THE QUANTITATIVE MEASUREMENT OF PROCESS SAFETY

S B Gibson
Division Engineering Department, ICI Limited, Mond Division, Runcorn

The risks associated with the Chemical Industry cannot be completely eliminated. Consequently there is a need to define an acceptable level of risk. In some cases, however, one cannot achieve this level by reasonable means. A practical and realistic approach is described whereby the consequences of an incident can be assessed in financial terms. The probable frequency of the incident can also be assessed and the incident cost can then be expressed as an annual cost. This annual cost could be reduced by a variety of preventive or protective measures and these can also be expressed as an annual cost. The suggested course of action would be to implement the measures which gave the minimum total annual cost of preventive or protective measures plus incident cost adjusted to take account of the reduced risk.

1 SUMMARY

The approach to the reduction of risk to employees, the public and the environment must be a practical one. Since life is full of risks, we cannot completely eliminate risks associated with industry, but we should be able to establish levels of risk which society considers acceptable and deploy our resources in the most effective manner in trying to achieve these levels. We therefore need quantitative criteria to define these socially acceptable levels. If the criteria are thoughtfully and responsibly chosen, we should find that they can usually be met, but inevitably there will be a few isolated cases where the level will be extremely difficult to achieve. We therefore also need a policy which ensures that in these cases we neither ignore the problem, nor do we use our resources inefficiently by trying to eliminate that particular problem at all costs when there are many other problems which could be more fruitfully tackled with the same resources.

In other words, we need to be able to define consistently in quantified terms the phrase used in statutory regulations "so far as is reasonably practicable".

This note defines risk criteria which I suggest might be accepted by society and describes an approach for dealing with risks which exceed these criteria. The approach suggested is a cost benefit analysis; one of the difficulties in this area and one that others have reported (refs 1, 2, 3) is assigning a value to the amount of money which should be spent to save a life. To take some of the emotion out of the subject, I have called this amount the "Socially Acceptable Premium (SAP)".

2 RECOMMENDATIONS

2.1 A common approach to all hazards should be adopted whether the hazards involve employees, the public, customers or the environment.

2.2 The approach should be to reduce all hazards to a socially acceptable level. If this proves particularly onerous the risk should be reduced as far as possible in a cost effective way. If there is no cost effective solution which will reduce the hazard to the specified level, the risk may be accepted until such time as new techniques, equipment, knowledge, etc make a solution feasible.

2.3 The socially acceptable level for risks to any employee at work arising from hazards associated solely with the processes should be a Fatal Accident Frequency Rate (FAFR) of 2 if all the risks have been identified, or 0.4 for any single risk if they have not.

2.4 A socially acceptable FAFR for the public should be chosen and widely agreed.

2.5 Other criteria should be developed as circumstances demand.

2.6 In cost benefit analysis the SAP to be used needs further debate but a figure in the range £100,000 to £1M seems appropriate.

3 INTRODUCTION

During the 1960's the chemical industry was developing rapidly, and to achieve the benefits of scale, chemical plants were getting larger and more sophisticated. One or two dangerous incidents in ICI brought us to the realisation that our safety approach must keep pace with the technological development of the company. It is not unfair to say that the traditional safety approach is to learn from experience, developing codes of practice, devising precautions, and writing operating instructions to try to ensure that past incidents are not allowed to recur. In many modern processes the scale of an incident could be so large that this retrospective approach alone is not sufficient.

Recognising this, we developed a programme of hazard studies which is carried out for all new chemical projects. Each study is an examination of the project at a different stage to identify potentional hazards. The depth of the studies varies, but when the final line diagrams are completed they are subjected to a very detailed critical examination to discover what effects deviation from design intent and from normal operating conditions could have (ref 4 and 5).

Having identified the hazards, we can eliminate them completely only by abandoning the project, but bearing in mind that all human activity, whether at work or at leisure, carries some risk the approach we need to adopt is to decide how much risk we should be prepared to take.

The first step is to assess what risk is present in an activity.

This is a question which is easily answered when only material damage is concerned but which becomes much more difficult when lives are involved. It is for this reason that the frequency of a plant failure or hazardous incident is a poor parameter for measuring risk and is not used here. A much more meaningful parameter is one which measures the risk to the people involved in the incident and because this note is concerned with serious incidents a parameter which serves this purpose is the Fatal Accident Frequency Rate.

4 ASSESSING THE RISKS

Although this is a digression from the purpose of the paper it may be helpful to illustrate briefly how one can assess risks.

Having identified the possibility of an explosion in the plant shown in Fig 1A we start with this as our top event in Fig 1B. We can then develop our fault tree downwards by repeatedly asking the question "how"?

How do we get an explosion? - from a combination of an explosive mixture and a source of ignition.

How do we get an explosive mixture? - as a result of a high fuel feed or a low oxidant feed ...

In this way we can develop our fault tree into sufficient detail for satisfactory data to be obtained on the frequencies or probabilities of the events at the tips of the branches. By then combining the figures upwards according to the logic described in the tree one can estimate the frequency or probability of the top event.

An estimate can be made of the magnitude of the explosion from which the potential damage cost can be assessed. Multiplying this by the frequency of the explosion will give the average annual losses from this hazard.

Similarly considering the frequency of the explosion and taking into account the probability that someone will be in the danger area when it occurs one can assess the risks to the people involved.

The next step is to decide how safe is safe enough? (Ref 6)

5 ESTABLISHING THE SOCIALLY ACCEPTABLE LEVEL OF RISK FOR EMPLOYEES

The Fatal Accident Frequency Rate (FAFR) is defined as the number of deaths in every 10^8 hours exposed to risk. For industrial risks, we can consider a man to work for 2,500 hours per year for his working lifetime of, say, 40 years and therefore the FAFR for a particular risk is equivalent to the number of deaths to be expected from 1,000 men subjected to that risk for their entire working lifetime. Some examples of risks for various activities are given in the following tables

FAFR for Various Industries

Chemical industry	3.5
British industry	4
Steel industry	8
Fishing	35
Coal mining	40
Railway shunters	45
Construction workers	67
Air crew	250
Professional boxers	7,000
Jockeys (National Hunt racing)	50,000

FAFR for Non-Industrial Occupations

Staying at home	3
Travelling by bus	3
Travelling by train	5
Travelling by car	57
Pedal cycling	96
Travelling by air	240
Moped riding	260
Motor scooter driving	310
Motor cycling	660
Canoeing	1,000
Rock climbing	4,000

The tables come from reference 7 in which T A Kletz recommends that since the FAFR for the chemical industry was about 3.5 at the time the paper was written, then any single risk to an employee in the chemical industry should not exceed about 10% of this, namely 0.35 or, say, 0.4.

On examining the statistics for ICI employees we in Mond noted that in about only one half of the cases were the risks caused by hazardous chemicals, or processes, the remaining half being caused by accidents such as falls or being struck by falling or moving objects. We concluded therefore that these latter risks must remain the province of the traditional safety approach but that by close attention to design and operation we should aim to ensure that the sum of all specific process risks as opposed to general background risk should be not greater than an FAFR of 2.

This FAFR of 2 was reached subjectively by arguing that our past record was good, that by comparison with the risks in the above tables, risks in ICI were at the low end of the spectrum of life's risks. Examination of the accident statistics for the employees actually working on the chemical plants lead to the choice of 2 as an improvement over our past average performance, and since it is axiomatic that our past average is made up of high and low risks, if in future we reduce the high risks to our target level we shall inevitably improve our performance even further. It is our view that these arguments stand up well on moral grounds, and the question of cost does not enter into them. Nevertheless, whilst we are advocating that any risk below this level is socially acceptable, it does not necessarily follow that a level above this is socially unacceptable since the benefits may far outweigh the risks.

It is inevitable that there will be situations where the risk is greater than the adopted socially acceptable level and where to reduce it is extremely difficult or costly. Some people might argue that we must achieve that level at all costs; but the obvious disadvantage of this approach is that it makes ineffective use of safety resources (ref 8), spending a lot on one difficult problem, whereas those resources could have given a more effective return in terms of safety if they had been expended on some other less intractable problems. This suggests the need to have a policy which would enable us to decide the correct course of action in these cases. We should then be in a position to calculate the safety level at which we are working and use our resources in the most effective way in trying to improve the level if it exceeds our figure for social acceptability.

Before going on to outline the policy it is worth considering the situation where the risks are lower than the socially acceptable level but where multiple fatalities are involved, since the emotional reaction to these suggests that they should be given special treatment. Some authors have suggested that the acceptable risk level should be reduced by various factors in situations where multiple fatalities could occur.

Factors of N, Log N, KN (where N is the number of fatalities and K is an arbitrary constant) have been suggested but there is no logical reason for selecting any of these.

For a given population an incident causing 1 death every 100 years gives the same FAFR as one causing 100 deaths in 10,000 years and if the FAFR is acceptable for the first incident, then the second incident, which is 100 times less probable should - logically - also be considered acceptable.

In Section 6.2 we shall consider the costs of the official and public reactions which can be different for single as opposed to multiple fatalities but this is only for the situation where the risk is greater than that considered socially acceptable.

Since we have considerable experience of carrying out Hazard Analysis calculations with reference to operations where employees are at risk, let us first consider what our approach should be for them.

6 OPERATIONS WHERE EMPLOYEES ARE AT RISK AND THE CRITERION IS NOT MET

In the design of new projects there is little difficulty in meeting the criterion and it is in existing plants and activities where the problems usually occur.

Having assessed the problems and calculated the risks to the employees, in cases where the socially acceptable criterion is not met, there are the following possibilities:

I accept the risk and do nothing,

II improve the design or situation and accept the residual risk even if it is still in excess of the socially acceptable level,

III shut down the process or don't build the plant.

Each of these possibilities (and II may include a variety of alternative partial solutions) will have its own costs, penalties, benefits and residual risk and what we must try to do is select the alternative which presents the best compromise. In other words, we are seeking to improve the situation "so far as is reasonably practicable" but we must also remember that if the residual risk is not below the socially acceptable level, we must improve further should improved technology and future knowledge provide us with a reasonably practicable way.

There cannot be a simple single rule for assessing the best alternative since for each we must consider the standard of living and quality of life of those people who benefit from the availability of the product concerned, the expenditure to be incurred, the residual risk, the cost of an incident, the loss of life, public or official reaction to the incident, and possibly even employment opportunities. This paper therefore advocates an economic analysis as an aid to balancing all the factors and assessing the alternatives. We must balance the cost of an incident in terms of money against the cost of preventing or reducing it.

6.1 Cost of an Incident

The cost of an incident will include:-

Human life lost
Public or official reaction
Plant or other material damage

and these are examined in more detail in Sections 6.1.1-6.1.4.

6.1.1 Human life lost. Placing a monetary value on life is one of the most emotive subjects and to take away some of the emotion I am suggesting the phrase Socially Acceptable Premium to describe the value which will be used in our calculations. It is the amount of money we believe we should be prepared to spend to save a life in a hazardous situation.

To establish a value for the SAP, we must consider:-

a) Our responsibility to our employees, in terms of safety

b) Our good image

c) Our responsibility to other bodies already using their own SAP

d) Our responsibility to other bodies still to start using an SAP, because as industrial leaders, our standard may well have a strong influence on statutory legislation

e) Our responsibility to our employees, customers and the public in terms of product price

Figures used in other activities are: (ref 1, 2, 3)

Medical field:	Hundreds to thousands of pounds. One author (ref 9) talks of £5,000 per case for saving a life as "Such astronomical costs".
Roads:	The current value of a life used in economic analyses of road improvement schemes is £39,300.
Firefighting services:	Values of between £15,000 and £60,000 have been used in economic assessments of providing firefighting facilities.
Courts (legal settlements):	A few tens of thousands are often awarded as compensation for loss of life.
Chemical industry safety:	It is impossible to obtain an overall figure for safety expenditure but individual cases have covered the range right up to tens of millions of pounds.

The highest sums have tended to be spent on hazards with a very low probability - reflecting the past attitude that incidents must never happen and risks must be eliminated at all costs.

Now that it is more widely recognised that this attitude is not realistic, we realise that in terms of safety effectiveness, such high sums are a poor investment. We therefore conclude that if the chemical industry sets its SAP at £100,000, it would use its safety resources more effectively in the future. Further, by comparison with the other activities quoted, £100,000 does seem socially defensible. However, since this figure would inevitably be criticised on the grounds that the industry's profits are increased at the expense of employees lives, there is a good argument for choosing a much higher value and a figure in the range of £100,000 - £1M seems appropriate.

6.1.2 Effects of public or official reaction. We have already mentioned that where the risk is acceptable there is no logical reason to differentiate between incidents involving single fatalities and those involving multiple fatalities because the probability of the latter is correspondingly smaller than that of the former. However, where the average risk is greater than the socially acceptable level we must consider the seriousness of the incident to assess the financial penalties which will be incurred because of public or official reaction, and which must be included in our assessment.

For example, one could imagine that a small incident might result in tightening inspection procedures whereas a major disaster could result in a complete prohibition of any similar future activity, and these would obviously have widely different effects on the economics. By analysing the problem in the way we are suggesting, we obviate the use of a meaningless simple multiplication factor which some people have proposed for adjusting the socially acceptable level in situations which could involve multiple fatalities.

6.1.3 Material damage. This is probably the easiest to estimate and no explanation is needed here as to how to assess it.

6.1.4 Production and consequential loss. This figure will vary depending upon the magnitude of the event, but again no detailed explanation is needed here.

6.2 Cost of Prevention or Improvement

In general this cost will be a capital sum required to install some material safeguards or it could be an annual revenue cost to institute some routine inspection or special operating procedure.

There may be occasions when one must also take into account such special features as job opportunities - these may be lost if a plant is shutdown or not built; effect on living standards - creating a shortage of a vital product like VC, chlorine or the anaesthetic Fluothane, or some other social benefit. These may be difficult or impossible to cost and may have to be used subjectively to influence the final decision on the alternatives.

6.3 Assessing the Alternatives

Having completed the evaluations outlined in 6.1 and 6.2 we shall have the annual costs for the incident. These will decrease as the frequency or the consequences of the incident are reduced by the preventive measures. The optimum solution is the one with the minimum total annual cost of preventive measures and any other relevant costs, plus the cost of the incident commensurate with those preventive measures.

It is worthwhile emphasising at this stage that shutting down or not building the plant should always be one of the alternatives evaluated.

6.4 Graphical Representation of the Approach

Consider Fig 2; the origin O is the starting point. It represents the risk identified and the annual losses due to that risk are OA + AB + BC.

If we reduce the risk by either reducing the consequences or the frequency of the incident then the annual losses in each of the three areas (material damage and losses, loss of life, public or official reaction) will decrease.

We can represent four partial or complete solutions by the crosses P, Q, R, S, whose positions are located by the residual risk and the cost of implementation (expressed as an annual cost) superimposed on the overall cost curve at that risk value. In general, the cost of implementation will increase as the risk is reduced but this may not always be so. Nevertheless, the optimum solution will be that which gives the lowest total cost, which in Fig 2 is case R.

As far as we are able to quantify benefits and risks, this lowest cost will represent the lowest overall cost to society and not to just the operating company.

7 OPERATIONS WHERE THE PUBLIC ARE AT RISK

The principles described in Section 6 can be applied in the same way when the risk is to the public. The arguments used in establishing the SAP are just as valid for the public as for employees and therefore the SAP should be unchanged. However, employees are trained for the hazards of an industry, given protective clothing and, by choosing to work for a company, can be said to accept the risk voluntarily. Members of the public on the other hand have the risks imposed upon them, and it is reasonable to suggest that the latter risks should be considerably lower than for employees.

The case for establishing an FAFR of 2 resulting solely from the processes as a socially acceptable level of risk for employees is based on a considerable amount of statistical data and precedent. Since few members of the public are killed by industrial activities (excluding purely vehicular accidents) we must seek other guidelines to help us choose the level for the public.

The following table lists a wide variety of risks to people in the UK. They are quoted as FAFR's and it is therefore necessary to point out that some of the risks are averaged over an entire lifetime, whilst those marked with an asterisk only exist for limited periods, eg "run over by a road vehicle", is the risk of being run over by a road vehicle averaged out over one's entire life, whilst the risk of death by driving a car is only considered to be relevant whilst actually driving the car.

CAUSE	RISK FAFR
Travelling by air	240 *
Driving a car	60 *
Lung cancer (Merseyside)	7
Lung cancer (average)	5
Travelling by train	5 *
Average for British industry	4
Travelling by bus	3
Staying at home	3 *
Influenza	2
Run over by a road vehicle	1
Leukaemia	0.8
Taking the contraceptive pill	0.2 *
Accidental poisoning by aspirin	0.02
Death from the bite of a venomous creature	0.002
Lightning	0.001
Explosion of pressure vessels in USA (public not employees)	0.0006
Transport of dangerous goods (eg petrol)	0.0005
Falling aircraft	0.0002

This table offers some leads to the choice of an acceptable level of risk to the public arising from industrial activities. But much further debate is required amongst industrialists, public authorities, factories inspectors, etc before agreement can be reached. On the face of it, a figure in the range 0.001 - 0.02 ought to cause little public concern. The lower the figure chosen the harder and more costly it will be to achieve. This, in turn, could increase the cost of the product, reduce the standard of living and quality of life of those who purchase it or reduce the competitiveness of the company carrying out the operation, or on the broader context, the country adopting an over-stringent target.

This was recognised by John Locke the Director of the UK Health and Safety Executive in a recent article in "Trade and Industry" in which he stated: "It is often difficult to find cases where the amount of money involved really looks as if it will have a major effect on the competitive power of the firm concerned, but there are cases where you can see that there is something in this, and we shall more and more by trying to get common standards agreed throughout the EEC, so that no manufacturer in a hazardous process which he is required to keep safe, is at a competitive disadvantage with anybody else".

I would like to hear views from this seminar on how we should set about choosing a figure for risk to the public.

8 OPERATIONS WHERE OUR CUSTOMERS ARE AT RISK

So far, this has not been seen as a problem area and therefore little quantitative work has been done here, but apart from perhaps establishing a fresh socially acceptable level, the basic policy could still be applied.

9 OPERATIONS WHERE THE ENVIRONMENT IS AT RISK

Where the environment is at risk there are likely to be two different sets of targets:

The first will be for known, permissible levels of continuous or intermittent emissions such as effluents into rivers or discharge from vents and the policy I have outlined is not applicable in this context.

The second will be for occasional accidental releases or excursions over the permissible limits. These will be either targets which we industrialists have established ourselves to ensure we are good neighbours and because we are aware of our long-term social responsibilities, or statutory limits laid down by Government, local authorities, water boards, etc. It is quite possible that some of the targets we establish ourselves could be adopted more generally or even become statutory. The policy I have outlined would be applicable where this second set of targets was used.

CONCLUDING REMARKS

Society now demands an increasing supply of new products and materials, the production of which imposes risks on employees, the public and the environment. At the same time society is becoming more aware of the risks both present and future and demanding that they shall be controlled. Quantitative risk assessment is seen by ICI as an aid to such control and our first approach was that the acceptability of any risk should be judged by fixed stringent targets. This approach is not always practicable and in this paper I have suggested an approach which has evolved and which attempts to define objectively the statutory phrase "so far as is reasonably practicable". It also provides numerical guidance to help in consistent, effective decision making.

Although I realise that quantitative analysis is an art rather than a science and is still developing, I submit that this approach is a responsible moral but realistic and practical way of reconciling society's conflicting demands.

ACKNOWLEDGEMENTS

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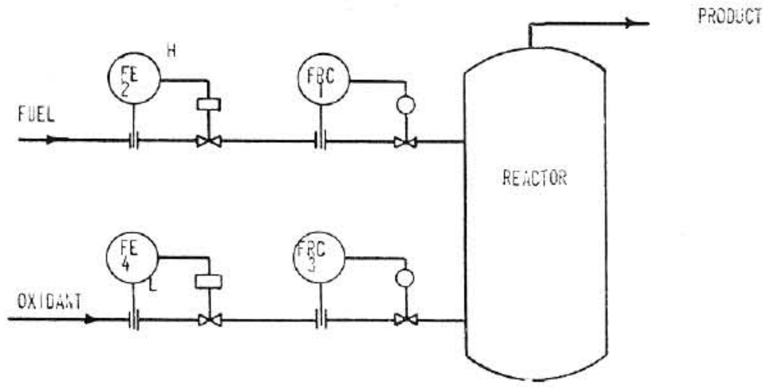


Figure 1A Hypothetical Plant

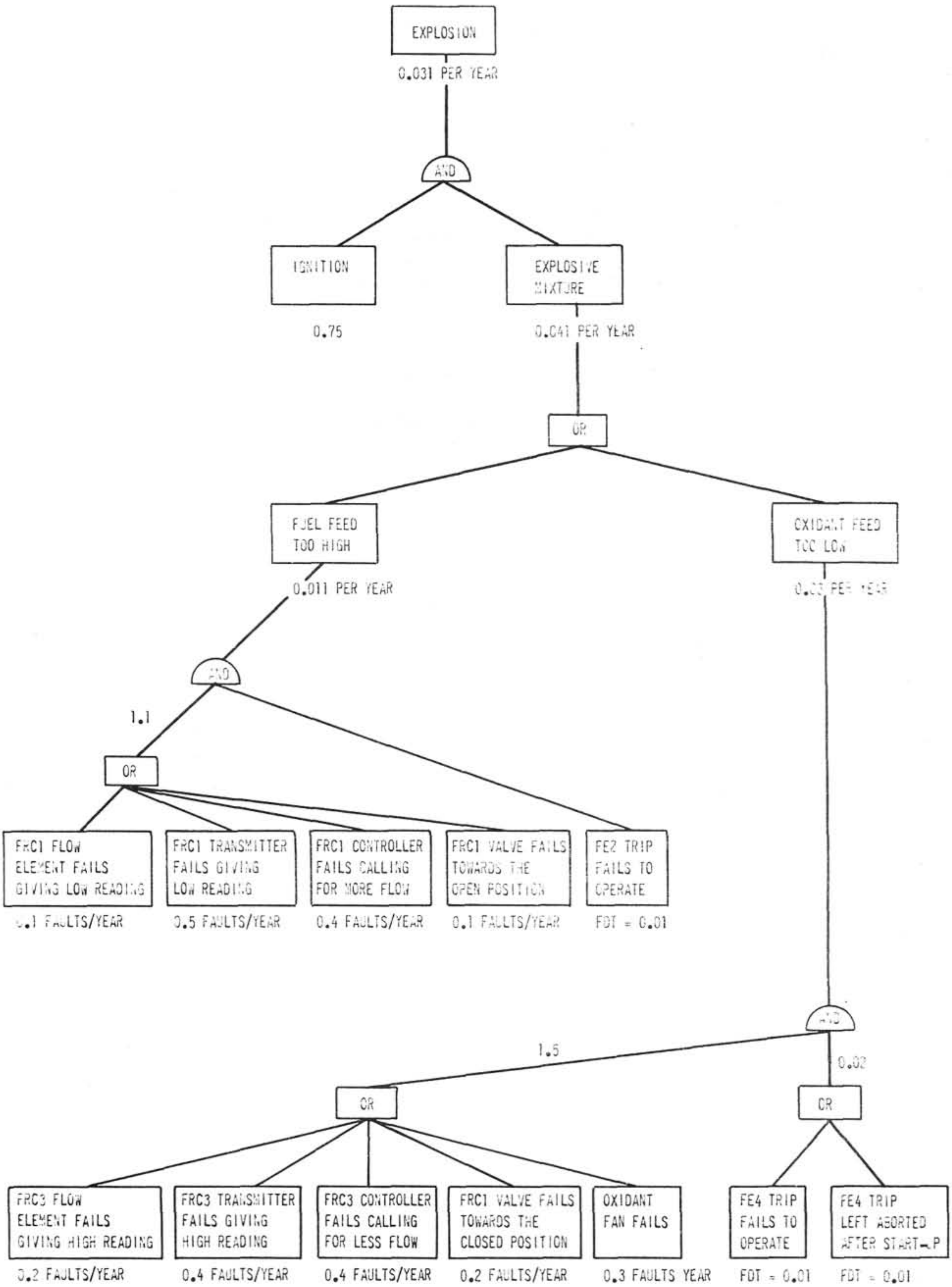
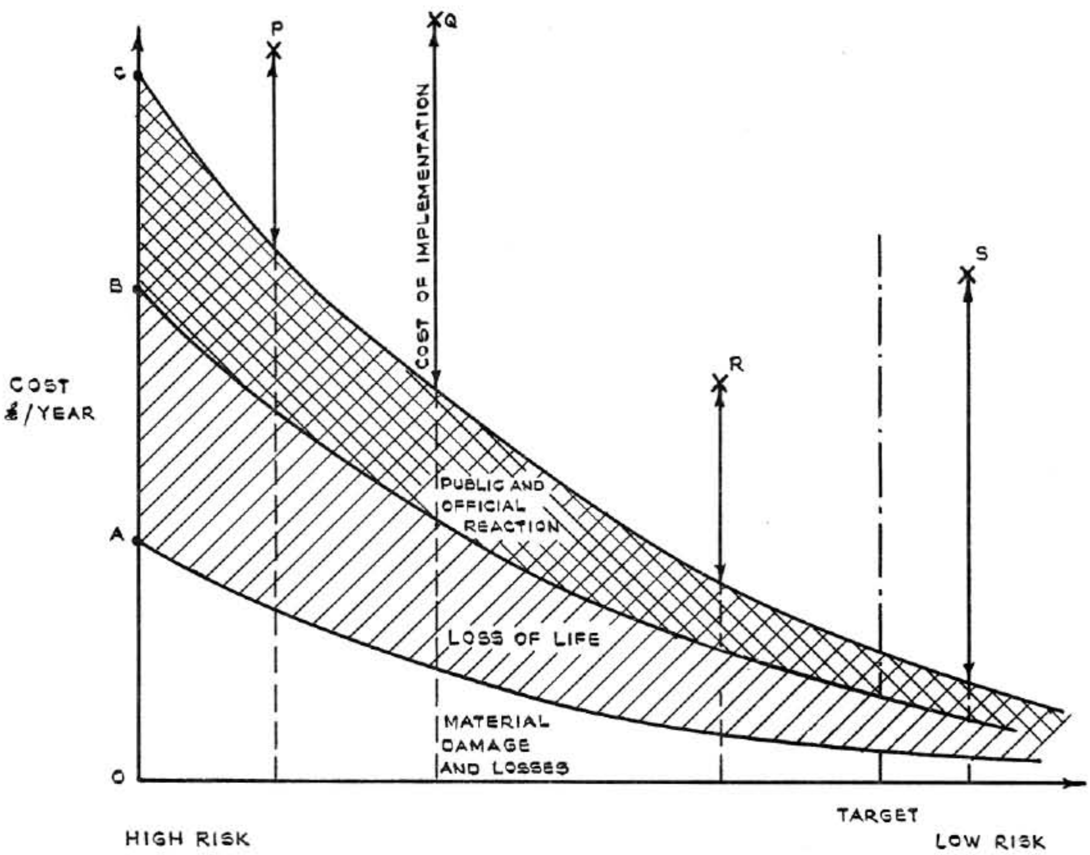


Figure 1B Fault tree for an explosion in the reactor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LOSS OF LIFE
MATERIAL
DAMAGE
AND LOSSES
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HIGH RISK
LOW RISK