that while such a risk may perhaps be acceptable to the country as a whole if the country took the whole risk equitably, it is quite a different matter if it is focussed on a community of 30,000 people.

An estimation of the maximum death risk by fire to any individual that might be acceptable may be obtained from the information in Table 1 which gives 11.7 and 3.7 fatalities/10^6 p.y. for D and $\bar{D}$ fires respectively. Since the smaller the number of fatalities the greater the likelihood of all those killed to have been receiving benefit from the risk activity, then the correction for a no benefit $\bar{D}$ situation is probably nearer 1/50 rather than 1/20 to 1/40. This gives the probability of a fatality to a neutral bystander in a $\bar{D}$ fire as rather less than 10^{-7}/p.y. which is in line with other accidental risks to bystanders. However, the probability of an individual dying in a catastrophic fire is much less than this, e.g. in the above mentioned case 10^{-9}/p.y. If a risk is such that there is a high likelihood of producing death in catastrophes as opposed to death in non-catastrophes, then in protecting the community from catastrophe the neutral individual will be substantially safer from a $\bar{D}$ risk than he would otherwise be.

It might be argued that this catastrophe aversion factor is illogical. This is probably the case although there are undoubtedly rational elements in it. The sum of public anxiety in a community concerning incidents could well be much more than the sum of the individual anxieties if these individuals were not in a community, but this may reflect the likelihood that a single accident that caused one hundred deaths might disrupt the community much more than one hundred accidents each causing one death. Moreover, catastrophes of a similar kind occurring anywhere in the world might well upset a community more than the corresponding number of fires killing one or two people at a time. The nation as a whole might well make a decision to counteract this supposed illogicality by deciding for example that a total neutral $\bar{D}$ fire risk of a project should not exceed 10^{-7}p.y. or whatever, no matter what the local catastrophic risks. But this decision could well be taken as a precedent and applied generally to the eventual detriment of at least the feeling of safety within a community.

A major difficulty about the low figures as quoted above at the present time is that the techniques for calculating such low probabilities with confidence have not yet been formulated even for a well designed plant under the highest degree of control. If this is so then it is understandable that people under threat should request that the project should not go ahead. At least the calculation should be pursued with such rigour as is possible now with the case for accepting the risk hinging on the availability of a number of defence mechanisms that might enhance safety being held in reserve. These may later be put into effect if calculated safety is shown to be in error.

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TABLE 1 - Multiple Fatality Fires in the UK 1963-73

	Fires Originating in Dwellings (D)		Fires not Originating in Dwellings ($\bar{D}$)*	
Total Number of Deaths	7,059		2,213	
	Total number	Number per million per year	Total number	Number per million per year
Fires with 1 or more deaths	5,765	9.52	1.543	2.548
Fires with 2 " "	587	0.969	279	0.461
Fires with 6 " "	7	0.0115	22	0.0363
Fires with 7 " "	3	0.00495	14	0.0231
Fires with 8 " "	1	0.00165	10	0.0165
Fires with 9 " "	0	0	9	0.0148
Fires with 10 " "	0	0	8	0.0132
Fires with 20 " "	0	0	5	0.0083
Fires with 30 " "	0	0	1	0.0016
Fires with 40 " "	0	0	0	0
Probability of death per annum in fire	1.17×10^{-5}		3.65×10^{-6}	
Probability of death per annum in fire with ten or more fatalities	0		2.75×10^{-7}	

* These include fires classified as occurring in caravans, which most probably were being used as dwellings. About 10 per cent of the 2+ $\bar{D}$ fires but none of the 6+ $\bar{D}$ fires were caravan fires.

TABLE 2 - Fires Causing Six or More Deaths in the UK 1960-1978

Year	Number of Deaths	Location	Type of Property
1960	19 (Fire Brigade and Fire Salvage)	Glasgow	Bond whisky warehouse
"	7	Renfrewshire	Nitro glycerine explosion
"	10	Liverpool	Departmental Store
1961	19	Bolton	Club premises above factory
1962	11	Isle of Wight	Aircraft crash
"	7	Glasgow	Flat in tenement block
1963	8	Croydon	Block of flats
1966	6	Wallasey	Terraced dwelling
"	7	*Sunderland*	*Shaft tunnel of cargo ship*
"	8	London	Commercial and office premises in multiple occupation.
"	6	London	Three-storey flats
"	7	Glasgow	Terraced dwelling
1967	35	Stockport	Aircraft crash
1968	22	Glasgow	Furniture manufacturers, warehousing and offices.
"	6	Merthyr Tydfil	Dwelling
"	24	Shrewsbury	Shelton hospital
"	7	Brighton	Hotel
1969	6	Brixton, London	Dwelling
"	6	Ayr	Hotel
"	11	Saffron Walden	Hotel
"	6 (All (Fire Brigade)	Dudgeons Wharf, London E14	Storage tank containing residue turpentine and solid residues.
1970	7	Birkenhead	Motor van in collision.
"	14	At sea off Portsmouth	Tanker 'Pacific Glory' in collision.
"	6	Wembley, London	Dwelling
"	6	Manchester Ship Canal	Petroleum on canal surface and ferry boats.
1971	6	Hackney, London	Doctors surgery and dwellings.
"	21	Clarkston Toll	Row of shops
"	6	*M6 Motorway Staffs*	*Motorcar in collision*
"	9	Paddington, London	Hotel
1972	30	Sherborne, Dorset	Coldharbour Hospital
"	7 (All (Fire Brigade)	Glasgow	Cash and Carry textile warehouse.
1973	10	Oban	Hotel
"	6	Sheffield	Gas works plant
"	6	Birmingham	Munition works
"	7	At sea off Dover	MV "San Antonio" in accommodation area

TABLE 2 - Cont'd

Year	Number of Deaths	Location	Type of Property
1974	28	Flixborough	Chemical plant and buildings
"	6	Lambeth, London	Hotel
"	8	Islington,London	Hotel
"	18	West Bridgford	'Fairfield' Old People's Home
"	7	Paddington, London	Hotel (used as staff hostel by hotel group).
1975	7	Scunthorpe	Molten steel in torpedo containing water.
"	6	Wigan	Dwelling
"	6	Arbroath	Boardinghouse.
1976	8	Newcastle upon Tyne	Destroyer under construction
1977	11	Hessle	'Wensley Lodge' Old People's Home
"	7	Dover	Restaurant with flats above
"	7	Manchester	Sandwich bar with commercial premises above
"	6	Bristol	Restaurant with domestic premises above
1978	12	Taunton	Train
"	9	Clacton on Sea	Multi-occupancy dwelling (psychiatric patients)

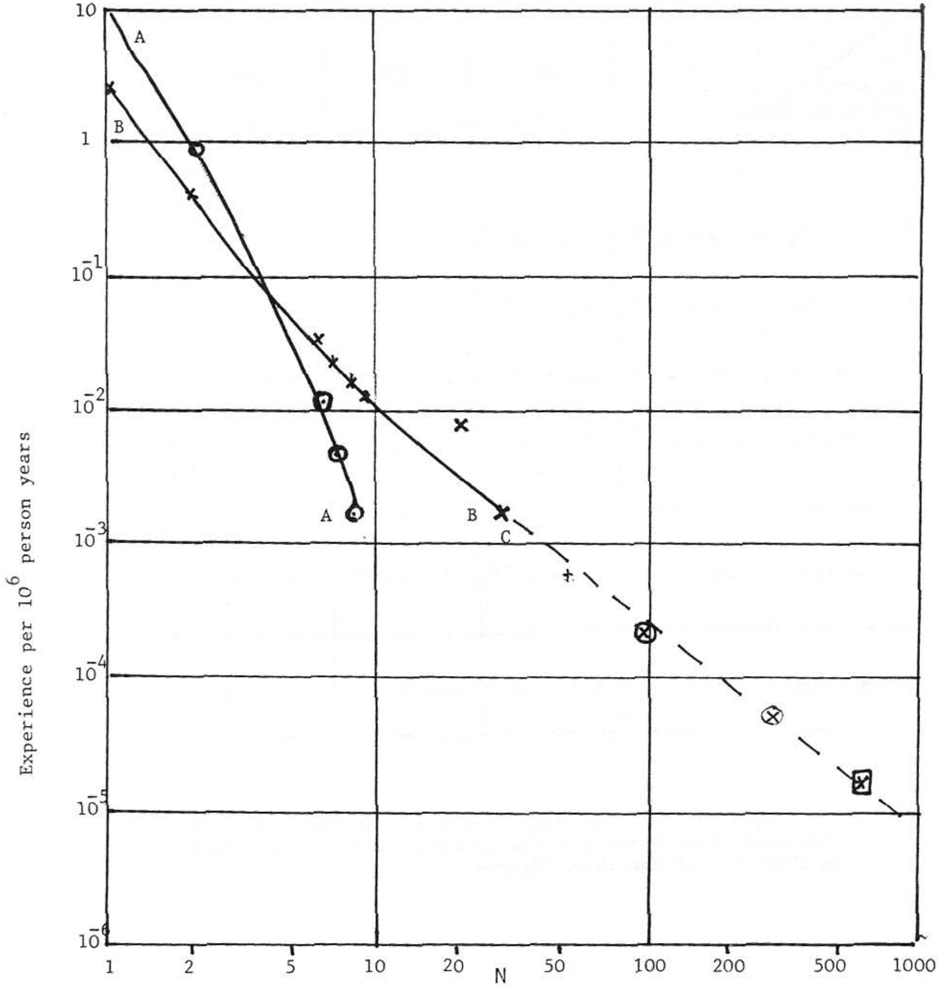
TABLE 3 - Suggested maximum frequency per annum of all non dwelling ($\overline{D}$) fires with N or more fatalities for communities of different size. (Based on BBCC curves Fig 1).

N Size of community at risk	1	10	100	1,000
1	2.6×10^{-6}			
10	2.6×10^{-5}	1.2×10^{-7}		
100	2.6×10^{-4}	1.2×10^{-6}	2.6×10^{-8}	
1,000	2.6×10^{-3}	1.2×10^{-5}	2.6×10^{-7}	8×10^{-9}
10,000	2.6×10^{-2}	1.2×10^{-4}	2.6×10^{-6}	8×10^{-8}
100,000	2.6×10^{-1}	1.2×10^{-3}	2.6×10^{-5}	8×10^{-7}
1 million	2.6	1.2×10^{-2}	2.6×10^{-4}	8×10^{-6}
56 million	153	6.7×10^{-1}	1.45×10^{-2}	4.5×10^{-4}

NB: It is suggested (see text) that risk due to a single activity of marginal or no benefit to the community affected should be less than 1/20 of the above figures.

Fig 1: Experience per 10^6/person years of fires with N or more fatalities

United Kingdom (but extrapolated with reference to other developed countries).



A ⊙ United Kingdom experience D type fires 1963-73
B x United Kingdom experience $\bar{D}$ type fires 1963-73
C + Point based on biggest fire British Isles 1949-78
C ⊗ Points based on four biggest fires rich countries 1949-78 (excl.Japan)
C ⊠ Dubios point based on biggest peace-time type fire rich countries 1879-1978

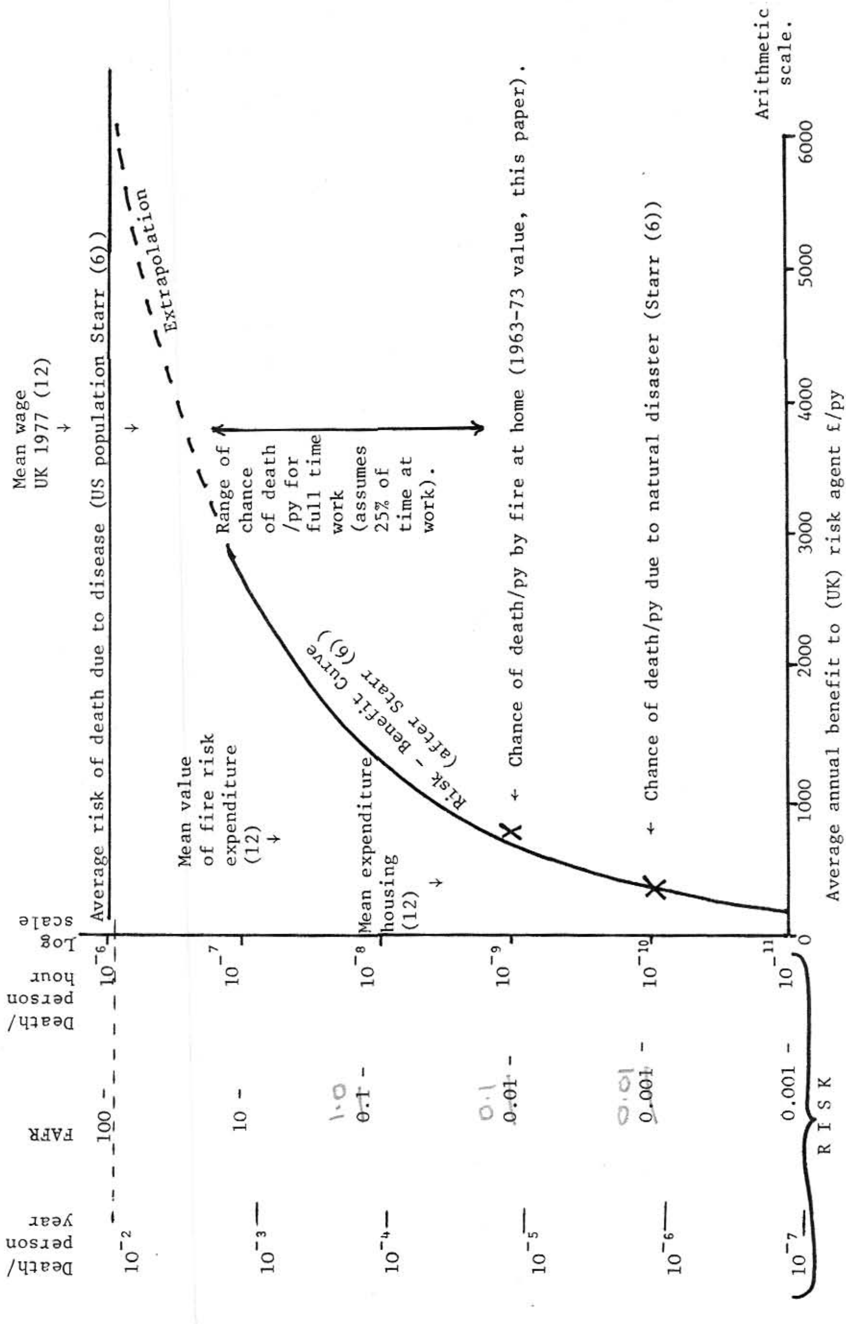


FIG 2 - Risk - Benefit Relationship for Involuntary Risk.