IFAL - A NEW RISK ANALYSIS TOOL

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The Insurance Technical Bureau has developed a method of calculating the expected average loss from fire and explosion for plants handling flammable materials. The method is synthetic, calculating the course of the events leading to loss from data on the materials being handled, the main plant items, and the layout. The method is outlined and the sort of results which come from it are discussed.

A significant part of the overall hazard is the result of management ability: a method for assessing this is included in the overall system.

INTRODUCTION

Any operation handling flammable materials in considerable quantities must - or at least should - make every effort to understand as far as possible the nature and magnitude of the fire hazard. The owners need to keep their plant running and to avoid causing harm to their own staff or the general public at large: they will pass the residual risk in terms of financial loss to an insurer, who clearly needs to know what he is taking on. The regulatory authorities (e.g. H.S.E. in the U.K.) require assurance that all reasonable precautions have been taken for safety.

The hazard can never be reduced to zero; it is therefore necessary to understand as much as possible about the residual risk - how often will it happen, which parts of the operation are the most likely causes, which parts will suffer most, is there a danger of harm outside the plant limits, what emergency procedures need to be devised etc. etc.

Historically, probability of fire and magnitude of the consequences have been assessed from past experience: in the modern large petrochemical, oil and similar industries, there are too few similar plants in existence in the world to give reliable data. The IFAL risk analysis method has been *developed to enable the fire and explosion hazard to be calculated - for an* individual plant, from knowledge of the process, equipment, material properties etc. - that is, it is a synthetic method.

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THE METHOD IN PRINCIPLE

As indicated above, insufficient data for whole plants exists to give experience-based knowledge of the fire hazard. But any given plant is made up of many individual components - pumps, heat exchangers, columns, tanks, boilers etc. whose total population is quite large taken over industry as a whole, and for which, therefore, historically based reliability data is available. The applicability and precision of these data need to be carefully considered; the important point, though, is that there is a lot of it.

Certain, easily definable, things have to happen before a loss from fire or explosion can happen. Considering first events external to the equipment there are four steps, all of which must occur to give a loss:

1. Loss of containment

    Flammable material must escape from the process equipment: such an escape may be planned such as a pressure relief system, or the result of a failure - a flange leak, gland leak, pipe rupture etc.

2. Spread

    The flammable material must spread from its source, evaporating in part if necessary, mixing with air as it goes, in order to provide a mixture capable of burning.

3. Ignition

    The flammable mixture must meet a sufficient source of ignition.

4. Damage

    Some damage to plant or property must result.

The method divides a plant into a number of blocks: for each block it then looks at each major process item in the block in turn to determine the likelihood of loss of containment for different sizes of release, the magnitude of spread, the probability of ignition and the expected damage suffered by each block - and adds it all up.

THE METHOD IN MORE DETAIL

Put baldly like that it all seems rather simple. But as I am sure you will have already realised, there is a lot more to it. In a paper of this length it is not possible to give more than a glimpse of the main features.

Five types of fire are addressed in turn. The first is 'Internal Explosion' which is a two-part situation. An internal explosion in itself is likely to damage not only the item in which it occurs, but others by missiles: and it is likely to cause a large release of process material which may then be involved in an external fire or explosion. Models built in to the programme estimate the frequency from process and equipment parameters, the energy likely to be released and the damage as a function of energy.

External fires are next considered. To reduce the purely mathematical effort, losses of containment are divided into four ranges. Liquid and vapour releases are treated separately, estimates being made of the probable amount of release as a function of the effective leak orifice size, pressure, temperature etc. of the material and the quantity of material available to leak out: for each loss of containment range the frequency is estimated. The cloud or pool size resulting from the spread of the escaped material is calculated from its physical properties; the layout and location of ignition sources lead to the probability of ignition and the resulting heat load on the equipment leads to the damage suffered.

The next step deals with external explosions. The frequency and size of cloud are determined in the previous step; when a vapour cloud meets an ignition source, it may fail to ignite; it may burn; or it may explode. The relative frequencies are built into the previous step: the effects are now considered, treating unconfined and confined cloud explosions separately. For example, for unconfined explosions a minimum quantity in the cloud is needed.

Since it is necessary to address each of the five types of fire situation resulting from possible emissions from each major item of equipment, it is easy to see that an enormous number of calculations are needed. Clearly many steps need mathematical models - e.g. how much material escapes from at $10mm^2$ effective orifice at a given T and P: and over what area will nearly total damage occur after an explosion with a given energy. We have judged that it is unjustified to incorporate great sophistication in these models: we are, after all, aiming to calculate an average result, not a precise one-off. Simple models are therefore used, and in many cases empirical models or tabular data are incorporated. Complete plant details are never available, so many assumptions have to be made. These have all been carefully considered and are clearly specified: they can be changed if necessary.

A flow chart for the calculation process is given in Fig.1.

THE RESULTS

It may fairly be asked whether, in view of the simplifications and assumptions which, as indicated, have to be made to make a practical general programme, the results have sufficient validity to be useful. From our experience the answer is clearly "YES" - so let us go on to look at some of the results.

The final result of the computation is a single figure - say 6.0. This means that, averaged over a very long (theoretically infinite) period of time, the average loss from fire and explosion would be $6/1000^{ths}$ of the value of the plant per year. (Here you can see the insurance influence - this figure is the technical burning cost). It can now be explained how the acronym IFAL

arises. The result is the

> <u>I</u>nstantaneous   —   because it refers to conditions at
> the time the computation was done.

> <u>F</u>ractional   —   because the result expresses the
> loss as a fraction of the value at risk.

> <u>A</u>nnual   —   because the result is the loss averaged over
> infinite time with unchanged conditions
> referred to one year.

> <u>L</u>oss   —   because the result is a financial loss.

This single figure is useful in itself – but it is, of course, made up of a
large number of components, which can be extracted from the computation.

These components shew the distribution of the hazard – which areas of the
process are the major sources of fires and explosions; which areas suffer
the most damage; whether small, medium, large or catastrophic losses are
most important, which type of fire or explosion is most important; and so
on. One can consequently see in which areas loss reduction measures are
best applied. A typical breakdown is shewn in Table I.

The result of a single computation, done in the normal way using the basic
programme, is valid for the conditions and assumptions incorporated into the
programme which has been selected to represent "Standard Good Practice". If
one is aiming to compare different routes to the same product, or different
types of process to each other, no modifications need be made. In analysing
an existing particular plant, or considering a detailed new design, the
assumptions built into the programme are unlikely to be correct. But they
have been tabulated and built into the programme so that they can readily be
modified to suit a real case: for example the normal programme assumes that
a loss of containment continues for 10 minutes before it can be isolated:
if you have an Emergency Shut Down system which can detect and isolate a
leak in two minutes, the programme can readily be modified to use this new
datum. The two computations – one using 10 minutes and one using 2 minutes
– will shew the value of the ESD system in reducing fire loss; this is one
more piece of information in the cost/benefit analysis of whether the system
is worth-while.

Many other situations where you may need to know the effect of a design
change will immediately come to mind: differences in layout; application
of water cooling or insulation to structures or vessels; process or control
alterations – etc. etc. Provided the new conditions can be expressed in a
way acceptable to the programme its effect can be computed – both on the
overall figure and its distribution.

What about the accuracy of the results? Here there is a problem, because as
indicated at the beginning, experience is a doubtful reference point. We
are dependent therefore on the accuracy of each component of the
calculation. We believe that each step is justifiable: each individual
step may not be of high accuracy, but the combination of a large number of
steps whose errors are probably more or less randomly distributed must
reduce greatly the error of the final result. This seems to be confirmed by
some sensitivity analyses we have done, which shew that the final result is

not greatly affected by quite large variations in individual data and
assumptions. Further, our results to date are in fairly general agreement
with insurers' experience.

On a comparative basis, as for example when determining the effect of a
change in design, errors in the absolute values will cancel out to a marked
degree: in this mode, therefore, good accuracy can be expected.

We have now done more than seventy computations on various processes, at
differing capacities, and with varying conditions. The results - of these
computations - shew that for a given process, the average loss is directly
proportional to the square root of the throughput: if this effect is
decoupled the results can be shewn on a nomogram whose structure is given in
figure 2. This shews what one might call the 'inherent' hazard range.

THE METHOD IN PRACTICE

It is clear that a lot of information has to be collected about the process,
the equipment, the layout, the materials etc. to enable all the steps to be
computed. It is this data collection and manoeuvring it into a suitable
form, which is the main time consuming job. For a large complex plant such
as a refinery with many output streams about three man weeks are needed.
Hand-on operating experience of the plant is not essential; but some
general chemical process understanding is necessary. In many cases not all
the data will be readily available and engineering judgement has to be
exercised to fill in the gaps; and for an analysis of a real plant an
understanding of the basis built-in assumptions, and where they have to be
modified, is essential.

Having organised the data entry the computations take up to a few hours.
But once the main data entry has been completed, modifications can be fed in
very readily: the effect of layout changes - an example is given in figure
3 - loss prevention measures such as drenchers, changes in process,
inventory etc. can be calculated in a few hours, or less for a simple
process. Currently the programme is written to run on the Hewlett-Packard
200 series computers: the programme is menu-driven, and stored on 2 x 3½"
floppy discs: it can also be on 8" disc.

THE EFFECT OF MANAGEMENT

The programme assumes that the Management is of a good standard - its
quality does not figure in the computation. In practice, the Management
does have a substantial effect on the safety of any plant both by the
guidelines and standards it lays down for the design and construction stage,
and by the systems and techniques it employs during operation. The first
part - design and construction - can be allowed for by modifying appropriate
parts of the programme data for the process hazard calculation. For
example, data on leak rates of pump glands are based on an average practice:
if a design employs a gland system which is significantly different e.g.
double mechanical seals with smothering fluid between them, the basic leak
rates built in to the programme can be modified accordingly.

The second part has been addressed as a separate exercise the result of which is applied as a coefficient to the process hazard calculation. The scheme has been developed by the ITB in conjunction with the Applied Psychology Department of Surrey University - it is a witches brew of psychologists and engineers.

The most important constraint is, that however the assessment of Management quality is done, the person who, in practice, has to do it is neither a psychologist nor (in most cases) an engineer. The problem then is to find a way to assess people (this is what assessing Management really is) without having to judge them; and then to decide whether the assessed result is good enough for the plant being managed without understanding the finer points of the process hazard.

It soon became clear that we really have a two-part problem: firstly to assess how good the Management is (we are of course looking at loss prevention almost exclusively); and secondly, to compare the assessed goodness with some standard which is a function of the hazard of the plant being managed. The first part is mainly the psychological part of the problem, but some engineering is involved to estimate the possible effects of Management behaviour; the second is a combination deciding how good the Management of a given plant must be to be called 'average'; and consequently determining whether the actual one is better or worse.

The procedure, which was the outcome of a lot of investigation work, is a simple one. A questionnaire containing fifty questions about various Management functions which affect hazard has to be filled in by the investigator. The answers in each case are graded in five steps as a reasonable compromise between resolution and subjectivity. The questions are obviously not of equal importance - so the answer scores have to be weighted. The factors required were devised from the judgement of a group of experts - who agreed with each other remarkably well. The products of score and weighting factor are combined in a set way to give four figures which represent how good the Management is at loss prevention looked at from four different angles. This is the end of stage 1 - How Good.

The four "How Good" figures now have to be compared against some standard - because the higher the plant hazard the better the Management must be at loss prevention. The standard used so far is the average fractional loss - the IFAL values for the process. The How Good figures (Surrey Factors) are individually scaled and ranged against the IFAL value (they are not necessarily of equal importance) and scaled again so that the resulting "Management factor" M = 1.0 when everything is average. The ranging and scaling factors currently used are arbitrary, and were chosen to give what appears a good range for 'M'. Experience in the field will shew whether changes are needed.

SUMMARY

The IFAL method was originally intended to rank risks for which historical data are too sparse to be useful: it has been developed into a risk *analysis tool with several important advantages:*

* It is basically quantitative and objective;

* It calculates the long-term average loss from fire and explosion;

* It can shew the effects of design changes, process changes, loss prevention measures etc;

* It includes a method of assessing Management with the minimum practical subjectivity;

* It is transparent in the sense that changes in data and assumptions can readily be made;

* It is of use to industry, designer, insurer and regulatory bodies in quantifying hazard.

ACKNOWLEDGEMENT

TABLE 1 - TYPICAL RESULT SHEET

'p' Factor Results by CATEGORY & BLOCK.
(All results are presented as 'per 1000').

	Fires		Explosions			Sub-totals
	Pool	Vapour	PUVCEs	Confined	Internal	
CONTROL as Target	0.0000	0.0000	0.0071	0.0000	0.0000	0.0071
CONTROL as Source	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ADMIN as Target	0.0000	0.0000	0.0012	0.0000	0.0000	0.0012
ADMIN as Source	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PUMPS as Target	0.0010	0.0000	0.0002	0.0000	0.0000	0.0013
PUMPS as Source	0.0011	0.0002	0.0000	0.0000	0.0000	0.0012
DRUMS as Target	0.0001	0.0001	0.0014	0.0000	0.0000	0.0016
DRUMS as Source	0.0001	0.0000	0.0003	0.0000	0.0000	0.0004
ROADRAIL as Target	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ROADRAIL as Source	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
REACTION as Target	0.3971	0.2163	0.1254	0.0000	0.0000	0.7387
REACTION as Source	0.3971	0.2163	0.1826	0.0000	0.0000	0.7960
UTILITIES as Target	0.0289	0.0232	0.0062	0.0000	0.0000	0.0583
UTILITIES as Source	0.0289	0.0232	0.0000	0.0000	0.0000	0.0521
RECOVERY as Target	0.2215	0.2839	0.0414	0.0000	0.0000	0.5469
RECOVERY as Source	0.2215	0.2839	0.0000	0.0000	0.0000	0.5055
	0.6487	0.5235	0.1829	0.0000	0.0000	1.3552

p' Factor Results by EMISSION RANGE & CATEGORY

	Range 1 - 20 tonnes	Range 20-100 tonnes	Range 100 + tonnes	Range Catast-rophic	-	Sub totals
Pool fires	0.3583	0.2905	0.0000	0.0000	0.0000	0.6487
Vapour fires	0.5056	0.0180	0.0000	0.0000	0.0000	0.5235
PUVCEs	0.1469	0.0360	0.0000	0.0000	0.0000	0.1829
Confined explosions	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Internal explosions	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	1.0108	0.3444	0.0000	0.0000	0.0000	1.3552

TABLE 2 - PROCESSES ANALYSED

No.	Product	Process	Product Rate 10^5 t/a
1	Vinyl Acetate Monomer	VSI Chemicals	.5
2	Ethanol	Hibernia	1
3	Formaldehyde	Methanol (oxidation/ dehydrogenation)	1
4	Benzene	Toluene Demethylation	.5
5	Cyclohexanone	Stamicarbon	1
6	Refinery Products	Hydroskimming Refinery	50
7	Cyclohexane	IFP	.5
8	Butadiene	BASF	.5
9	Isopropanol	Hibernia	1
10	Methanol	ICI Low Pressure	5
11	Refinery Products	Catalytic Cracking Refinery	50
12	Isobutylene	CFR	.5
13	Acrylonitrile	Sohio	.5
14	Acetic Acid	High Pressure BASF	1
15	Acetone	Deutsche Texaco AG	.5
16	Polyethlene	Low Density Monsanto	.5
17	Polybutadiene Rubber	JSRC (solution) Process	.5
18	Styrene Butadiene Rubber	Emulsion Polymerisation	.5
19	Adipic Acid	Oxidation of ol/one	.5
20	Polyvinyl Chloride	Suspension Polymerisation	.5
21	Vinyl Chloride Monomer	Oxychlorination	5
22	Polypropylene	Low Pressure Ziegler	.5
23	Ethylene Oxide	Scientific Design	1
24	Ethyl Benzene	Benzene Ethylation	5
25	Styrene	Ethylbenzene Dehydrogenation	5
26	Liquefied Natural Gas	Separation & Liquefaction	50
27	Isobutane	Gas Phase Isomerisation	1
28	Isobutene	UOP Gas Phase Isomerisation	1
29	Methyl t-Butyl Ether	Snam Progetti	5
30	Ammonia	Natural Gas Reforming	5
31	Phenol	Toluene Oxidation	1
32	Styrene	Ethylbenzene Dehydrogenation	.5
33	Styrene	Ethylbenzene Dehydrogenation	1
34	Styrene	Ethylbenzene Dehydrogenation	10
35	Styrene	Ethylbenzene Dehydrogenation (Double Stream)	50

| No.	Product	Process	Product Rate 10^5 t/a
36	Liquefied Natural Gas	Storage and Vaporisation	1
37	Propylene Oxide	Propylene Oxidation	1
38	Acetaldehyde	Ethanol Oxidation	1
39	Pyridine	Synthesis (Acetaldehyde)	1
40	Methyl Ethyl Ketone	Butylene Oxidation	.5
41	Ethylene Glycol	Hydrolysis of Ethylene Oxide	1
42	Ethylene Glycol	Ethylene Feed	1
43	Ethylene Oxide	Ethylene Oxidation	1
44	Ethylene	Naphtha Steam Cracking	5
45	Ethylene	Natural Gas Steam Cracking	5
46	*Natural Gas Liquids*	*70% Ethane Recovery*	10
47	Natural Gas Liquids	0% Ethane Recovery	10
48	N/A		
49	N/A		
50	Pyridine/Acetaldehyde	Ethanol via Acetaldehyde	1.1
51	Ethanol/Acetaldehyde/Pyridine	Ethylene Feed	1.1.1
52	Ethylene/Ethanol/ Acetaldehyde/Pyridine	Naphtha Feed	2.1.1.1
53	Propylene Oxide	Cumene Feed	1
54	VCM/PVC	Ethylene Feed	5.0.5
55	Ethylene/VCM/PVC	Naphtha Feed	5.5.0.5
56	Styrene	Ethylbenzene Dehydrogenation	50
57	Styrene/SBR	Ethylbenzene Feed	1.0.5
58	Ethylbenzene/Styrene/SBR	Ethylene Feed	5.1.0.5
59	Methyl Ethyl Ketone	Butylene Oxidation	1
60	Ethyl Benzene	Benzene Ethylation	10
61	Methanol	ICI Low Pressure	10
62	Formaldehyde	Methanol (oxidation/ dehydrogenation)	5
63	Benzene	Toluene Demethylation	1
64	Methyl Ethyl Ketone	Butylene Oxidation (pressure change)	.5
65	Refinery Products (hydrocracking)	Hydrocracking Refinery	50
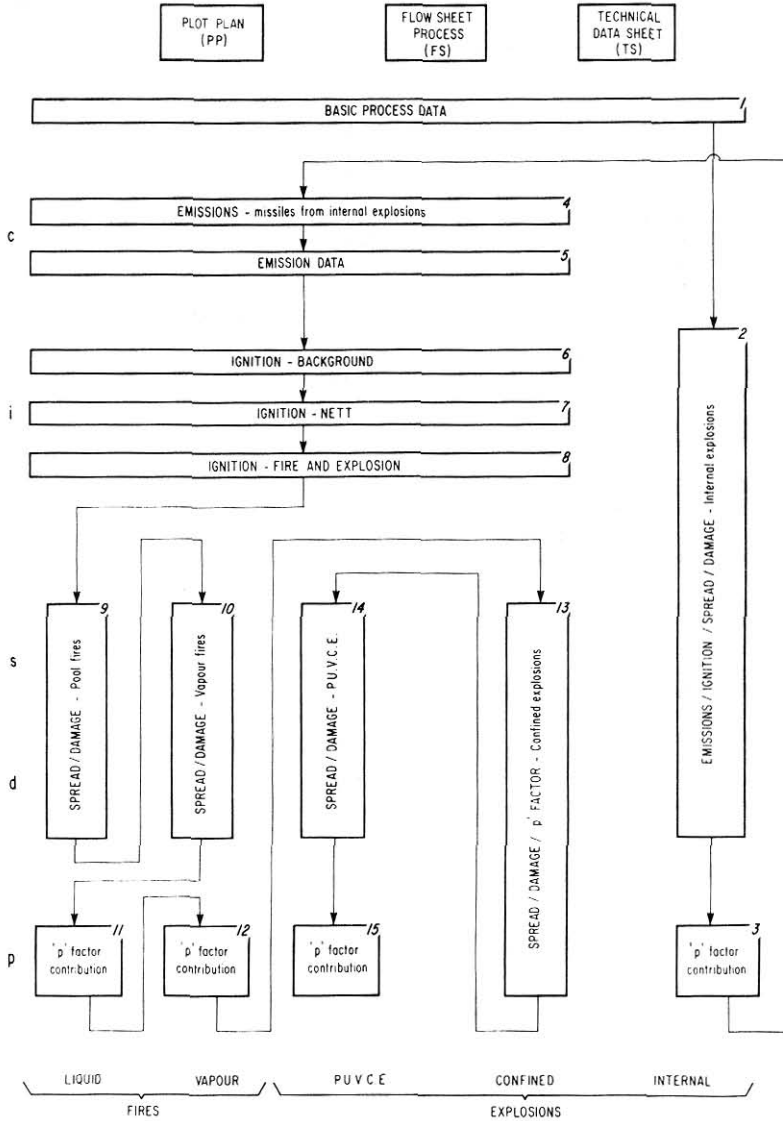
Fig.I Flow chart for an IFAL calculation
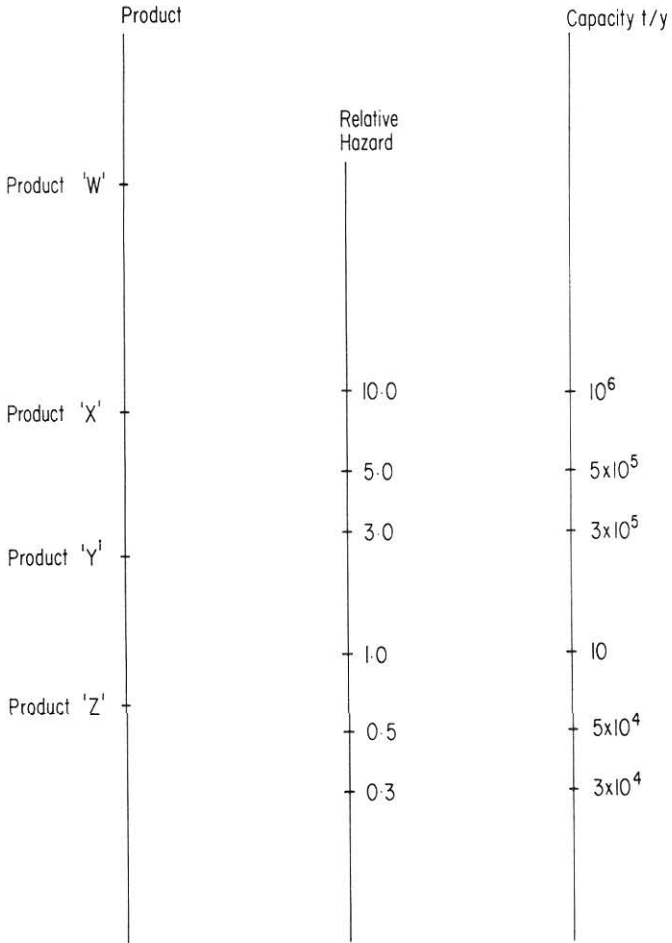
Fig. 2 Nomogram structure
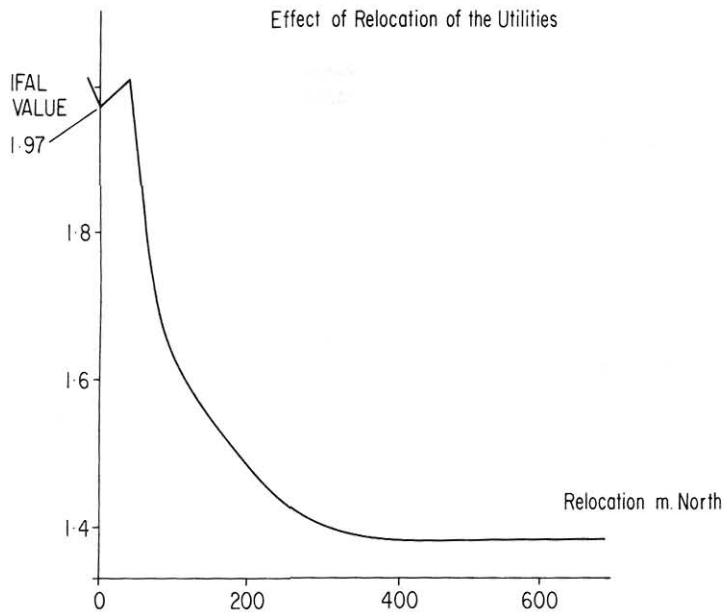
Fig. 3 Effect of moving a boiler house