A Modular Method for Hazard and Operability Studies of Process Plant

By

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In memory of my dad

Dr Alan Jefferson

1945-1999

Abstract

The identification of hazards in chemical plants has become increasingly important. Not only have chemical plants become larger and more complex, but some countries now have regulations requiring that some form of formal hazard identification be carried out. With the increased speed of many other parts of the design process, hazard identification is becoming the log-jam in attempts to speed up the design of new plants still further.

One of the most popular techniques for hazard identification is a hazard and operability study (HAZOP), in which a group of people attempt to identify creatively the possible hazards by applying a methodical process whereby the effect of deviations to every process variable is considered in every part of the plant.

The aim of this thesis is to explore methods of improving hazard identification through the development of the HAZOP technique. This thesis examines possible improvements that can be made through a better understanding of activities and how they are carried out in HAZOP, discusses the possibilities of automated hazard identification based on HAZOP, and in particular presents a novel, modular HAZOP methodology.

Modular HAZOP is based around identifying the modules that make up a chemical plant and then using previously generated HAZOP results associated with each of the modules. The hazards associated with these modules will therefore be known and rules are required to deal with the interconnections between modules. Application of these rules determines any additional hazards that might arise from the interconnection of modules.

A number of important principles have been identified including, the level of decomposition required, the use of interchangeable sub-modules within modules, the fact that the majority of cause-consequence scenarios exist in adjacent modules, and the categorisation of locally and remotely propagated effects. These provide for a procedure which is adaptable to different plant configurations, but can also be quickly and easily applied. The latter principles enable the simpler fault paths, which make up most of the cause-consequence scenarios, to be identified quickly, leaving a much reduced number of fault paths which require a more thorough analysis.

Acknowledgements

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1 Introduction

1.1 Project Overview

The identification of possible hazards in chemical plants has become increasingly important. Not only have chemical plants become larger and more complex, but also some countries now have regulations requiring that some form of formal hazard identification be carried out. Moreover, environmental regulations have been tightened as the public has become aware of the dangers posed by large chemical plants. In the United States it is also a legal requirement to carry out some form of hazard identification retrospectively for plants already built and operating but which have not previously been subjected to any formal hazard identification (OSHA 1992).

There are a number of hazard identification techniques available. These techniques consist of procedures, rules and guidelines to be followed in order to make the identification of hazards as efficient and as effective as possible. Over the years many companies have refined particular techniques to suit their own particular needs and to try to increase their effectiveness and efficiency. However, in general, this has not reduced the time taken to carry out hazard identification.

With the increased speed of many other parts of the design process, hazard identification is becoming the logjam in attempts to speed up the design of new plants still further. The speeding up of hazard identification has become an urgent priority as the chemical industry seeks to speed up the building of new chemical plants. However, above all, it is necessary that any hazard identification procedure maximises the number of hazards identified and any improvement should not reduce the number of hazards identified. In order to improve hazard identification techniques, improvements need to be made to the procedures, rules and guidelines that make up these techniques.

There are three main techniques for hazard identification:

Checklists - a list of hazardous plant arrangements, equipment designs, operating regimes, etc. are compared with the plant under consideration to see if similar circumstances exist which may give rise to hazards.

What If - a group of people attempt to identify creatively the possibility for hazards by applying the question, "What if?", in combination with known failure mechanisms for equipment and systems, to all the items in the plant.

Hazard and Operability Studies (HAZOP) - a group of people attempt to identify creatively the possibility for hazards by applying a methodical process whereby the effect of deviations to every process variable is considered in every part of the plant.

Following the identification of hazards, a combination of steps may be taken to reduce the likelihood of the hazard occurring and to minimise the effect of the hazard. What steps are required to be taken, and the effectiveness of these steps may be assessed by applying a rigorous, quantitative, analysis of the hazard, this is quantitative risk assessment (QRA). Typically, hazard identification techniques are essentially qualitative; a determination of the likelihood of causes and the effects of hazards based on a crude judgement made by the people involved. QRA includes techniques such as fault tree analysis (FTA) and failure modes, effects and criticality analysis (FMECA).

The aim of this thesis is to improve hazard identification through the development of the HAZOP technique. In considering how to improve HAZOP there would seem to be three options. Firstly there is the possibility that the methodology could be improved through a better understanding of activities and how they are carried out in HAZOP. Secondly there is the possibility that a methodology can be developed to allow HAZOP of chemical plants on a modular basis. Rather than carrying out HAZOP on a line by line basis, modules will exist which have already had a HAZOP carried out on them, and so the hazards associated with these modules will already be known. A few rules can then be applied to determine any additional hazards that

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analyse how effective HAZOP is in practice, and whether there were any lessons to be learned. This was done by studying the original HAZOP results for part of a fairly complex plant and comparing the problems identified therein with problems that had subsequently come to light on the plant and trying to establish whether and/or how improvements could have been made (details confidential).

1.3 Layout of the Thesis

This thesis starts by detailing the HAZOP procedure and some of the history behind its development. Having dealt with this background information, an analysis of the possible improvements to conventional HAZOP is provided. In particular, this covers the composition and structure of HAZOP meetings and the use of computer tools. The development and role of automated HAZOP is then outlined.

The latter half of this thesis deals with the theory and procedure of modular HAZOP. As identified above, this technique for hazard identification breaks the plant down into modules that have already been subject to some form of hazard identification and are provided with a set of HAZOP style results of this hazard identification. These latter chapters of the thesis deal with how the plant is broken down into modules, how the interconnection between modules is dealt with and gives an example of the application of this technique. The appendices provide a further example of the application of the modular HAZOP procedure and examples of HAZOP style results for some modules.

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2 Conventional HAZOP

2.1 Origins of HAZOP

The 1960s saw significant developments in the process industries. Throughout this period plants became more complex and significantly larger than previous chemical plants. In addition processes were developed which required higher pressures and temperatures placing additional demands on materials of construction and process control. It was during this time that it was recognised that the existing approach to dealing with hazards was no longer acceptable. With previous smaller plants, no attempt was made to identify the possibilities for hazards. Instead, hazards were allowed to occur, on the understanding that the losses would not be significant, and that subsequent development of the plant and the drafting of appropriate codes, meant it would not happen again. Process plant safety concentrated on minimising the effect of any hazards. Butler (1973) describes how Dow Chemical's safety policy is based upon, amongst other things, physically dividing the plant up so that damage due to fire or explosion does not exceed a certain limit, the wearing of safety goggles and helmets, training of new plant operators and anonymous reporting of near miss incidents.

This trial and error approach to hazard identification was no longer justifiable given that losses resulting from hazards on new process plant could indeed be significant. This was brought sharply into focus following the Flixborough disaster in 1974. Kletz (1992) sums up the approach taken as follows:

"The traditional method of identifying hazards - in use from the dawn of technology to the present day - was to build the plant and see what happens - 'every dog is allowed one bite'. Until it bites someone we can say that we did not know it would. This is not a bad method when the size of the incident is limited but is no longer satisfactory now that we keep dogs, which may be as big as Bhopal (over 2000 killed in one bite), or even Flixborough (28 killed). We need to identify hazards before the accidents occur".

HAZOP was first developed and used by ICI in the late 1960s. HAZOP was a development of method studies and the earliest account of their use and evidence of their origins can be found in Elliot & Owen (1968). They describe a technique called critical examination and although the majority of their paper is concerned with optimising the design process, it does include a section discussing how the technique could be used to carry out gives "hazard surveys". In particular it describes its use as follows:

"Another useful application of the questioning approach of critical examination is in the study of operability and hazards. Using the "finished" line diagram as a basis, the detailed operations required to start up, run, and shut down both normally and in emergency are examined for every item of plant."

They also identify that the value lies in the way the thinking is done

"We re-emphasise that the techniques are an aid not a substitute for thinking. Their value almost always arises as a result of the manner in which the thinking is done - systematically, logically, and in depth, and yet retaining flexibility and imagination."

I believe that this is an important point, which seems to have been lost as HAZOP has developed. In many cases, it now seems that people expect that the application of the technique will automatically produce the answers. In developing the procedure some of the principles have been lost.

Lawley (1973) published the first complete paper on the HAZOP technique. Originally referred to as an "operability study", it was developed on the supposition that the failure to identify most hazards was due to the complex nature of the plant, rather than a lack of knowledge on the part of the design team. It is summarised as follows:

"In essence [an operability study] is an abbreviated form of "critical examination" based on the principle that a problem can only arise when there is a deviation from what is normally expected. The procedure, therefore, is to search the proposed scheme systematically for every conceivable deviation, and then look backwards for possible causes and forwards for the possible consequences."

The reference to "critical examination" clearly links this work to that of Elliot & Owen (1968) described above. As well as a thorough description of the "operability study" procedure, and a detailed set of results for an operability study of part of an olefin dimerisation plant, the paper also describes a technique called "hazard analysis" using logic trees to derive a quantitative assessment of serious hazards following their identification. This is easily recognisable as FTA.

2.2 HAZOP Procedure

The basic principle of HAZOP is to apply guide words to a model of the system being analysed. The guide words are applied on a section by section basis to appropriate system variables to generate relevant deviations. The size of sections is determined by the level of detail required for the study. For continuous process plant, the basic model of the system will be the finished piping and instrumentation diagram (P&ID) or engineering line diagram (ELD) and the sections will correspond to lines on the P&ID or ELD. For batch processes the model of the system may be the batch operating instructions and the sections will correspond to individual operations.

There are numerous texts that give detailed instructions on how to carry out HAZOP in chemical plants (Chemical Industries Association Ltd, 1977; Kletz, 1992; Knowlton, 1992; Lees, 1996). The basic principle for a continuous plant is for a group of people to apply certain defined guide words to lines, on a piping and instrumentation diagram (P&ID) or engineering line diagram (ELD), on a line by line basis in an effort to identify causes and consequences of process deviations. The approach taken is outlined in figure 2.1. This figures is a modified version of that presented in the above texts. The two steps in the middle of the procedure, "Examine possible causes" and "Examine consequences" are normally illustrated by showing the latter following the former, i.e. indicating that the "Examine possible causes" step is carried out before the "Examine consequences" step. In practice these steps may be applied, particularly by more experienced HAZOP teams, in either order. This is generally dependent on the likelihood of a particular cause or the severity of a particular consequence. Where likely causes are readily identified, time is spent subsequently on determining possible consequences. Alternatively, the ready identification of a moderate or serious consequence may then lead to time being spent on analysis of possible causes.

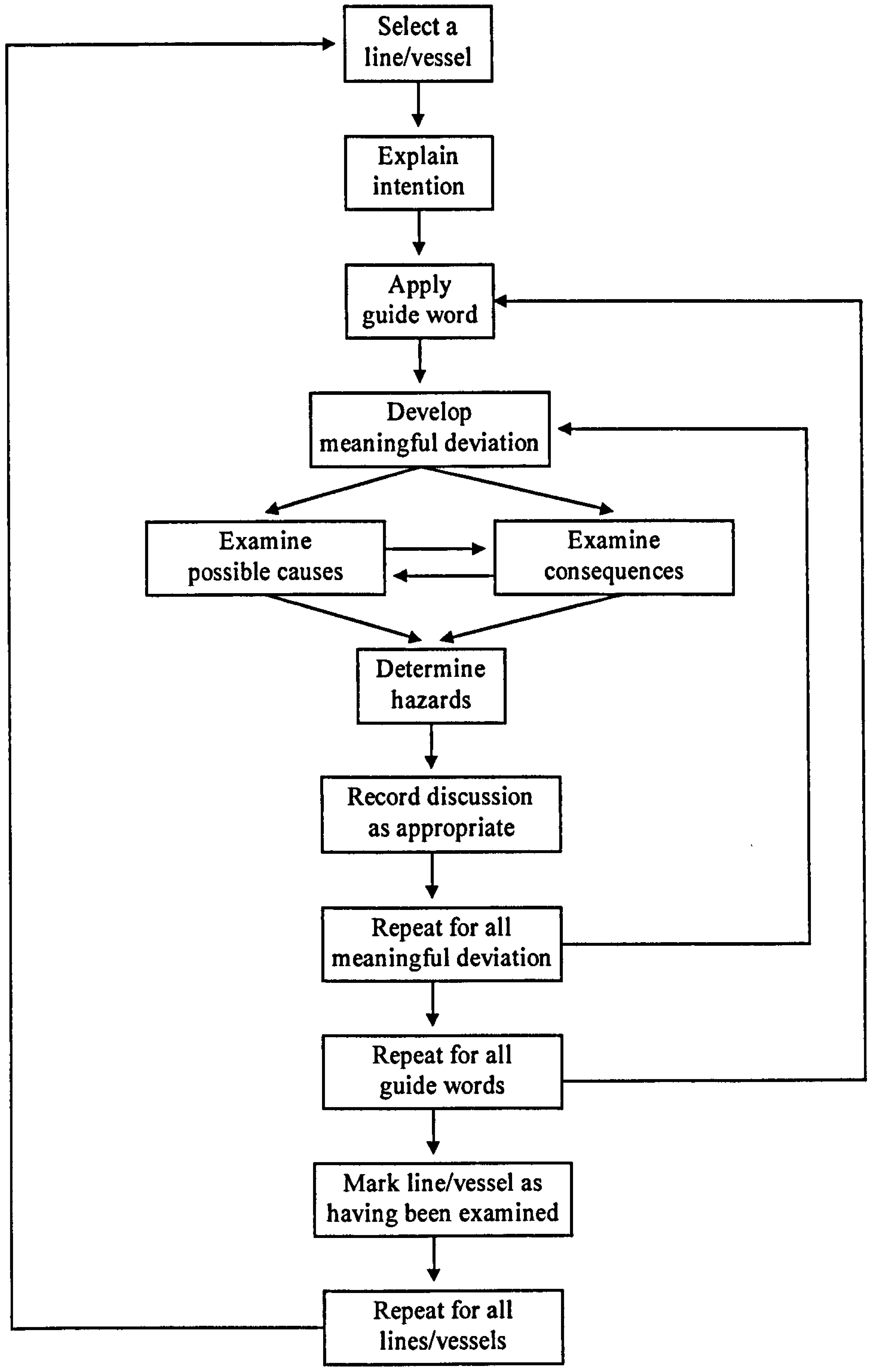

Figure 2.1 - Basic method for conventional hazard and operability studies (HAZOP)

2.3 HAZOP Failings

Before looking at how HAZOP has developed and the possible methods for improvement in the future, it is worth looking at the current failings of HAZOP and why these failing exist. Ironically HAZOP is now suffering from the same problem that chemical plants were suffering from 20 years ago. The problem used to be that because a chemical plant or process had never been involved in any incidents then it was assumed that there were no hazards associated with it. One of the reasons that HAZOP was introduced was to combat this attitude and provide a tool for deciding whether potential problems existed or not. The problem now is that because, on the whole, potential problems with the application of the HAZOP methodology have not been associated with any incidents, no one sees any need to change it. (See Crawley (1995) for an exception).

The problem stems from the perceived high cost of HAZOP due to the length of time it takes to carry out HAZOP and the apparent lack of benefits. In fact, data collected from 125 HAZOP based hazard studies shows the cost of a hazard study is only 0.16% of the capital cost of a project (Gillet, 1995). In addition, the tangible benefits, the benefits *seen* by project managers, the actual addition of safety measures and provision of protective equipment which safeguard the company assets, is only a small part of the total benefit. There are considerable intangible benefits including behavioural, quality and corporate image benefits (Gillet, 1995). The main intangible benefit realised by HAZOP is the training and knowledge gained by team participants. This translates into more efficient commissioning of plant and improved plant operation. For more intangible benefits see Pully (1993). Also, as designers, at least in some companies, are becoming more aware of possible hazards and are coming up with better designs, HAZOP identifies very few, if any, real hazards.

This perceived high cost of HAZOP has resulted in companies using less experienced personnel to carry out HAZOP. In addition as any technique becomes more widespread the standard of performance fails (Kletz, 1995). HAZOP was developed by SHE experts and the guide words provided convenient handles on which they could hang their expertise. In effect, each guide word prompted the experts to consider certain problems and HAZOP would have been just as effective whatever words were used. The guide words provided a convenient alternative to long checklists. In this way the HAZOP methodology also overcame one of the main drawbacks of checklists. It is very easy to prove that checklists are incomplete. It has never been possible to prove how complete HAZOP is. HAZOP also enables a certain amount of flexibility in its application. One of the advantages of this being that a certain amount of redundancy was introduced, so if a problem was missed first time round there was still likely to be the opportunity to pick it up elsewhere. However, this flexibility also introduces potential problems in the form of ambiguities. For example it is ambiguous when studying high flow whether that refers to high flow in to the line being studied or high flow out of it. Among experienced HAZOP leaders these ambiguities are realised and they have developed their own rules for dealing with them. This also relies on the leader having good control over the members of the team so that the team accepts the interpretation of the guide words supplied by the leader and they do not stray into considering interpretations that the leader feels are inappropriate.

Less experienced HAZOP teams do not have the expertise to realise the problems associated with each of the guide words and have not developed rules for overcoming the ambiguities. The first of these problems means that HAZOP results are not as complete as they could be. The latter problem leads to HAZOP taking longer than it should. This only serves to reinforce the perception that HAZOP has a high cost for little benefit. These problems are exacerbated by the lack of adequate training available for HAZOP team leaders. Although there are plenty of courses available to teach the basics of leading HAZOP teams, the best training can only be through experience of HAZOP meetings. Further, this experience should go beyond simply contributing to HAZOP meetings. The ideal role to gain the necessary experience must be as a HAZOP secretary with appropriate coaching from the HAZOP team leader. However, in order to reduce the perceived cost of HAZOP meetings, the number of people involved in each meeting is being reduced and the first role to go is that of HAZOP secretary, often to be replaced by a computer.

2.4 HAZOP Effectiveness

It is also worth trying to understand why HAZOP is so effective. Two primary factors have been identified for effective hazard identification (Lowe & Solomon, 1983). These are, the availability of appropriate information and having a systematic method for applying the knowledge. They also identify two different procedures, comparative methods, where a design is checked against codes, and fundamental methods, such as HAZOP. Obviously HAZOP studies satisfy the systematic requirement and, if conducted properly, all the appropriate information should be available. There are other methods that satisfy these requirements but the results are apparently not as good as those achieved with HAZOP. Systematic methods similar to HAZOP include WHATIF and checklist studies. Checklist studies are a comparative approach whereas WHATIF studies are another fundamental approach.

How are WHATIF, checklist and HAZOP studies similar? The HAZOP and WHATIF techniques rely on stimulating thought amongst a team of people using a team leader to apply the method correctly and to ask questions as necessary. They can all be applied to study a detailed line diagram and their primary objective is to identify cause-consequence scenarios. The WHATIF study is based on asking questions about possible causes. What is really being asked is 'What are the consequences of...?' The checklist study involves trying to identify whether or not certain circumstances exist that have been found to create possible hazards. These circumstances are identified on a list and the study requires comparison of the proposed plant with the list. Checklist studies are systematic but there are two important deficiencies using checklists. Firstly, creative input is limited. Secondly they can only be used to identify arrangements of components that have previously been shown to be possible causes of hazards. Checklists, however, provide a quick way of checking designs for basic errors. It is anticipated that computers could be used to check automatically P&IDs or ELDs generated using a computer aided design (CAD) system.

The important point about HAZOP studies is that they can be used either to identify a consequence of a certain deviation or to identify a cause of a deviation. The team can move from a deviation forward to a consequence or backward to a cause. This would seem to maximise the opportunities for creative input and reduce the possibilities of oversights.

2.5 Development of HAZOP Procedure

2.5.1 General Development of HAZOP Procedure

The basic principles of HAZOP have remained unchanged since its development by the process industry, and in particular ICI, 25 years ago. However, it is now used by a wide range of industries extending far beyond the process industry including the construction, electrical and transportation industries (Eggert, 1995 & Sankaran 1993). Of course each industry and each individual company has made modifications to the procedure to maximise the efficiency and effectiveness of HAZOP (Rushton et al., 1994).

Along with the development of the HAZOP procedure, ICI developed a six stage procedure designed to identify hazards at different stages in the life of the plant, from initial project exploration through to commissioning and normal plant operation (Gibson, 1976). Duxbury & Turney (1989) give a more detailed description of this procedure. Hazard Study I is intended to make sure that the hazards associated with the materials present in the plant are understood. It provides the basis for a safe design. Hazard Study II is a top down consideration of the major hazards that may exist within the plant. Potentially major events, such as fire, explosion, toxic release, etc., are analysed to see which represent hazards and suitable designs will be developed, if necessary, to reduce these hazards. The HAZOP procedure is part three (Hazard Study III) of this six stage process. However, there is little time saving gained by using this six stage approach. Hazard Studies I and II identify possibly problem areas and address particularly hazardous situations but they do not have the same rigorous and detailed methodology that lies behind the success of HAZOP in identifying possible hazards. Hazard Studies IV, V and VI exist to check that the plant is built as designed, that no new hazards have been introduced during commissioning and that any unforeseen hazards or operability problems are dealt with.

2.5.2 Development of Guide Words and Checklists

The list of basic guide words for continuous process plant has remained generally unchanged since HAZOP originated. Table 2.1 gives a list of the guide words and their meanings taken from the CIA Guide (CIA, 1977).

GUIDE WORDS	MEANINGS	COMMENTS
NO or NOT	The complete negation of these intentions	No part of the intentions is achieved but nothing else happens.
MORE	Quantitative increase	Increase in quantities and properties such as flow rates and temperature as well as activities like heat and react.
LESS	Quantitative decrease	As above but decrease.
AS WELL AS	Qualitative increase	All the design and operating intentions are achieved together with some additional activity.
PART OF	Qualitative decrease	Only some of the intentions are achieved; some are not.
REVERSE	The logical opposite of the intention	Applies to activities such as flow or reaction. It can also be applied to substances, e.g. poison instead of antidote or d instead of l optical isomers.
OTHER THAN	Complete substitution	No part of the original intention is achieved. Something quite different happens.

Table 2.1 - Guide words as originally applied in HAZOP. (From CIA 1977).

Having been developed largely in the petrochemicals division of ICI, the original HAZOP procedure (Lawley, 1973) was biased heavily towards continuous processes. This is illustrated by the types of deviation associated with each of the guide words:

NONE - No flow.

MORE OF - More of flow, temperature, pressure, viscosity, etc., i.e., higher flow, higher temperature, or whatever, than there should be.

LESS OF - Lower flow, temperature, pressure, viscosity, etc., than there should be.

AS WELL AS - Impurities present, e.g., ingress of air, water, acids. Extra phase present, e.g., vapour, solids.

PART OF - Change in composition of the stream, e.g., ratio of components different from what it should be.

REVERSE – Reverse flow.

OTHER - What else apart from normal operations can happen, e.g., start-up, shutdown, maintenance, catalyst change, failure of plant services.

These deviations are generated by combining the guide words with relevant process variables for continuous plant. Clearly however, there are certain combinations of guide word and process variable that are not valid. These would be things such as *no temperature* and *no viscosity*. The relevant deviations for continuous plant can be defined explicitly, the above set being used for batch processes with a couple of additions. This eliminates the need to combine a guide word with an intention. For continuous plant the following list of deviations should be considered:

HIGH FLOW
LOW FLOW
NO FLOW
REVERSE FLOW

HIGH/LOW PRESSURE
HIGH/LOW TEMPERATURE
HIGH/LOW LEVEL
HIGH/LOW MIXING
STATIC
HIGH/LOW CONCENTRATION
CONTAMINANTS
TESTING
START-UP
SHUT-DOWN
COMMISSIONING & MAINTENANCE.

Other deviations which have been suggested for consideration following hazards which have occurred and for which the potential was not identified in HAZOP (Crawley, 1995) are:

VIBRATION
IMPACT
NATURAL FREQUENCY
ENTRAINMENT
VORTEX

Rushford (1977) took the development of deviations for continuous process plant further. Along with the guide words and the process deviations for continuous plant, there is also a list of possible causes and consequences that may need to be considered with respect to these deviations. This checklist type guide word aid was developed further by ICI. Lees (1996) presents an extensive list, called a guide diagram, of the process deviations for continuous plant and possible causes of these deviations. Other companies have similarly developed guide word aids (Sweeney, 1993 & Kelly, 1991). Kelly (1991) details some changes that have been made to the HAZOP procedure within the company he works for (M. & M. Protection Consultants, Cedar Knolls N.J.). They have developed three process hazards checklists to aid the HAZOP procedure. The first deals with initiating problems, the second with consequences and the third with hazardous events. These checklists are then used at the appropriate point in the HAZOP procedure. The initiating problems checklist is used to try to identify causes of process deviations. The consequences list is used to try to identify consequences. Finally the hazardous events checklist is used to try to determine how serious the final outcome may be. One problem with Kelly's approach is that it places too much emphasis solely on the identification of hazards. HAZOP is important in that it also identifies operability problems. Indeed one of the main benefits of HAZOP is the reduction in the number of start-up modifications required.

In addition to the guide diagram for continuous processes, ICI have subsequently developed guide diagrams for batch processes, mechanical handling equipment, computer control systems and building design and operability (ICI, 1993). A similar type of guide diagram is also available, developed by Unocal Corporation for electrical systems (Sankaran, 1993).

More recent developments on the use of checklists to aid HAZOP of continuous plant have occurred during the last few years as computing tools have been developed to assist the carrying out of HAZOP (PrimaTech, 199?; LamdaDelta, 1995). Many of these tools contain databases of possible causes and consequences of deviations for many items of common process plant equipment. The use of computers to assist HAZOP is discussed later in Chapters 3.3.

The process deviation is developed, if necessary, to define explicitly the problem in a meaningful way. For example if the guide word is *high* and the process variable under consideration is *pressure*, the process deviation is obviously *high pressure*. Then, for a long pipeline, possible distinct problem areas are, liquid hammer, delivery pump overpressure and thermal expansion of locked in liquid. Each of these distinct deviation scenarios would be addressed in turn by members of the HAZOP team. They are asked to try to identify possible causes and consequences of the deviation scenario under consideration. An evaluation is then carried out by the group to establish the need for action. This action could take the form of further analysis, such as fault tree analysis of any hazards identified, or suggestions for possible changes to the plant, such as addition of alarms or the provision of trace heating.

These checklists were introduced partly to address the lack of completeness noticed in some HAZOP results. However the checklists are by no means as rigorous as a proper checklist and there is still a reliance on the expertise of the team to fully realise possible consequences. In fact it is only likely to make things worse. There is the possibility that the checklist aspect becomes a crutch for inexperienced teams to lean on, and, because it is a very meagre checklist, the results cannot be expected to be complete. This use of lists is not helped by the computer HAZOP aids available, which present lists of relevant parameters, causes and consequences. It can restrict the study to the everyday parameters such as flow, pressure and temperature, when it may be more appropriate to consider alternative parameters which might be suggested if the original HAZOP procedure was applied.

2.6 Worked Examples of HAZOP Application

The following papers contain worked examples of the application of conventional HAZOP to chemical plant.

Lawley (1974) presents the results of the application of HAZOP to the feed section of an olefin dimerisation plant. The part of the process studied is the transfer of olefin from storage to a buffer and settling tank where the water impurity is settled out. Although only a limited section of the plant is studied, the results given are thorough and detailed.

Lawley (1976) gives the results for a study of an ethylene oxide feed system to a group of batch reactors. As with Lawley's other example, the scope is limited but the results given are detailed and thorough.

Rushford (1977) gives the results for a simple section of a cracker unit. The section studied is the gas drying section where the gaseous product from the cracker is heated and passed through a suction catchpot before being fed to a compression train. The results are detailed and include a wide variety of problems, a significant number of which are generated by the consideration of the guide word "other than". Relatively few problems were identified by the consideration of the guide words "more" and "less".

Austin & Jeffreys (1979) carry out a HAZOP on the reactor section of the methyl ethyl ketone plant described in their book. This HAZOP is interesting in that the reactor section operates in a semi-batch manner, that is the normal operating conditions of this part of the plant alter with time. There is plenty of background information included as part of this worked example, including the design intention and the design conditions for the different operating conditions of the part of the plant being studied. The results presented are quite extensive and detailed. However, there is no attempt made to identify any problems that may be due to such things as start-up, shut-down and, of particular importance, maintenance. Austin & Jeffreys note that this is a "truncated operability study" as only an isolated part of the plant is being studied. They recognise that this introduces difficulties because deviations originating upstream of the truncation point can only be specified in general terms. However, their intention for presenting the study is to illustrate the principle of HAZOP and so the completeness of the results is not paramount.

Kletz (1985) analyses a 10km cross-country pipeline which transfers liquid propane from a storage tank to a consumer plant buffer tank. This study generated 39 actions for just one line, the results generated being very clear and detailed.

Ozog (1985) applies HAZOP to a flammable reagent storage tank. The tank has a nitrogen blanket to provide an inert atmosphere in the tank and a pump to deliver liquid to the process. However, the tank as drawn would appear to have two major safety flaws, one of which is not queried in the HAZOP results. Firstly there is no tank overflow; instead it seems from the HAZOP results that they are expecting the tank to overflow via the relief valve RV-1. The query (column G) relating to overfilling of the tank due to "unloading too much reagent from tank truck" (cause 6 in column C) is "Is RV-1 designed to relieve liquid at loading rate?". This is definitely not a safe way to design for overfilling. Many tanks are only designed to withstand a couple of inches of water head. If liquid is not allowed to overflow from a properly designed overflow below the top of the tank but instead is allowed to fill into pipework above the top of the tank, then it is quite conceivable that the tank will rupture. Secondly there is a valve V-8 included between the tank and its relief valve. This leaves the tank without any overpressure rupture protection if V-8 is closed. This is not noted in the HAZOP results given, although it is present in the FTA analysis included in the paper. In addition to these problems the HAZOP results shown are lacking in detail.

Although not presented as a set of HAZOP results McCluer & Whittle (1992) detail some important safety recommendations generated by HAZOP of fluid catalytic cracking units (FCCUs). HAZOP of three FCCUs yielded between 150 and 200 recommendations for each unit. From these detailed, specific recommendations, 11 generalised recommendations were derived and these are outlined in the paper along with a brief description of the nature of the problem and how hazards may be realised. These generalised recommendations largely relate to hazards and not operability problems. Also included is a detailed description of the operation of an FCCU and a description of the structure of the HAZOP.

Sankaran (1993) shows how HAZOP has been applied to some non-process related projects. Three different sets of results are illustrated. They are for an electrical distribution system, a urea storage and shipping operation, and an underground tank removal. Although the results are not complete for any of these projects, they are detailed and some background material is included discussing each of these projects and how the HAZOP meetings were conducted. This paper provides very good examples, which illustrate how HAZOP could be applied in a wide variety of industries and the benefits that are achievable.

2.7 Summary

This chapter provided an extensive review of the development of the conventional HAZOP procedure. It also highlighted the failings and effectiveness of HAZOP. The next chapter will consider the different ways of improving the performance of conventional HAZOP.

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3 Improving Conventional HAZOP Performance

This chapter looks at how conventional HAZOP performance can be improved. Firstly the composition of HAZOP teams is looked at to see how their effectiveness can be maximised. Secondly, lessons from HAZOP experts, people with many years' experience of carrying out HAZOP in industry are considered. Finally the role of computer aids in conventional HAZOP is looked at, and the pros and cons of their use considered.

3.1 Effective HAZOP Teams

3.1.1 HAZOP Team Composition

One of the reasons that HAZOP is so effective is because it stimulates a group of people of different disciplines to creatively think about and discuss possible problems. To maximise this effectiveness the team composition is vitally important. Basically it is necessary that the team should have amongst them the appropriate knowledge and experience required to identify the problems that may exist with the system under consideration. Along with this requirement for knowledge and experience, the team should also include an experienced HAZOP team leader and a HAZOP secretary. However in order to remain disciplined and efficient it is necessary that the team should not be too large. It would be recommended that no more than six people made up the team.

The members of the team should be selected to achieve the right balance of knowledge and expertise. For HAZOP of a new chemical plant design, the most likely composition of a HAZOP team would be, project engineer, process engineer, instrumentation design engineer, and an independent team leader. In addition it may include a research chemist if necessary. For HAZOP of an existing plant the team would normally consist of the following people, plant supervisor, plant foreman, plant engineer, instrument manager, process investigation manager and independent team leader. For HAZOP of a modification or extension to an existing plant then some combination of these two groups would be used, bearing in mind that the total ought not to exceed six (Kletz, 1985).

3.1.2 HAZOP Secretary

The HAZOP secretary or scribe plays an important part in the team, particularly in recording, as appropriate, the discussions of the team as a whole. Goyal (1994) identifies the following requirements of a good scribe, basic engineering/technical knowledge, linguistic skills, ability to type reasonably fast and familiarity with the recording system. In addition the scribe should have the ability to listen and pay attention to detail. However, in order to reduce the number of participants in a team, some companies are combining the roles of the HAZOP leader and the HAZOP secretary (Kletz, 1985). Apart from the advantage of reducing the personnel requirement, there is also the advantage that the HAZOP leader knows what is being recorded and that nothing important has been missed out. There would seem to be one significant disadvantage with this method and that is the rest of the HAZOP study team are often left waiting whilst the HAZOP team leader writes up his notes. In particular, this may impact on the ability of the HAZOP team leader to effectively manage the team. With a separate secretary this is not so much of a problem. Having a separate secretary also provides a good platform for training novice HAZOP team leaders. Alternatively the project engineer could also be used as the secretary. He will already be familiar with the reference numbers for different parts of the plant and will have a good incentive to make sure that all relevant discussion is captured.

3.1.3 HAZOP Team Leader

The HAZOP team leader is mainly responsible for making sure that the team follows the HAZOP procedure. In addition he should make sure that the team works efficiently and effectively, primarily by controlling the discussion and stimulating team thinking. Although HAZOP studies have a definite systematic methodology it is widely recognised that many HAZOP team leaders adopt different approaches. It has also been shown (Freeman et al., 1992) that expert HAZOP team leaders will conduct a hazard study faster than their novice counterparts. Our own study (Jefferson et al, 1995a) confirms the finding of Freeman et al.

The main question arising from our analysis is, "How can novice HAZOP team leaders be trained most effectively?" An important feature of HAZOP is that it can be applied flexibly, either to identify first a consequence of a certain deviation or to identify first a cause of a deviation. However, novices do not appreciate this flexibility. This does not necessarily compromise the integrity of the HAZOP but can lead to inefficient use of time. Proper training of novices is required to reduce this inefficiency. Expert team leaders are marked out by their ability to choose, by some mechanism, the most appropriate route for the team to follow to identify efficiently the cause consequence scenarios of interest. Novices should be made aware that they can be flexible when leading HAZOP meetings. It works most effectively when there is no prescribed direction to follow from deviation to cause or deviation to consequence.

3.1.4 HAZOP Meetings

One option for improving HAZOP is to make sure that the meetings are set up in such a way that the HAZOP team members are given the best opportunity to perform at their most effective. This includes things such as, making sure meetings are not too long, allowing sufficient breaks during meetings and having a good environment for the meeting.

Determining the maximum length of individual HAZOP meetings would seem to be a compromise between reducing the overall time span required for the HAZOP and allowing HAZOP participants as much time as possible to carry out their normal duties. However, there is evidence that no such compromise is necessary. It has been noted (Pully, 1993) that for a complete HAZOP of similar units, the number of hours spent on the HAZOP was halved when meetings were held for only four hours per day rather than 8 hours per day (half day sessions as opposed to full day sessions). In other words the overall time span for the complete HAZOP was the same. Dowell (1994) suggests that meetings are restricted to 3-4 days per week with 6 hours of meeting sessions each day. The general consensus is that if any more hours per week are spent carrying out the meetings, the participants become fatigued and there is more pressure for them to miss HAZOP meetings in order to continue their normal duties. Fatigue results in a lack of drive, enthusiasm and creativity, and makes for less efficient and effective meetings. The pressure to miss HAZOP meetings results in at least late arrivals and early departures, and this disruption further impedes the progress of the study. On the other hand, if any less time is spent per week, then a significant proportion of that time is spent getting back up to speed on the details of the P&IDs, the process and the HAZOP procedure. Sweeney (1993) suggests that if 8 hours of meetings per day are required to facilitate an urgent HAZOP, then these should not extend beyond two weeks before a substantial break is provided. However, I think it is fairly clear given the observations above that unless the entire HAZOP can be completed within those two weeks then it is probably not worthwhile. Indeed, Jones (1992) reckons that in practice, for studies lasting more than about a week, a five hour per day meeting schedule can accomplish almost as much as one lasting eight hours per day.

3.2 Lessons Learned from HAZOP in Industry

A number of papers exist, written by people who have carried out HAZOP for a number of years, detailing additional guide lines that they have developed over the years in order to make the HAZOP as efficient and effective as possible.

These suggestions can usefully be differentiated into two main groups, those that are applicable in the setting up of the HAZOP meeting, those that are applicable in the carrying out of the meeting. Establishing a safe environment for team members is an example of a requirement that must be met in the setting up of a HAZOP meeting. This sort of requirement would need to be used by both HAZOP team leaders and managers in charge of setting up HAZOP meetings. Giving too little credit for safeguards is applicable to the carrying out of the meeting. Suggestions applicable to the carrying out of meetings would need to be recognised and utilised by HAZOP team leaders.

There are a large number of papers available discussing the selection of members of the HAZOP team. These papers are written by experienced HAZOP practitioners, generally HAZOP team leaders, and provide valuable guidelines on how team selection can affect HAZOP performance.

Lihou (1986) gives some valuable insights into how team members should perform within a HAZOP team. He identifies the following roles and suggests team members should be able to move freely between roles:

- **Expert Informant:** The person who can explain how a new process is intended to operate or how an existing plant is operated.
- **Experienced Unbeliever:** The person who recognises similarities between the item being examined and others that have been problematical.
- **Enthusiastic Pupil:** The person who asks from clarification from the "experts" and/or the unbeliever thereby helping them to be sure that their advice is relevant in the current situation.
- **Logical Goalkeeper:** The person who prevents fallacious solutions to possible hazards identified being included in the "action" lists.

These can be grouped together and I will refer to them subsequently as **HAZOP team selection.**

He also details the responsibilities of HAZOP team leaders and gives some guidance on other aspects of carrying out effective HAZOP.
Jones (1992) has put together a very detailed list of potential pitfalls and common mistakes made during HAZOP, as well as detailing some potential HAZOP benefits. The possible benefits of HAZOP that he identifies are:

- A systematic and thorough review can be made of existing plant.
- Evaluation of the consequences of human error can be made.
- Subtle sequences of events that lead to unique accidents are identified.
- Plant efficiency can be improved.
- A better understanding of plant operations is gained by operators and engineers.

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Potential HAZOP pitfalls identified are:

- Poor understanding by management of the HAZOP procedure and resources required.
- Inexperienced HAZOP team.
- Inadequately trained or inexperienced HAZOP team leader.

Some of the mistakes he identifies are those associated with the role of the team leader. They are:

- Failing to establish a "safe" environment (in terms of being free from recriminations) for team members.
- Consequences of events not carried to conclusion.
- Giving unwarranted credit to safeguards.
- Too little or no credit given for safeguards.
- Making recommendations where follow-up is difficult.
- Poor recording of HAZOP.

General mistakes that can occur and which can hamper the progress of HAZOP are:

- Failure to HAZOP start-up and shutdown procedures.
- Poorly updated P&IDs.
- Carrying out a HAZOP in place of properly executed design reviews.
- Wrong technique for the system being reviewed.
- HAZOP sessions that run too long each day.

Using the recommendations from the above references and separating them into two groups, I have generated the following lists of suggestions for improving HAZOP.

Suggestions for HAZOP managers and HAZOP team leaders for setting up HAZOP meetings:

- Select the correct HAZOP team.
- Establish a 'safe' environment for team members.
- Schedule HAZOP sessions in a reasonable way.
- Make sure proper resources are available.
- Use properly trained HAZOP team leaders.
- Make sure proper design reviews have been carried out.
- Use up-to-date P&IDs.

Suggestions for HAZOP team leaders for carrying out HAZOP meetings:

- Make sure HAZOP sessions do not run on too long.
- Allow plenty of breaks at suitable intervals.
- Give appropriate credit for safeguards.
- Make sure recommendations are suitable.
- Make sure a proper record of the meeting is made.
- Make sure start-up and shutdown procedures are analysed.
- Make sure all necessary information is available.

3.3 Computer Aids in Conventional HAZOP

In the past few years, a number of computer programs have been developed to assist in the carrying out of HAZOP (e.g. PrimaTech, 1994; Sigma-Lambda, 1995). On the whole these are simple secretarial tools to provide a convenient way of turning the deliberations of a HAZOP meeting into a formal, structured report. They also provide a prompt for the team, suggesting the next guide word and process variable requiring consideration. However, these computer tools have also, in general, not reduced the time taken for hazard identification.

3.4 Conclusions

The conventional HAZOP procedure has been established for a long time. Some work has been done on improving the HAZOP procedure and on shortening the time required for HAZOP meetings based on experience. However, there is a limit to what can be achieved due to the exhaustive nature of the approach taken in HAZOP. More radical approaches will need to be considered in order to bring about drastic improvements.

In the future there is the possibility that HAZOP will be performed automatically by computer. Loughborough University is at the forefront of these developments (Chung, 1993 & Jefferson et al., 1995b). Automated HAZOP offers a considerable reduction in the amount of time required for hazard identification, however it is unclear how effective it will be in identifying all hazards. The next chapter looks at the possibilities for improvement afforded by automating hazard identification.

Chapters 5 to 7 will deal comprehensively with the idea and methodology of modular HAZOP that has been developed through this project.

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4 Automated HAZOP

One possible route for speeding up the identification of hazards in chemical plant is to use computers to identify hazards automatically. The pioneering work in this area was first carried out by Parmar and Lees (Parmar 1987; Parmar and Lees 1987a, 1987b). They set out to develop a hazard identification tool based earlier work by Lees and colleagues on fault propagation and fault tree synthesis (Martin-Solis et al 1977, 1980, 1982; Kelly and Lees 1986a, 1986b, 1986c, 1986d). They did not originally assume that it would necessarily emulate HAZOP. They considered variants more akin to fault trees and to failure modes and effects analysis, but concluded that the HAZOP approach of examining every potential deviation in every line does offer the best assurance of completeness and therefore developed their initial version of HAZID as, in effect, a HAZOP emulator. There are now a number of research prototypes described in the literature that adopt the same approach developed by Parmer and Lees (Zerkani and Rushton 1993; Venkatsubramanian and Vaidhyanathan 1994; Jefferson et al. 1995b; Larkin et al. 1997; Wakeman et al. 1997).

The purpose of this chapter is twofold. First, it provides a general description of the common approach that is used in many of the automated HAZOP systems developed so far. Second, it highlights the research issues that need to be addressed in order to build fully functional systems that will be accepted by engineers.

4.1 Representing Causal Relationships

To emulate HAZOP, a program needs to be able to infer how a process plant behaves in qualitative terms, i.e. how the increase, or decrease, in one process variable will affect other variables in the plant. Given a process plant description, it is possible to declare causal relationships between all of the process variables in the plant. Consider the small plant fragment shown in figure 4.1. If we only consider the property of flow in this system then we can define ten process variables, i.e. the flow at each inlet and outlet of each piece of equipment. Any given variable may depend on any of the other nine. There are ninety dependencies in all. Once these dependencies have been declared, then it becomes a simple task to see the effect that a change in one variable has on other variables in the system.

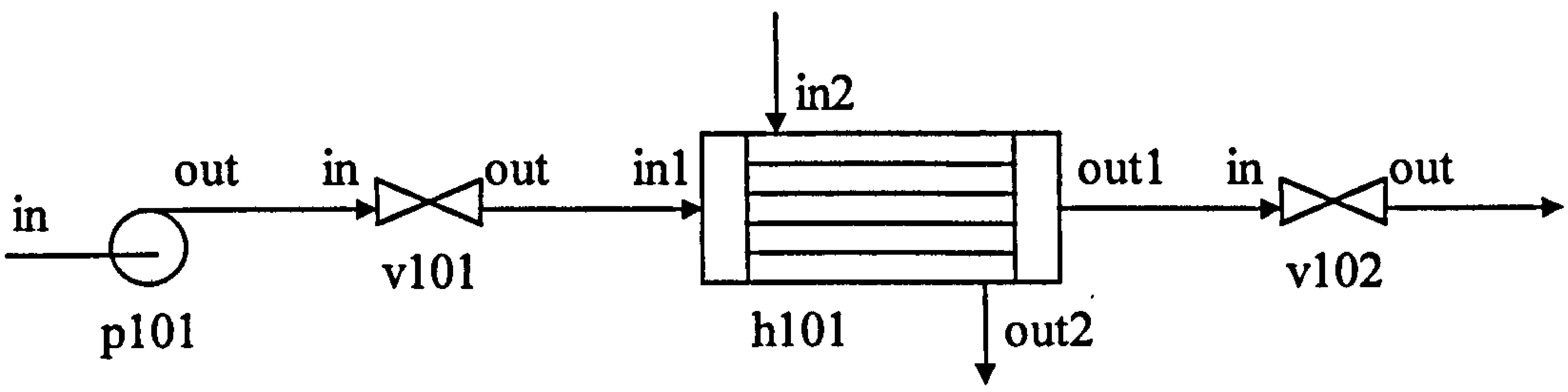

Figure 4.1 - Small plant fragment

In a large plant it is unrealistic to expect that every causal relationship could be explicitly declared. A more economic approach, taken here, uses the assumption that the causal relationships within an item of equipment are independent of the context of equipment in the plant, together with a method of generating causal dependencies between adjacent equipment. This approach dramatically reduces the number of dependencies that need to be declared and still allows the dependencies between remote process variables to be deduced. Because the description of causal relationships is at the equipment level, rather than at the plant level, it is easier to ensure and to maintain correctness and completeness.

A common representation for modelling causal relationships is the Signed Directed Graph (SDG). SDGs were first used for studying process plants by Iri et al. (1979). Since then the SDG representation has been widely used by other researchers.

A directed graph consists of a network of nodes and arcs. A node represents a variable. An arc from a node, X, to another node, Y, indicates that a change in the variable X will cause a change in the variable Y. In other words, Y is dependent on X. Therefore, a directed graph can also be called an influence diagram or dependence diagram (MacCallum, 1981). An SDG is an extension of a directed graph. Each arc of the graph is labelled with a sign "+" or "-". The sign "+" indicates a positive influence, i.e. Y will increase if X is increased and Y will decrease if X is decreased.

The sign "-" indicates a negative influence, i.e. Y will decrease if X is increased and Y will increase if X is decreased.

An SDG can be derived empirically or from conventional differential and algebraic equations that model the behaviour of a particular plant in numerical terms. However, as mentioned earlier, constructing a SDG from scratch for a complete plant can be a very time consuming process. Fortunately, process plants, like other physical systems, are built by connecting a set of smaller equipments together to perform the required functions. The behaviour of each of these equipments can be described in a system independent manner. By combining the equipment descriptions the behaviour of a whole plant can then be analysed. This idea of generating a complete plant model from equipment descriptions is used by a number of researchers (Lees and Kelly, 1986; Oyeleye and Kramer, 1989; Catino, et al., 1991). For the SDG representation, an equipment description consists of a mini-SDG - a set of propagation arcs - which shows how a change in one process variable affects another variable within the same equipment. A deviation in one equipment can be propagated either upstream or downstream through the inport and outport connections. Therefore, the SDG for a complete plant is generated by joining the appropriate mini-SDGs together as appropriate for the plant topology.

4.2 Automated HAZOP System Overview

A general architecture for an automated HAZOP system is shown in figure 4.2. The unit library contains unit models, which are mini-SDGs of common items of equipment found in continuous plants. The unit model of an item of equipment describes the behaviour of process variables, failure modes and the consequences associated with the failure modes and deviations. The plant model is a description of the plant under analysis based on the equipment in the plant and how it is connected. The equipment in the plant is declared by reference to unit models in the unit library. The main element of the system is the inference engine. It has three basic functions, which are:

- Creation of the plant SDG from the information given in the plant model and the component library.

- Emulation of the conventional HAZOP procedure.
- Search of the plant SDG for causes and consequences for a given deviation.

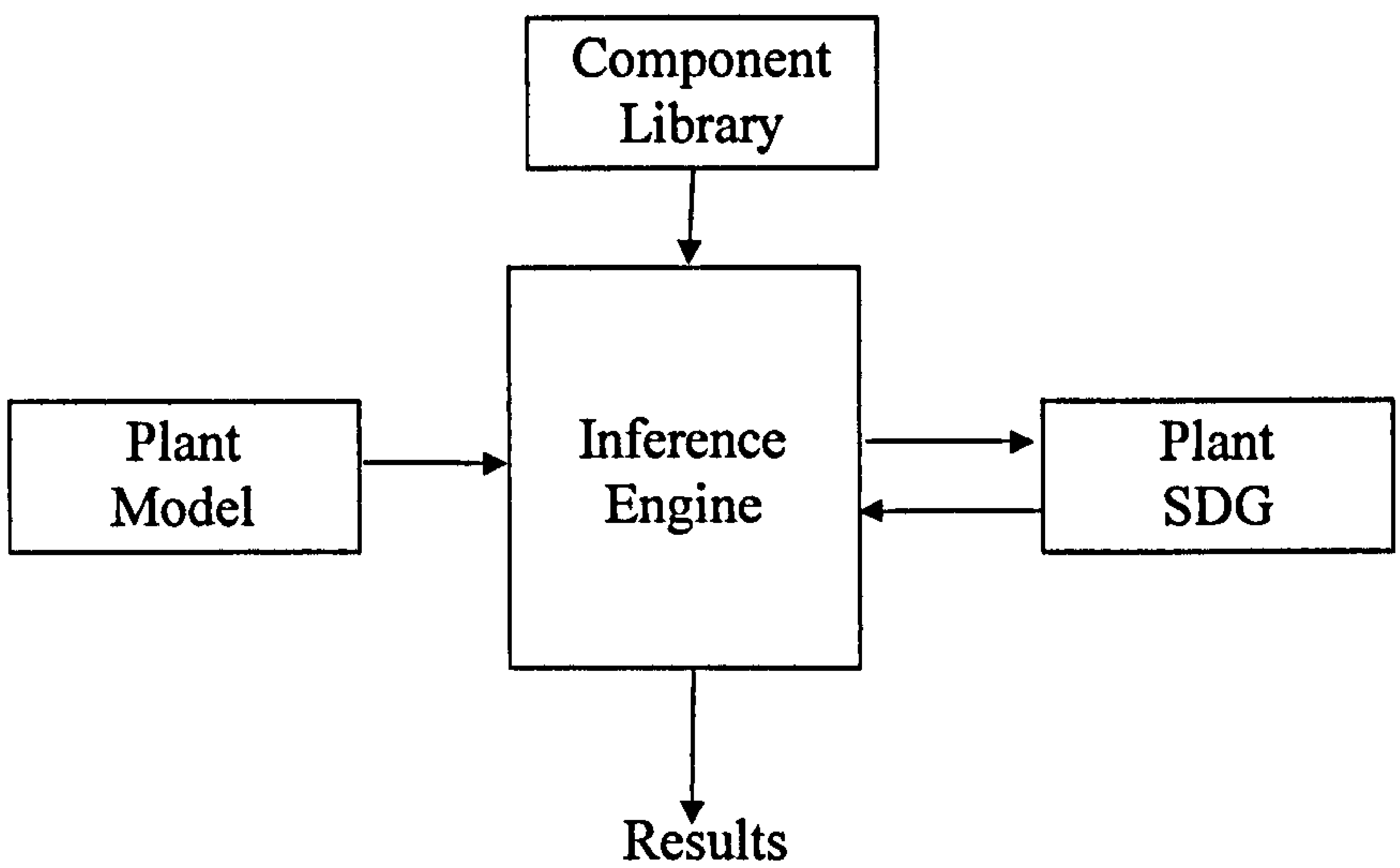

Figure 4.2 - General Architecture for Automated HAZOP System

4.2.1 Unit Models

Unit models in the component library define the default behaviour and attribute values for different types of equipment. Each unit model is specified as a frame, which is similar to the idea of an object in object-oriented programming (Coad and Yourdon, 1991). For example the unit model for a pipe is defined as:

```
frame( pipe isa unit,
   [inports is [in],
    outports is [out],
    propLinks are [
      arc([in, flow],+,[out,flow]),
      arc([out, flow],+,[in, flow]),
      arc([fault,leak],-,out,flow]),
      arc([fault,leak],+,[in,flow]),
      arc([fault,leak],+,[consequence, contaminate environment]),
      arc([in,temp],+,[out,temp]),
```

```
arc([in,pressure],+,[out,pressure]),
arc([in,composition],+,[out,composition]),

...
other arcs]
....
other attributes related to a pipe
....]).
```

This says that a *pipe* is a sub-class of *unit*, i.e. it inherits the attributes and the default values associated with a *unit*. A pipe has one inport called *in* and one outport called *out*. The attribute *propLinks* stores a list of arcs that define the mini-SDG related to a pipe. The first eight lines represent the SDG fragments shown in figure 4.3.

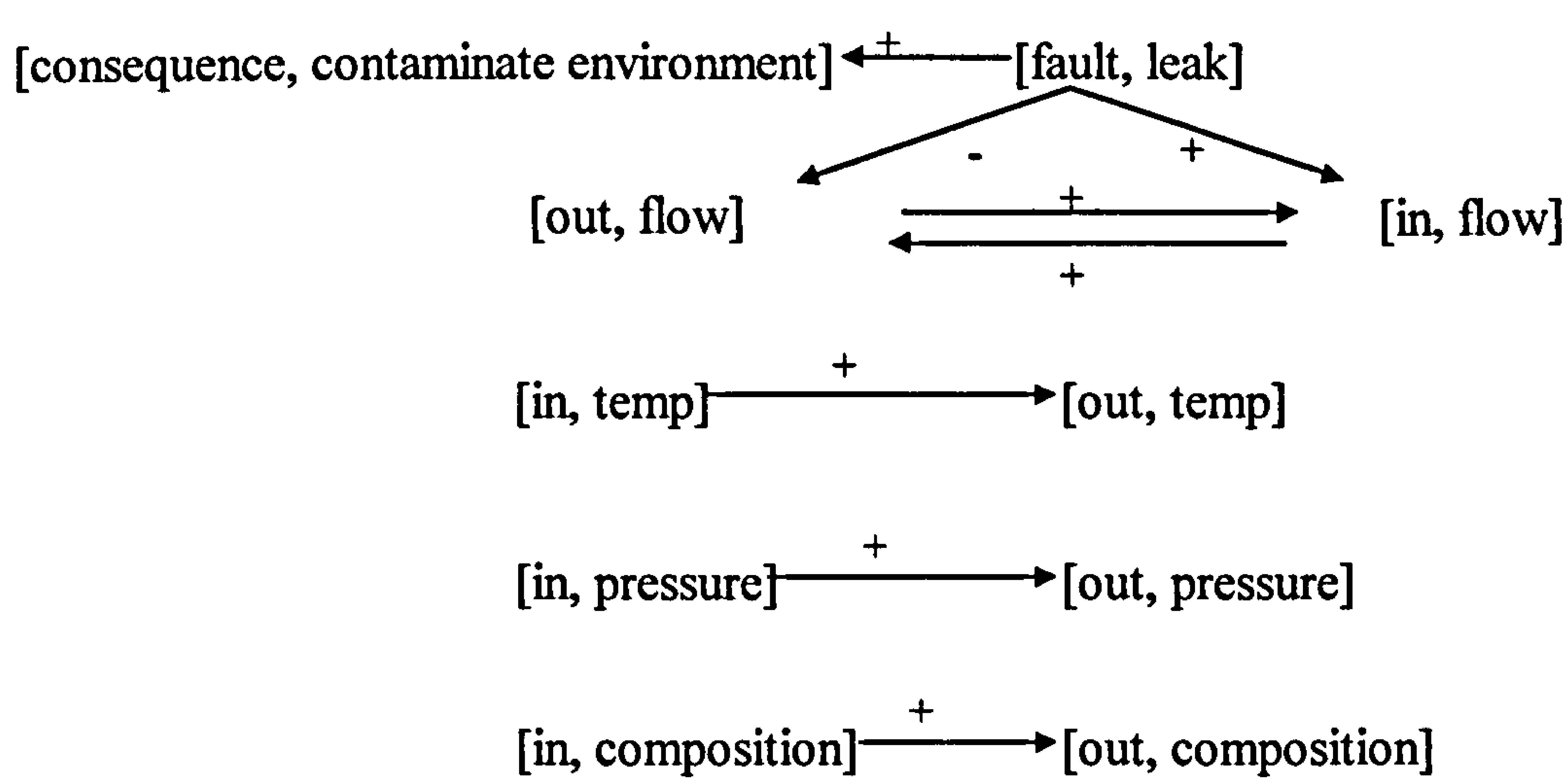

Figure 4.3 - Partial signed directed graph for a pipe

4.2.2 Plant Description

The plant model is a description of a plant constructed with respect to the way in which its process equipment is connected. The equipment in the plant is declared by referencing unit models in the unit library. The description file can be generated from a CAD system or constructed using a text editor. The plant fragment shown in figure 4.1 is described as:

```
instance(p101 isa pump, outports info [out is [v101,in]]).
instance(v101 isa valve, outports info [out is [h101, in1]]).
instance(h101 isa heatExchanger, outports info [out1 is [v102, in]]).
instance(v102 isa valve).
```

4.2.3 Inference Engine

The inference engine takes a plant description as input and builds up the plant SDG from the textual representations of arcs in the unit library with regard to the unit models and their connections as specified in the plant description. The inference engine also has a HAZOP emulation driver. By searching the plant SDG in an appropriate manner it effectively emulates conventional HAZOP. The detail of HAZOP emulation is described in the following sections.

4.3 HAZOP Emulation - PRELIMINARY STEPS

Figure 4.4 illustrates steps in the method used to emulate conventional HAZOP.

Conventional HAZOP is a powerful technique and has been developed for use on both continuous and batch processes. However, automated HAZOP systems have so far only been developed to handle continuous processes. This reduces the number of guide words and intentions that need to be handled. For continuous plant the main process deviations that can be generated from the combination of guide word and intention are:

HIGH/LOW FLOW
NO FLOW
REVERSE FLOW
HIGH/LOW PRESSURE
HIGH/LOW TEMPERATURE
HIGH/LOW LEVEL

These process deviations are considered in turn for every port, although there is an exception with HIGH and LOW LEVEL which are applied to vessels only.

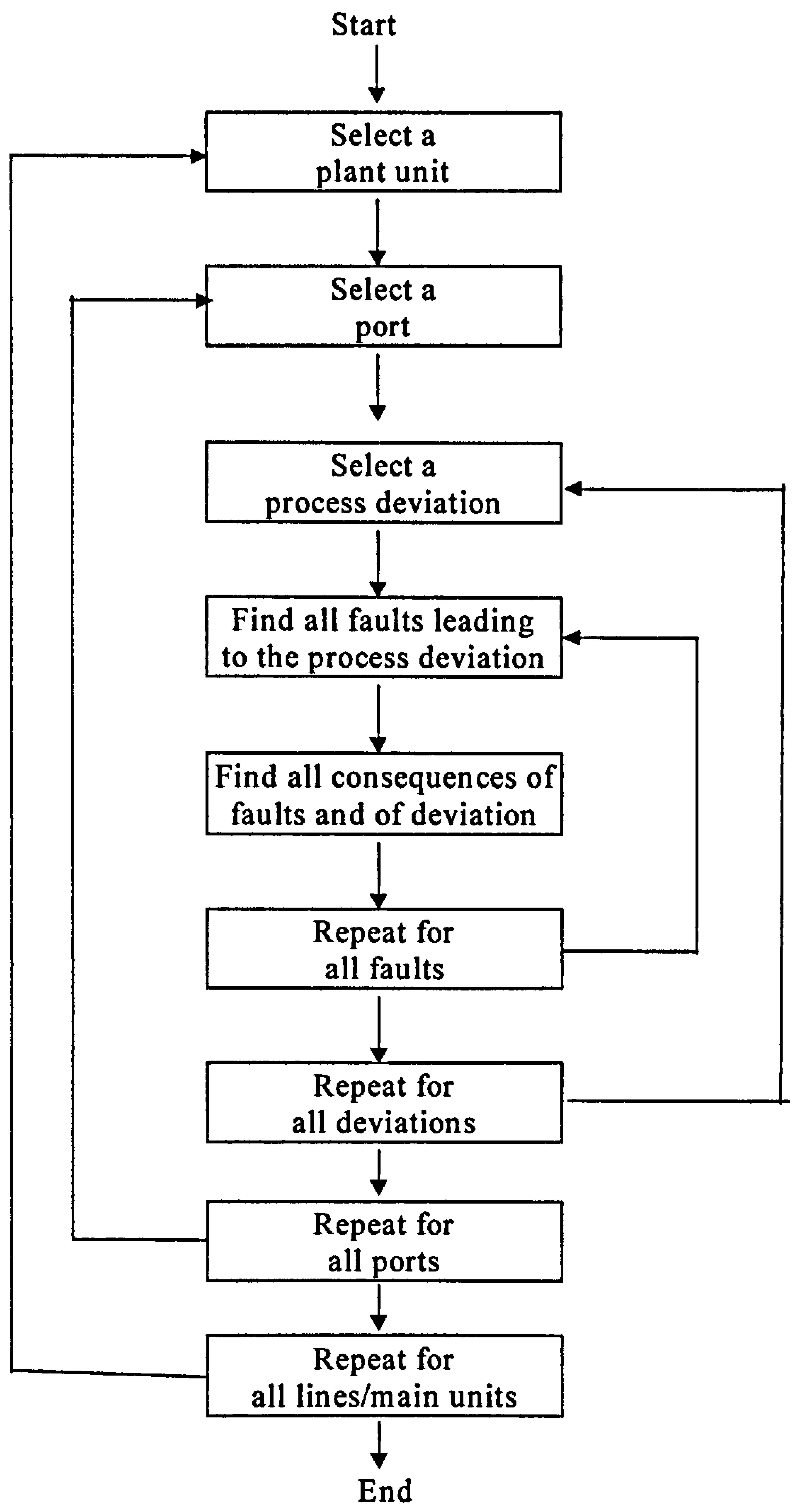

Figure 4.4 - Basic method for automated HAZOP

4.4 HAZOP EMULATION - Identifying Faults and Consequences

4.4.1 Representing Faults and Consequences

Figure 4.5 shows part of the SDG of a plant fragment with two pipes and a valve. Pipe1 is connected to the inport of valve1 and the outport of valve1 is connected to the inport of pipe 2. The top, middle and bottom parts of the figure are the mini-SDGs for pipe1, valve1 and pipe2 respectively. The three parts are joined together by linking the appropriate interfacing nodes.

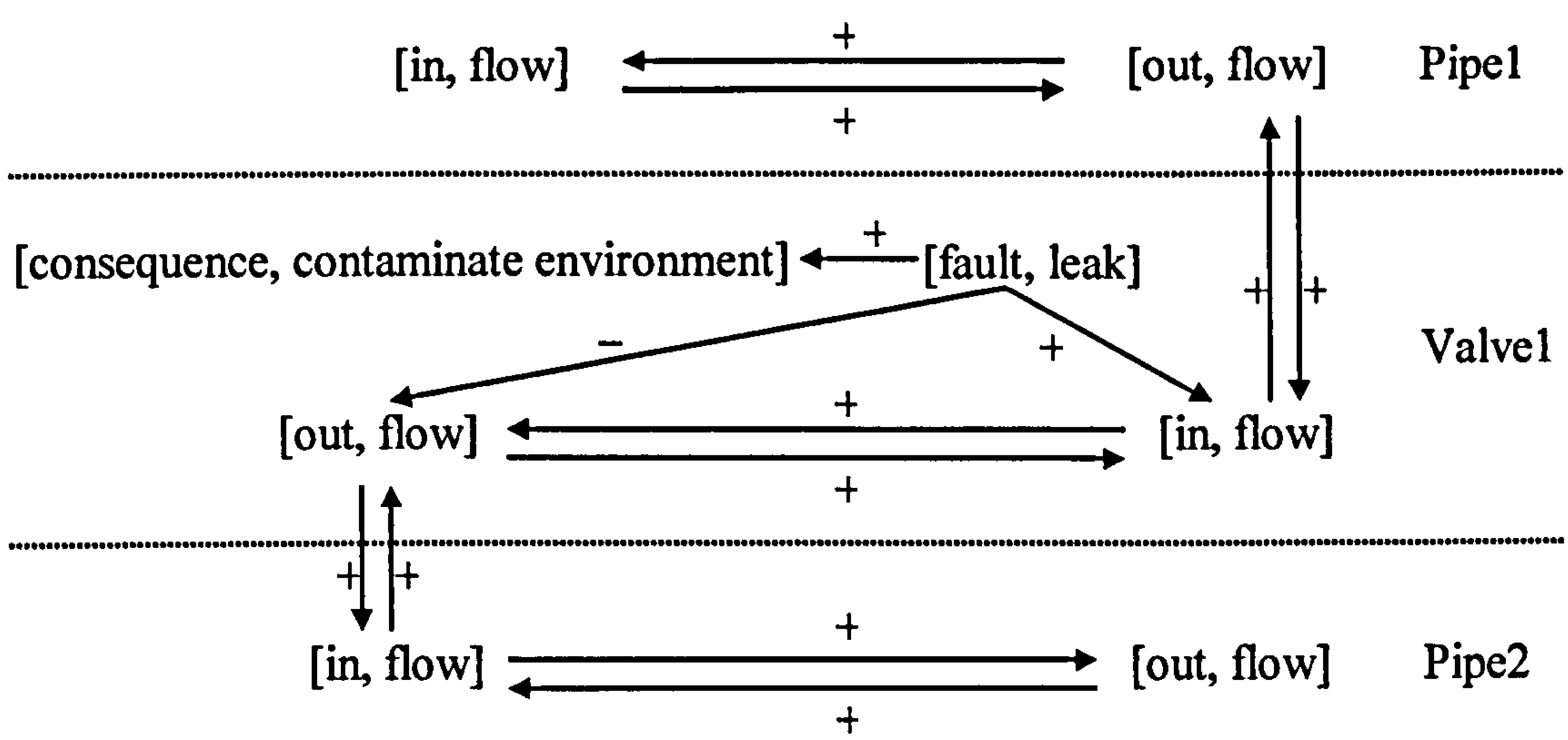

Figure 4.5 - Signed Directed Graph

In the notation that is used here, each node in the graph that makes reference to a process variable has two parts. The first part specifies the port and the second the particular process variable. When a node represents a fault condition, the first part is the word 'fault' and the second part is the fault description. When a node represents a consequence, the first part is the word 'consequence' and the second part is the consequence description. Note that only nodes related to flow, and only one fault condition and one consequence are shown in the figure.

4.4.2 Identifying Process Variable Influences

Given the SDG of a plant, the way in which one variable affects another can be established by identifying an acyclic path joining the two nodes of interest. An acyclic path has no node repeated in it. The sign of the influence that a change in the initial node has on the final node in the path is the product of all the signs in the path. For example, given the SDG in figure 4.5, the way in which the change in pipe1 [in, flow] affects pipe2 [in, flow] is determined by the following acyclic path:

Pipe1		Valve1		Pipe2
[in, flow] —+→ [out, flow]	—+→	[in, flow] —+→ [out, flow]	—+→	[in, flow]

The product of all the signs in the path is "+". Therefore, an increase in pipe1 [in, flow] will give rise to an increase in pipe2 [in, flow]; a decrease in pipe1 [in, flow] will give rise to a decrease in pipe2 [in, flow]. If we consider the effect of a leak in Valve1 then it has a positive influence on the in flow of pipe1 upstream but has a negative influence on the outflow of pipe2 downstream, i.e. a leak will result in more flow in pipe1 but less flow in pipe2:

Pipe1		Valve1		Pipe2
[out, flow]	←+—	[in, flow] ←+— [fault, leak] —-→ [out, flow]	—+→	[in, flow]

If there does not exist a path joining any two nodes then the two nodes are independent.

4.4.3 Search Strategies

Given the ability to represent local causal relationships for a process plant, what will a system need in order for it to be able to reason about those dependencies? At the most fundamental and general level, two types of questions exist in hazard identification:

- What can cause event A to happen? Example questions include "What could cause the storage tank to rupture?" and "What could cause high temperature at the heat exchanger outlet?"

- What will happen as a result of event B happening? An example question is "What will happen if this pump stops?"

The answers to each type of question are found by using two different search strategies, known as backward and forward searches respectively. To answer the first type of question, we construct a path from the final event by following the arcs backwards in order to determine what sequence of influences could have caused it. To answer the second type of question, we construct a path from the initial cause by following the arcs forward to determine any consequences of that event.

In emulating HAZOP we are interested in exploring all the faults that will lead to a particular deviation and all the consequences associated with the deviation. Therefore, searches have to be done exhaustively, whether searching forward or backward from a given node. The term exhaustive here refers to the requirement that from some point in the graph we must ensure that all possible paths through the graph to its boundaries are developed. Only by doing this can we be sure that all influences between the given node and every other node have been considered.

Two common search strategies, which can be used to traverse a graph exhaustively, are the breadth first search and the depth first search (Winston, 1984). The breadth first search method proceeds from some start point and develops all paths from that point in parallel. If the start point has N arcs connecting it to other nodes then the first step of the search will produce N paths of length 1. If each of those N arcs lead to nodes which have M arcs leaving, then the next step will produce N*M paths of length 2.

The depth first search method proceeds from some start point by first developing a single path as deeply as possible. When that path reaches a terminating node, the algorithm will backtrack to the last node from which a new sub-path remains to be developed and attempt to extend from that node. Again this new development will go as deep as possible before backtracking.

For an exhaustive search there is no difference in the efficiency of these two strategies. Both will traverse the same number of arcs and produce the same end result.

4.4.4 Linking Causes and Consequences

In conventional HAZOP, having established a possible process deviation from a guide word and intention, the team will simultaneously attempt to identify possible faults that give rise to this deviation and consequences of this deviation. The intention is to come up with a realistic cause-consequence scenario. If no consequences are found then causes are not a problem and if no causes can be found the consequences should never occur. If no realistic cause-consequence scenario can be found then the HAZOP team will move on to consider the next process deviation.

In the SDG representation consequences can be linked to both faults and process deviations. The inference engine is directed to search backwards first, from a process deviation to a cause. Having established different faults as causes, then a fairly simple method is used for identifying consequences. Firstly, consequences are identified if they are directly linked to the process deviation, at the item of equipment and the port under consideration. Secondly, consequences are identified if they are directly linked with any faults leading to the process deviation under consideration. Thirdly, consequences are identified if they are linked to any of the deviations between any of the faults and the process deviation under consideration.

Considering figure 4.6, if the original query was made concerning *deviation 3*, then the inference engine traces back and finds two faults: *cause 1* and *cause 2*. Having found these faults it looks for consequences. *Consequence 5* is directly linked to *deviation3*. *Consequences 1* and *2* are directly linked to *cause 1*. *Consequence 4* is also identified as it is linked to *deviation 1* which is in the path between the fault and *deviation 3* (the deviation under consideration). *Consequence 3* is identified as it is linked to *cause 2*. The output generated is shown in table 4.1.

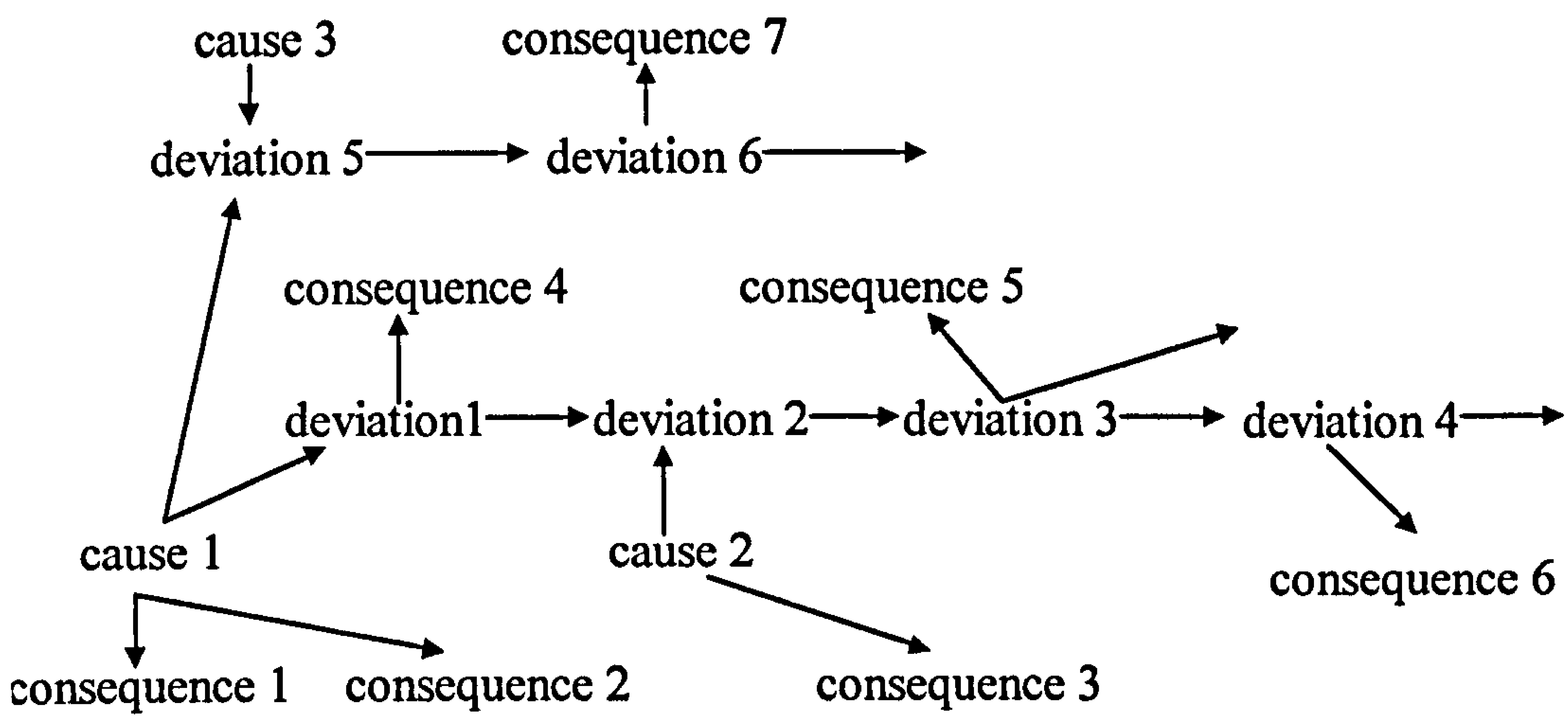

Figure 4.6 - Connection between faults and consequences

Deviation	Possible causes	Consequences
deviation 3	cause 1	consequence 1, 2, 4 & 5
	cause 2	consequence 3 & 5

Table 4.1- Partial output from hazard identification system

4.5 Research and Development Issues

The preceding sections have given a general overview of the basic features of an automated HAZOP system. This section highlights the research and development issues that typically arise in developing a tool of this kind.

4.5.1 Configuration Defects

A particular class of problem in plant design is that associated with the configuration of the units. There are certain configurations which may be questioned, based on experience of problems with similar configurations, without resort to fault propagation. An example is the case of a control valve at the end of a long pipeline containing liquid. This configuration immediately suggests potential for water hammer. This type of situation can therefore be dealt with by a simple configuration rule.

4.5.2 Data Acquisition

A common problem in computer aids for process plant design is that of data acquisition. The value of the tool is greatly reduced or even negated if the data input overheads are excessive. It might be expected, since computer aided design (CAD) systems have been around for some time, that there should be little problem in downloading basic plant data, but in fact this is not the case. CAD systems are still fragmented and there is not a universal interface into which a computer aid of the kind described can be "plugged". The designer of such a system is therefore faced with the need to provide the interfaces necessary for the acquisition of the required data. The main pieces of information required to represent a chemical plant are:

Plant Description: Essential data are those given in the Engineering Line Diagram (ELD) of the plant, namely the constituent units, including the controls, and their connectivities. Equally essential are data on the properties, state and composition of the fluids in the plant and the design envelope of the plant defined in terms of pressure, temperature, *etc.* It is also necessary to have what may be termed "configurational" information. For example, it is necessary to know whether a set of two pumps shown piped up in parallel is to be run as a set of two pumps operating in parallel or as a set with one normally operating and one on standby. Likewise, if there are two pressure relief valves in parallel it is necessary to know their duty and capacity.

Operating Instructions: It is then necessary to create within the program a plant representation which conforms with the method of analysis to be used. This also is not a trivial problem. For example, a plant is, or should be, designed to be operated in a particular way. The operating procedures therefore constitute a further set of information required for effective hazard identification.

Unit Models: In the methodology used, the individual units are each represented by a unit model. Each unit model is a set of qualitative relations equivalent to a signed directed graph. The formulation of high quality models requires some experience and effort. The provision of a unit model library is a partial solution, but experience shows that in most cases when constructing a new plant description it is necessary to configure one or two new models. It is necessary therefore to provide some form of tool to assist the user in creating these models. The user can expect to find in the unit model library the great majority of the models required. Guidance, however, should be provided to ensure a correct selection. This points to the need for a sound structure for the library.

4.5.3 Protections

HAZOP record sheets often have a column which indicates the protections available for the deviations examined. These protections are typically alarms, pressure relief devices, controls and trips. A computer aided method is more complete if it can identify where such protections exist. Early work on dealing with control in the context of fault tree synthesis was carried out by Shafahi et al. (1984). Chung (1993) has developed an algorithm for analysing the propagation of control signals using signed directed graphs. The algorithm is used in the CHEQUER system (Jefferson et al., 1995 (b)) for generating the protection column entries for HAZOP.

4.5.4 Search Efficiency

Another issue is search efficiency and program run time. Despite the power of current PCs, it is still necessary to try to limit the searches and to make them as economical as practical. Some work on improving the search algorithm was carried out at Loughborough University under the STOPHAZ project (McCoy, 1999).

4.5.5 Output Quality

With regard to the format of the output record, the intent is that an automated hazard identification system should broadly follow that of a conventional HAZOP. It is characteristic of computer generated searches that they tend to produce output which users do not find "natural". The issue of casting the output in a form acceptable to users should be specifically addressed.

Another characteristic of computer-generated output in HAZOP emulations is that it tends to include an excessive number of unimportant consequences. In a conventional HAZOP these are "filtered out", often almost unconsciously. Handling of the large number of "false positives" is perhaps the single most significant problem in developing an acceptable tool. It is necessary to rank the consequences and to remove the less significant, though the user can be given some control over the threshold for reporting consequences. (McCoy et al. 1999)

Even if a consequence is retained as significant, there can still be a problem with an excessive number of causes, most of which are unimportant. This again requires specific treatment.

Another aspect of quality in the output is completeness in identifying important consequences. Such completeness is largely a function of the quality of features such as the unit models and fluid model.

Finally, the output needs to be as free as possible of the outright errors and nonsenses to which computer-generated output tends to be prone. The only solution to this problem is high quality work throughout the system.

4.6 Conclusions

This chapter described how hazard identification can be automated by emulating conventional hazard and operability studies (HAZOP). There are a number of major research projects that have been carried out in this area. Although the basic fault propagation methodology is simple, there are major research and development issues that need to be addressed before such a tool will reach a level that is acceptable and used by engineers.

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5 Modular HAZOP Theory and Principles

The first section of this chapter gives a summary of what has been done in modular HAZOP related work to set the scene. The rest of the chapter discusses the theory and principles behind the modular HAZOP approach. In particular it sets out definitions that are used in modular HAZOP.

5.1 Literature Relating to Modular HAZOP.

There is no literature that I am aware of that makes reference to the form of modular HAZOP developed in this thesis. The most similar developments of HAZOP appear to be those described by Black & Ponton (1993) and Toola (1992).

Black & Ponton describe a method for hierarchical HAZOP which is based upon the decomposition of process plant according to Douglas (1988). However, the type of decomposition he describes is not suitable for the type of modular HAZOP we are interested in. The levels of decomposition described by Douglas are:

1. Process input-output structure.
2. Recycle structure.
3. Separation sequence.
4. Energy integration.

For hierarchical HAZOP, Black & Ponton, apply the HAZOP procedure to each level of the above decomposition of the plant as it is designed. Although, as they identify in their conclusion, this form of HAZOP enables hazards to be identified earlier, it would seem more appropriate to apply a method like the ICI six stage hazard study procedure (Duxbury & Turney, 1989). There are two possible advantages of the hierarchical HAZOP approach over the ICI six stage hazard study. Firstly it may be able to identify hazards due to interactions between equipment at an earlier stage. Secondly, it may make the final HAZOP simpler. On the first of these points, I suspect that very few interaction hazards are apparent until the detail of equipment is known and for the other point it is unclear whether the time saved in the final HAZOP is either significant or is not negated by additional time spent on earlier HAZOP.

Toola (1992) describes an approach to hazard identification at the plant level. This plant level safety analysis includes a HAZOP of the plant using a functional block diagram as the model of the system rather than a P&ID or ELD. This approach was compared by Toola with a conventional detailed HAZOP of the plant using a P&ID. The differences in hazards identified reflected the level of detail presented in each case. For the plant level analysis, hazards were more easily identified where they were due to the interaction between the blocks making up the functional block diagram. Although detailed HAZOP of a plant should identify hazards due to the interaction between distant units, the sheer scale of the plant and size of the drawings involved makes this a difficult task. For the detailed analysis the hazards were more easily identified at the component level. A modular HAZOP methodology ought to be able to identify both of these types of hazards.

5.2 Decomposition of Plant for Modular HAZOP

The principal reason for developing modular HAZOP is to reduce the time taken for effective hazard identification through the use of sets of previously generated HAZOP results. These sets of results will be referred to as preHAZOPed results. These preHAZOPed results are generated for equipment modules. In order for there to be any significant time saving, these preHAZOPed results must be of reasonably sized sections of plant. Conversely, they must not be so large as to make the preHAZOPed results useless with regards to applicability to new plant. This section looks at the problems that need to be addressed in looking at the level of decomposition required in creating equipment modules for the generation of preHAZOPed results. To some extent in existing HAZOP meetings, the plant may be broken into modular sections in order to simplify the study procedure. For example, a pump set is unlikely to be decomposed into its component parts - valves, impeller, motor, etc. - and each considered separately. Instead, a set of knowledge relevant to the module will be used. In the case of a pump this would include knowledge of motor failure and impeller failure.

5.2.1 Levels of Decomposition

Firstly at the lowest practical level of decomposition (figure 5.1) we can break each item of a plant up into its basic constituent elements. These component modules are connected either by electrical, hydraulic or mechanical links. A pump may be broken down into a motor, gearbox, impeller, etc. This level of decomposition goes even further than the line by line decomposition employed, certainly by experienced HAZOP teams, in conventional HAZOP.

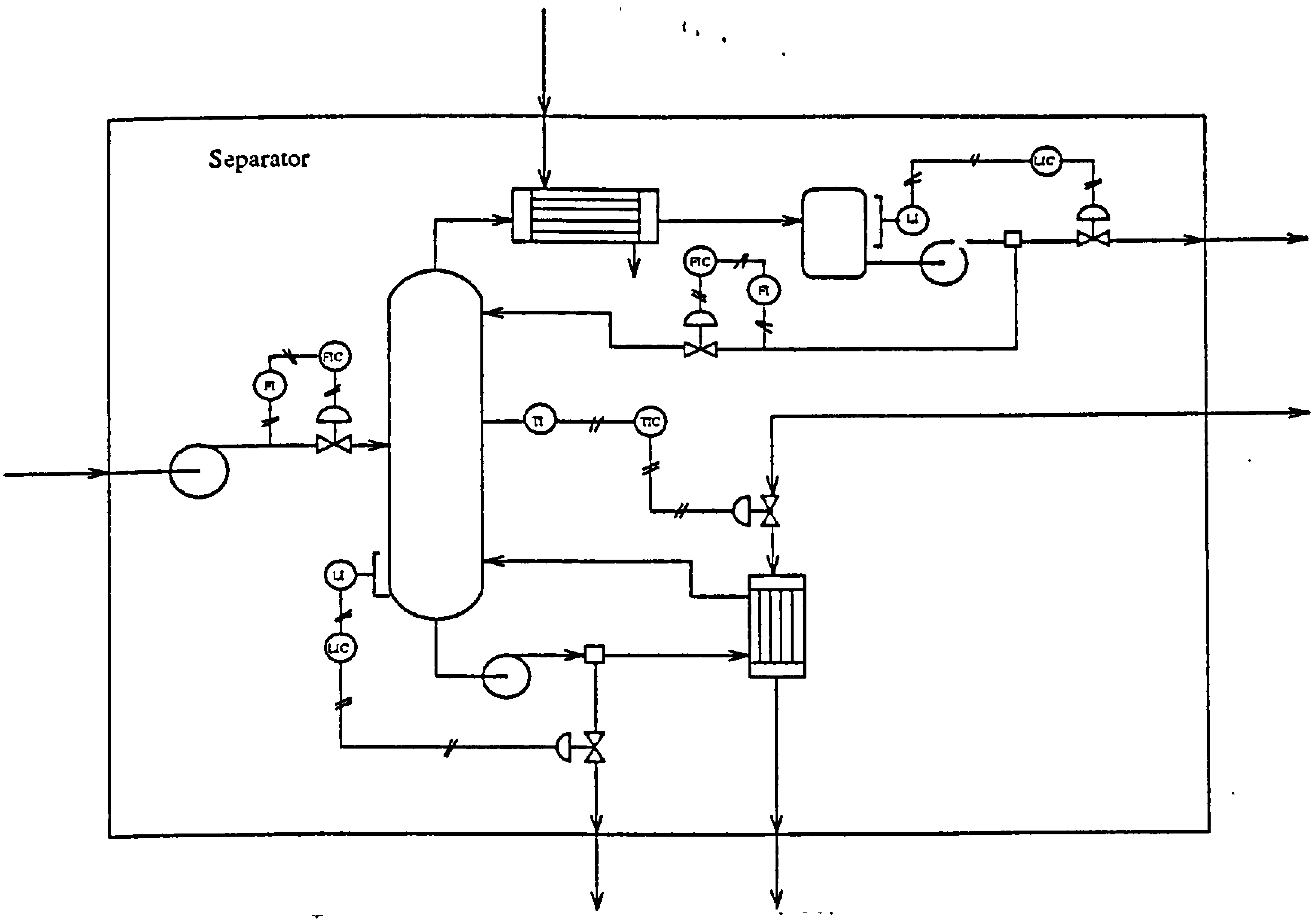

Figure 5.1 - First level of decomposition. Component level.

At the next level of decomposition (figure 5.2) we can consider the plant being made of equipment modules. These are groups of components which perform functions at a very simple level. These equipment modules may be pumps, heat exchangers, pipelines, vessels, etc. Included within these modules will be the relevant valves and connecting pipes. This is the level at which experienced HAZOP leaders conduct their meetings. They know that they do not need to consider each valve or pipe and they have built up a set of knowledge, particularly of faults and consequences for many of these equipment modules.

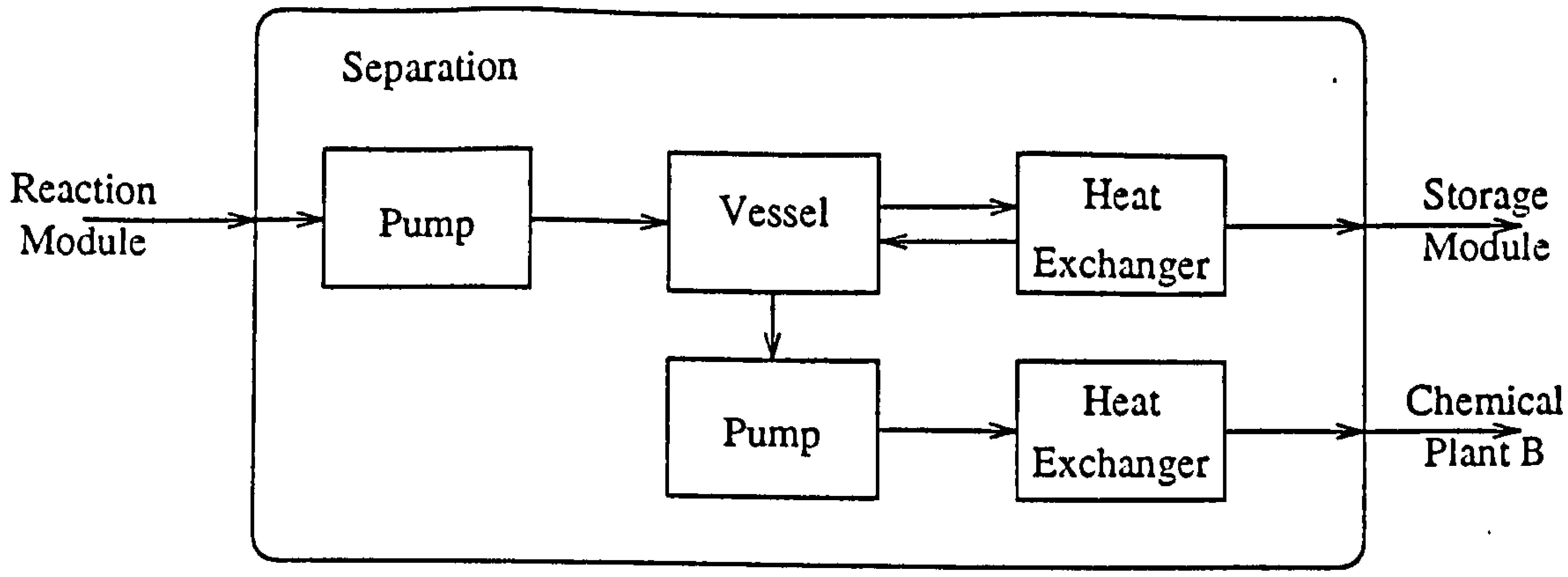

Figure 5.2 - Second level of decomposition. Equipment modules.

The next level of decomposition (figure 5.3) is to consider the plant as being made up of a set of functional modules. These might be functions such as reaction, separation, storage, refrigeration etc. These modules will be interconnected in some way and they may also have connections to the outside world. The main problem here would seem to be defining exactly what constitutes a functional module. For example, a separation module may be defined as being made up of pumping equipment, vessels, and condensers, or it may be more simply defined as just a separating vessel. From a hazard identification point of view the main problem is whether or not it is possible to identify all the hazards within these functional modules. In terms of reducing the time taken to perform hazard identification the larger the modules are the less time it is likely to take to carry out modular HAZOP. On the other hand, the larger the modules are the less likely it is that they will be re-used in future plants.

This level of decomposition may be used in conventional HAZOP in certain circumstances. For example, some of the connections to the plant may not be subject to rigorous HAZOP, only known causes and consequences will be considered based on the functionality of the system connected. Examples might be cooling water supplies, nitrogen supplies and power supplies. In the case of a power supply the HAZOP team would probably only consider complete failure. Although other failure modes could be conceived, based on their previous experience of power supplies, only complete failure would be considered. No consideration is normally given to the components making up the power supply, it is treated strictly on a functional basis.

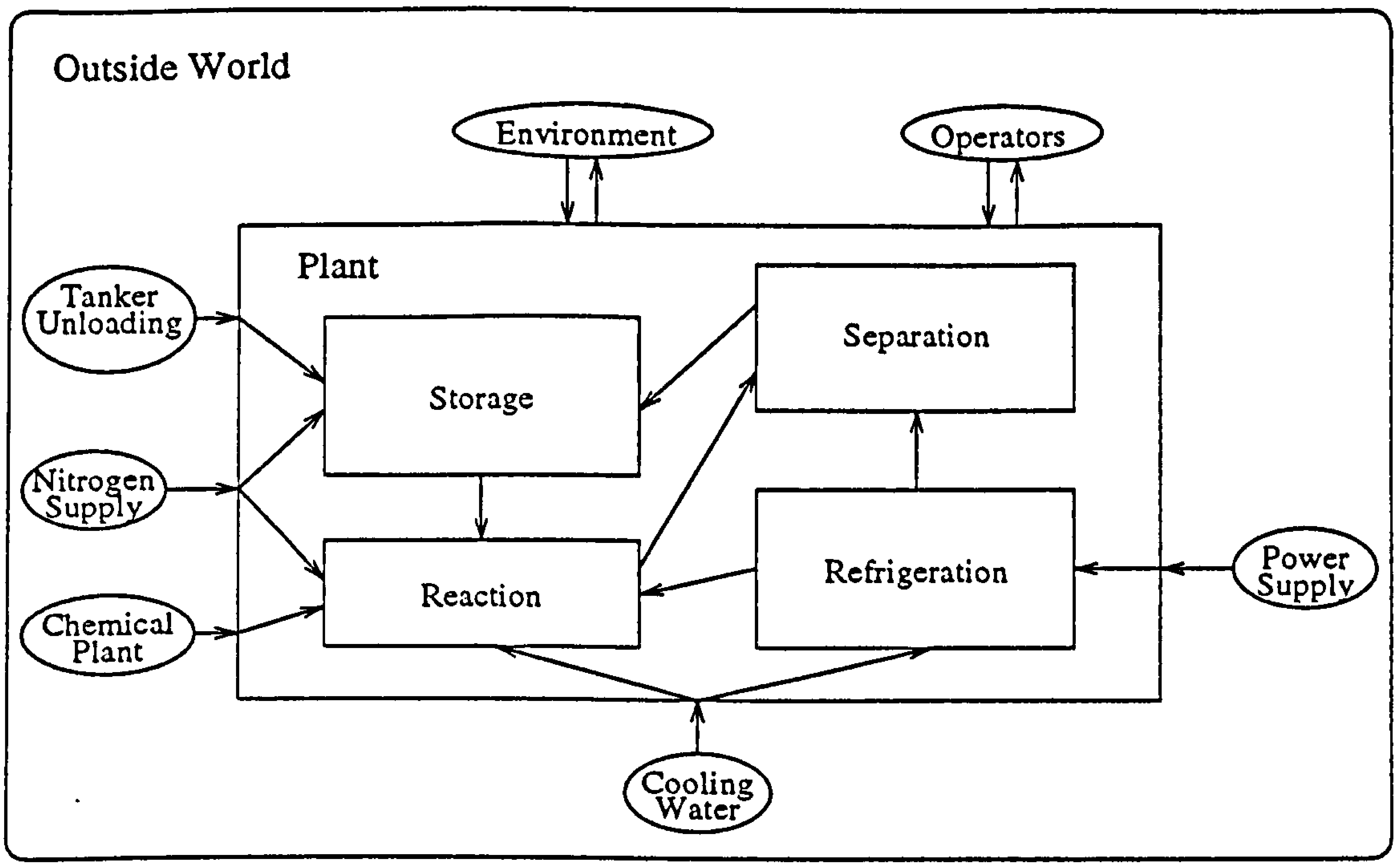

Figure 5.3 - Third level of decomposition. Functional modules.

At the highest level of decomposition (figure 5.4) we can take a plant as a complete entity with connections to the outside world. These connections to the outside world will include the environment and operating personnel as well as physical connections to other plants or tanker loading and unloading facilities. Hazard identification is applied to try to identify the possible hazardous effects that the plant may have on people and the environment. However, unless the plant is identical to one for which all the possible hazards are known then there is no way to identify the hazards at this level of decomposition. Figure 5.4 illustrates this top level of decomposition.

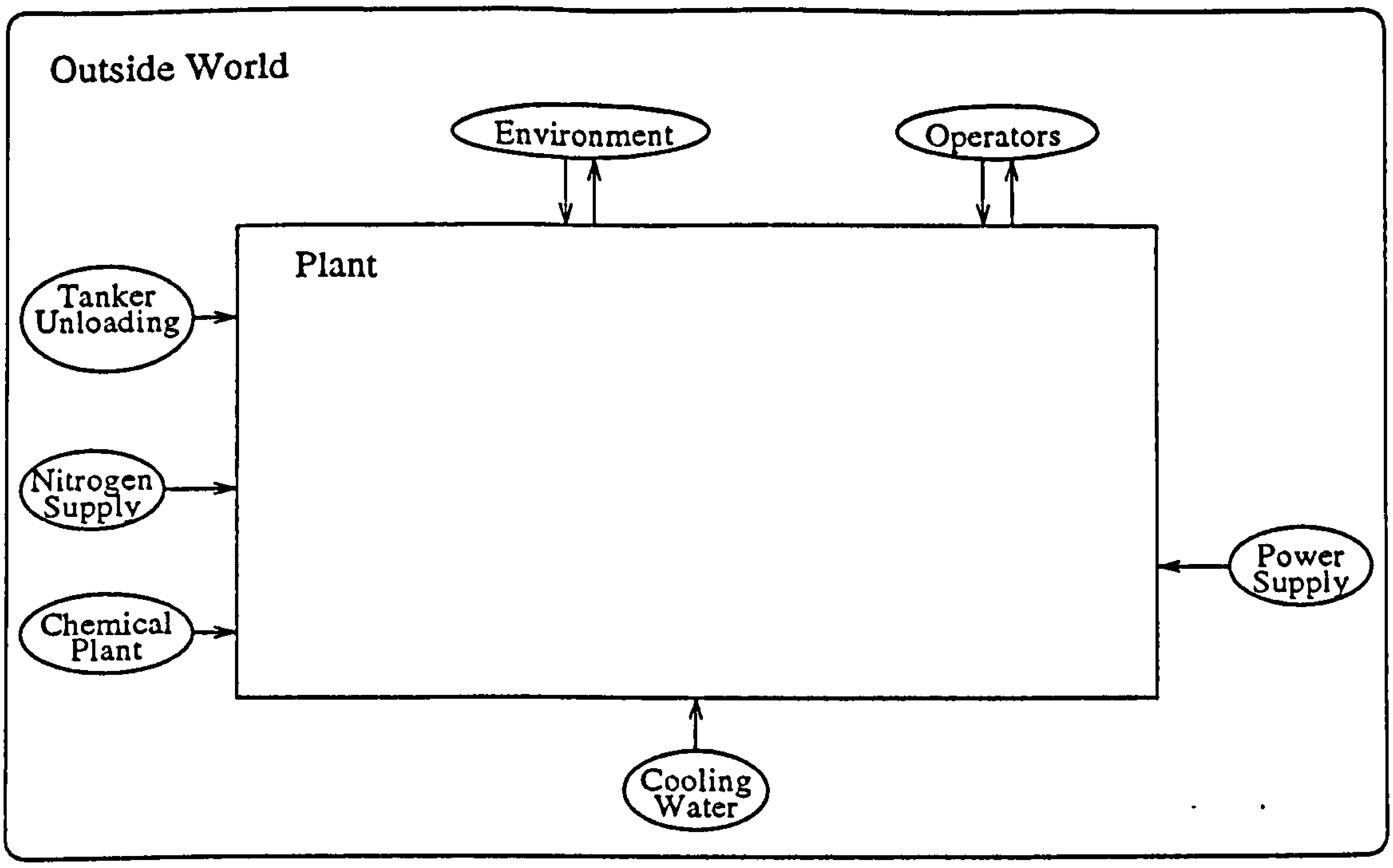

Figure 5.4 - Fourth (highest) level of decomposition. Plant level.

It should be noted that there is some overlap between each of these levels of decomposition as illustrated above. For example, a valve could be considered as an equipment module and broken down into its component parts or it may be considered as a component of say a pump module. A condenser could be considered as either a functional module or an equipment module. It may be considered an equipment module when it forms part of a distillation column, but a functional module if it occurs in isolation. There are no formal definitions of where the boundaries between these different levels of decomposition lie. Nor is any needed as the different levels of decomposition are intended as illustration only.

This discussion illustrates several things. Modules must contain sufficient detail that the results generated are accurate and complete. In terms of time saving, ideally we would like to be able to identify hazards in modules at the functional level. The larger the modules that we use, the more time can be saved over conventional HAZOP. This will reduce considerably the number of items studied at HAZOP while still identifying (hopefully) all the possible hazards. However, the larger the module, the less likelihood there is that it can be reused in future projects. If the module cannot be reused then there is potentially no time saving, although the overall time taken for modular HAZOP of a complete plant may still be less than the time taken for conventional HAZOP of the same plant, even if time is spent generating preHAZOPed results for modules which may have no or limited possibility of reuse.

5.2.2 Sub-modules

To solve the conflicting requirements of making the modules as large as possible to save time but small enough to be useful in numerous projects and to be sufficiently detailed, the concept of sub-modules was introduced. The aim is to optimise the effectiveness and efficiency of the modules while minimising the number required. The intention is that rather than having a large number of different preHAZOPed module results, one for every variation of equipment and its arrangement that might make up a module, it should be possible to create these results by piecing together results for sub-modules. The approach taken is that, modules are defined on a functional level and are made up of a number of sub-modules which are defined substantially at an equipment level. The connections between sub-modules within a module are defined explicitly so there is no significant time taken up in generating the preHAZOPed results for a module from the preHAZOPed results for each sub-module.

As an example of the use of sub-modules and particularly how they introduce flexibility for applying the same sub-modules to analysis of different plants, consider a stock tank. The basic stock tank module consists of the following sub-modules, inlet sub-module, tank itself, outlet sub-module and a vent sub-module. The outlet sub-module could be a single pump, or two pumps operating continuously or two pumps, one running, one spare. The inlet sub-module could be a continuous feed from another part of the plant or it may be a batch feed from a tanker. The vent sub-module could either be an open vent to atmosphere or an inert gas blanket. These few simple examples provide 12 different stock tank arrangements. As a further example, the preHAZOPed results for a stock tank with a heating coil would only require the addition of the results for a heating coil sub-module to be added to the standard stock tank results.

In some cases it may not be necessary to create new preHAZOPed results for each variation of a sub-module as the effects on the module may be very slight and the same results could be used for a variety of different sub-module configurations. If we consider an inert gas venting sub-module for a stock tank module, it is possible to envisage a couple of different control strategies. However, in this case, similar problems are encountered whatever arrangement is used, so it would not seem necessary to have a different set of sub-module results for each, though some additional comments may be appropriate.

The main problem envisaged is dealing with the interaction between sub-modules. It is foreseeable that there are cases where the choice of one sub-module affects the preHAZOPed results of another sub-module. It is hoped that through appropriate comments in the preHAZOPed results most problems can be overcome. However there may be cases where it is necessary to select different sub-module results for a given sub-module depending on the selection of other sub-modules that make up a particular module.

5.3 Principles of Hazard Identification Using Modular HAZOP

5.3.1 Dealing with Interconnections

The approach taken in modular HAZOP for dealing with the interconnections between modules is to consider the effects modules will have on each other. For each module there will be four sets of effects that will need to be considered. These effects are illustrated in figure 5.5.

1. Effects from the module - a set of possible effects on other modules.

2. A set of module vulnerabilities - effects (from outside the module) that have an effect on the module. These can either give rise to hazards inside the module or new effects on other modules.

3. A set of internal module problems.

4. Effects (from another module) which will pass straight through the module.

Figure 5.5 illustrates these sets of effects with respect to a module.

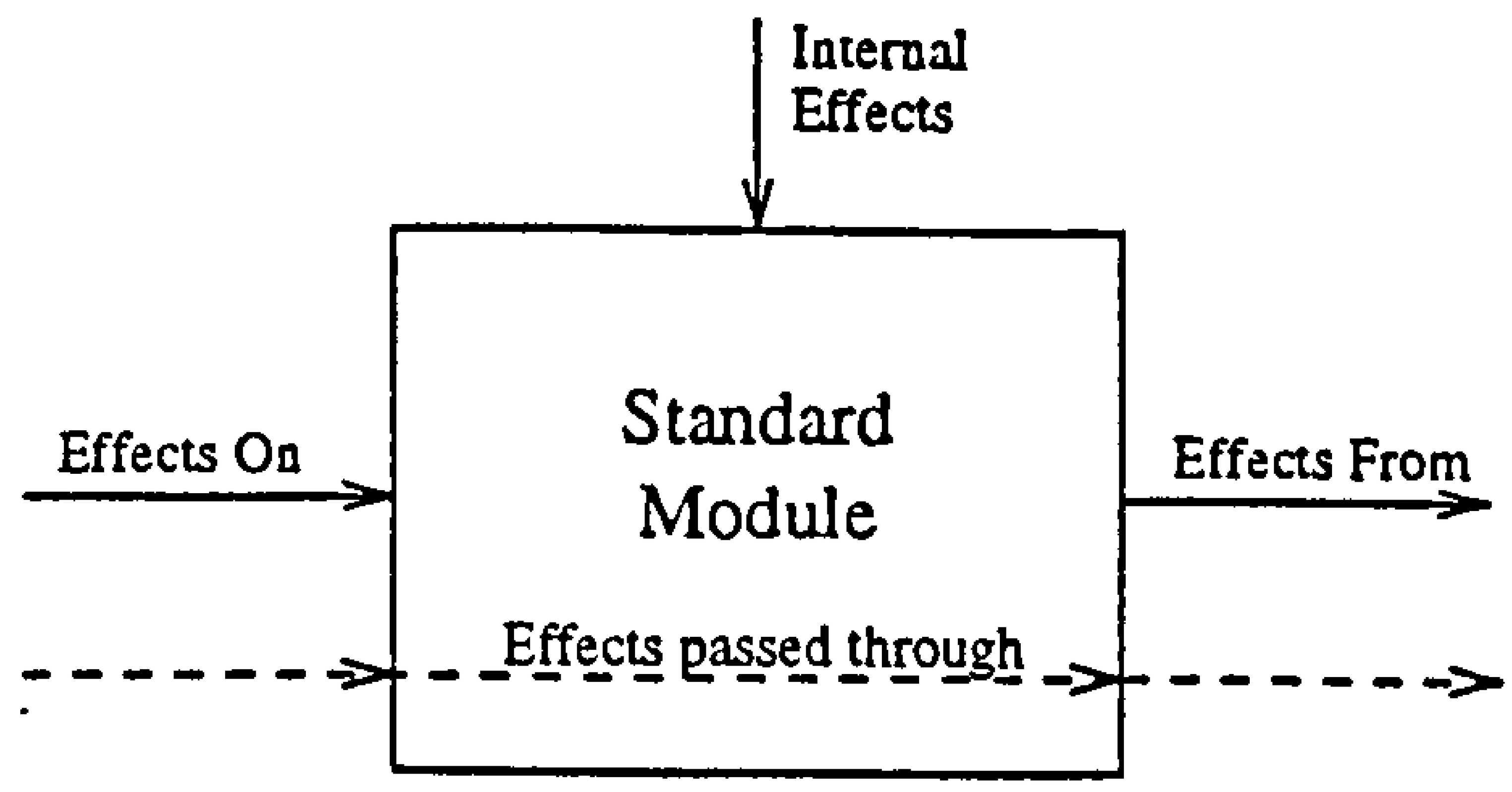

Figure 5.5 - Four sets of effects need to be considered for each module

If modules are connected together, then to identify hazards due to this relationship we need to match the possible effects from one module with the vulnerabilities in another module. For example effects from one module may be less flow and high temperature. The vulnerabilities of another module may be high flow and high temperature. Connecting these two would immediately lead us to the consideration of high temperature as being a problem. Figures 5.6 and 5.7 show what effects would need to be considered if two or three modules are connected in series.

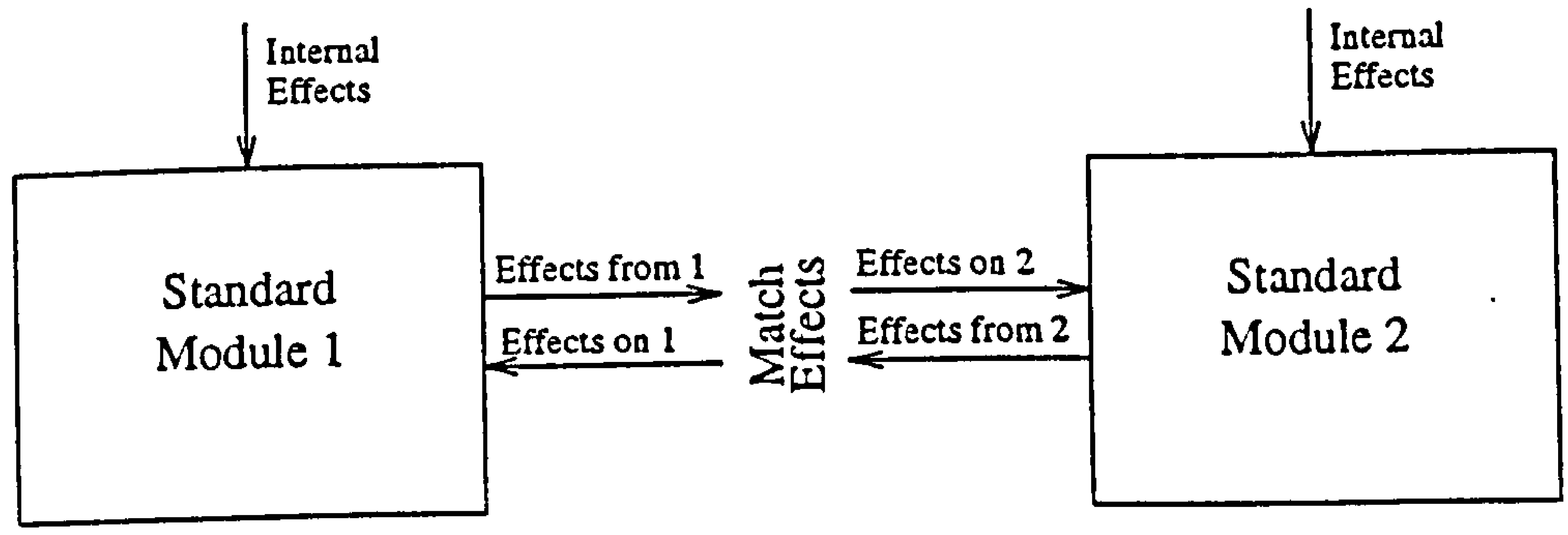

Figure 5.6 - Effects needing consideration when two modules are connected.

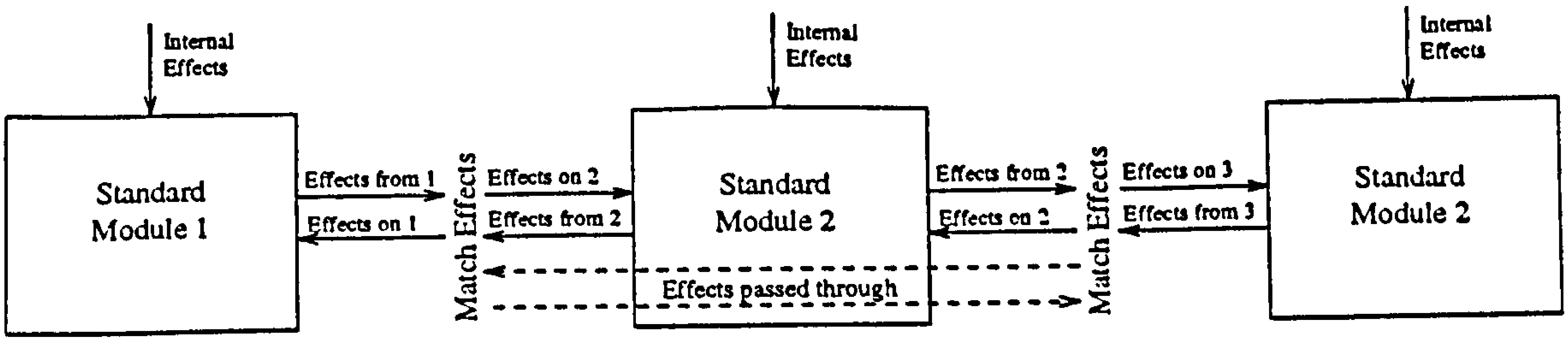

Figure 5.7 - Effects needing consideration when three modules are connected in series.

This propagation of faults has been used as the basis for attempts to automate hazard identification procedures (Parmar & Lees, 1987), and forms the core of current attempts to automate HAZOP (Jefferson et al, 1995b). The originating causes are defined as initial causes and the realisable consequences are defined as end effects. The possible effects and vulnerabilities are defined as variable deviations. An initial cause may be connected either directly or via any number of variable deviations to an end effect. Of course, many initial causes will not connect to any end effects and vice versa. Figure 5.8 illustrates possible paths that may exist between different initial causes, variable deviations and end effects. Obviously for hazard identification, the paths of interest are complete paths that start at initial causes (causes) and end at end effects (consequences). Asterisks indicate incomplete paths.

Initial cause (a) → End effect (d)

Initial cause (a) → End effect (e)

Initial cause (a) → Variable deviation (f) → End effect (j)

*Initial cause (b) → Variable deviation (g)

*Variable deviation (c) → End effect (h)

Figure 5.8 Possible paths between initial causes, variable deviations and end effects.

For the variable deviations, we will use applicable process . However, in order to reduce the number of matches and hence the number of effects that are propagated between modules these may be qualified where appropriate by the addition of the state of the material involved, i.e. liquid or vapour. If no qualification is given then the effect applies to all material states. Possible hazards are generated when either an initial cause is linked to a end effect within a module or an initial cause in one module is linked via matching variable deviations to a end effect in another module.

5.3.2 Cause and Consequence Types in Conventional HAZOP

It has already been discussed how simply providing HAZOP results of individual modules that make up a plant, without dealing with the connections, would probably not save much time in identifying the hazards present in the plant. It would be necessary to explore the whole plant again to determine any possible effects that there may be due to the connection of modules. There is a requirement therefore to develop rules so that any problems there may be with connection can be identified simply and effectively.

In order to illustrate how a cause in one part of a plant can have a consequence in a different part of a plant, a study was made of conventional HAZOP results. Causes and consequences are defined as either being local or distant. Local causes or consequences occur somewhere on the line being studied. Distant causes or consequences occur on a different line to that being studied. This results in four possible combinations of cause consequence scenario

Local cause - local consequence (local - local). The cause and the consequence are in the same line.

Local cause - distant consequence (local - distant). A cause identified in the line under consideration gives rise to a consequence in another line.

Distant cause - local consequence (distant - local). A consequence identified in the line under consideration is due to a cause in another line.

Distant cause - distant consequence (distant - distant). A deviation in the line under consideration is due to a cause in another line and gives rise to a consequence also in a different line.

These can be divided into two categories. Local cause consequence scenarios and remote cause consequence scenarios. Local cause consequence scenarios consist only of local cause - local consequence type scenarios. Remote cause consequence scenarios make up the remainder where the cause and consequence are in different lines.

Table 5.1 illustrates local and distant causes and consequences for one of the lines in the HAZOP results presented by Lawley (1974). This set of HAZOP results generates 8 remote cause consequence scenarios and 9 local cause consequence scenarios. Investigation of numerous other sets of HAZOP results, from HAZOP studies carried out by ICI, reveals that on average one third of the cause consequence scenarios generated are remote. However, no attempt was made in this investigation to try and establish whether either of these scenarios gave rise to consequences which were generally more severe than consequences of the other scenario. This could form the basis of future work. If the more severe consequences were due to local cause consequence scenarios then a checklist approach may be acceptable for hazard identification. If not then some form of configuration checking is necessary for adequate hazard identification.

Line from intermediate storage to buffer/settling tank					
Guide word		**Cause**	Local/distant cause	**Consequence**	Local/distant consequence
No Flow	1	No hydrocarbon at intermediate storage	Local	Loss of feed to reaction section and reduced output. Polymer formed in heat exchanger under no flow conditions	Distant
	2	J1 Pump fails (motor fault, loss of drive, impeller corroded away etc.)	Local	As for 1	Distant
	3	Line blockage, isolation valve closed in error or LCV fails shut	Local	As for 1	Distant
			Local	J1 pump overheats.	Local
	4	Line fracture	Local	As for 1	Distant
			Local	Hydrocarbon discharged into area adjacent to public highway.	Local
More Flow	5	LCV fails open or LCV bypass open in error.	Local	Settling tank overfills	Local
			Local	Incomplete separation of water phase in tank, leading to problems on reaction section.	Distant
More Pressure	6	Isolation valve closed in error or LCV closes, with J1 pump running	Local	Transfer line subjected to full pump delivery or surge pressure	Local

	7	Thermal expansion in an isolated valved section due to fire or strong sunlight	Local	Line fracture or flange leak	Local
More Temperature	8	High intermediate storage temperature	Local	Higher pressure in transfer line and settling tank	Local
Less Flow	9	Leaking flange or valve stub not blanked and leaking	Local	Material loss adjacent to public highway	Local
Less Temperature	10	Winter conditions	Local	Water sump and drain line freeze up.	Local
High water conc. in stream	11	High water level in intermediate storage tank	Local	Water sump fills up more quickly. Increased chance of water phase passing to reaction section.	Distant
High conc. of lower alkanes or alkenes	12	Disturbance on distillation columns upstream of intermediate storage.	Distant	Higher system pressure	Local & distant
Organic acids present	13	As for 12	Distant	Increased rate of corrosion of tank base, sump and drain line	Local
Maintenance	14	Equipment failure, flange leak, etc.	Local	Line cannot be completely drained or purged.	Local

Table 5.1 Example of HAZOP results (from Lawley, 1974), illustrating local and distant causes and consequences.

5.4 Cause and Consequence Types in Modular HAZOP

On the face of it the same definitions for cause consequence scenarios could be used for modular HAZOP. However, there is an important difference in the types of causes or consequences that would be considered local or distant for modular HAZOP and the types of causes or consequences that would be considered local or distant for conventional HAZOP. This is because the conception of locality in relation to modular HAZOP is at the level of modules and sub-modules and in conventional HAZOP it is at the level of lines. A line in a conventional HAZOP would include the items of equipment at either end of it. Therefore a fault in an item of equipment at one end of the line leading to a consequence in an item of equipment at the other end of the line would still be considered a local cause consequence scenario in conventional HAZOP. Modular HAZOP would consider the items of equipment at either end of the line as distinct modules and therefore the above cause-consequence scenario would be either local-distant or distant-local depending upon the viewpoint. In order to make this distinction clear, cause consequence scenarios are defined in a different manner for modular HAZOP.

The types of causes defined for modular HAZOP are initial causes, and vulnerabilities.

The types of consequences defined for modular HAZOP are end effects, directly propagated effects and indirectly propagated effects.

An initial cause is a fault within a module that gives rise to some effect, either a propagated effect or an end effect. This terminology is used to explicitly define its position as the potential start of a fault path.

An end effect is a realisable consequence. This terminology is used to explicitly define its position as the potential end of a fault path.

A directly propagated effect is a variable deviation, representing a type of consequence, which will give rise to an effect in an adjoining sub-module of an adjoining module to that being studied, equivalent to an effect in the other end of a line in a conventional HAZOP. It is either a consequence of a vulnerability or a consequence of an initial cause.

An indirectly propagated effect is a variable deviation, representing a type of consequence, which will give rise to an effect in a non-adjoining sub-module. This will lead to an end effect equivalent to a distant consequence in conventional HAZOP. It may be a consequence of a vulnerability but in the majority of cases it will be a consequence of an initial cause.

A vulnerability is a variable deviation, representing a type of cause, which has effects on a sub-module. I.e. The sub-module is vulnerable in some way to the variable deviation specified. This vulnerability gives rise either to an end effect or to some type of propagated effect.

The term propagated effect without an initial qualification is used to indicate that the source of the effect is unknown. It could either be local or remote.

The relationships generated by combining the cause and consequence types will have the following representations in modular HAZOP:

Initial cause - end effect. The cause and consequence lie entirely within one module. For example, in a heat exchanger this might be a shell side leak giving rise to environmental contamination (figure 5.9). This is a subset of conventional local-local cause-consequence relationships.

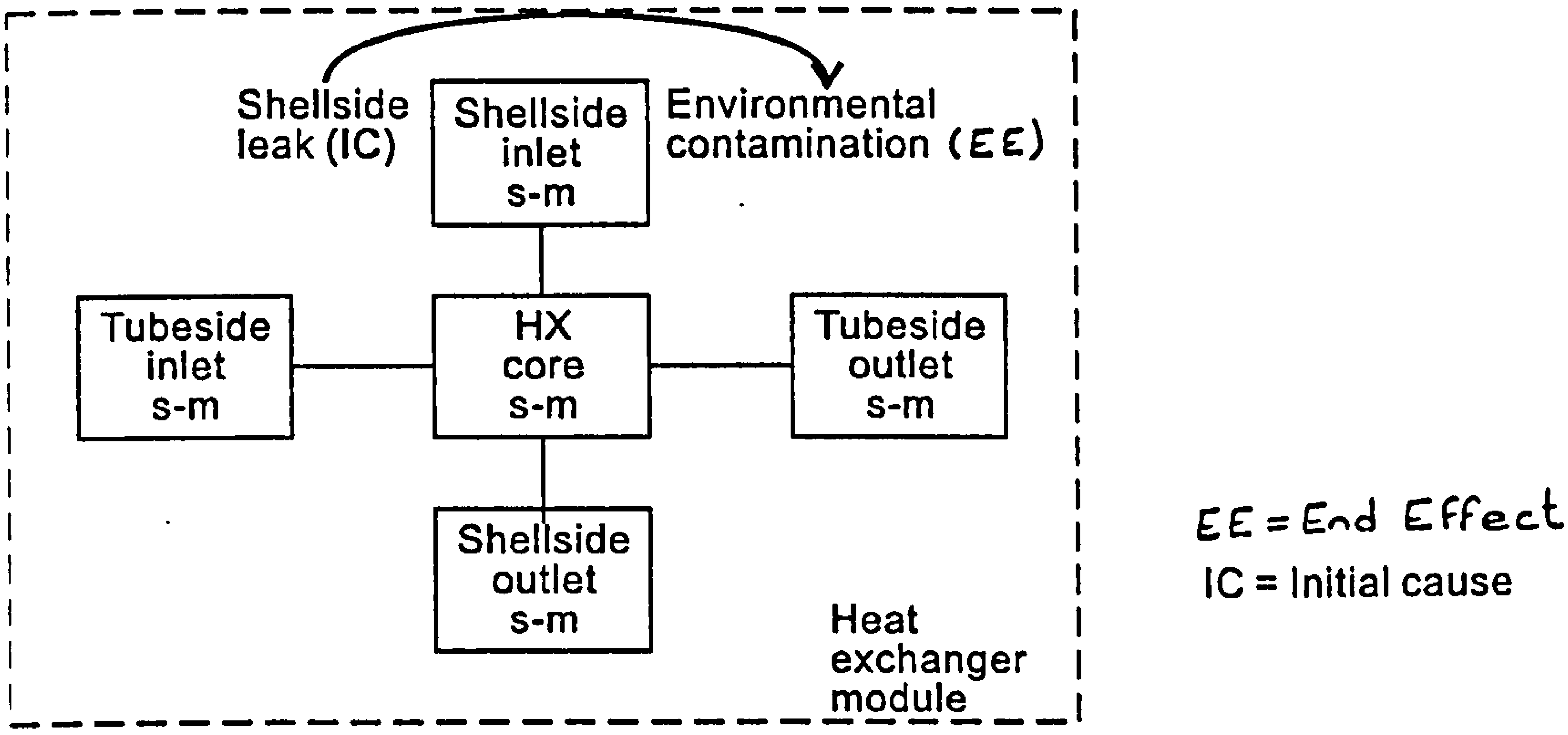

Figure 5.9 An example of an initial cause-end effect type of cause-consequence relationship.

Initial cause - directly propagated effect. A cause in one sub-module gives rise to a consequence in an adjacent sub-module of an adjoining module. The sub-modules are directly connected and represent either end of a conventional line. For example this might be fouling of heat exchanger tubes leading to low flow out of tube side of heat exchanger (figure 5.10). Given a vulnerability in the directly adjoining sub-module to the propagated effect we can develop three different possible scenarios. If the vulnerability has an end effect associated with it, then a conventional local cause consequence relationship is formed. If the vulnerability is associated with a directly propagated effect (which will only occur rarely), then this may give rise to additional local-local cause-consequence scenarios. Finally, if the vulnerability leads to an indirectly propagated effect this may give rise to local-distant cause-consequence scenarios. Of course if there is no vulnerability to any of the propagated effects involved then there is no end effect linked to the initial cause, there is no complete fault path and no cause consequence relationship exists.

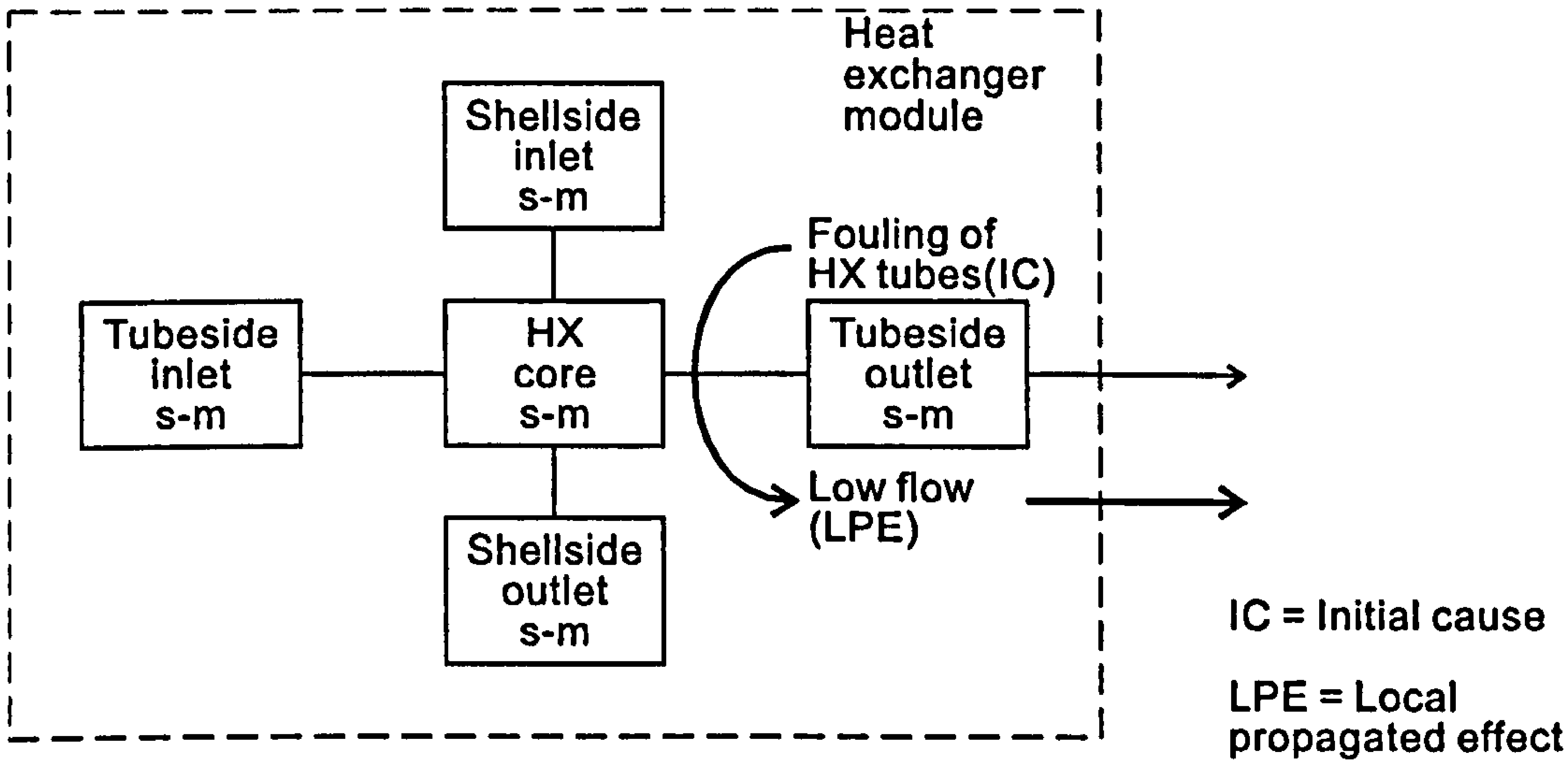

Figure 5.10 - An example of an initial cause-directly propagated effect type of cause-consequence relationship.

Initial cause - indirectly propagated effect. Cause in one sub-module gives rise to consequence in an unconnected sub-module. For example fouling of heat exchanger tubes gives rise to high/low temperature (depending on heat exchanger duty) out of shell side of heat exchanger (figure 5.11). This combination of cause and consequence types will typically give rise to local-distant cause-consequence scenarios if a complete fault path exists.

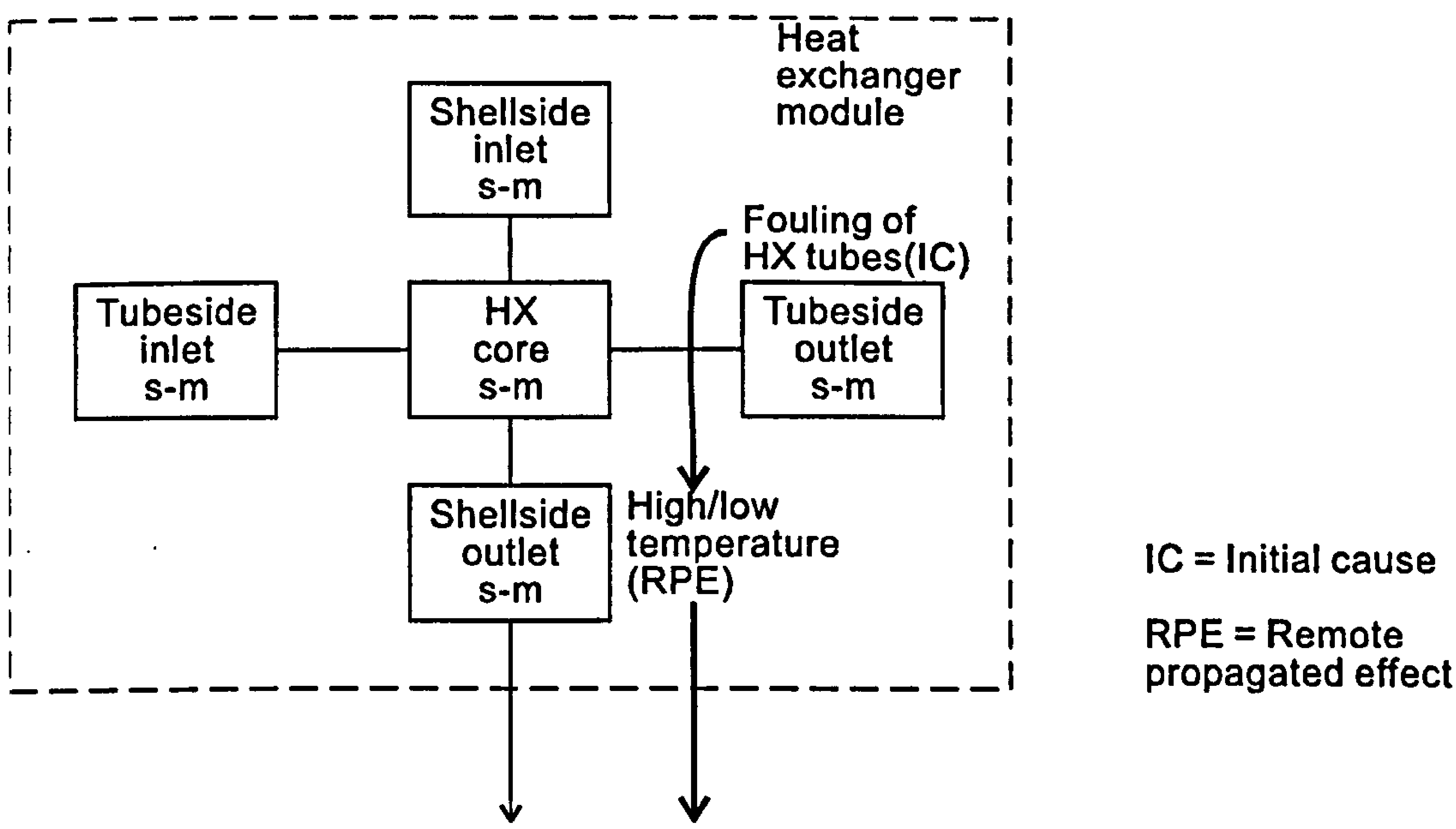

Figure 5.11 - An example of an initial cause-indirectly propagated effect type of cause-consequence relationship

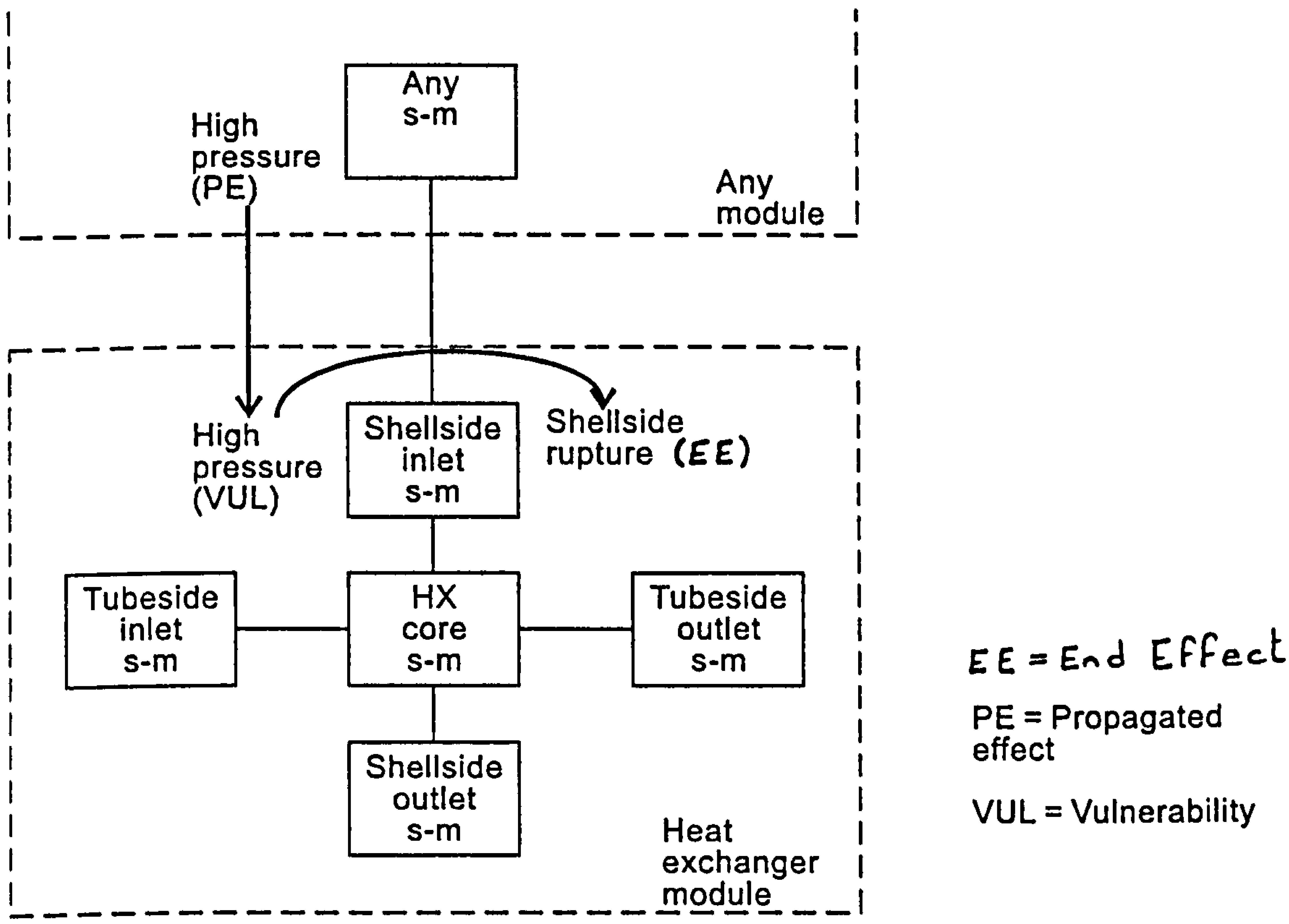

Figure 5.12 - An example of a vulnerability-end effect type of cause consequence relationship

Vulnerability - end effect. Vulnerability in one sub-module gives rise to a consequence in that sub-module. For example high pressure in a sub-module upstream of the shellside of a heat exchanger leads to heat exchanger rupture (figure 5.12). This combination of cause and consequence types may give rise to either local-local or distant-local cause-consequence scenarios depending on the type of cause in the connecting sub-module. For example polymerisation of fluid in tubeside of heat exchanger due to low flow of cooling stream at sub-module downstream of shellside of heat exchanger (figure 5.14). This is an example of a distant-local cause-consequence scenario.

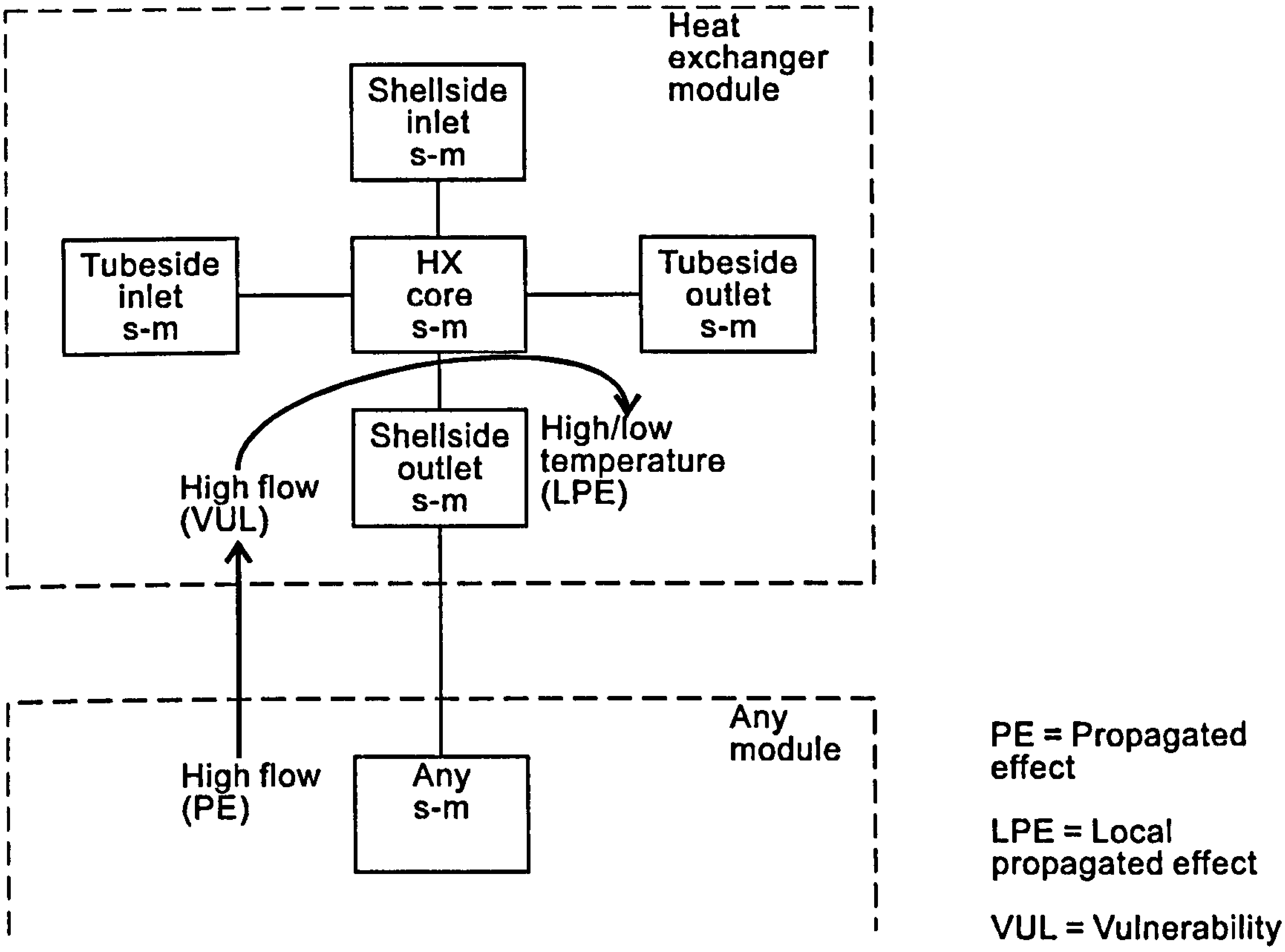

Figure 5.13 - An example of a vulnerability-directly propagated effect type of cause consequence relationship.

Vulnerability - directly propagated effect. Vulnerability in one sub-module gives rise to a propagated effect which affects a directly adjoining sub-module. For example, high flow in sub-module downstream of shellside of heat exchanger leads to high/low temperature (depending on heat exchanger duty) in that downstream sub-module (figure 5.13). This combination of cause and consequence types can give rise to any type of cause-consequence scenario depending on the type of cause and the type of consequence in connecting sub-modules.

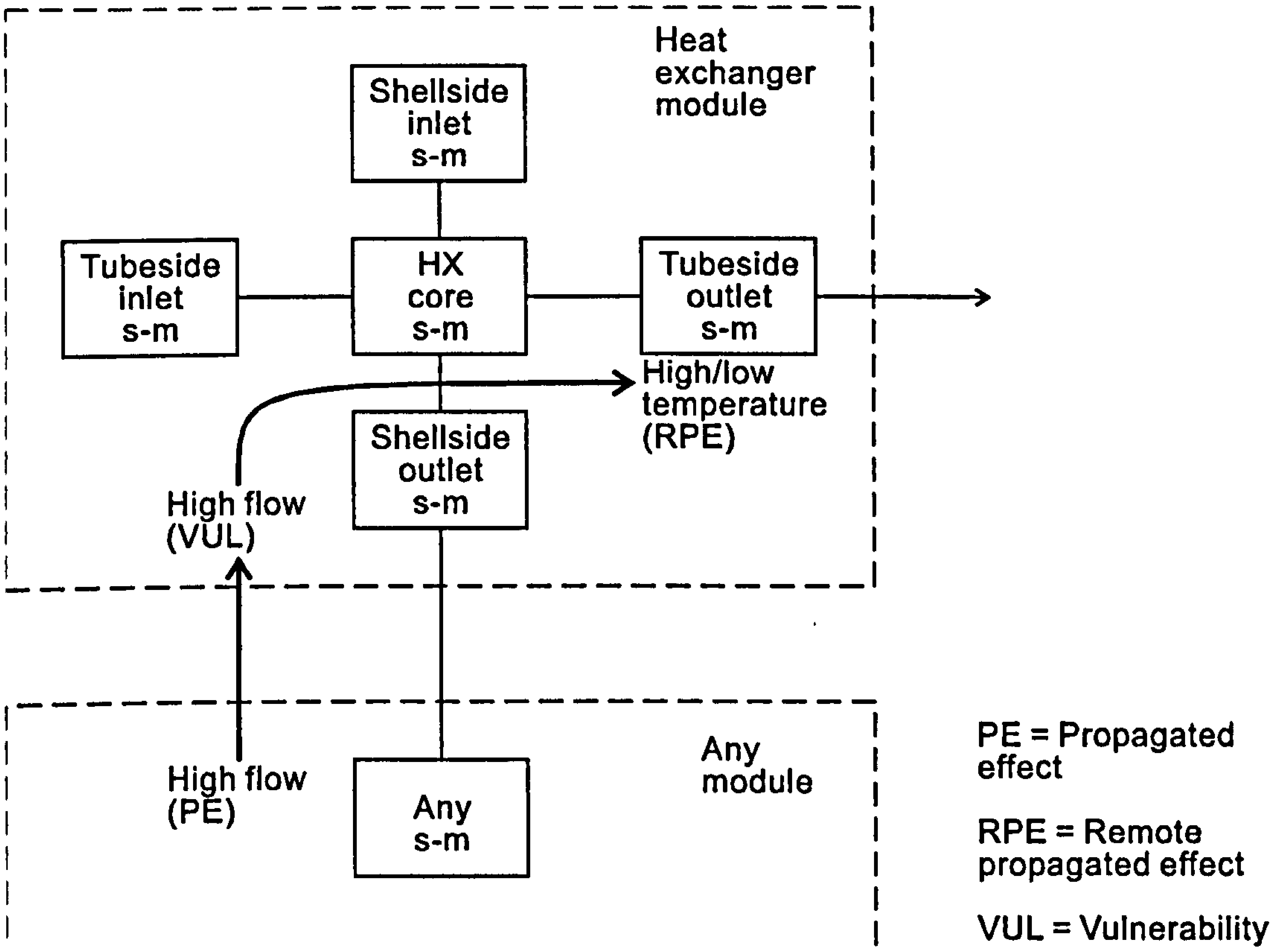

Figure 5.14 - An example of a vulnerability-end effect type of cause-consequence relationship.

Vulnerability - indirectly propagated effect. Vulnerability in one sub-module leads to consequence in unconnected sub-module. For example, high flow in sub-module downstream of shellside of heat exchanger leads to high/low temperature (depending on heat exchanger duty) in sub-modules downstream of tubeside of heat exchanger (figure 5.15). This will form either local-distant or distant-distant scenarios.

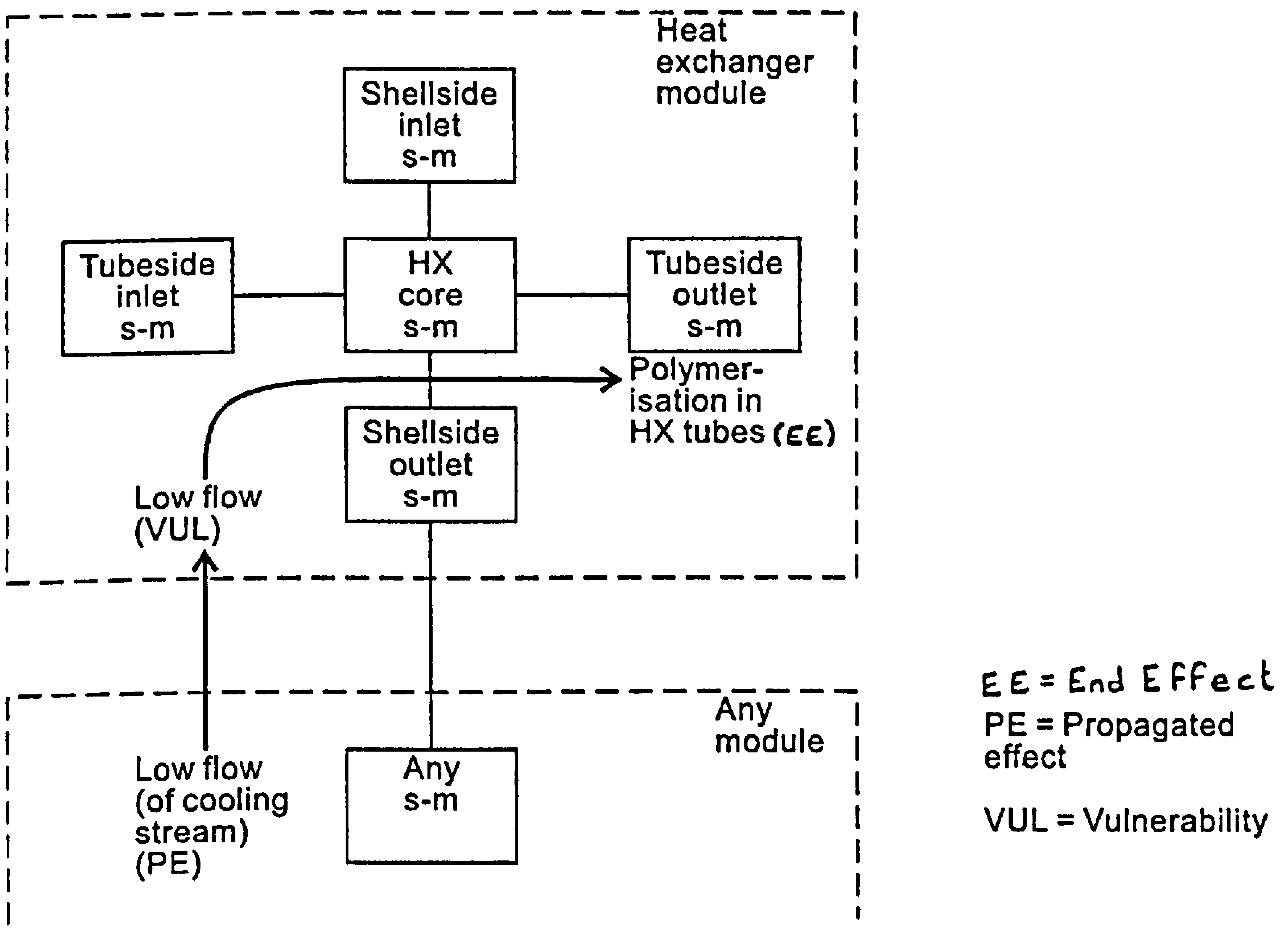

Figure 5.15 - An example of a vulnerability-indirectly propagated effect type of cause-consequence relationship.

Figure 5.16 gives examples of possible fault paths that can be generated. The asterisks indicate incomplete paths, i.e. where there is no link between an initial cause and a end effect.

Initial cause (a)	→	**end effect (b)**		
Initial cause (c)	→	**propagated effect (d)**	→	**vulnerability (d)**
	→	**end effect (e)**		
***Initial cause (f)**	→	**propagated effect (g)**		
Initial cause (g)	→	**propagated effect (h)**	→	**vulnerability (h)**
	→	**propagated effect (i)**	→	**vulnerability (i)**
	→	**end effect (j)**		
***Vulnerability(k)**	→	**end effect (l)**		

Figure 5.16 - Possible paths between cause and consequence types in modular HAZOP

5.4.1 Cause - Consequence Types in Hybrid HAZOP

Hybrid HAZOP occurs when a line that is being studied using conventional HAZOP joins a module that has a set of preHAZOPed results associated with it. The line being studied should be defined so that the appropriate sub-module forms one end of the line. The definitions used for types of causes and consequences in conventional and modular HAZOP apply in hybrid HAZOP as appropriate. The sub-module end of the line has types of causes defined as initial causes and vulnerabilities. For the other end of the line two types of causes will need to be considered, local causes and distant causes. Similarly for types of consequences, at the sub-module end they are defined as locally propagated effect, remotely propagated effects and end effects. For the other end of the line local consequences and distant consequences will need to be considered.

As well as the combinations of causes and consequences that arise entirely within the conventional section or entirely within the module, combinations exist where the cause and consequence are in different sections. The following combinations of causes and consequences exist where the cause and consequence are in different sections.

Cause in conventional section - Consequence in module

Local cause - Locally propagated effect
Local cause - Remotely propagated effect
Local cause - End effect
Distant cause - Locally propagated effect
Distant cause - Remotely propagated effect
Distant cause - End effect

Cause in module - Consequence in conventional section

Initial cause - Local consequence
Initial cause - Distant consequence
Vulnerability - Local consequence
Vulnerability - Distant consequence

5.5 Summary

This chapter has looked at the theory behind modular HAZOP and provides definitions of terms used in modular HAZOP. This terminology will be used in the following chapters in which the modular HAZOP procedure is further explained. In particular, this chapter provides an analysis of the size and form of modules used in the modular HAZOP procedure and how these modules are broken down into sub-modules. It also shows how fault paths are built up between initial causes and end effects through propagated effects and vulnerabilities. These fault paths enable the determination of effects due to the connection of modules and the particular procedure adopted is explained in the next chapter.

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6 Modular HAZOP Procedure

This chapter looks at the practicalities of applying modular HAZOP using the theoretical ideas explored in the previous chapter. This chapter is divided into three parts. The first part gives an overview of how the theory from the previous chapter can be used as a general method for modular HAZOP. The second part details the specific method developed. It is anticipated that modular HAZOP can be used in a variety of situations in a similar way to conventional HAZOP. The third part outlines some of these applications.

6.1 Outline of Modular HAZOP Procedure

As with all hazard identification procedures, the first requirement is to have up-to-date information on the plant to be studied.

The first step in the modular HAZOP procedure is to select the required modules and then the appropriate sub-modules that make up the plant under consideration. The modules and sub-modules selected should be documented and the connections between them need to be made explicit. Except for the simplest plants it is quite likely that preHAZOPed results will not exist for some modules and particularly for certain sub-modules. For these modules and sub-modules it is necessary to draw up the required preHAZOPed results and record them for future use. In the most preferred cases, the plant will have been designed on a modular basis, wherein detailed pre-designed and preHAZOPed modules are put together to form the required plant, and the modules and sub-modules will already be known.

In order to lessen the time taken to perform hazard identification, it is necessary that the majority of sub-modules should already have preHAZOPed results preferably taken from a module library. Such a library should include a description of the module, the sub-modules making up the module, a representation of the sub-modules and, of course, the preHAZOPed results for each sub-module. It is not necessary that the plant sub-modules be identical to library sub-modules. Variation in the indication, alarm and manual valving arrangements is generally acceptable. The main similarities that must be satisfied are, that for control valves, the same control variable is being used, for pumps, the same type of pump is being used, for single or multiple pumps, the appropriate sub-module is used, and for any vessels similar vent arrangements are used. Requirements for matching sub-modules should ideally be included in the module library.

Required generic sub-modules	Available Specific Sub-Modules	HAZOP-PC Node No.	Comments
Storage tank vessel	Storage tank vessel	5	
Storage tank feed(s)	Storage tank feed with flow control (No	10	Use as many as are required to represent different reactor feeds.
	Storage tank feed with level control	1	
	Storage tank feed without control valve	13	
Storage tank outlet	Storage tank outlet with flow control	11	
	Storage tank outlet without control valve	4	
Storage tank vent system	Storage tank vent to atmosphere	2	For a simple vent to atmosphere.
	Nitrogen blanket supply, continuous feed through RO.	6	For a nitrogen blanketed vent system use one blanket supply node and one vent to header node from these nodes.
	Nitrogen blanket supply with pressure control	7	
	Vent to header without control valve	8	
	Vent to header with pressure control	9	
Storage tank overflow	Storage tank overflow	3	
Additional generic sub-modules	None.		

Table 6.1 - Module library contents – atmospheric pressure storage tank.

Table 6.1 gives an example of the sub-modules available for a storage vessel module in a module library. For each sub-module there exist line diagrams and preHAZOPed results.

The next step is to use the preHAZOPed results to generate the HAZOP results for the plant. The HAZOP results are created by identifying all possible cause consequence scenarios which exist either within modules or through the connection of modules. Any causes which do not lead to consequences or consequences which have no cause are generally eliminated. This is done by tracing paths forward from all the initial causes to see if they lead to terminal consequences.

Many of the initial causes will be linked explicitly to terminal consequences within the same module. These are obviously the simplest fault paths as there are no propagated effects or vulnerabilities between the initial cause and terminal consequence.

At a slightly more complex level are those initial causes and terminal consequences, which occur, in directly adjacent sub-modules. These are however, relatively easy to identify. It is only necessary to match locally propagated effects due to initial causes with vulnerabilities, which give rise to terminal consequences in the directly adjacent sub-module. These cause consequence scenarios are equivalent to causes and consequences at either end of a line in conventional HAZOP.

The most complex cause consequence scenarios to identify are those where the initial causes and terminal consequences exist in sub-modules which are not directly adjacent. In order to identify cause consequence scenarios of this type, it is necessary to match remotely propagated effects with vulnerabilities.

The suggestion is that any remaining consequences, which are not linked to causes, are reviewed to determine if the vulnerability leading to that consequence could have some cause. This is particularly appropriate where the consequences could have severe effects. As an example consider a pump handling a flammable fluid. One vulnerability associated with the pump is that no flow at downstream units causes the pump to cavitate, overheat and the pump seals fail leaking flammable fluid. Clearly this could have devastating consequences and although no particular cause of *no flow* may have been identified in the particular plant being studied, it is nevertheless a realistic occurrence. Hazardous scenarios such as this should be recorded as part of the modular HAZOP results.

Any conventional HAZOP results proforma can be used to record cause-consequence scenarios from the preHAZOPed results. The guide word, process parameter, deviation, cause and consequence are recorded along with the safeguards and any actions or recommendations. The safeguards are taken from the preHAZOPed results. These are considered in the normal HAZOP manner to determine what action may be necessary. Recommendations are entered in the appropriate column. Recommendations may either be taken from the preHAZOPed results or entered by the user. Table 6.2 illustrates headings that may be found on a conventional HAZOP proforma.

Guide Word	Para-meter	Devia-tion	Causes	Consequences	Existing Protections and Safeguards	Actions and Recommend-ations
More	Flow	1 High flow	1.1High supply pressure	1.1.1 Inadequate venting. Vessel overpressure rupture.	1.1.1.1 Relief valve	1.1.1.1 Ensure vent is sized adequately.
				1.1.2 Static build up.	1.1.2.1 Dip tubes	
			1.2 Level control valve fails open	1.2.1 Tank overflows	1.2.1.1 High level alarm 1.2.1.2 Overflow	1.2.1.1 Tank to be bunded if necessary.

Table 6.2 - Conventional HAZOP proforma.

As stated above, the first step in the modular HAZOP procedure is to select the required modules and then the appropriate sub-modules that make up the plant under consideration. The modules and sub-modules selected should be documented and the connections between them need to be made explicit.

As part of a modular design procedure the selection of modules and sub-modules would be relatively simple, as the design would be based on appropriate modules and sub-modules. Any description of the plant would reference the selected modules and sub-modules and would include information on the connections between them.

Given that modular design procedures do not yet exist for chemical plant the selection of modules and sub-modules would have to be made based upon traditionally available design documents. For conventional HAZOP a detailed ELD is required, however, for modular HAZOP, the same level of detail is not required, indeed it may not be desirable. This is because a large amount of detail can be encompassed within the sub-modules. All that is required is enough information to be able to select the correct sub-modules. A process flow diagram may be a little short of information for this selection of sub-modules. PFDs will generally only have enough information to define the modules involved. This is not to say that a modular HAZOP cannot be performed with just a PFD. If information is available on which sub-modules should be used in particular situations, based on connecting modules and chemicals involved, then it should be possible to select the required sub-modules. This approach would only be recommended as part of a unified modular design and modular HAZOP approach. This thesis is not concerned with modular design though the use of sub-modules can be seen to be a useful technique in a modular design procedure.

One possible approach may be to adopt a *semi-modular* design philosophy. Modules are determined according to the PFD and sub-modules are roughly outlined based on the process requirements and normal company practice. Details are then filled in by reference to the appropriate sub-modules in the sub-module library.

The intention is that specification of sub-modules either as part of a modular HAZOP library of modules or a modular design library of modules will include a detailed P&ID, a checklist of necessary design considerations and the preHAZOPed results. The preHAZOPed results should be a complete and accurate HAZOP of the sub-module within the context of the relevant module including the vulnerabilities and propagated effects that need to be taken into consideration.

Given that modular HAZOP does not require as much ELD detail as conventional HAZOP, then it can be applied at an earlier stage of design. This has numerous benefits. In particular it is easier to include any modifications suggested and the overall design time required can be reduced with significant savings. Because conventional HAZOP can only start once a complete ELD has been produced, design and HAZOP cannot be carried out in parallel, and, in order to have the plant operational as soon as possible, ordering and construction often start while HAZOP is still on-going.

The next step in the modular HAZOP procedure is the use of preHAZOPed results to generate the HAZOP results for the plant. In the outline of the modular HAZOP procedure above, it is stated that the identification of cause consequence scenarios is done by starting with initial causes and following deviations through to terminal consequences. In fact, the identification of cause consequence scenarios can be done in two ways, either by starting with all the initial causes and tracing paths forward to see if they lead to terminal consequences or starting with all the terminal consequences and tracing backwards to see if there are any initial causes. However, the way that cause and consequence types have been defined and the effect this has on the generation of preHAZOPed results, means that it is only sensible to trace forward starting from initial causes. To trace backwards would have required direct and indirect vulnerabilities to have been defined with just one type of propagated effect, rather than one type of vulnerability and two types of propagated effect. This change of definition would also affect the preHAZOPed results. Providing the correct definitions are used then there are no advantages or disadvantages in the amount of work required whether paths are traced forwards or backwards. However, I would suggest that it is more intuitive to trace paths forward from initial causes and this is the method that has been adopted and expounded here.

6.2 PreHAZOPed Modules

In order to provide some flexibility within the preHAZOPed module results, the concept of sub-modules has been introduced. The aim is to optimise the effectiveness and efficiency of the modules while minimising the number required.

In developing preHAZOPed module results, work was carried out at two levels. The level of detail required differs depending on what is trying to be achieved. At a low level of detail, generic preHAZOPed module results were developed to provide a general framework on which more detailed modules can be built. However, they are still useful for assessing the potential of modular HAZOP, in particular how well the faults and deviations are propagated through the plant. At this level of detail, it is mainly just the susceptibilities and propagated effects that are required, and it is only necessary to define the module by its function and its inlets and outlets. At a high level of detail fully preHAZOPed module results were developed. This requires that modules are fully defined in order that accurate and complete results can be drawn up.

The generic preHAZOPed modules have been developed with one primary aim. The aim is to illustrate how the different module interactions behave when modules are connected. To this end effort was concentrated on using guide words which are most likely to give rise to interactions. This has meant concentrating on the No/Less/More guide words. However, for those guide words, which have been considered, the corresponding causes, consequences and safeguards should be complete. Obviously in order to complete the generic preHAZOPed modules and convert them to fully preHAZOPed modules, other guide words such as start-up, shut-down and maintenance need to be considered.

The fully preHAZOPed results are intended to combine the detail of a checklist for each module with the interface information using the standard HAZOP guide words. The checklist approach enables past experience and expert knowledge to be included. This means that less experienced engineers can perform competent hazard identification. In these cases it is proposed that a substantially complete modules are developed. Specification of these modules will include a detailed P&ID, a checklist of necessary design considerations, a complete and accurate HAZOP of the module itself and the vulnerabilities and propagated effects that need to be taken into consideration.

6.3 Computer support

Any modification to the HAZOP procedure should be easy to use. In order to make the system as easy to use as possible, HAZOP-PC (PrimaTech, 1994) was used for development and recording of the preHAZOPed module results. HAZOP-PC was chosen primarily because it was available in the Department of Chemical Engineering at Loughborough University, having been provided at a substantial discount by PrimaTech. In the event, the ability with HAZOP-PC to categorise causes and consequences, and to subsequently generate a HAZOP report filtered on these categories, proved to be of significant value. It would therefore be recommended that any computerised HAZOP recording tool used for modular HAZOP should have a similar functionality.

HAZOP-PC is a computer tool for conventional HAZOP. Essentially it is used to record the deliberations of HAZOP teams in conventional HAZOP and it provides an efficient alternative to more conventional documentation means. In particular it provides for the generation of various formatted reports from the inputted data. In addition to being a recording tool HAZOP-PC will also provide prompts for guide words and parameters. It can also provide information on causes and consequences that should be considered. There are a large number of columns that can be used not only for recording HAZOP meetings but also for recording the progress of actions subsequent to any meeting. HAZOP-PC can also generate various types of report.

Using some of the features of HAZOP-PC it has been possible to make the modular HAZOP method fairly user friendly. In particular HAZOP-PC can be used to filter the output of the preHAZOPed modules in various ways so that only particular sets of causes and consequences are generated. This has advantages when it comes to matching propagated effects with vulnerabilities in order to try to identify links between initial causes and terminal consequences. Other advantages are the availability of extensive areas of help in HAZOP-PC and the ability to generate reports easily.

HAZOP-PC has been used to store the preHAZOPed module results. The preHAZOPed results are intended to combine the detail of a checklist for each module with the interface information using the standard HAZOP guide words. The checklist approach enables past experience and expert knowledge to be included. This means that less experienced engineers can perform competent hazard identification.

HAZOP-PC has a large number of columns that can be used for recording HAZOP information. For preHAZOPed results the following columns are used.

Guide word
Parameter
Deviation
Cause
Cause category
Consequence
Consequence category
Safeguards
Safeguards category
Recommendations

These HAZOP-PC columns are used in the following manner.

The guide word column is used for the guide words, as in conventional HAZOP, no, more, less, reverse, other than, etc.

The parameter column is used in the same way as it would be for conventional HAZOP, for the parameters, flow, pressure, temperature, composition, etc.

The deviation column is derived by developing the guide word with the parameter, again as in conventional HAZOP.

The causes column is used in a different way to normal and contains two types of information which have particular meaning in modular HAZOP. Firstly there are the initial causes. These are in lower case letters and represent possible faults that may occur within the module. Secondly there are vulnerabilities. These are in capital letters and represent deviations which have some effect on the module.

The next column is the cause category column. This column is important as it is used as a basis for filtering the HAZOP-PC output to facilitate the modular HAZOP procedure. The two categories are IC and VUL. IC represents types of cause which are initial causes and VUL represents types of causes which are vulnerabilities.

The consequences column contains three types of consequences. Firstly there are the terminal consequences. Again these are in lower case letters and represent consequences that manifest themselves within the module. Then there are local and remote propagated effects. These are in capital letters and represent deviations, which are transferred beyond the module boundary.

The consequence category column is used in a similar way to the cause category column. The categories are TC, LPE and RPE. These represent terminal consequence, local propagated effect and remote propagated effect types of consequences.

The safeguards column is intended to give some idea of possible safeguards, which may already exist, or which maybe required either to protect against the consequences or to remove a particular cause.

The safeguards category column is intended to show whether the safeguard reduces the likelihood of a particular cause or whether it reduces the severity of a consequence.

Finally the recommendations column details design and operating procedure considerations which should be taken into account in order to reduce hazards and operability problems.

Using HAZOP-PC it is possible to generate from the preHAZOPed results a sub-set of these results which is made up of only those types of causes which are initial causes. The remaining sub-set of the preHAZOPed results contains only those types of causes that are vulnerabilities. It is then necessary to match propagated effects and vulnerabilities to determine if fault paths exist.

The practical use of HAZOP-PC to carry out the modular HAZOP procedure is discussed more in the following chapter.

6.4 Applications of Modular HAZOP Procedure

A procedure has been developed for identifying hazards in process plant using results of hazard studies carried out on the modules that make up the plant. These preHAZOPed results can be developed from results for generic modules, modified from existing specific modules or existing module results can be reused. Which of these is used may depend on the situation in which modular HAZOP is being applied. Four anticipated applications for modular HAZOP, which illustrate how the different developments of preHAZOPed modules are used, are:

1. Application of existing preHAZOPed module results to new plants.
2. Replacement of one module with a different module in an existing plant.
3. Modification of a module within the context of an existing plant.
4. Addition of a module to an existing plant.

For example a plant may contain a number of similar heat exchangers HX101-HX106. PreHAZOPed results will be similar for each of these heat exchangers and can be developed from the master heat exchanger preHAZOPed results document. When preHAZOPed results have been developed for all modules that make up the plant, the modular HAZOP procedure will then be applied. This will take in to account the different surroundings of each of the modules. If a new plant is developed with similar heat exchangers then the preHAZOPed results can be reused. On the other hand if one of the heat exchangers is to be replaced, say with HX201, then preHAZOPed results for this module can be compared with the original preHAZOPed results. The full modular HAZOP procedure can then be applied to the differences found between the two sets of preHAZOPed results. Similarly, if a plant is modified by the addition of a new module, the modular HAZOP procedure can be used to determine the possible effects of the new module on the rest of the plant. Finally, if a module is modified, the existing preHAZOPed results can be modified and the modular HAZOP procedure applied to the differences again.

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7 Case study

7.1 Introduction

This chapter illustrates how the modular HAZOP procedure is used to carry out hazard identification for chemical process plant.

7.2 Procedure

For this exercise, the preHAZOPed results were generated by myself, with some input from more experienced personnel at ICI Technology and Loughborough University, using PrimaTech's HAZOP-PC v3.02.

PrimaTech's HAZOP-PC v3.02 is essentially a prompting and recording tool for conventional HAZOP study meetings. However, it is particularly useful in this application because it is possible, when generating reports, to use user defined filters. In particular, it is possible to categorise causes and consequences and then generate a report filtered on these categories. In generating preHAZOPed results, the causes were categorised as either "VUL", for vulnerabilities, or "IC", for initial causes. Consequences were categorised as either "EE" for end effects, "DPE" for directly propagated effects, or "IPE" for indirectly propagated effects. Each of these categories corresponds to the previously defined cause-consequence associations. For efficiently carrying out modular HAZOP, two reports were generated to make up the preHAZOPed results for a sub-module. The first report, the initial causes report, was filtered on "IC" and the second, the vulnerabilities report, on "VUL". The reports generated comprise all the columns associated with conventional HAZOP study meetings with the addition of the cause and consequence category columns so that the type of cause-consequence association could be easily ascertained. Table 7.1 illustrates a typical initial causes report, the filtering have been carried out to include only those sections of the report where a cause having a cause categorised as "IC" exists. The vulnerabilities report has the remaining sections of the preHAZOPed results where a cause having a cause categorised as "VUL" exists, see table 7.2.

Cooling Water top up - single supply, single pump and float valve.					
DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS
1. No Flow	1.1. Inline filter blocked. Float valve fails shut. Pump failure.	IC	1.1.1. Level in cold well cannot be maintained. Cooling water supply may be restricted.	EE	
2. More Flow	2.1. Float valve fails open.	IC	2.1.1. Cold well overflows. Contamination due to dosing chemicals.	EE	2.1.1.1. Suitable overflow to drain.
2. Lower Temperature	2.1. Low ambient temperature leads to freezing, particularly as there may be no flow for long periods of time.	IC	2.1.1. Prolonged cold weather may reduce availability of cooling water.		

Table 7.1 - Example of initial causes filtered results.

Cooling water top up - single supply, single pump and float valve.						
DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	RECOMMENDATIONS
1. No Flow	1.2. NO FLOW FROM UPSTREAM SUPPLY	VUL	1.2.1. Level in cold well cannot be maintained. Cooling water supply may be restricted.	EE		1.2.1.1. If the supply is unreliable consider the need for a backup supply. See appropriate node.

Table 7.2 - Example of vulnerability filtered results.

To make the modular HAZOP procedure as easy as possible, all sub-module vulnerabilities are included in the vulnerabilities report against their corresponding deviation. For example, a sub-module's vulnerability to low pressure will be included in the causes column of the preHAZOPed results alongside the deviation less pressure, even though it may have a low flow related consequence. Such a cause-consequence relationship might, in a conventional HAZOP study meeting, be identified under the deviation less flow. This is part of the redundancy associated with conventional HAZOP guide words which is not needed with modular HAZOP. Instead, in order to achieve an efficient and effective alternative, less flexibility in the procedure is required.

To generate the completed modular HAZOP report, it is necessary to find and detail all the possible initial cause to end effect paths in the plant. This is done by finding where propagated effects in one sub-module have corresponding vulnerabilities in another sub-module, and replacing the propagated effect by the consequences associated with the vulnerability. In this way, the steps in the paths between initial causes and end effects, where they exist, are eliminated until the report consists substantially only of initial causes and end effect pairs.

To this end, it is first necessary to collate all the preHAZOPed results relating to the plant being examined based on the modules and sub-modules identified. The above procedure can then be carried out relatively simply by going through the initial causes report and for each propagated effect, recognised by either "DPE" or "IPE" in the consequences category column, determining whether a corresponding vulnerability exists in the appropriate sub-module, by referring to the vulnerabilities report of the preHAZOPed results of that sub-module, and replacing the propagated effect by all the consequences associated with the vulnerability, including any propagated effects. When including indirectly propagated effects it will be useful to add a label specifying which sub-module they were originally associated with. This will help in identifying the appropriate sub-module to refer to when determining whether or not there is a corresponding vulnerability.

The easiest way of achieving this is to edit the initial causes report using a word processor, the HAZOP-PC generated reports having been suitably converted.

Any propagated effects which do not have a corresponding vulnerability can be deleted, except for propagated effects which have effects beyond the boundaries of the plant being scrutinised. These should be left in the final report until their effects can be determined either by conventional HAZOP, by linking up with a modular HAZOP report for a different plant, or by some other means.

Similarly, vulnerabilities which exist at the plant boundaries should be transferred into the final modular HAZOP report so that effects on the plant from causes originating beyond the plant boundary can be determined.

Such vulnerabilities and effects should be highlighted for future action.

Once the modular HAZOP report has been reduced to initial cause-end effect pairs, it is necessary to review the report to remove any of these pairs that are irrelevant to the plant being studied. This procedure can be aided by incorporating into the preHAZOPed results appropriate remarks. For example, certain end effects may be applicable only if a flammable material is being used. This fact can be included in a remarks column and the modular HAZOP report can be reviewed on the basis of the comments in this column.

The preHAZOPed results may also be provided with a list of safeguards that can be used to warn of impending problems or mitigate consequences. These may be used in one of two ways. Either preexisting plant safeguards only may be left in this column in which case once the modular HAZOP report is analysed the efficacy or otherwise of these preexisting measures can be determined, or all the safeguard may be included in the final modular HAZOP report in which case the need or otherwise of the specified safeguards can be determined when the modular HAZOP report is analysed.

7.3 Results

For the purpose of this exercise a simple plant was devised on a modular basis using modules and sub-modules from the module library.

The plant is a waste acid treatment plant. Waste acid from the waste acid storage tank is reacted with alkali supplied via a pipeline in a reactor provided with a cooling recycle arrangement. The neutralised product of this reaction is stored before being transferred to tankers for disposal. A cooling water system is provided to provide coolant for the reactor recycle.

This is an imaginary plant and was used as an example as part of a presentation and workshop that I gave to ICI personnel. The modules that make up the plant are considered to be relatively common modules with a large degree of similarity and it is for this reason that I put these modules together to form the plant. Furthermore, during the development of preHAZOPed results, I had concentrated on developing such common modules and there was therefore little further work required in developing these modules for the presentation. These common modules are ones that offer the greatest potential time savings as the preHAZOPed results can be frequently reused.

Figure 7.1 illustrates the plant configuration.

Tables 7.3 to 7.6 give the modules and sub-modules chosen to represent the plant.

The results of the modular HAZOP procedure are given in table 7.7.

Module Name: Waste acid storage				
Module Type: Atmospheric liquid storage tank				
Generic Sub-modules required	**Specific sub-modules selected**		**Connectivity**	
(Refer to module library)	**Name**	**Node no.**	**Module**	**sub-module**
Storage tank inlet	Storage tank inlet w/o control valve	11		
Storage tank outlet	Storage tank outlet, parallel pump w/o control valve	4	Neutralisation reactor	Reactor feed
Storage tank vessel	Storage tank vessel	5	-	-
Storage tank vent system	Storage tank vent to atmosphere	2	-	-
Storage tank overflow	Storage tank overflow to seal pot	3	-	-

Table 7.3 - Sub-modules for waste acid storage module.

Module Name: Neutralisation reactor				
Module Type: Exothermic liquid phase reactor				
Generic Sub-modules required	**Specific sub-modules selected**		**Connectivity**	
(Refer to module library)	**Name**	**Node no.**	**Module**	**sub-module**
Reactor feed (1)	Reactor feed with flow control	1	Waste acid storage	Storage tank outlet
Reactor feed (2)	Reactor feed with concentration control	12		
Reactor outlet	Reactor liquid outlet with level control	11	Treated waste storage tank	Storage tank inlet
Reactor vent system	Reactor vent to atmosphere	14	-	-
Reactor cooling system	Reactor cooling via recycle	6		
	Cooling stream in		Cooling water supply	CWS Main
	Cooling stream out		Cooling water supply	CWS Return

Table 7.4 Sub-modules for neutralisation reactor module.

Module Name: Treated waste storage				
Module Type: Atmospheric liquid storage tank				
Generic Sub-modules required	**Specific sub-modules**		**Connectivity**	
(Refer to module library)	**Name**	**Node no.**	**Module**	**sub-module**
Storage tank inlet	Storage tank inlet w/o control valve	11	Neutralisation reactor	Reactor outlet
Storage tank outlet	Storage tank outlet, parallel pump w/o control valve	4	Treated waste disposal	Tanker loading
Storage tank vessel	Storage tank vessel	5	-	-
Storage tank vent system	Storage tank vent to atmosphere	2	-	-
Storage tank overflow	Storage tank overflow to seal pot	3	-	-

Table 7.5 - Sub-modules for treated waste storage module.

Module Name: Cooling water supply				
Module Type: Cooling water system				
Generic Sub-modules required	**Specific sub-modules selected**		**Connectivity**	
(Refer to module library)	**Name**	**Node no.**	**Module**	**sub-module**
Cooling water top up	Water top up from reservoir	1	-	-
Cooling water return	Cooling water return	2	Neutralisation reactor	Cooling stream out
Cooling water main	Cooling water main with multiple pumps	5	Neutralisation reactor	Cooling stream in
Dosing	Dosing	4, 6 & 11	-	-
Purge	Purge	9		

Table 7.6 - Sub-modules for cooling water supply module.

Figure 7.1 – Modular HAZOP example - waste acid plant configuration.

Waste Acid Neutralisation Plant				
Node: 1Cooling Water top up - single supply, single pump and float valve.				
Parameter: Flow				
Intention:				
DEVIATION	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATIONS**
No Flow	Inline filter blocked. Float valve fails shut. Pump failure.	Level in cold well cannot be maintained. Cooling water supply may be restricted.		
	NO FLOW FROM UPSTREAM SUPPLY	Level in cold well cannot be maintained. Cooling water supply may be restricted.		If the supply is unreliable consider the need for a backup supply. See appropriate node.
More Flow	Float valve fails open.	Cold well overflows. Contamination of environment by dosing chemicals.	Suitable overflow to drain.	
Node: 1Cooling Water top up - single supply, single pump and float valve.				
Parameter: Temperature				
Intention:				
Lower Temperature	Low ambient temperature leads to freezing, particularly as there may be no flow for long periods of time.	Prolonged cold weather may reduce availability of cooling water.		
Node: 2Cooling water return to tower.				
Parameter: Flow				
Intention: Maintain circulation of cooling water.				
Less Flow	Purge to drain valve left open or fails open.	Cooling water tower performance falls off. Cooling water supply may be restricted during periods of high demand.	Regualr inspection.	
Node: 3Cooling Water Dosing - Chromate Dosing Outlet. Feed controlled by automatic dosing control.				
Parameter: Flow				
Intention:				
Node: 4Cooling water supply main - 2 or more pumps.				
Parameter: Flow				
Intention:				
Less Flow	Pump failure.	Reaction in reactor does not proced as required. Poor conversion side reactions, etc.	Appropriate alarms on pumps.	Only likely to be a problem during periods of high demand.
			Low flow alarm on supply main.	

Table 7.7 Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
			High temperature alarm	
		Possible runaway reaction. Possible explosion	High temperature alarm.	
			Low flow alarm	
		Inadequate venting of storage tank. Vessel overpressure rupture.	Storage tank relief valve.	
		Static build up in storage tank.	Dip tubes for filling storage tank.	Flammable fluids only. If filling is not done via dip tubes check design assumptions.
Reverse Flow	Pump not running	Reverse flow through pump back into cooling water pond.	Separate non-return valves on all pump discharges.	
Node: 4Cooling water supply main - 2 or more pumps.				
Parameter: Maintenance				
Intention:				
Maintenance	High cooling water demand e.g. due to hot weather.	Unable to meet demand due to pump down for maintenance. Unable to carry out maintenance due to high cooling water demand.		Planned maintenance should be scheduled for periods of low cooling water demand.
Node: 5Cooling Water Purge to drain - manually adjusted.				
Parameter: Flow				
Intention:				
More Flow	Chemical concentration monitoring fails requiring purge valve to be opened more than necessary. Purge valve Inadvertantly left further open than required.	Wastage of cooling water and dosing chemicals.	Orifice plate to minimise maximum possible flow rate.	
Less Flow	Purge valve insufficiently open.	Increased scaling, general solids deposition, and fouling problems.		
Node: 6Cooling Water Acid dosing - automatically controlled.				
Parameter: Flow				
Intention:				
Less Flow	Automatic dosing control fails, delivering less acid than required.	pH should be maintained between pH7-8 to maintain non-scaling, non-corrosive conditions in the system.	Routine and regular testing.	

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
			Low level alarm.	
	Acid supply exhausted.			
More Flow	Automatic dosing control fails, delivering more acid than required.	pH should be maintained between pH7-8 to maintain non-scaling, non-corrosive conditions in the system.	Routine and regular testing.	
Node: 7 Waste acid Storage tank vent to atmosphere				
Parameter: Flow				
Intention:				
No/Less Flow	Vent line blocked or partially blocked	Tank overpressure rupture on filling.	Relief valve	Minimise opportunities for vent blockage
				Ensure flame arrestor is maintained correctly.
		Tank vacuum collapse on discharge	Vacuum relief valve.	Minimise opportunities for vent blockage.
				Ensure flame arrestor is maintained correctly
Node: 7Waste acid Storage tank vent to atmosphere				
Parameter: Temperature				
Intention: Maintain temperature tank				
Node: 7Waste acid Storage tank vent to atmosphere				
Parameter: Pressure				
Intention: Maintain atmospheric pressure in tank				
Node: 8Waste acid Storage tank overflow				
Parameter: Flow				
Intention: Allow tank to overflow safely				
No/Less Flow	Overflow blocked or partially blocked	No/partial tank overflow available. Possible tank rupture on overfilling	Level control	Ensure opportunities for overflow blocking are minimised.
			Level indicator	
			High level alarm	
Node: 8Waste acid Storage tank overflow				
Parameter: Temperature				
Intention:				
Node: 8Waste acid Storage tank overflow				
Parameter: Pressure				
Intention:				
Node: 9Waste Acid Storage tank outlet				
Parameter: Flow				

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
Intention: Allow continuous flow of material to process				
No Flow	Outlet line blocked between tank and pump. Pump fails.	No reaction in reactor.	Low flow alarm	
			Composition control	
	Flow control valve fails shut. Outlet line blocked downstream of pump.	No reaction in reactor.	Low flow alarm	
			Composition control	
		Full head pump pressure developed. High pressure rupture risk to outlet line. Pump overheats, seals damaged, possible leak.	Kick back line.	Consider designing equipment to withstand maximum pump delivery pressure.
			Low flow alarm.	
More Flow	Control valve fails open	Incomplete conversion of reactants.	Composition control	
	Spare pump running in error	Incomplete conversion of reactants.	Flow control.	Ensure operating and Maintenance instructions preclude running parallel pumps Incorrectly.
			Composition control.	
	Outlet line ruptured	Tank contents lost to environment	Emergency isolation valve	Ensure tank is adequately bunded.
				Locate isolation valve as near as possible to tank.
				Consider need for remote operation of Isolation valve.
	Pump seals fail.	Environmental contamination	Emergency isolation valve.	Use canned or seal-less pump if appropriate.
				Pump to be adequately bunded.
				Consider need for remote operation of Isolation valve.
Less Flow	Outlet line partially blocked. Pump running incorrectly.	Reaction in reactor does not proceed as required. Poor conversion rate.	Flow control	
			Low flow alarm	
			Composition control	
	Control valve fails insufficiently open.	Reaction in reactor does not proceed as required. Poor conversion rate.	Low flow alarm.	

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
			Composition control	
As Well As Flow	Contamination of tank contents	Unwanted reaction.		Consider testing tank contents on a routine basis.
Node: 9Waste Acid Storage tank outlet				
Parameter: Temperature				
Intention:				
Node: 9Waste Acid Storage tank outlet				
Parameter: Pressure				
Intention:				
Lower Pressure	Storage tank inlet line blocked. Level control valve fails shut	Low tank level leading to low pressure, low flow and poor conversion in reactor.	Low flow alarm	
			Low level alarm	
			Level indicator	
			Composition control	
Node: 10Waste Acid Storage tank feed inlet without control valve.				
Parameter: Flow				
Intention:				
No Flow	Feed line blocked.	Possible inability to continue process at normal production rates		
		Low tank level leading to outlet pump cavitation.	Low level alarm	
			Level indicator	
		NO FLOW AT UPSTREAM UNITS		
	NO FLOW FROM UPSTREAM UNIT	Possible inability to continue process at normal production rates.		
		Low tank level leading to outlet pump cavitation.	Low level alarm	
			Level indicator	
More Flow	HIGH FLOW FROM UPSTREAM UNIT	Inadequate venting. Vessel overpressure rupture.	Relief valve.	
		Static build up.	Dip tubes for filling.	Flammable fluids only. If filling is not done via dip tubes check design assumptions.

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
Less Flow	Feed line partially blocked.	LOW FLOW FROM UPSTREAM UNIT	Level indicator.	
As Well As Flow	WRONG MATERIAL AT SOURCE	Material incompatability		Ensure appropriate measures exist to check incoming material.
	CONTAMINATION OF MATERIAL AT SOURCE	Material incompatibility		
Reverse Flow	REVERSE FLOW AT SOURCE	Liquid siphoned out of tank.	Siphon break on dip tubes.	
			Non-return valve	
Node: 10Waste Acid Storage tank feed inlet without control valve.				
Parameter: Temperature				
Intention:				
Higher Temperature	HIGH TEMPERATURE FROM UPSTREAM UNIT	Rapid evaporation of tank contents.	Temperature indicator	For system with vent header system, can system cope with increase in venting due to hot weather acting on several tanks?
			High temperature alarm	
		Increased vapour concentration around tank, possibly rising to a hazardous level.	Temperature indicator.	Only a problem for tanks with open vent. Consider installing appropriate gas detection equipment if appropriate.
			High temperature alarm.	
Node: 10Waste Acid Storage tank feed inlet without control valve.				
Parameter: Pressure				
Intention:				
Higher Pressure	Feed line isolated.	Expansion of locked in fluid causes hydraulic overpressure rupture of line.	Hydraulic pressure relief	Ensure operating instructions preclude deliberate isolation of line without having first drained line.
				Ensure design minimises opportunites for isolation in error due to control valves failing etc.

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
	Manual valve on storage tank inlet closes quickly.	Liquid hammer.		Only a problem for long pipelines. Ensure closing time on control valves and manual valves is long enough to avoid liquid hammer.
	HIGH PRESSURE FROM SOURCE	Vessel overpressure rupture	Relief valve.	Ensure adequate venting.
			Pressure indicator.	
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)				
Parameter: Flow				
Intention:				
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)				
Parameter: Pressure				
Intention:				
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)				
Parameter: Composition				
Intention:				
Node: 12Neutralisation Reactor liquid feed with flow control				
Parameter: Flow				
Intention:				
No Flow	Feed line blocked. Control valve fails shut.	Reaction does not proceed as required. Poor conversion, side reactions etc.	Low flow alarm	
		Full head pump pressure developed in storage tank outlet pump. High pressure rupture risk to downstream equipment. Pump overheats, seals damaged, possible leak.	High pressure/low flow pump cut out switches.	Design equipment to withstand maximum pump delivery pressure.
			Kick back line	
			Integral pump high pressure relief valve	
			Pressure indicator	
			Low flow alarm	
More Flow	Control valve fails open	Incomplete conversion of reactants		

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
		Inadequate storage tank venting. Storage tank overpressure rupture.	Relief valve	
		Static build up in storage tank.	Use dip tubes for filling storage tank.	Flammable fluids only. If filling is done via dip tubes check design assumptions.
Less Flow	Control valve fails insufficiently open	Reaction does not proceed as required. Poor conversion, side reactions etc.	Low flow alarm	
Node: 12Neutralisation Reactor liquid feed with flow control				
Parameter: Temperature				
Intention:				
Node: 12Neutralisation Reactor liquid feed with flow control				
Parameter: Pressure				
Intention:				
Lower Pressure	Feed line leaking.	Reaction does not proceed as required. Poor conversion, side reactions etc.	Pressure control	
			FLow control	
		Environmental damage.		
Node: 12Neutralisation Reactor liquid feed with flow control				
Parameter: Composition				
Intention:				
As Well As Composition	CONTAMINATION FROM UPSTREAM UNITS	Reaction may not proceed as required.		
Node: 13Neutralisation Reactor liquid outlet with level control				
Parameter: Flow				
Intention:				
No Flow	Outlet line blocked. Pump failure. Level control valve fails shut.	Reactor overflows	Low flow alram	
			High level alarm	
		Low storage tank level leading to outlet pump cavitation.	Low flow alarm	
More Flow	Level control valve fails open.	Level lost in reactor. Possible overheating, poor conversion, side reactions, etc.		
		Inadequate venting of storage tank. Vessel overpressure rupture.	Storage tank relief valve.	

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
		Static build up in storage tank.	Dip tubes for filling storage tank.	Flammable fluids only. If filling is not done via dip tubes check design assumptions.
	Outlet line ruptured.	Reactor contents lost to environment.	Emergency isolation may be required.	
Less Flow	Level control fails to open control valve sufficiently.	Possible reactor overflow.	High level alarm	
			Low flow alarm	
Reverse Flow	Pump failure	Liquid siphoned out of storage tank.	Siphon break on dip tubes.	
			Non-return valve	
Node: 14Neutralisation Reactor liquid feed with concentration control				
Parameter: Flow				
Intention:				
No Flow	Feed line blocked. Control valve fails shut.	Reaction does not proceed as required. Poor conversion, side reactions etc.	Low flow alarm	
		NO FLOW FROM UPSTREAM UNITS		
	NO FLOW FROM UPSTREAM UNITS	Reaction does not proceed as required.	1.2.1.1. Low flow alarm	
More Flow	Control valve fails open	Incomplete conversion of reactants		
		Inadequate venting of storage tank. Vessel overpressure rupture.	Storage tank relief valve.	
		Static build up in storage tank.	Dip tubes for filling storage tank.	Flammable fluids only. If filling is not done via dip tubes check design assumptions.
		HIGH FLOW FROM UPSTREAM UNITS		
	HIGH FLOW FROM UPSTREAM UNITS	Incomplete conversion of reactants		
		Inadequate venting of storage tank. Vessel overpressure rupture.	Storage tank relief valve.	

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
		Static build up in storage tank.	Dip tubes for filling storage tank.	Flammable fluids only. If filling is not done via dip tubes check design assumptions.
Less Flow	Control valve fails insufficiently open	Reaction does not proceed as required. Poor conversion, side reactions etc.	Low flow alarm	
		LESS FLOW FROM UPSTREAM UNIT	Low flow alarm	
	LESS FLOW FROM UPSTREAM UNITS	Reaction does not proceed as required. Poor conversion, side reactions etc.	Low flow alarm	
Node: 14Neutralisation Reactor liquid feed with concentration control				
Parameter: Temperature				
Intention:				
Node: 14Neutralisation Reactor liquid feed with concentration control				
Parameter: Composition				
Intention:				
As Well As Composition	CONTAMINATION FROM UPSTREAM UNITS	Reaction may not proceed as required.		
Node: 15Neutralisation Reactor Cooling stream in with temperature control				
Parameter: Flow				
Intention:				
No/Less Flow	Control valve fails shut or fails to open sufficiently.	Runaway reaction. Possible explosion.	Low flow alarm High temperature alarm. High pressure alarm. Install relief valve	
		Catalyst destroyed.	Low flow alarm High temperature alarm. High pressure alarm.	If present.
		Reaction does not proceed As required. Poor conversion, side reactions, etc.	Low flow alarm High temperature alarm.	

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
			High pressure alarm.	
		Rapid evaporation of storage tank contents. Increased vapour concentration around storage tank, possibly rising to a hazardous level.	Low flow alarm	Only a problem for tanks with open vent. Consider installing appropriate detection equipment if appropriate.
			High temperature alarm.	
			High pressure alarm.	
More Flow	Control valve fails open	Reaction does not proceed as required. Poor conversion, side reactions, etc.		
		High cooling water demand.		Can cooling water system maintain adequate supply to remaining systems?
Node: 15Neutralisation Reactor Cooling stream in with temperature control				
Parameter: Temperature				
Intention:				
Node: 16Neutralisation Reactor Cooling stream out with temperature control				
Parameter: Flow				
Intention:				
No Flow	Recycle isolation valve closed in error.	Reaction temperature too high. Reaction does not proceed as required. Poor conversion, side reactions, etc. Catalyst destroyed	Low flow alarm	Check operating procedures.
			High temperature alarm	
		Possible explosion risk.	Relief valve.	
			Low flow alarm	
			High temperature alarm	
		Rapid evaporation of storage tank contents. Increased vapour concentration around storage tank, possibly rising to a hazardous level.	Low flow alarm	Only a problem for tanks with open vent. Consider installing appropriate detection equipment if appropriate.
			High temperature alarm	
Node: 17Neutralisation Reactor cooling via recycle				
Parameter: Flow				
Intention:				
No/Less Flow	Pump failure or poor pump performance.	Reactor begins to overheat. Reaction may begin to run away. Possible risk of explosion.		Some form of emergency cooling may be necessary to avoid explosion where that possibility exists.

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
As Well As Flow	Contamination of recycle stream by cooling water due to heat exchanger interface failure.	Reaction does not proceed as required. Poor conversion, side reactions, etc.		
Node: 18Treated Waste Storage tank vent to atmosphere				
Parameter: Flow				
Intention: Enable flow into or out of tank to maintain atmospheric pressure				
No/Less Flow	Vent line blocked or partially blocked	Tank overpressure rupture on filling	Relief valve	Minimise opportunities for vent blockage
				Ensure flame arrestor is maintained correctly.
		Tank vacuum collapse on discharge	Vacuum relief valve.	Minimise opportunities for vent blockage.
				Ensure flame arrestor is maintained correctly
Node: 18Treated Waste Storage tank vent to atmosphere				
Parameter: Temperature				
Intention: Maintain temperature tank				
Node: 18Treated Waste Storage tank vent to atmosphere				
Parameter: Pressure				
Intention: Maintain atmospheric pressure in tank				
Node: 19Treated Waste Storage tank feed inlet without control valve.				
Parameter: Flow				
Intention:				
No Flow	Feed line blocked.	Possible inability to continue process at normal production rates		
		Low tank level leading to outlet pump cavitation.	Low level alarm	
			Level indicator	
		Reactor overflows.		Provide suitable overflow arrangement.
Node: 19Treated Waste Storage tank feed inlet without control valve.				
Parameter: Temperature				
Intention:				
Node: 19Treated Waste Storage tank feed inlet without control valve.				
Parameter: Pressure				
Intention:				

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS
Higher Pressure	Feed line isolated.	Expansion of locked in fluid causes hydraulic overpressure rupture of line.	Hydraulic pressure relief	Ensure operating instructions preclude deliberate isolation of line without having first drained line.
				Ensure design minimises opportunites for isolation in error due to control valves failing etc.
	Manual valve on storage tank inlet closes quickly.	Liquid hammer		Only a problem for long pipelines. Ensure closing time on control valves and manual valves are long enough to avoid liquid hammer.
Node: 20Treated Waste Storage tank overflow				
Parameter: Flow				
Intention: Allow tank to overflow safely				
No/Less Flow	Overflow blocked or partially blocked	No/partial tank overflow available. Possible tank rupture on overfilling	Level control	Ensure opportunities for overflow blocking are minimised.
			Level indicator	
			High level alarm	
Node: 20Treated Waste Storage tank overflow				
Parameter: Temperature				
Intention:				
Node: 20Treated Waste Storage tank overflow				
Parameter: Pressure				
Intention:				

Table 7.7 (cont.) Waste acid treatment plant modular HAZOP results.

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8 Conclusions

This chapter provides some conclusions relating to the work described in this thesis and in particular the modular HAZOP procedure. The final part of this chapter looks at how this work may be taken forward in the future.

8.1 Contributions

In looking at how to improve hazard identification of chemical plant through the HAZOP procedure, three possible areas for improvement were identified. Firstly possible improvements to the conventional procedure were reviewed. Secondly, the role of automated HAZOP was discussed and finally a new, modular HAZOP procedure was put forward.

It is fairly clear that minor modifications to the conventional HAZOP procedure will have only a marginal impact on the overall time taken to complete the hazard identification of chemical plant. However, there may be useful lessons which should be borne in mind, particularly by inexperienced HAZOP teams. There being no substantial time gains foreseen by improving HAZOP in this way, this thesis has been restricted largely to reviewing the literature relating to such improvements.

As discussed earlier in the thesis, automated HAZOP is an area that has attracted much research effort. It offers potentially the greatest timesaving but a large amount of further work is necessary before automated hazard identification of a chemical plant produces complete and reliable results. Because of the large amount of work being done by other people in this field, this thesis has been restricted to reviewing the state of the art.

The development of a modular HAZOP procedure has formed the major part of this thesis. In developing this procedure a number of important principles have been identified. Firstly, the level of decomposition required, and in particular the use of interchangeable sub-modules, provides for a procedure which is adaptable to different plant configurations but can also be quickly and easily applied. This is particularly important for a procedure which, as developed, is carried out manually by only one or two people. This contrasts starkly with the level of decomposition used in automated HAZOP, which requires that each pump, valve, etc. be modelled. In particular it allows for known problems with combinations of equipment to be represented. As such, it is possible to include much more expert knowledge in a sub-module than in a collection of more detailed models making up that sub-module. Secondly, the fact that the majority of cause-consequence scenarios exist in adjacent modules, and the categorisation of locally and remotely propagated effects, reduces the complexity of the procedure. It enables the simpler fault paths, which make up most of the cause-consequence scenarios, to be identified quickly, leaving a much reduced number of fault paths which require a more thorough analysis. Finally, I think the usefulness of the categories and a filtering tool, such as that provided by HAZOP-PC, in simplifying the application of the procedure should not be underestimated.

I believe that the modular HAZOP procedure detailed in this thesis can be used to provide quick hazard identification of chemical plant. Its application may be limited to plant that have a large number of fairly standard items, but in such cases it can provide a significant improvement in the time taken for hazard identification. The size and structure of the models, and in particular the preHAZOPed results, allows a large amount of information, and in particular expert knowledge regarding known hazard and operability problems, to be represented, whilst retaining the flexibility that enables their use on a wide variety of chemical plant.

8.2 Limitations

The main limitation surrounding this work at present is the lack of a substantial library of sub-modules and corresponding preHAZOPed results.

It should also be noted that the current preHAZOPed results should be treated as examples only. They are by no means complete, and a fair amount of technical expert input is required to develop them and bring them to an acceptable and industrially applicable standard.

As identified above, the modular HAZOP procedure is not going to be universally applicable. For certain plant, particularly where they are new, complex or otherwise unique, the required preHAZOPed results may not exist and it may not be worth compiling them. In such cases, the conventional HAZOP procedure provides the best route for hazard identification.

It should also be noted that the procedure described for modular HAZOP is applicable only to continuous process plant.

8.3 Further Work

One of the main problems to be overcome in modular HAZOP is how to use the results. In particular, how to make sure that consideration is given to whether or not sufficient protection exists to prevent or reduce the effects of a possible hazard.

In terms of reducing the amount of time taken to carry out hazard studies it would seem best to use the results as follows. The preHAZOPed results will contain all protections necessary for safe operation of the module when considered in isolation. No further consideration will need to be given to the need for additional protections due to hazards arising entirely within the module. For faults that have been propagated to find distant consequences then consideration will have to be given to determine whether the existing protections are adequate or not. The main drawback with this approach is that modules may contain protective systems that are not actually required and the capital and operating costs of the module will be higher than necessary. However, it may be possible to reduce the number of protections necessary through reference to remarks in the preHAZOPed results. For example, a stock tank containing a non-flammable non-toxic substance may not require a high level alarm and the possibility for this alarm to be omitted will be included in the preHAZOPed results (table 8.1).

Deviation	Cause	Consequence	Safeguards	Recommendations	Remarks
High level	Level control fails	Tank contents lost to environment	Overflow High level alarm Level indicator	Overflow to be below tank roof Tank to be adequately bunded	High level alarm may not be required for non-flammable, non-toxic liquids.

Table 8.1 - Part of preHAZOPed results for storage tank showing how remarks column can be used.

The alternative approach is to make it a requirement that all the results should be checked to ensure that safeguards and protections are adequate and not excessive. However this will dramatically increase the time taken to carry out modular HAZOP and there will no significant time benefit over conventional HAZOP. The advantage with this approach is that the preHAZOPed results do not need to be as detailed as for the first method given that there is scope for whoever is checking the results to add safeguards as necessary.

It may of course be possible to combine the two above approaches. The former approach could be used for modules that occur commonly and for which we can draw up the detailed preHAZOPed results required. The latter approach can be used for modules which do not yet have detailed preHAZOPed results though it is still necessary that all vulnerabilities and propagated effects are included. Detailed results can be drawn up for modules during a conventional HAZOP study of the module and these can subsequently be used (modified slightly if needed) whenever similar modules are considered in the future.

As identified above, the procedure is currently applicable only to continuous process plant. In order to be able to be used for batch plant, appropriate terms would have to be defined to describe the effects transmitted between modules, so that correct matching across module boundaries could be carried out and fault paths developed. It would probably also be necessary to have modules, or possibly sub-modules, connected in time as well as space, i.e. each different operation carried out in a particular item of equipment would require a different set of preHAZOPed results, and the effect of following one operation by another in the same item of equipment need to be considered. This is also likely to require, as its basis, a more systematic approach to HAZOP of batch process plants than that originally specified. Work on developing such an approach has only recently begun (Mushtaq and Chung, 2000).

It is not clear how applicable the modular HAZOP procedure is to other similar continuous process industries, for example food processing. In fact the modular HAZOP procedure may be more applicable to such industries where a modular approach to design is already taken. The identification of particular industries, chemical, chemical related and other, where the modular HAZOP procedure could be more easily and productively applied could form the basis of useful investigations.

8.4 Implementing Modular HAZOP in an Industrial Environment

A further problem to be overcome is the transfer of the modular HAZOP procedure to a real environment. Following the initial development of the HAZOP procedure and its acceptance as the standard technique for hazard identification, changes have been adopted gradually and slowly, mainly as individual hazard study leaders applied new techniques they regarded or found to be improvements over the old techniques. The modular HAZOP procedure is however more of a fundamental change and its acceptance will require the support of senior SHE personnel. This of course requires that the modular HAZOP procedure gives results at least as good as can be expected from conventional HAZOP. It will also be necessary to show a significant time saving over conventional HAZOP. One possibility is that modular HAZOP will be used by an individual prior to a formal HAZOP meeting. It will be used to develop questions and possible solutions for problems that will later be identified in the HAZOP meeting.

Further examples will need to be tested before the completeness and ease of application of modular HAZOP are fully known. In particular this requires the further development of modules. Examples of modules that would be particularly useful are sought. Furthermore, as I identified at the start, modular HAZOP will become more effective and attractive as the design procedure becomes more modular in nature.

8.5 Automated modular HAZOP

Because of the simplicity and methodical nature of the modular HAZOP procedure, it should be possible to automate it. This would provide another route to automating the HAZOP procedure. The level of decomposition chosen for modular HAZOP is considered to be much more useful for representing expert knowledge relating to hazards in chemical plant, and this route may therefore have advantages over the automated HAZOP routes currently being investigated.

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9 References

Andow, P. K., Lees, F. P. & Murphy, C. P.; "THE PROPAGATION OF FAULTS IN PROCESS PLANTS: A STATE OF THE ART REVIEW". IChemE Symposium Series No. 58, 1980; pp. 225-243.

Austin, D. G. & Jeffreys, G. V.; "The Manufacture of Methyl Ethyl Ketone from 2-Butanol." IChemE, London, 1979; Chapter 12.

Black, J. M. & Ponton, J. W.; "A Hierarchical Method for Line-by-Line Hazard and Operability Studies." Interactions Between Process Design and Process Control, 1993; Chapter 32, pp. 227-233.

Butler, P.; "Motivating people is the key to safety on process plant sites." Process Engineering, August 1973; p. 79.

Catino, C. A., Grantham, S. D. and Ungar L. H.; "Automatic Generation of Qualitative Models of Chemical Process Units." Computers and Chemical Engineering, Vol. 15, No 8, 1991; pp 583-599.

Chemical Industries Association Ltd.; "A Guide to Hazard and Operability Studies". Chemical Industry Safety and Health Council of the Chemical Industries Association, 1977.

Chung, P. W. H. " Qualitative Analysis of Process Plant Behaviour." Proceedings of 6th International Conference on Industrial and Engineering Applications of Artificial Intelligence, Gordon and Breach Science Publishers, 1993; pp. 277-283.

Coad, P. & Yourdon, E. "Object-oriented Analysis." 2nd edition; Prentice Hall, 1991.

Crawley, F. K.; "Do hazard and operability studies have their limitations?" IChemE Loss Prevention Bulletin, Issue 121, February 1995; pp. 3-5.

Douglas, J. M.; "Conceptual Design of Chemical Processes." McGraw-Hill, 1988.

Dowell, III, A. M.; "Managing the PHA Team." Process Safety Progress, Vol. 13, No. 1, January 1994; pp. 30-34.

Duxbury, H. A. & Turney, R. D.; "TECHNIQUES FOR THE ANALYSIS AND ASSESSMENT OF HAZARDS IN THE PROCESS INDUSTRIES." Paper presented to the New Mexico Technology Research Centre for Energetic Materials Open Seminar on Safety and Hazards Evaluation, 11 April 1989.

Eggert, G. IChemE Safety and Loss Prevention Subject Group HAZOP Workshop. Alderley Edge, 15 September 1985.

Elliot, D. M. & Owen, J. M.; "Critical Examination in Process Design." The Chemical Engineer, 223, 1968; pp. CE377

Freeman, R. A., Lee, R. & McNamara, T. P.; "Plan HAZOP Studies with an Expert System." Chemical Engineering Progress, August 1992; pp. 28-32.

Gibson, S. B.; "WE FIXED THE FLOWSHEET SAFELY." Process Engineering, June 1976; pp. 119- 120.

Gillet, J. E.; "Hazard study management in the pharmaceutical industry." IChemE Loss Prevention Bulletin, Issue 125, October 1995; pp. 17-25.

Goyal, K. R.; "PRACTICAL EXAMPLES OF SAFETY RISK ASSESSMENT IN BAPCO." Loss Prevention Bulletin, 112, 1994; pp. 7-14.

Hunt, A.; "Rules for Modelling In Computer Aided Fault Tree Synthesis." PhD Thesis, Department of Chemical Engineering, Loughborough University of Technology, 1992.

Hunt, A., Kelly, B. E., Mullhi, J. S., Lees, F. P. & Rushton, A. G.; "The propagation of faults in process plants: 6, Overview of, and modelling for, fault tree synthesis." Reliability Engineering and System Safety, 39, 1993; pp. 173-194.

Imperial Chemical Industries Ltd.; "Safety, Health and Environment (SHE) Guide 13." 1993.

Iri, M., Aoki, K., O'Shima, E. & Matsuyama, H.; "An Algorithm for Diagnosis of System Failures in the Chemical Process." Computers in Chemical Engineering, Vol 3, 1979; pp. 489-493.

Jefferson, M., Illidge, J. T. & Rushton, A. G.; "Activities and time usage in Hazard and Operability Studies." IChemE Research Event, Edinburgh, January 1995 (a).

Jefferson, M., Chung, P. W. H. & Rushton, A. G.; "Automated Hazard Idetification by Emulation of Hazard and Operability Studies." 8th International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems, Melbourne, Australia, July 1995 (b); pp. 765-770.

Jones, D. W.; "Lessons from HAZOP experiences." Hydrocarbon Processing, April 1992.

Kelly, B. E. & Lees, F. P. "The Propagation of Faults in Process Plant, 1, Modelling of Fault Propagation." Reliability Engineering, 16, 1986 (a); p. 1.

Kelly, B. E. & Lees, F. P. "The Propagation of Faults in Process Plant, 2, Fault Tree Synthesis." Reliability Engineering, 16, 1986 (b); p. 39.

Kelly, B. E. & Lees, F. P. "The Propagation of Faults in Process Plant, 3, An interactive, computer-based facility." Reliability Engineering, 16, 1986 (c); p. 63.

Kelly, B. E. & Lees, F. P. "The Propagation of Faults in Process Plant, 4, Fault Tree Synthesis of a Pump Changeover System" Reliability Engineering, 16, 1986 (d); p. 87.

Kelly, W. J.; "Oversights and mythology in a HAZOP program." Hydrocarbon Processing, October 1991.

Kletz, T. A.; "Eliminating Potential Process Hazards." Chemical Engineering, April 1, 1985; pp. 48-68.

Kletz, T. A.; "HAZOP and HAZAN." 3rd Edition, Hemisphere, 1992.

Kletz, T. A.; "Some thoughts on Frank Crawley's article." IChemE Loss Prevention Bulletin, Issue 121, February 1995; p. 5.

Knowlton, R. E.; "A Manual of Hazard and Operability Studies." Chemetics International, 1992.

Lapp, S. A. & Powers, G. J.; IEEE Trans on Reliability, R-26, April 1977; pp 2-11.

Larkin, F. D., Rushton, A. G., Chung, P. W. H., Lees, F. P., McCoy, S. A. & Wakeman S. J.; "Computer-aided Hazard Identification: Methodology and System Architecture." IChemE Symposium SeriesNo. 141, Hazards XIII Process Safety – The Future, 1997; pp. 337-348.

Lawley, H. G. "Operability Studies And Hazard Analysis." Eighth Symposium on Loss Prevention in the Process Industries, Philadelphia, November 1973; Loss Prevention vol. 8, pp. 105-116. [Also available in: Chemical Engineering Progress, Vol. 70, No. 4, April 1974; pp. 45-56.]

Lawley, H. G.; "Size Up Plant Hazards This Way." Hydrocarbon Processing, Volume 55, No. 4, April 1976; pp. 247-258.

Lees, F. P.; "Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control. Volumes 1 to 3." Second edition, Butterworths, Oxford, 1996.

Lees, F. P. & Kelly, B. E.; " The Propagation of Faults in Process Plants." Reliability Engineering, Vol. 16, 1, 1986.

Lihou, D.; "Operability studies for busy people." The Chemical Engineer, May 1986; pp. 52,53.

Lowe, D. R. T. & Solomon, C. H.; "Hazard Identification Procedures." 4th International Symposium On Loss Prevention And Safety Promotion In The Process Industries, Vol. 1, 80, pp. 246-282, 1983.

MacCallum, K. J.; "Understanding Relationships in Marine Systems Design." Proceedings of First International Marine Systems Design Conference, London, 1981; pp 1-9.

McCluer, R. E. and Whittle, D. K.; "Lessons learned from HAZOP reviews of FCCUs." Hydrocarbon Processing, August 1992; pp. 140-C-140-L.

McCoy, S. A., Wakeman, S. J., Larkin, F. D., Jefferson, M., Chung, P. W. H., Rushton, A. G., Lees, F. P. & Heino, P. M.; "HAZID, A Computer Aid for Hazard Identification." Trans IChemE, Vol. 77, Part B, 1999; pp. 317-327.

Martin-Solis, G., Andow, P. K. & Lees, F. P.; "An Approach to Fault Tree Synthesis for Process Plants." Proceedings 2nd International Symposium on Loss Prevention and Safety Promotion in the Process Industries, Heidelberg, 1977; p. 367.

Martin-Solis, G., Andow, P. K. & Lees, F. P.; "Fault Tree Synthesis for Real-Time and Design Applications." Trans IChemE, Vol. 60, 1980; pp. 14-20.

Mushtaq, F. & Chung, P. W. H.; "A Systematic HAZOP Procedure for Batch Processes, And Its Application to Pipeless Plants." Journal of Loss Prevention in the Process Industries, 13, 2000; pp. 41-48.

OSHA; "Process Safety Management of Highly Hazardous Chemicals, Explosives and Blasting Agents; Final Rule." Department of Labour, Occupational Safety and Health Administration, Federal Register, 1992; pp. 6356-6417.

Oyeleye, O. O. & Kramer M. A.; "Qualitative Simulation of Chemical Process Systems: Steady-State Analysis." AIChE Journal, Vol. 34, no. 9, 1988; pp.1441-1454.

Oyeleye, O. O. & Kramer M. A.; "Guidelines for Developing Signed Directed Graph Models." MIT, Laboratory for Intelligent Systems in Process Engineering Report 90-069, 1989.

Ozog, H.; "Hazard Identification, Analysis and Control." Chemical Engineering, 92, 1985; pp. 161-170.

Parmar, J. C. "A Method of Computer-Aided Hazard Identification In Chemical Process Plant." PhD Thesis, Loughborough University, 1987.

Parmar, J. C. & Lees, F. P.; "The Propagation of Faults in Process Plants: Hazard Identification." Reliability Engineering, 17, 1987(a); pp. 277-302.

Parmar, J. C. & Lees, F. P.; "The Propagation of Faults in Process Plants: Hazard Identification for a Water Separator System." Reliability Engineering, 17, 1987(a); pp. 303-307.

PrimaTech Inc.; "HAZOP-PC. Version 3.00." 1994.

Pully, A. S.; "Utilization and Results of Hazard and Operability Studies in a Petroleum Refinery." Process Safety Progress, Vol. 12, No. 2, April 1993; pp. 106-

110.

Roach, J. R. & Lees, F. P.; "Some Features of and Activities in Hazard and Operability (HAZOP) Studies." The Chemical Engineer, October 1981; pp. 456-462.

Rushford, R.; "Hazard and Operability Studies in the Chemical Industries." Transactions of the North East Coast Institution of Engineers and Shipbuilders, Vol. 93, no. 5, 1977; pp. 117-124.

Rushton, A. G., Gowers, R. E., Edmondson, J. N. & Al-Hassan, T.; "HAZARD AND OPERABILITY STUDY OF OFFSHORE INSTALLATIONS - A SURVEY OF VARIATIONS IN PRACTICE." Hazards XII European Advances in Process Safety, IChemE, Rugby, 1994; pp. 341-350.

Sankaran, N.; "Management of Change - The Systematic Use of Hazard Evaluation Procedures and Audits." Process Safety Progress, Vol. 12, no. 3, July 1993; pp. 181-192.

Shafaghi, A., Andow, P. K. & Lees, F. P. "Fault Tree Synthesis Based on Control Loop Structure." Chemical Engineering Research and Design, Vol. 62, 1984; pp. 101-110.

Sigma-Lambda Software (Ility Engineering); "HAZOPlus." 1995.

Smith, C., Inder, R. & Chung, P. W. H. "Knowledge Acquisition and Representation for Product Configuration: Charting a Way Through a Company's Information Jungle." Proceedings of the First International Conference on Industrial & Engineering Applications of Artificial Intelligence & Expert Systems, ACM Press, 1988; pp. 805-811.

Sweeney, J. C.; "ARCO Chemical's HAZOP Experience." Process Safety Progress, Vol. 12, No. 2, April 1993; pp. 83-91.

Toola, A.; "Plant level safety analysis." Journal of Loss Prevention in the Process Industries, Vol. 5, No. 2, 1992; pp. 119-124.

Venkatsubramanian, V. & Vaidyanathan, R. "A Knowledge Based Framework for Automating HAZOP Analysis." AIChE Journal, Vol. 40, No. 3, 1994; pp. 496-505.

Wakeman, S. J., Chung, P. W. H., Rushton, A. G., Lees, F. P., Larkin, F. D. & McCoy, S. A.; "Computer-aided Hazard Identification: Fault Propagation and Fault-Consequence Scenario Filtering." IChemE Symposium Series No. 141, Hazards XIII Process Safety – The Future, 1997; pp. 305-316.

Winston, P.H.; "Artificial Intelligence", Addison Wesley, 1984.

Zerkani, H. & Rushton, A. G.; "Computer Aid for Hazard Identification." Proceedings of 6th International Conference on Industrial and Engineering Applications of Artificial Intelligence, Gordon and Breach Science Publishers, 1993; pp. 102-109.

Appendix 1 – Case Study preHAZOPed Results

This appendix contains the full list of preHAZOPed results used to generate the results of the case study of Chapter 7.

Table A1.1 gives the preHAZOPed results generated by filtering to include only those cause-consequence scenarios having an initial cause (IC) type of cause.

Table A1.2 gives the preHAZOPed results generated by filtering to include the remaining cause-consequence scenarios, i.e. those having a vulnerability (VUL) type of cause.

<table>
<tr><td colspan="7">Waste Acid Neutralisation Plant</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Node: 1Cooling Water top up - single supply, single pump and float valve.</td></tr>
<tr><td colspan="7">Parameter: Flow</td></tr>
<tr><td colspan="7">Intention:</td></tr>
<tr><td>DEVIATION</td><td>CAUSES</td><td>CAT</td><td>CONSEQUENCES</td><td>CAT</td><td>SAFEGUARDS</td><td>RECOMMENDATIONS</td></tr>
<tr><td>1. No Flow</td><td>1.1. Inline filter blocked.
Float valve fails shut.
Pump failure.</td><td>IC</td><td>1.1.1. Level in cold well cannot be maintained.
Cooling water supply may be restricted.</td><td>EE</td><td></td><td></td></tr>
<tr><td>2. More Flow</td><td>2.1. Float valve fails open.</td><td>IC</td><td>2.1.1. Cold well overflows.
Contamination due to dosing chemicals.</td><td>EE</td><td>2.1.1.1. Suitable overflow to drain.</td><td></td></tr>
<tr><td colspan="7">Node: 1Cooling Water top up - single supply, single pump and float valve.</td></tr>
<tr><td colspan="7">Parameter: Temperature</td></tr>
<tr><td colspan="7">Intention:</td></tr>
<tr><td>2. Lower Temperature</td><td>2.1. Low ambient temperature leads to freezing, particularly as there may be no flow for long periods of time.</td><td>IC</td><td>2.1.1. Prolonged cold weather may reduce availability of cooling water.</td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Node: 2Cooling water return to tower.</td></tr>
<tr><td colspan="7">Parameter: Flow</td></tr>
<tr><td colspan="7">Intention: Maintain circulation of cooling water.</td></tr>
<tr><td>1. Less Flow</td><td>1.1. Purge to drain valve left open or fails open.</td><td>IC</td><td>1.1.1. Cooling water tower performance falls off. Cooling water supply may be restricted during periods of high deamand.</td><td>EE</td><td>1.1.1.1. Regualr inspection.</td><td></td></tr>
<tr><td colspan="7">Node: 3Cooling Water Dosing - Chromate Dosing Outlet. Feed controlled by automatic dosing control.</td></tr>
<tr><td colspan="7">Parameter: Flow</td></tr>
<tr><td colspan="7">Intention:</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Node: 4Cooling water supply main - 2 or more pumps.</td></tr>
<tr><td colspan="7">Parameter: Flow</td></tr>
</table>

Table A1.1 – Waste acid plant preHAZOPed results – IC filtered.

Intention:						
1. Less Flow	1.1. Pump failure.	IC	1.1.1. LESS FLOW TO DOWNSTREAM UNITS. Only likely to be a problem during periods of high demand.	DPE	1.1.1.1. Appropriate alarms on pumps.	
					1.1.1.2. Low flow alarm on supply main.	
2. Reverse Flow	2.1. Pump not running	IC	2.1.1. Reverse flow through pump back into cooling water pond.	EE	2.1.1.1. Separate non-return valves on all pump discharges.	
Node: 4Cooling water supply main - 2 or more pumps.						
Parameter: Maintenance						
Intention:						
1. Part Of Maintenance	1.1. High cooling water demand e.g. due to hot weather.	IC	1.1.1. Unable to meet demand due to pump down for maintenance. Unable to carry out maintenance due to high cooling water demand.	EE		1.1.1.1. Planned maintenance should be scheduled for periods of low cooling water demand.
Node: 5Cooling Water Purge to drain - manually adjusted.						
Parameter: Flow						
Intention:						
1. More Flow	1.1. Chemical concentration monitoring fails requiring purge valve to be opened more than necessary. Purge valve inadvertantly left further open than required.	IC	1.1.1. Wastage of cooling water and dosing chemicals.	EE	1.1.1.1. Orifice plate to minimise maximum possible flow rate.	
2. Less Flow	2.1. Purge valve insufficiently open.	IC	2.1.1. Increased scaling, general solids deposition, and fouling problems.	EE		
Node: 6Cooling Water Acid dosing - automatically controlled.						
Parameter: Flow						
Intention:						

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

1. Less Flow	1.1. Automatic dosing control fails, delivering less acid than required.	IC	1.1.1. pH should be maintained between pH7-8 to maintain non-scaling, non-corrosive conditions in the system.	EE	1.1.1.1. Routine and regular testing.	
					1.1.1.2. Low level alarm.	
	Acid supply exhausted.					
2. More Flow	2.1. Automatic dosing control fails, delivering more acid than required. Acid supply exhausted.	IC	2.1.1. pH should be maintained between pH7-8 to maintain non-scaling, non-corrosive conditions in the system.	EE	2.1.1.1. Routine and regular testing.	
Node: 7Waste acid Storage tank vent to atmosphere						
Parameter: Flow						
Intention:						
1. No/Less Flow	1.1. Vent line blocked or partially blocked	IC	1.1.1. Tank overpressure rupture on filling	EE	1.1.1.1. Relief valve	1.1.1.1. Minimise opportunities for vent blockage
						1.1.1.2. Ensure flame arrestor is maintained correctly.
			1.1.2. Tank vacuum collapse on discharge	EE	1.1.2.1. Vacuum relief valve.	1.1.2.1. Minimise opportunities for vent blockage.
						1.1.2.2. Ensure flame arrestor is maintained correctly
Node: 7Waste acid Storage tank vent to atmosphere						
Parameter: Temperature						
Intention: Maintain temperature tank						
Node: 7Waste acid Storage tank vent to atmosphere						
Parameter: Pressure						
Intention: Maintain atmospheric pressure in tank						
Node: 8Waste acid Storage tank overflow						
Parameter: Flow						
Intention: Allow tank to overflow safely						
1. No/Less Flow	1.1. Overflow blocked or partially blocked	IC	1.1.1. No/partial tank overflow available. Possible tank rupture on overfilling	EE	1.1.1.1. Level control	1.1.1.1. Ensure opportunities for overflow blocking are minimised.
					1.1.1.2. Level indicator	

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

					1.1.1.3. High level alarm	
Node: 8Waste acid Storage tank overflow						
Parameter: Temperature						
Intention:						
Node: 8Waste acid Storage tank overflow						
Parameter: Pressure						
Intention:						
Node: 9Waste Acid Storage tank outlet						
Parameter: Flow						
Intention: Allow continuous flow of material to process						
1. No Flow	1.1. Outlet line blocked between tank and pump. Pump fails.	IC	1.1.1. NO FLOW TO DOWNSTREAM UNIT	DPE	1.1.1.1. Low flow alarm	
	1.2. Flow control valve fails shut. Outlet line blocked downstream of pump.	IC	1.2.1. NO FLOW TO DOWNSTREAM UNIT	DPE	1.2.1.1. Low flow alarm	
			1.2.2. Full head pump pressure developed. High pressure rupture risk to outlet line. Pump overheats, seals damaged, possible leak.	EE	1.2.2.1. Kick back line.	1.2.2.1. Consider designing equipment to withstand maximum pump delivery pressure.
					1.2.2.2. Low flow alarm.	
2. More Flow	2.1. Control valve fails open	IC	2.1.1. HIGH FLOW TO DOWNSTREAM UNIT	DPE		
	2.2. Spare pump running in error	IC	2.2.1. HIGH FLOW TO DOWNSTREAM UNIT	DPE	2.2.1.1. Flow control	2.2.1.1. Ensure operating and maintenance instructions preclude running parallel pumps incorrectly.
	2.3. Outlet line ruptured	IC	2.3.1. Tank contents lost to environment	EE	2.3.1.1. Emergency isolation valve	2.3.1.1. Ensure tank is adequately bunded.
						2.3.1.2. Locate isolation valve as near as possible to tank.

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

						2.3.1.3. Consider need for remote operation of isolation valve.
	2.4. Pump seals fail.	IC	2.4.1. Environmental contamination	EE	2.4.1.1. Emergency isolation valve.	2.4.1.1. Use canned or seal-less pump if appropriate.
						2.4.1.2. Pump to be adequately bunded.
						2.4.1.3. Consider need for remote operation of isolation valve.
3. Less Flow	3.1. Outlet line partially blocked. Pump running incorrectly.	IC	3.1.1. LESS FLOW TO DOWNSTREAM UNIT	DPE	3.1.1.1. Flow control	
					3.1.1.2. Low flow alarm	
	3.2. Control valve fails insufficiently open.	IC	3.2.1. LESS FLOW TO DOWNSTREAM UNIT	DPE	3.2.1.1. Low flow alarm.	
4. As Well As Flow	4.1. Contamination of tank contents	IC	4.1.1. CONTAMINATION OF DOWNSTREAM UNIT	DPE		
5. Reverse Flow	5.2. Outlet line ruptured.	IC	5.2.1. REVERSE FLO W FROM DOWNSTREAM UNIT	DPE		
Node: 9Waste Acid Storage tank outlet						
Parameter: Temperature						
Intention:						
Node: 9Waste Acid Storage tank outlet						
Parameter: Pressure						
Intention:						
2. Lower Pressure	2.1. Storage tank inlet line blocked.	IC	2.1.1. Low tank level leading to LOW PRESSURE AT DOWNSTREAM UNIT	DPE	2.1.1.1. Low flow alarm	
					2.1.1.2. Low level alarm	
	Level control valve fails shut.					
					2.1.1.3. Level indicator	
Node: 10Waste Acid Storage tank feed inlet without control valve.						

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

Parameter: Flow						
Intention:						
1. No Flow	1.1. Feed line blocked.	IC	1.1.1. Possible inability to continue process at normal production rates	EE		
			1.1.2. Low tank level leading to outlet pump cavitation.	EE	1.1.2.1. Low level alarm	
					1.1.2.2. Level indicator	
			1.1.3. NO FLOW AT UPSTREAM UNITS	DPE		
3. Less Flow	3.1. Feed line partially blocked.	IC	3.1.1. Vessel takes longer to fill than normal	EE	3.1.1.1. Level indicator.	
			3.1.2. LOW FLOW FROM UPSTREAM UNIT	DPE	3.1.2.1. Level indicator.	
Node: 10Waste Acid Storage tank feed inlet without control valve.						
Parameter: Temperature						
Intention:						
Node: 10Waste Acid Storage tank feed inlet without control valve.						
Parameter: Pressure						
Intention:						
1. Higher Pressure	1.2. Feed line isolated.	IC	1.2.1. Expansion of locked in fluid causes hydraulic overpressure rupture of line.	IC	1.2.1.1. Hydraulic pressure relief	1.2.1.1. Ensure operating instructions preclude deliberate isolation of line without having first drained line.
						1.2.1.2. Ensure design minimises opportunites for isolation in error due to control valves failing etc.

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

	1.3. Manual valve on storage tank inlet closes quickly.	IC	1.3.1. LIQUID HAMMER. HIGH PRESSURE TO UPSTREAM UNITS.			1.3.1.1. Only a problem for long pipelines. Ensure closing time on control valves and manual valves is long enough to avoid liquid hammer.
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)						
Parameter: Flow						
Intention:						
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)						
Parameter: Pressure						
Intention:						
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)						
Parameter: Composition						
Intention:						
Node: 12Neutralisation Reactor liquid feed with flow control						
Parameter: Flow						
Intention:						
1. No Flow	1.1. Feed line blocked.	IC	1.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	1.1.1.1. Low flow alarm	
	Control valve fails shut.					
			1.1.2. NO FLOW FROM UPSTREAM UNITS	DPE	1.1.2.1. Low flow alarm	
			1.1.3. LOW CONCENTRATION OF REACTANT / CONTAMINATION TO UNITS DOWNSTREAM OF REACTOR OUTLETS	IPE	1.1.3.1. Low flow alarm	
					1.1.3.2. Concentration alarm	
			1.1.4. LESS FLOW TO UNITS DOWNSTREAM OR REACTOR LIQUID OUTLET	IPE	1.1.4.1. Low flow alarm	

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

2. More Flow	2.1. Control valve fails open	IC	2.1.1. Incomplete conversion of reactants	EE		
			2.1.2. HIGH CONCENTRATION OF REACTANT / CONTAMINATION TO DOWNSTREAM UNITS			
			2.1.3. HIGH FLOW TO UNITS DOWNSTREAM OF REACTOR LIQUID OUTLET	IPE		
			2.1.4. HIGH FLOW FROM UPSTREAM UNITS	DPE		
3. Less Flow	3.1. Control valve fails insufficiently open	IC	3.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	3.1.1.1. Low flow alarm	
			3.1.2. LESS CONCENTRATION OF REACTANT / CONTAMINATION TO UNITS DOWSNTREAM OF REACTOR OUTLET	IPE	3.1.2.1. Low flow alarm	
					3.1.2.2. Concentration alarm	
			3.1.3. LESS FLOW FROM UPSTREAM UNIT	DPE	3.1.3.1. Low flow alarm	
Node: 12Neutralisation Reactor liquid feed with flow control						
Parameter: Temperature						
Intention:						
Node: 12Neutralisation Reactor liquid feed with flow control						
Parameter: Pressure						
Intention:						
2. Lower Pressure	2.2. Feed line leaking.	IC	2.2.1. Reactionn does not proceed as required. Poor conversion, side reactions etc.	EE	2.2.1.1. Pressure control	
					2.2.1.2. FLow control	

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

			2.2.2. Environmental damage.	EE		
Node: 12Neutralisation Reactor liquid feed with flow control						
Parameter: Composition						
Intention:						
1. More Composit ion	1.1. HIGH CONCENTRATION FROM UPSTREAM UNITS		1.1.1. Reaction does not proceed as required.			
			1.1.2. CONTAMINATION (BY REACTANT) TO UNITS DOWNSTREAM OF REACTOR OUTLETS. (Unless some form of concentration control is used).			
2. Less Composit ion	2.1. LOW CONCENTRATION FROM UPSTREAM UNITS		2.1.1. Reaction does not proceed as required			
			2.1.2. CONTAMINATION TO UNITS DOWNSTREAM OF REACTOR OUTLETS. (Unless some form of concentration control is used).			
3. As Well As Composit ion	3.1. CONTAMINATION FROM UPSTREAM UNITS		3.1.1. Reaction may not proceed as required.			
			3.1.2. CONTAMINATION TO UNITS DOWNSTREAM OF REACTOR OUTLETS.			
Node: 13Neutralisation Reactor liquid outlet with level control						
Parameter: Flow						
Intention:						

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

1. No Flow	1.1. Outlet line blocked.	IC	1.1.1. Reactor overflows	EE	1.1.1.1. Low flow alram	
	Pump failure.				1.1.1.2. High level alarm	
	Level control valve fails shut.					
			1.1.2. NO FLOW FROM UNITS UPSTREAM OF REACTOR FEED	IPE	1.1.2.1. Low flow alarm	
2. More Flow	2.1. Level control valve fails open.	IC	2.1.1. Level lost in reactor. Possible overheating, poor conversion, side reactions, etc.			
			2.1.2. HIGH FLOW TO DOWNSTREAM UNITS	DPE		
	2.2. HIGH FLOW TO DOWNSTREAM UNITS		2.2.1. Level lost in reactor. Possible overheating, poor conversion, side reactions, etc.			
	2.3. Outlet line ruptured.	IC	2.3.1. Reactor contents lost to environment.	EE	2.3.1.1. Emergency isolation may be required.	
3. Less Flow	3.1. Level control fails to open control valve sufficiently.	IC	3.1.1. Possible reactor overflow.	EE	3.1.1.1. High level alarm	
					3.1.1.2. Low flowalarm	
			3.1.2. LESS FLOW TO DOWNSTREAM UNITS	DPE	3.1.2.1. Low flow alarm	
4. Reverse Flow	4.1. Pump failure	IC	4.1.1. REVERSE FLOW FROM DOWNSTREAM UNITS	DPE		
Node: 14Neutralisation Reactor liquid feed with concentration control						
Parameter: Flow						
Intention:						
1. No Flow	1.1. Feed line blocked.	IC	1.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	1.1.1.1. Low flow alarm	
	Control valve fails shut.					
			1.1.2. NO FLOW FROM UPSTREAM UNITS	DPE	1.1.2.1. Low flow alarm	

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

			1.1.3. LESS FLOW TO UNITS DOWNSTREAM OR REACTOR LIQUID OUTLET	IPE	1.1.3.1. Low flow alarm	
2. More Flow	2.1. Control valve fails open	IC	2.1.1. Incomplete conversion of yreactants	EE		
			2.1.2. HIGH FLOW TO UNITS DOWNSTREAM OF REACTOR LIQUID OUTLET	IPE		
			2.1.3. HIGH FLOW FROM UPSTREAM UNITS	DPE		
3. Less Flow	3.1. Control valve fails insufficiently open	IC	3.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	3.1.1.1. Low flow alarm	
			3.1.2. LESS FLOW FROM UPSTREAM UNIT	DPE	3.1.2.1. Low flow alarm	
Node: 14Neutralisation Reactor liquid feed with concentration control						
Parameter: Temperature						
Intention:						
Node: 14Neutralisation Reactor liquid feed with concentration control						
Parameter: Composition						
Intention:						
1. As Well As Composition	1.1. CONTAMINATION FROM UPSTREAM UNITS		1.1.1. Reaction may not proceed as required.			
			1.1.2. CONTAMINATION TO UNITS DOWNSTREAM OF REACTOR OUTLETS.			
Node: 15Neutralisation Reactor Cooling stream in with temperature control						
Parameter: Flow						
Intention:						
1. No Flow	1.1. Control valve fails shut.		1.1.1. Runaway reaction.		1.1.1.1. Low flow alarm	

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

					1.1.1.2. High temperature alarm.	
			1.1.2. Possible explosion.		1.1.2.1. Low flow alarm	
					1.1.2.2. High temperature alarm	
					1.1.2.3. High pressure alarm	
					1.1.2.4. Install relief valve	
			1.1.3. Catalyst destroyed.		1.1.3.1. As for consequence 1.1.1	
			1.1.4. Reaction does not proceed as required. Poor conversion, side reactions, etc.		1.1.4.1. As for consequence 1.1.1	
			1.1.5. NO FLOW DOWSNTREAM OF COOLING STREAM OUT		1.1.5.1. As for consequence 1.1.1	
			1.1.6. NO FLOW FROM UPSTREAM UNITS		1.1.6.1. As for consequence 1.1.1	
			1.1.7. HIGH TEMPERATURE DOWNSTREAM OF REACTOR LIQUID OUTLET			
			1.1.8. HIGH TEMPERATURE DOWNSTREAM OF REACTOR VAPOUR OUTLET			
	1.2. NO FLOW FROM UPSTREAM UNITS		1.2.1. As for cause 1.1 except as for consequence 1.1.6		1.2.1.1. As for cause 1.1	
2. More Flow	2.1. Control valve fails open		2.1.1. Reaction does not proceed as required. Poor conversion, side reactions, etc.			

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

			2.1.2. MORE FLOW DOWNSTREAM OF COOLING STREAM OUT			
			2.1.3. MORE FLOW FROM UPSTREAM UNITS			
			2.1.4. LOW TEMPERATURE DOWNSTREAM OF REACTOR LIQUID OUTLET			
			2.1.5. LOW TEMPERATURE DOWNSTREAM OF REATOR VAPOUR OUTLET			
	2.2. MORE FLOW FROM UPSTREAM UNIT		2.2.1. As for cause 1.1 except as for consequence 2.1.3		2.2.1.1. Flow control.	
					2.2.1.2. Temperature control.	
3. Less Flow	3.1. Control valve fails to open sufficiently		3.1.1. Possible runaway reaction.		3.1.1.1. High temperature alarm.	
					3.1.1.2. Low flow alarm	
			3.1.2. Possible explosion			
			3.1.3. Reaction does not proceed as required. Poor conversion, side reactions, etc.			
			3.1.4. LESS FLOW DOWNSTREAM OF COOLING STREAM OUT			
			3.1.5. LESS FLOW FROM UPSTREAM UNITS			
			3.1.6. HIGH TEMPERATURE DOWNSTREAM OF REACTOR LIQUID OUTLET			

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

			3.1.7. HIGH TEMPERATURE DOWNSTREAM OF COOLING STREAM OUT			
	3.2. LESS FLOW FROM UPSTREAM UNIT		3.2.1. As for cause 2.1 except as for consequence 3.1.5		3.2.1.1. Flow control	
Node: 15Neutralisation Reactor Cooling stream in with temperature control						
Parameter: Temperature						
Intention:						
1. Higher Temperature	1.1. HIGH TEMPERATURE FROM UPSTREAM UNIT		1.1.1. Reaction does not proceed as required. Poor conversion, side reactions, etc.		1.1.1.1. Temperature control	
			1.1.2. Cooling capacity reduced.			
			1.1.3. HIGH TEMPERATURE TO UNITS DOWNSTREAM OF COOLING STREAM OUT		1.1.3.1. Temperature control	
			1.1.4. HIGH TEMPERATURE TO UNITS DOWNSTREAM OF REACTOR LIQUID OUTLET		1.1.4.1. Temperature control	
2. Lower Temperature	2.1. LOW TEMPERATURE FROM UPSTREAM UNIT		2.1.1. Reaction does not proceed as required. Poor conversion, side reactions, etc.		2.1.1.1. Temperature control.	
			2.1.2. Reaction proceeds slower than expected.		2.1.2.1. Temperature control.	
			2.1.3. LOW TEMPERATURE TO UNITS DOWNSTREAM OF LIQUID OUTLET		2.1.3.1. Temperature control	

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

			2.1.4. LOW TEMPERATURE DOWNSTREAM OF COOLING STREAM OUT		2.1.4.1. Temperature control	
Node: 16Neutralisation Reactor Cooling stream out with temperature control						
Parameter: Flow						
Intention:						
1. No Flow	1.1. NO FLOW TO DOWNSTREAM UNIT		1.1.1. Reaction temperature too high.		1.1.1.1. Low flow alarm	
					1.1.1.2. High temperature alarm	
			Explosion.			
			Catalyst destroyed.			
			1.1.2. Reaction does not proceed as required. Poor conversion, side reactions, etc.		1.1.2.1. As for consequence 1.1.1	
			1.1.3. NO FLOW FROM UNITS UPSTREAM OF COOLING STREAM IN		1.1.3.1. As for consequence 1.1.1	
			1.1.4. HIGH TEMPERATURE DOWNSTREAM OF LIQUID OUTLET		1.1.4.1. As for consequence 1.1.1	
			1.1.5. HIGH TEMPERATURE DOWNSTREAM OF VAPOUR OUTLET		1.1.5.1. As for consequence 1.1.1	
2. More Flow	2.1. HIGH FLOW TO DOWNSTREAM UNIT		2.1.1. Low reaction temperature		2.1.1.1. Temperature control	
			2.1.2. Reaction does not proceed as required. Poor conversion, side reactions etc.		2.1.2.1. as for consequence 1.1.1	
			2.1.3. HIGH FLOW FROM UNITS UPSTREAM OF COOLING STREAM IN		2.1.3.1. As for consequence 1.1.1	

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

			2.1.4. LOW TEMPERATURE TO DOWNSTREAM UNITS		2.1.4.1. as for consequence 1.1.1	
			2.1.5. LOW TEMPERATURE DOWNSTREAM OF LIQUID OUTLET		2.1.5.1. As for consequence 1.1.1	
3. Less Flow	3.1. LOW FLOW TO DOWNSTREAM UNITS		3.1.1. High reaction temperature.			
			3.1.2. Possible runaway reaction.			
			3.1.3. Reaction does not proceed as required. Poor conversion, side reactions, etc.			
			3.1.4. LOW FLOW FROM UNITS UPSTREAM OF COOLING STREAM IN			
			3.1.5. HIGH TEMPERATURE TO DOWNSTREAM UNITS			
			3.1.6. HIGH TEMPERATURE DOWNSTREAM OF LIQUID OUTLET			
Node: 17Neutralisation Reactor cooling via recycle						
Parameter: Flow						
Intention:						
1. No/Less Flow	1.1. Pump failure or poor pump performance.	IC	1.1.1. Reactor begins to overheat. Reaction may begin to run away. Possible risk of explosion.	EE		1.1.1.1. Some form of emergency cooling may be necessary to avoid explosion where that possibility exists.
3. As Well As Flow	3.1. Contamination of recycle stream by cooling water due to heat exchanger interface failure.	IC	3.1.1. Reaction does not proceed as required. Poor conversion, side reactions, etc.	EE		

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

			3.1.2. CONTAMINATION WITH COOLING WATER TO UNITS DOWNSTREAM OF REACTOR OUTLET	IPE		
Node: 18Treated Waste Storage tank vent to atmosphere						
Parameter: Flow						
Intention: Enable flow into or out of tank to maintain atmospheric pressure						
1. No/Less Flow	1.1. Vent line blocked or partially blocked	IC	1.1.1. Tank overpressure rupture on filling	EE	1.1.1.1. Relief valve	1.1.1.1. Minimise opportunities for vent blockage
						1.1.1.2. Ensure flame arrestor is maintained correctly.
			1.1.2. Tank vacuum collapse on discharge	EE	1.1.2.1. Vacuum relief valve.	1.1.2.1. Minimise opportunities for vent blockage.
						1.1.2.2. Ensure flame arrestor is maintained correctly
Node: 18Treated Waste Storage tank vent to atmosphere						
Parameter: Temperature						
Intention: Maintain temperature tank						
Node: 18Treated Waste Storage tank vent to atmosphere						
Parameter: Pressure						
Intention: Maintain atmospheric pressure in tank						
Node: 19Treated Waste Storage tank feed inlet without control valve.						
Parameter: Flow						
Intention:						
1. No Flow	1.1. Feed line blocked.	IC	1.1.1. Possible inability to continue process at normal production rates	EE		
			1.1.2. Low tank level leading to outlet pump cavitation.	EE	1.1.2.1. Low level alarm	
					1.1.2.2. Level indicator	
			1.1.3. NO FLOW AT UPSTREAM UNITS	DPE		

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

3. Less Flow	3.1. Feed line partially blocked.	IC	3.1.1. Vessel takes longer to fill than normal	EE	3.1.1.1. Level indicator.	
			3.1.2. LOW FLOW FROM UPSTREAM UNIT	DPE	3.1.2.1. Level indicator.	
Node: 19Treated Waste Storage tank feed inlet without control valve.						
Parameter: Temperature						
Intention:						
Node: 19Treated Waste Storage tank feed inlet without control valve.						
Parameter: Pressure						
Intention:						
1. Higher Pressure	1.2. Feed line isolated.	IC	1.2.1. Expansion of locked in fluid causes hydraulic overpressure rupture of line.	IC	1.2.1.1. Hydraulic pressure relief	1.2.1.1. Ensure operating instructions preclude deliberate isolation of line without having first drained line.
						1.2.1.2. Ensure design minimises opportunites for isolation in error due to control valves failing etc.
	1.3. Manual valve on storage tank inlet closes quickly.	IC	1.3.1. LIQUID HAMMER. HIGH PRESSURE TO UPSTREAM UNITS.			1.3.1.1. Only a problem for long pipelines. Ensure closing time on control valves and manual valves is long enough to avoid liquid hammer.
Node: 20Treated Waste Storage tank overflow						
Parameter: Flow						
Intention: Allow tank to overflow safely						
1. No/Less Flow	1.1. Overflow blocked or partially blocked	IC	1.1.1. No/partial tank overflow available. Possible tank rupture on overfilling	EE	1.1.1.1. Level control	1.1.1.1. Ensure opportunities for overflow blocking are minimised.
					1.1.1.2. Level indicator	
					1.1.1.3. High level alarm	
Node: 20Treated Waste Storage tank overflow						
Parameter: Temperature						
Intention:						

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

Node: 20Treated Waste Storage tank overflow						
Parameter: Pressure						
Intention:						

Table A1.1 (cont.) – Waste acid plant preHAZOPed results – IC filtered.

Project Name: Waste Acid Neutralisation Plant						
Node: 1Cooling Water top up - single supply, single pump and float valve.						
Parameter: Flow						
Intention:						
DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	RECOMMENDATIONS
1. No Flow	1.2. NO FLOW FROM UPSTREAM SUPPLY	VUL	1.2.1. Level in cold well cannot be maintained. Cooling water supply may be restricted.	EE		1.2.1.1. If the supply is unreliable consider the need for a backup supply. See appropriate node.
Node: 1Cooling Water top up - single supply, single pump and float valve.						
Parameter: Temperature						
Intention:						
Node: 2Cooling water return to tower.						
Parameter: Flow						
Intention: Maintain circulation of cooling water.						
Node: 3Cooling Water Dosing - Chromate Dosing Outlet. Feed controlled by automatic dosing control.						
Parameter: Flow						
Intention:						
Node: 4Cooling water supply main - 2 or more pumps.						
Parameter: Flow						
Intention:						
Node: 4Cooling water supply main - 2 or more pumps.						
Parameter: Maintenance						
Intention:						
Node: 5Cooling Water Purge to drain - manually adjusted.						
Parameter: Flow						
Intention:						
Node: 6Cooling Water Acid dosing - automatically controlled.						
Parameter: Flow						
Intention:						
Node: 7Waste acid Storage tank vent to atmosphere						
Parameter: Flow						
Intention: Enable flow into or out of tank to maintain atmospheric pressure						
Node: 7Waste acid Storage tank vent to atmosphere						

Table A1.2 – Waste acid plant preHAZOPed results – VUL filtered.

Parameter: Temperature						
Intention: Maintain temperature tank						
Node: 7Waste acid Storage tank vent to atmosphere						
Parameter: Pressure						
Intention: Maintain atmospheric pressure in tank						
Node: 8Waste acid Storage tank overflow						
Parameter: Flow						
Intention: Allow tank to overflow safely						
Node: 8Waste acid Storage tank overflow						
Parameter: Temperature						
Intention:						
Node: 8Waste acid Storage tank overflow						
Parameter: Pressure						
Intention:						
Node: 9Waste Acid Storage tank outlet						
Parameter: Flow						
Intention: Allow continuous flow of material to process						
DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	RECOMMENDATIONS
1. No Flow	1.3. NO FLOW TO DOWNSTREAM UNITS	VUL	1.3.1. Full head pump pressure developed. High pressure rupture risk to downstream equipment. Pump overheats, seals damaged, possible leak.	EE	1.3.1.1. High pressure/low flow pump cut out switches.	1.3.1.1. Design equipment to withstand maximum pump delivery pressure.
					1.3.1.2. Kick back line	
					1.3.1.3. Integral pump high pressure relief valve	
					1.3.1.4. Pressure indicator	
					1.3.1.5. Low flow alarm	
5. Reverse Flow	5.1. Pump failure and REVERSE FLOW FROM DOWNSTREAM UNIT.	VUL	5.1.1. Material incompatability	EE	5.1.1.1. Non-return valve.	
Node: 9Waste Acid Storage tank outlet						
Parameter: Temperature						
Intention:						

Table A1.2 (cont.) – Waste acid plant preHAZOPed results – VUL filtered.

Node: 9Waste Acid Storage tank outlet						
Parameter: Pressure						
Intention:						
1. Higher Pressure	1.1. HIGH PRESSURE AT DOWNSTREAM UNIT	VUL	1.1.1. LOW FLOW TO DOWNSTREAM UNIT	DPE	1.1.1.1. Flow control	
2. Lower Pressure	2.1. LOW PRESSURE AT DOWNSTREAM UNIT	VUL	2.1.1. HIGH FLOW TO DOWNSTREAM UNIT	DPE	2.1.1.1. Flow control	
Node: 10Waste Acid Storage tank feed inlet without control valve.						
Parameter: Flow						
Intention:						
1. No Flow	1.2. NO FLOW FROM UPSTREAM UNIT	VUL	1.2.1. Possible inability to continue process at normal production rates.	EE		
			1.2.2. Low tank level leading to outlet pump cavitation.	EE	1.2.2.1. Low level alarm	
					1.2.2.2. Level indicator	
2. More Flow	2.1. HIGH FLOW FROM UPSTREAM UNIT	VUL	2.1.1. Inadequate venting. Vessel overpressure rupture.	EE	2.1.1.1. Relief valve.	
			2.1.2. Static build up.	EE	2.1.2.1. Dip tubes for filling.	2.1.2.1. Flammable fluids only. If filling is not done via dip tubes check design assumptions.
3. Less Flow	3.2. LOW FLOW FROM SOURCE	VUL	3.2.1. Vessel takes longer to fill than normal.		3.2.1.1. Level indicator.	
4. As Well As Flow	4.1. WRONG MATERIAL AT SOURCE	VUL	4.1.1. Material incompatability	EE		4.1.1.1. Ensure appropriate measures exist to check incoming material.

Table A1.2 (cont.) - Waste acid plant – preHAZOPed results VUL filter.

	4.2. CONTAMINATION OF MATERIAL AT SOURCE	VUL	4.2.1. Material incompatibility	EE		
5. Reverse Flow	5.1. REVERSE FLOW AT SOURCE	VUL	5.1.1. Liquid siphoned out of tank.	EE	5.1.1.1. Siphon break on dip tubes.	
					5.1.1.2. Non-return valve	
Node: 10Waste Acid Storage tank feed inlet without control valve.						
Parameter: Temperature						
Intention:						
1. Higher Temperature	1.1. HIGH TEMPERATURE FROM UPSTREAM UNIT	VUL	1.1.1. Rapid evaporation of tank contents.	EE	1.1.1.1. Temperature indicator	1.1.1.1. For system with vent header system, can system cope with increase in venting due to hot weather acting on several tanks?
					1.1.1.2. High temperature alarm	
			1.1.2. Increased vapour concentration around tank, possibly rising to a hazardous level.	EE	1.1.2.1. Temperature indicator.	1.1.2.1. Only a problem for tanks with open vent. Consider installing appropriate gas detection equipment if appropriate.
					1.1.2.2. High temperature alarm.	
Node: 10Waste Acid Storage tank feed inlet without control valve.						
Parameter: Pressure						
Intention:						
1. Higher Pressure	1.1. HIGH PRESSURE FROM SOURCE	VUL	1.1.1. Vessel overpressure rupture	IC	1.1.1.1. Relief valve.	1.1.1.1. Ensure adequate venting.
					1.1.1.2. Pressure indicator.	
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)						
Parameter: Flow						
Intention:						
1. No Flow	1.1. NO FLOW FROM UPSTREAM UNIT	VUL	1.1.1. Tanker not filled as required.	EE		
2. More Flow	2.1. MORE FLOW FROM UPSTREAM UNIT	VUL				

Table A1.2 (cont.) – Waste acid plant preHAZOPed results – VUL filtered.

3. Less Flow	3.1. LESS FLOW FROM UPSTREAM UNIT	VUL	3.1.1. Tanker takes longer to fill than normal.	EE	3.1.1.1. Overdue filling alarm.	
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)						
Parameter: Pressure						
Intention:						
1. Higher Pressure	1.1. HIGH PRESSURE FROM UPSTREAM UNIT	VUL	1.1.1. Tanker overpressure rupture.	EE	1.1.1.1. Relief valve	
2. Lower Pressure	2.1. LOW PRESSURE FROM UPSTREAM UNIT	VUL	2.1.1. Vessel takes longer to fill than normal	EE		
Node: 11Treated waste Inlet to tanker, controlled by batch meter (tanker loading operations)						
Parameter: Composition						
Intention:						
Node: 12Neutralisation Reactor liquid feed with flow control						
Parameter: Flow						
Intention:						
1. No Flow	1.2. NO FLOW FROM UPSTREAM UNITS	VUL	1.2.1. Reaction does not proceed as required.	EE	1.2.1.1. Low flow alarm	
			1.2.2. LOW CONCENTRATION OF REACTANT / CONTAMINATION TO UNITS DOWNSTREAM OR REACTOR OUTLET	IPE	1.2.2.1. Low flow alarm	
					1.2.2.2. Concentration alarm	
			1.2.3. LESS FLOW TO UNITS DOWNSTREAM OF REACTOR OUTLET	IPE	1.2.3.1. Low flow alarm	
2. More Flow	2.2. HIGH FLOW FROM UPSTREAM UNITS	VUL	2.2.1. Incomplete conversion of reactants	EE	2.2.1.1. Flow control	
			2.2.2. HIGH CONCENTRATION OF REACTANT / CONTAMINATION TO UNITS DOWNSTREAM OF REACTOR OUTLETS	IPE		

Table A1.2 (cont.) - Waste acid plant – preHAZOPed results VUL filter.

			2.2.3. HIGH FLOW TO UNITS DOWNSTREAM OF LIQUID REACTOR OUTLET	IPE	2.2.3.1. Flow control	
3. Less Flow	3.2. LESS FLOW FROM UPSTREAM UNITS	VUL	3.2.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	3.2.1.1. Low flow alarm	
			3.2.2. LOW CONCENTRATION OF REACTANT / CONTAMINATION TO UNITS DOWNSTREAM OF REACTOR OUTLET	IPE	3.2.2.1. Low flow alarm	
					3.2.2.2. Concentration alarm	
Node: 12Neutralisation Reactor liquid feed with flow control						
Parameter: Temperature						
Intention:						
1. Higher Temperature	1.1. HIGH TEMPERATURE FROM UPSTREAM UNITS	VUL	1.1.1. Reaction begins to runaway. Possible Explosion.	EE	1.1.1.1. Temperature control.	
					1.1.1.2. Relief valve required.	
			1.1.2. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	1.1.2.1. Temperature control	
2. Lower Temperature	2.1. LOW TEMPERATURE FROM UPSTREAM UNITS	VUL	2.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	2.1.1.1. Temperature control	
			2.1.2. Reaction does not proceed at required rate.	EE	2.1.2.1. Temperature control	
Node: 12Neutralisation Reactor liquid feed with flow control						
Parameter: Pressure						
Intention:						
1. Higher Pressure	1.1. HIGH PRESSURE FROM UPSTREAM UNITS	VUL	1.1.1. Reaction does not proceed as required. Poor conversion, side reactions, etc.	EE	1.1.1.1. Pressure control	

Table A1.2 (cont.) – Waste acid plant preHAZOPed results – VUL filtered.

2. Lower Pressure	2.1. LOW PRESSURE FROM UPSTREAM UNITS	VUL	2.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	2.1.1.1. Pressure control	
Node: 12Neutralisation Reactor liquid feed with flow control						
Parameter: Composition						
Intention:						
Node: 13Neutralisation Reactor liquid outlet with level control						
Parameter: Flow						
Intention:						
1. No Flow	1.2. NO FLOW TO DOWNSTREAM UNITS	VUL	1.2.1. Reactor overflows.	EE	1.2.1.1. Low flow alarm	
			1.2.2. NO FLOW FROM UNITS UPSTREAM OF REACTOR FEED.	IPE	1.2.2.1. Low flow alarm	
Node: 14Neutralisation Reactor liquid feed with concentration control						
Parameter: Flow						
Intention:						
1. No Flow	1.2. NO FLOW FROM UPSTREAM UNITS	VUL	1.2.1. Reaction does not proceed as required.	EE	1.2.1.1. Low flow alarm	
			1.2.2. LESS FLOW TOUNITS DOWNSTREAM OF REACTOR OUTLET	IPE	1.2.2.1. Low flow alarm	
2. More Flow	2.2. HIGH FLOW FROM UPSTREAM UNITS	VUL	2.2.1. Incomplete conversion of reactants	EE	2.2.1.1. Flow control	
			2.2.2. HIGH FLOW TO UNITS DOWNSTREAM OF LIQUID REACTOR OUTLET	IPE	2.2.2.1. Flow control	
3. Less Flow	3.2. LESS FLOW FROM UPSTREAM UNITS	VUL	3.2.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	3.2.1.1. Low flow alarm	
Node: 14Neutralisation Reactor liquid feed with concentration control						
Parameter: Temperature						
Intention:						

Table A1.2 (cont.) - Waste acid plant – preHAZOPed results VUL filter.

1. Higher Temperature	1.1. HIGH TEMPERATURE FROM UPSTREAM UNITS	VUL	1.1.1. Reaction begins to runaway. Possible explosion.	EE	1.1.1.1. Temperature control.	
					1.1.1.2. Relief valve required.	
			1.1.2. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	1.1.2.1. Temperature control	
2. Lower Temperature	2.1. LOW TEMPERATURE FROM UPSTREAM UNITS	VUL	2.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	2.1.1.1. Temperature control	
			2.1.2. Reaction does not proceed at required rate.	EE	2.1.2.1. Temperature control	
Node: 14Neutralisation Reactor liquid feed with concentration control						
Parameter: Composition						
Intention:						
Node: 15Neutralisation Reactor Cooling stream in with temperature control						
Parameter: Flow						
Intention:						
Node: 15Neutralisation Reactor Cooling stream in with temperature control						
Parameter: Temperature						
Intention:						
Higher Temperature	HIGH TEMPERATURE FROM UPSTREAM UNIT	VUL	Reaction does not proceed as required. Poor conversion, side reactions, etc.	EE	Temperature control	
			Cooling capacity reduced. High cooling water demand.	EE		
			Rapid evaporation of storage tank contents. Increased vapour concentration around storage tank, possibly rising to a hazardous level.	IPE	Temperature control	Only a problem for tanks with open vent. Consider installing appropriate detection equipment if appropriate.

Table A1.2 (cont.) – Waste acid plant preHAZOPed results – VUL filtered.

Lower Temperature	LOW TEMPERATURE FROM UPSTREAM UNIT	VUL	Reaction does not proceed as required. Poor conversion, side reactions, etc.	EE	Temperature control.	
			Reaction proceeds slower than expected.	EE	Temperature control.	
Node: 16Neutralisation Reactor Cooling stream out with temperature control						
Parameter: Flow						
Intention:						
Node: 17Neutralisation Reactor cooling via recycle						
Parameter: Flow						
Intention:						
Node: 18Treated Waste Storage tank vent to atmosphere						
Parameter: Flow						
Intention: Enable flow into or out of tank to maintain atmospheric pressure						
Node: 18Treated Waste Storage tank vent to atmosphere						
Parameter: Temperature						
Intention: Maintain temperature tank						
Node: 18Treated Waste Storage tank vent to atmosphere						
Parameter: Pressure						
Intention: Maintain atmospheric pressure in tank						
Node: 19Treated Waste Storage tank feed inlet without control valve.						
Parameter: Flow						
Intention:						
1. No Flow	1.2. NO FLOW FROM UPSTREAM UNIT	VUL	1.2.1. Possible inability to continue process at normal production rates	EE		
			1.2.2. Low tank level leading to outlet pump cavitation.	EE	1.2.2.1. Low level alarm	
					1.2.2.2. Level indicator	
2. More Flow	2.1. HIGH FLOW FROM UPSTREAM UNIT	VUL	2.1.1. Inadequate venting. Vessel overpressure rupture.	EE	2.1.1.1. Relief valve.	
			2.1.2. Static build up.	EE	2.1.2.1. Dip tubes for filling.	2.1.2.1. Flammable fluids only. If filling is not done via dip tubes check design assumptions.

Table A1.2 (cont.) - Waste acid plant – preHAZOPed results VUL filter.

3. Less Flow	3.2. LOW FLOW FROM SOURCE	VUL	3.2.1. Vessel takes longer to fill than normal.		3.2.1.1. Level indicator.	
4. As Well As Flow	4.1. WRONG MATERIAL AT SOURCE	VUL	4.1.1. Material incompatability	EE		4.1.1.1. Ensure appropriate measures exist to check incoming material.
	4.2. CONTAMINATION OF MATERIAL AT SOURCE	VUL	4.2.1. Material incompatibility	EE		
5. Reverse Flow	5.1. REVERSE FLOW AT SOURCE	VUL	5.1.1. Liquid siphoned out of tank.	EE	5.1.1.1. Siphon break on dip tubes.	
					5.1.1.2. Non-return valve	
Node: 19Treated Waste Storage tank feed inlet without control valve.						
Parameter: Temperature						
Intention:						
1. Higher Temperature	1.1. HIGH TEMPERATURE FROM UPSTREAM UNIT	VUL	1.1.1. Rapid evaporation of tank contents.	EE	1.1.1.1. Temperature indicator	1.1.1.1. For system with vent header system, can system cope with increase in venting due to hot weather acting on several tanks?
					1.1.1.2. High temperature alarm	
			1.1.2. Increased vapour concentration around tank, possibly rising to a hazardous level.	EE	1.1.2.1. Temperature indicator.	1.1.2.1. Only a problem for tanks with open vent. Consider installing appropriate gas detection equipment if appropriate.
					1.1.2.2. High temperature alarm.	
Node: 19Treated Waste Storage tank feed inlet without control valve.						
Parameter: Pressure						
Intention:						
1. Higher Pressure	1.1. HIGH PRESSURE FROM SOURCE	VUL	1.1.1. Vessel overpressure rupture	IC	1.1.1.1. Relief valve.	1.1.1.1. Ensure adequate venting.
					1.1.1.2. Pressure indicator.	

Table A1.2 (cont.) – Waste acid plant preHAZOPed results – VUL filtered.

Appendix 2 – Benzene Plant Modular HAZOP

This appendix has results for the modular HAZOP of a benzene plant. The plant is illustrated in figure A2.1. The results are presented in table A2.1.

This is a plant described and illustrated by Douglas (1988). This plant was used, in particular for assessing performance, during the development of the modular HAZOP methodology, the development of CHEQUER (Jefferson et al., 1995(b)) and for the STOPHAZ project (McCoy et al., 1999). This particular figure was drawn-up by S. A. McCoy.

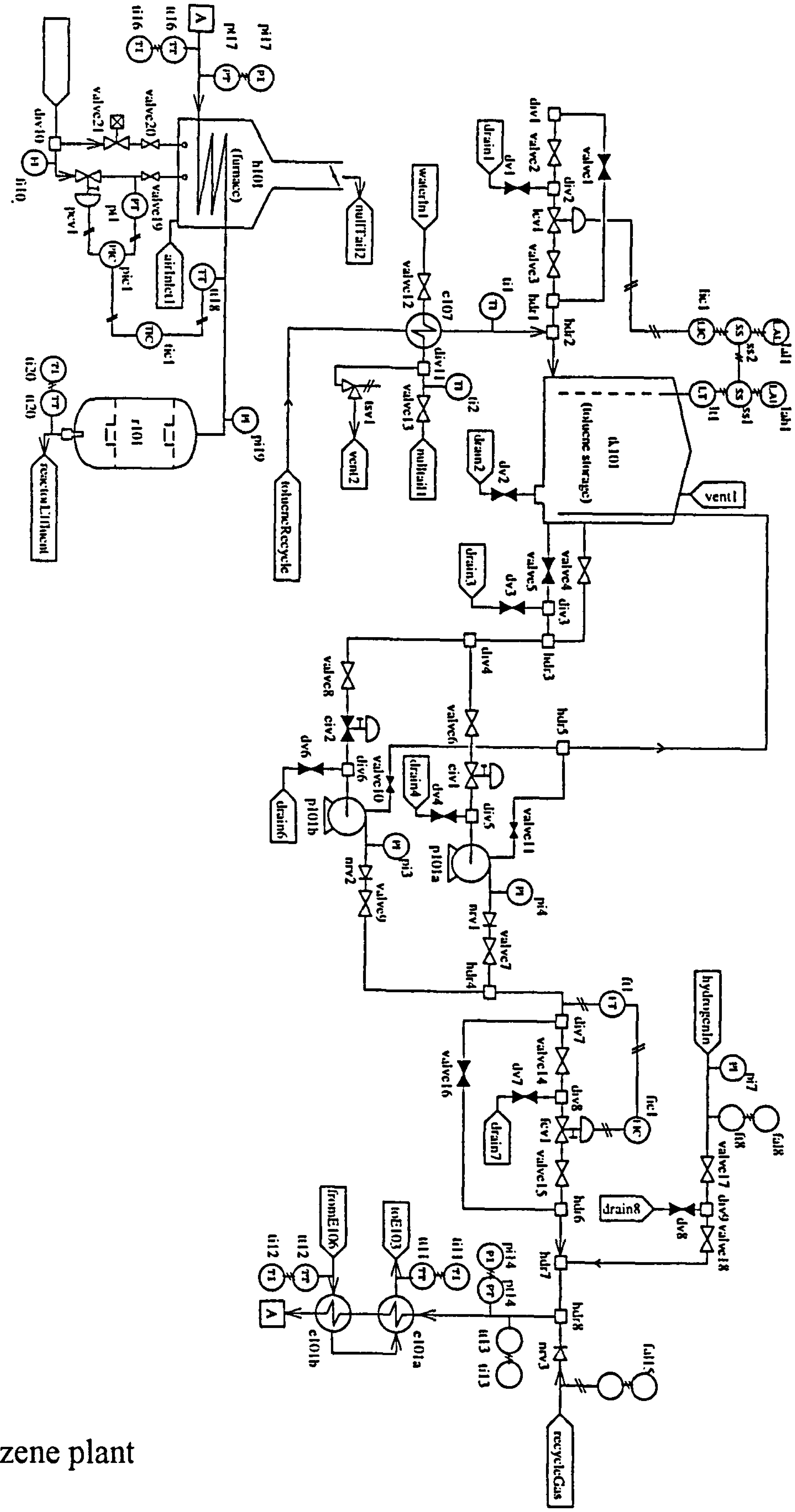


Figure A2.1 Benzene plant

Module	Sub-module	Deviation	Causes	Consequences	Safe-guards	Recommend-ations
TK101	Toluene feed from battery limit	No flow	Battery limit supply failure Feed line blocked. Level control valve fails shut	Possible inability to continue process at normal production rates		
		Low flow	Battery limit supply low pressure Level control valve fails part closed Feed line partially blocked	Vessel takes longer to fill than normal.		
		High flow	Battery limit high supply pressure	Inadequate venting. Vessel overpressure rupture.		Size vent adequately. Install relief valve.
				Static build up		Use dip tubes for filling if susceptible to static.
			Level control valve fails open.	As above.		As above.
				Tank overflows		Suitable overflow arrangements Tank to be bunded if necessary.
		Reverse flow	Back siphoning from tank	Contamination of battery limit supply source.		Use siphon breaks on dip tubes.
TK101	Toluene Recycle Feed	No flow	Feed line blocked	Possible inability to continue process at normal production rates		
		Less flow	Feed line partially blocked	Vessel takes longer than normal to fill		

Table A2.1 – Benzene plant modular HAZOP results.

	Self	High tempe rature	External fire	Rapid evaporation of tank contents. Structural weakening of tank.		Ensure adequate fire relief.
			High ambient temperature	Rapid evaporation of tank contents.		Insulate tank.
		Low tempe rature	Low ambient temperature	Vapour condenses. Air drawn into tank, possible flammable atmosphere.		Insulate tank. Use inert blanket if necessary.
				Vapour condenses. Vacuum collapse.		Insulate tank. Size vent adequately. Install vacuum relief.
TK101	Vent	No flow	Vent line blocked	Overpressure rupture		Maintain flame arrestor. Minimise oppurtunities for vent blockage. Install relief valve.
				Vacuum collapse		Maintain flame arrestor. Minimise oppurtunities for vent blockage. Install vacuum relief.
		Less flow	Vent line partially blocked	As for no flow.		As for no flow.
TK101	Overflow	No flow	Overflow blocked	Tank rupture on overfilling.	Level control valve.	Ensure opportunities for overflow blocking are minimised.

		Less flow	Overflow partially blocked.	As for no flow.	As for no flow.	As for no flow.
TK101	Outlet	No flow	Outlet line blocked.	Furnace tubes overheat. possible tube failure.		
		Less flow	Outlet line partially blocked.	LESS FLOW TO DOWNSTREAM UNIT	Flow control valve.	
		More flow	Outlet line ruptured	Tank contents lost to environment.		Bund tank. Install emergency isolation valve.
H101	Fuel gas in	No flow	Burner control fails shut	LESS TEMPERATURE HEATED PRODUCT OUT		
		More flow	Burner control fails open	MORE TEMPERATURE HEATED PRODUCT OUT		
				Furnace tubes overheat. Furnace tubes fail.	Burner control system	
			Burners fail to ignite	Release of flammable gas. Explosion risk.	Burner control system	Use explosion doors
		Less flow	Burner control fails partly open. Burners partially blocked.	Flame fails. Explosive atmosphere develops.	Burner control system	
				LESS TEMPERATURE HEATED PRODUCT OUT		

Table A2.1 (cont.) – Benzene plant modular HAZOP results.

	Stack	No flow	Stack blocked. Damper fails shut.	Flame fails. Flammable gas released to atmosphere.	Burner control system	
			Damper fails open.	MORE TEMPERATURE HEATED PRODUCT OUT		
			Stack partially blocked or damper fails partially open.	LESS TEMPERATURE HEATED PRODUCT OUT		
	Hot product	High tempe rature	Temperature control fails high	MORE TEMPERATURE HEATED PRODUCT OUT		
		Low tempe rature	Temperature control fails low	LESS TEMPERATURE HEATED PRODUCT OUT		
P101	Inlet/outl et	No flow	Pump fails.	NO FLOW FROM UPSTREAM UNITS		
				Furncae tubes overheat. Possible tube failure.		
			Flow control valve fails closed.	Full head pressure developed. Pump overheats. Seals damaged.	Kick back line.	
		More flow	Spare pump running in error.	MORE FLOW TO DOWNSTREAM UNIT		Ensure maintenance instructions preclude running parallel pumps incorrectly. Flow controller.

				MORE FLOW FROM UPSTREAM UNITS		As above.
			Pump seals fail	Environmental contamination.		Use canned pumps if necessary. Consider requirement for remote isolation.
				MORE FLOW FROM UPSTREAM UNITS		
				LESS FLOW TO DOWNSTREAM UNITS		
			Flow control valve fails open.	MORE FLOW TO DOWNSTREAM UNIT		
				MORE FLOW FRÓM UPSTREAM UNITS		
		Less flow	Flow control valve fails part open	LESS FLOW TO DOWNSTREAM UNITS		
				LESS FLOW FROM UPSTREAM UNITS		
E101	Heated Stream Out	As well as flow	Heat exchanger interface failure	CONTAMINATI ON DOWNSTREAM		
	Cooled Stream Out	As well as flow	Heat exchnager interface failure	CONTAMINATI ON DOWNSTREAM		

Table A2.1 (cont.) – Benzene plant modular HAZOP results.

H101	Fuel Gas In	No flow	Burner control fails shut	LESS TEMPERATURE		
		More flow	Burner control fails open	Furnace tubes overheat. Furnace tubes fail. Serious explosion risk.	Temperature indicator. □ Snuffing steam. □ Damper control.	Is there a need for high temperature alarm, high temperature trip?
			Burners fail to ignite	Explosion risk.	Flame failure alarm. □ Burner control system.	
		Less flow	Burner control fails to open sufficiently	Flame fails. Explosive atmosphere develops.	Flame failure alarm. Burner control system.	
				LESS TEMPERATURE	Damper control.	
		Less pressure	Burners partially blocked.	LESS TEMPERATURE	Damper control.	
	Stack	No flow	Stack blocked. Damper fails shut.	LESS TEMPERATURE		
				Flame fails. Explosive atmosphere develops.	Flame failure alarm. □ Burner control system.	

		More flow	Stack damper fails open	MORE TEMPERATURE		
		Less flow	Stack partially blocked. □ Stack damper fails to open sufficiently.	LESS TEMPERATURE		
	Feed	More flow	Furnace tubes leak.	Explosion risk.		
R101	Reactor feed from H101	Low pressure	Leak to environment	Environmental damage. Fire / explosion risk.		
	Recycle feed	No flow	Temperature control valve fails shut.	High temperature. □ Possible runaway reaction.	High temperature alarm. □ Temperature indicator.	
				HIGH TEMPERATURE		
		High flow	Temperature control valve fails open	Low temperature. Slow conversion.		
	Outlet	Less flow	Outlet line partially blocked by catalyst	LESS FLOW		
C101	Inlet	No flow	Compressor failure	NO FLOW		

Table A2.1 (cont.) – Benzene plant modular HAZOP results.

		Less flow	Compressor operating incorrectly	LESS FLOW		
	Outlet	Conta minati on	Compressor oil lube contaminates recycle stream	CONTAMINATI ON		

Appendix 3 – Modular HAZOP Library

The following pages provide some examples of components of a module library. These components could include descriptions of the modules and sub-modules including their design and operation philosophy, line diagrams and, of course, the preHAZOPed results.

The first part of this appendix describes the models and the second part contains the preHAZOPed results. The nodes referred to in the description of the model sub-modules refer to the preHAZOPed results.

A3.1 Cooling Water Supply System

A3.1.1 Sub-Modules Required

- Cooling Water Tower.
- Water top up.
- Cooling Water Pond.
- Cooling Water Supply Main.
- Cooling Water Return.
- Cooling Water Purge.
- Cooling Water Dosing.

A3.1.2 Specific Sub-Modules Available

The following specific sub-modules have been developed.

A3.1.2.1 Cooling Water Tower

- Single tower with fan.
- Multiple towers with fans.

A3.1.2.2 Water Top Up

- Pumped water top-up from reservoir. (Node 1)
- Water top up from header tank. (Node 10)
- Water top up from main.

A3.1.2.3 Cooling Water Pond

- Cooling Water Pond.

A3.1.2.4 Cooling Water Supply Main

- Cooling water supply main with multiple running pumps. (Node 5)

A3.1.2.5 Cooling Water Return

- Cooling water return. (Node 2)

A3.1.2.6 Cooling Water Purge

- Cooling water purge, manually adjusted. (Node 8)
- Cooling water purge, automatic control. (Node 9)

A3.1.2.7 Cooling Water Dosing

Choose sufficient dosing sub-modules to minimise problems due to corrosion, scaling, and micro-biological fouling.

- NALCO A.Z. LITE Scale and corrosion, automatic control. (Node 6)
- NALCO A.Z. LITE Scale and corrosion, manual control. (Node 7)
- Acid dosing, automatic control. (Node 11)
- Acid dosing, manual control. (Node 12)

A3.2 Reactor Modules

There are number of different types of reactor module. These exist mainly to differentiate between the different types of reaction that will occur, such as exothermic or endothermic and gas phase or liquid phase.

The sub-modules required will be different depending on the particular reactor module used.

A3.2.1 Exothermic Liquid Phase Reactor

Figure A3.1 illustrates how an exothermic reactor made up of a variety of different sub-modules taken from the module library for the reactor. This is an example to illustrate how the sub-modules can be added together to produce a fairly complex module.

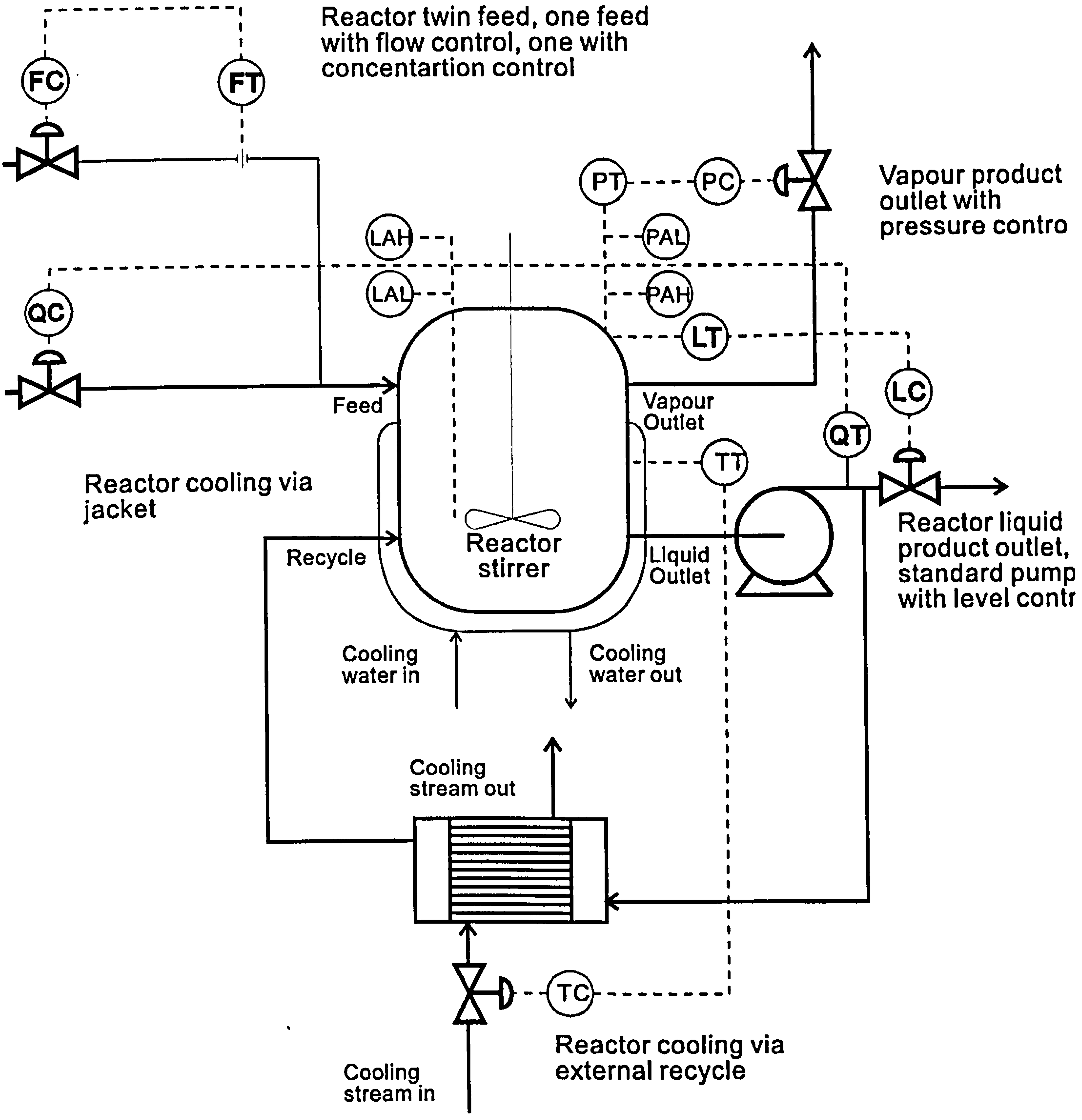


Figure A3.1 – Example reactor module made up of variety of sub-modules.

A3.2.2 Required sub-modules

- Reactor vessel.
- Reactor liquid feed(s).
- Reactor liquid outlet.
- Reactor cooling system.
- Reactor vent system.

A3.2.3 Additional generic sub-modules

- Stirrer.
- Catalyst.

A3.2.4 Exothermic Liquid Phase Reactor Specific Sub-Modules

A3.2.4.1 Reactor Vessel

Reactor vessel sub-module is illustrated in figure A3.2.

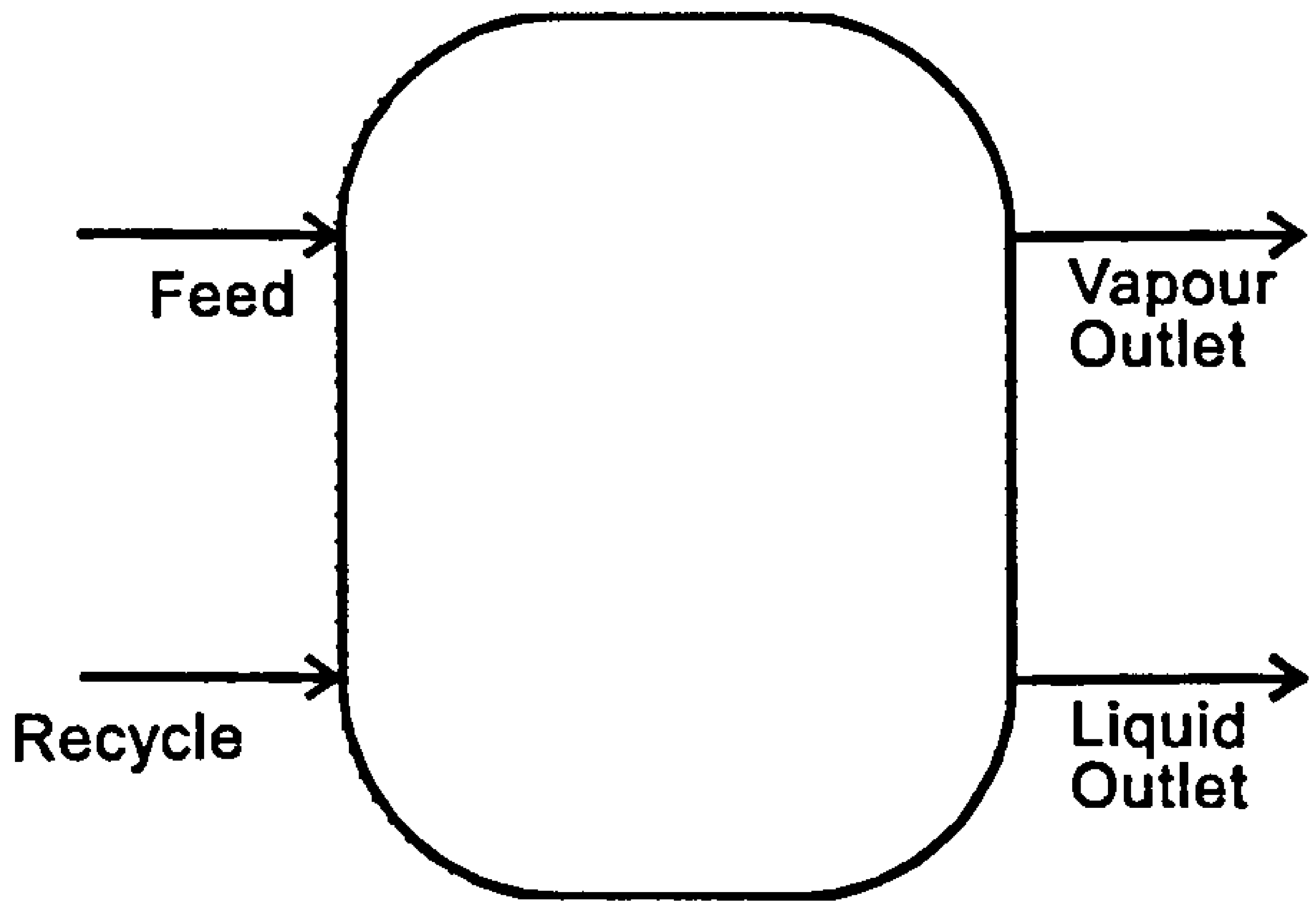


Figure A3.2 – Reactor vessel sub-module.

A3.2.4.2 Reactor Liquid Feed

The following sub-modules are available:

- Reactor liquid feed with flow control. (Node 1)

- Reactor liquid feed with concentration control. (Node 12)
- Reactor liquid feed with level control.

Use as many as are required to represent different reactor feeds. Figure A3.3 illustrates an arrangement of reactor feeds comprising one feed with flow control and one feed with concentration control comprising the appropriate sub-modules.

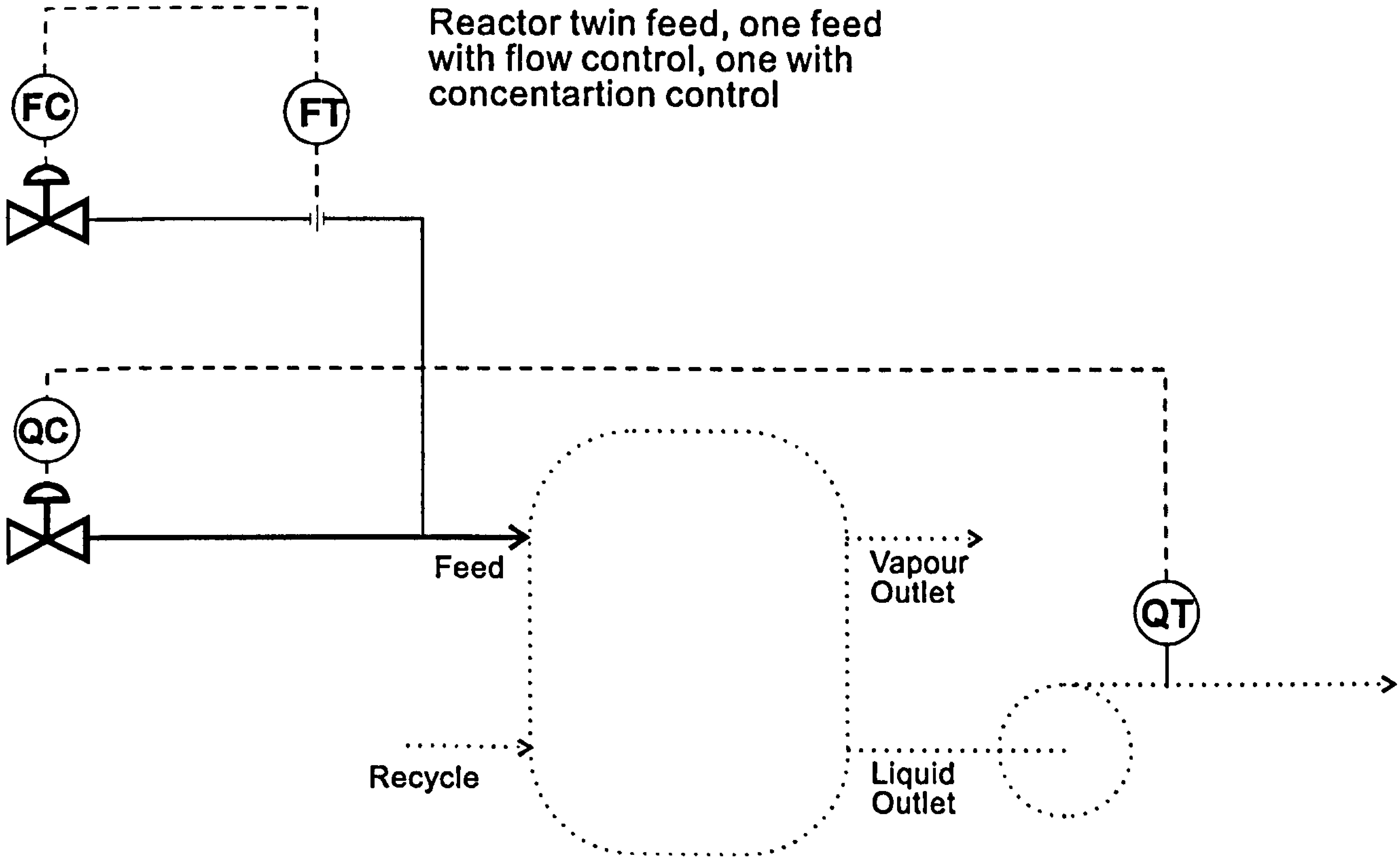


Figure A3.3 – Reactor twin feed with flow and concentration control.

A3.2.4.3 Reactor Liquid Outlet

Use one of the following nodes:

- Reactor liquid outlet with level control. (Figure A3.4) (Node 11)
- Reactor liquid outlet with flow control. (Node 3)

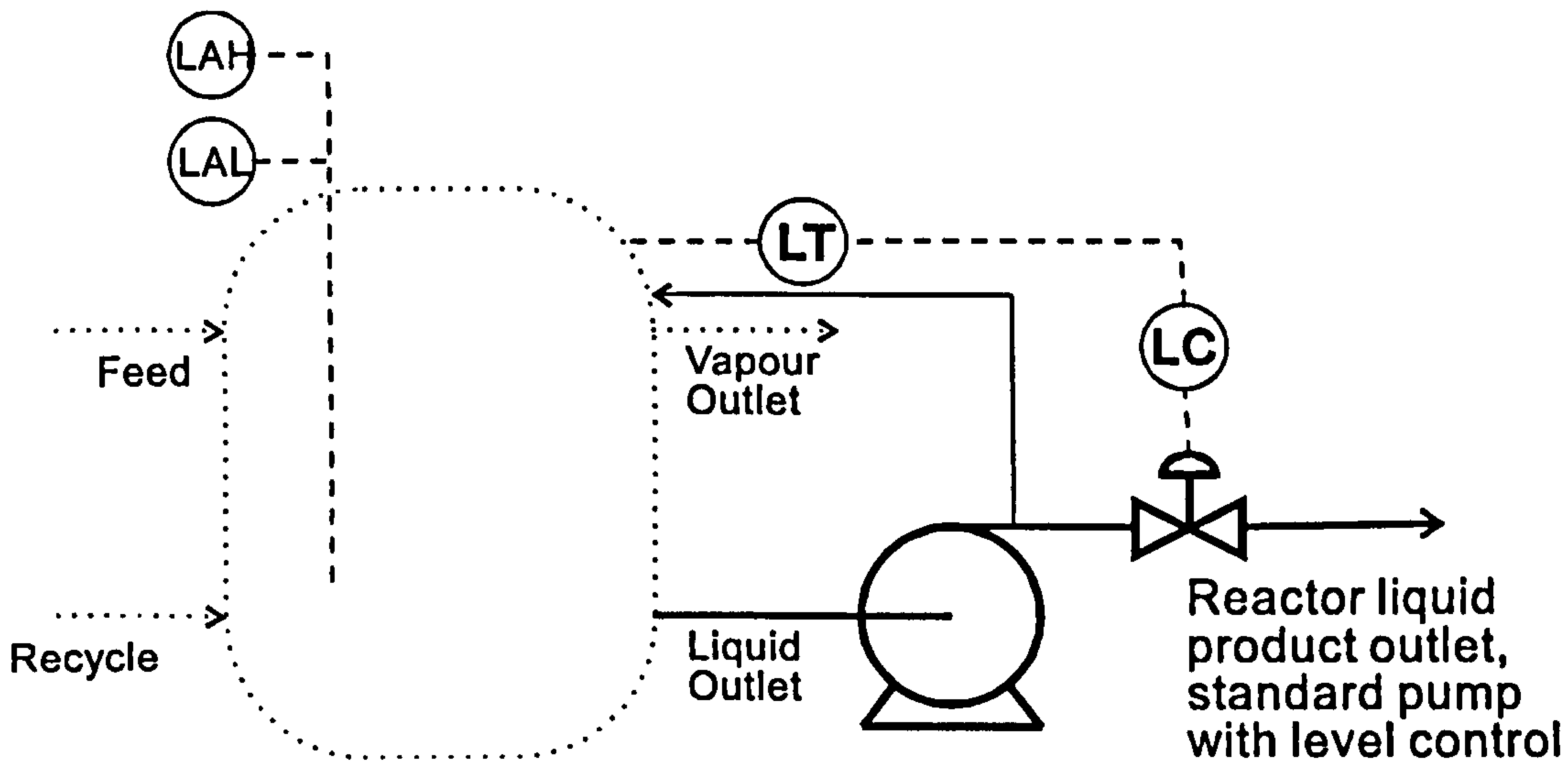


Figure A3.4 – Reactor sub-module – liquid outlet with level control.

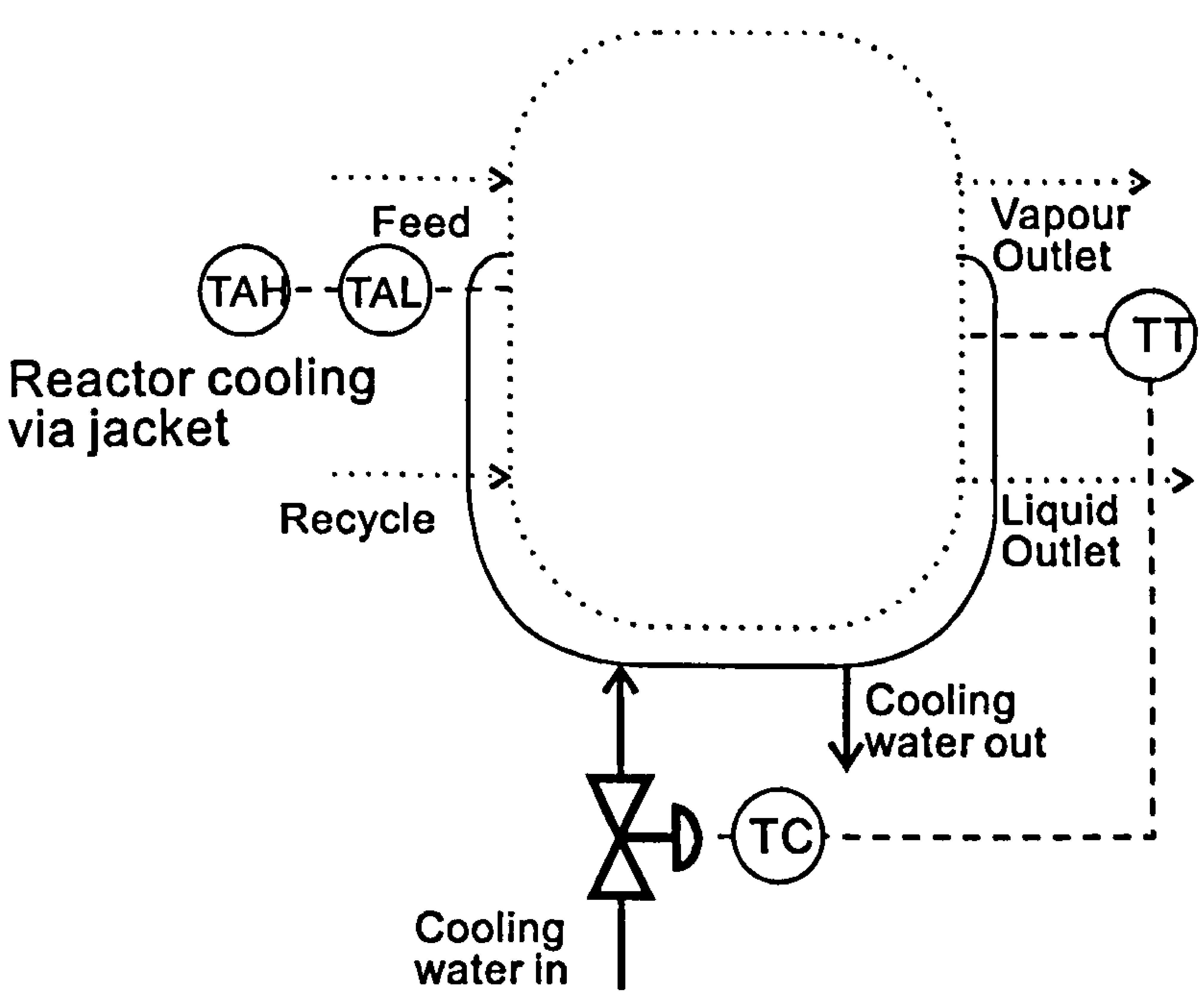
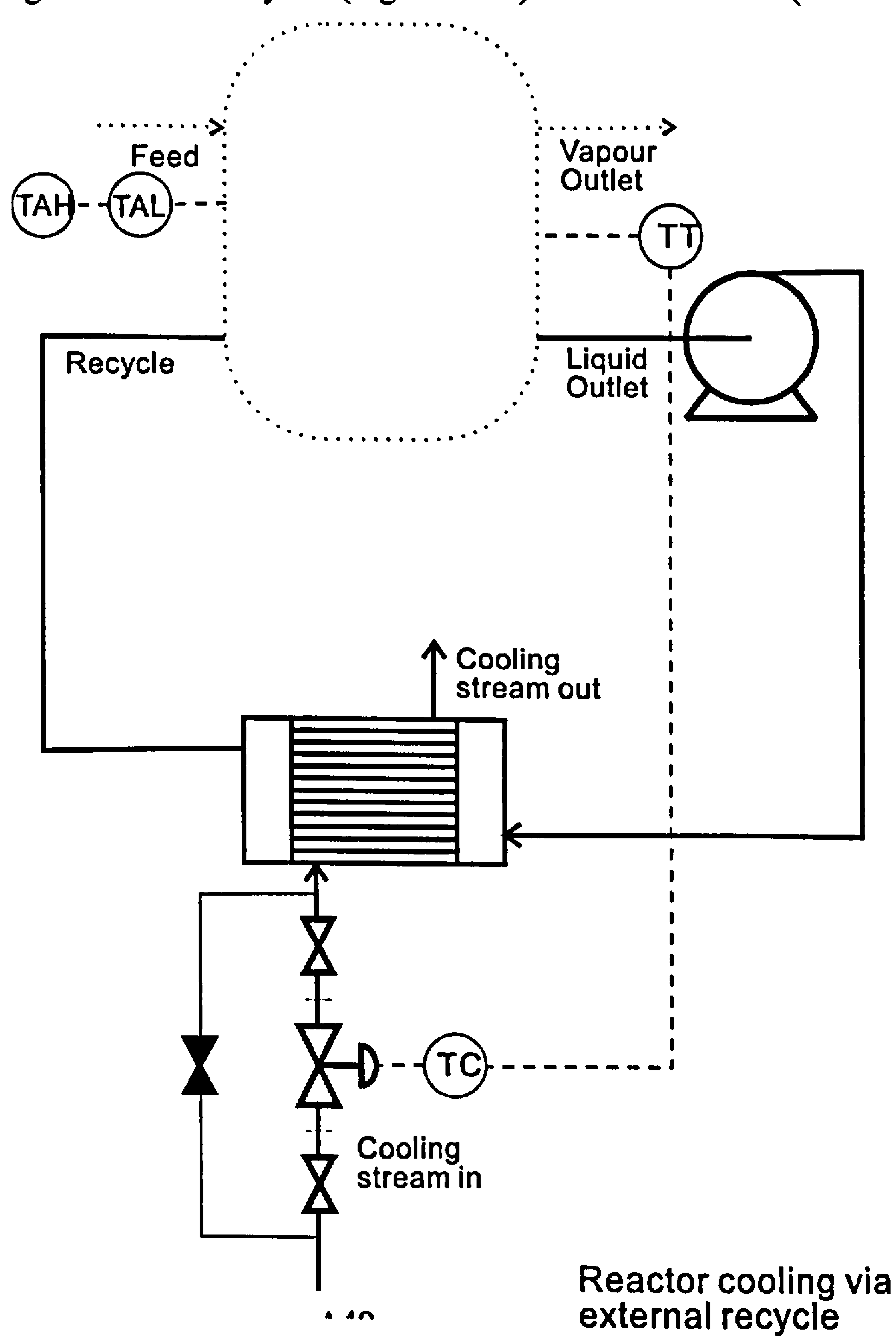


Figure A3.5 – Reactor cooling via jacket.

A3.2.4.4 Reactor Cooling System

The choice of nodes differs depending on the cooling system equipment used. One cooling stream in and one cooling stream out node will both be required. One other node is required to represent the interface equipment, either a reactor jacket or an external heat exchanger.

- Cooling stream in with temperature control. (Node 4)
- Cooling stream in without control valve. (Node 13)
- Cooling stream out. (Node 5)
- Reactor cooling by jacket. (Figure A3.5)
- Reactor cooling via external recycle. (Figure A3.6) (Node 6)



A3.6 – Reactor cooling via external recycle.

A3.2.4.5 Reactor Vent System

Choice of nodes depends on the gas outlet or venting arrangement.

For a simple vent to atmosphere use the following node:

- Reactor vent to atmosphere. (Node 14)

For a nitrogen blanketed vent system use the appropriate combination of the following nodes:

- Nitrogen vent supply, continuous feed through RO. (Node 15)
- Nitrogen vent supply with pressure control. (Node 16)
- Vent to header without control valve. (Node 17)
- Vent to header with pressure control. (Figure A3.7) (Node 18)

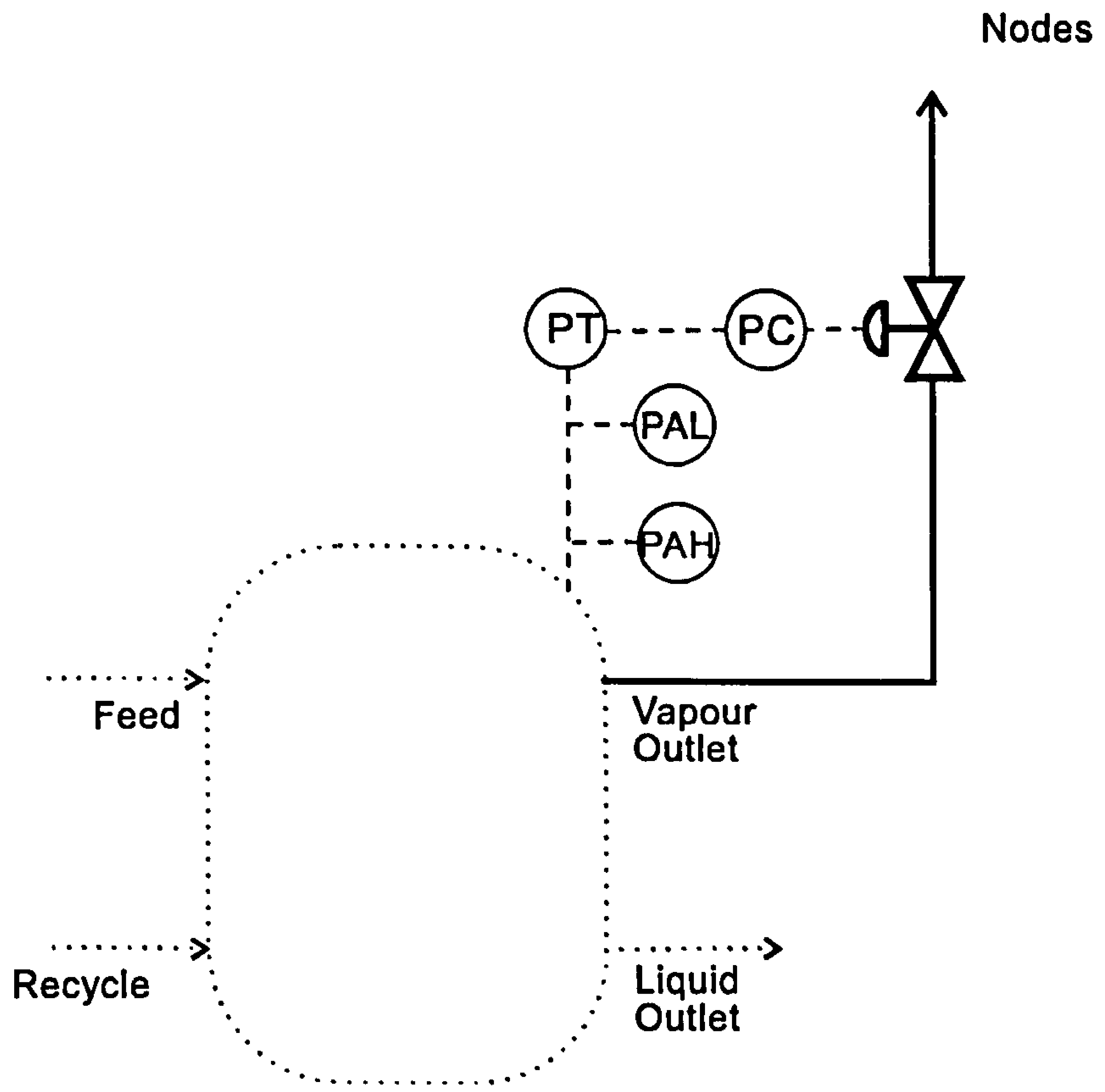


Figure A3.7 – Reactor sub-module – Vent to header with pressure control.

A3.2.4.6 Stirrer

Use the following node:

- Reactor Stirrer. (Figure A3.8)

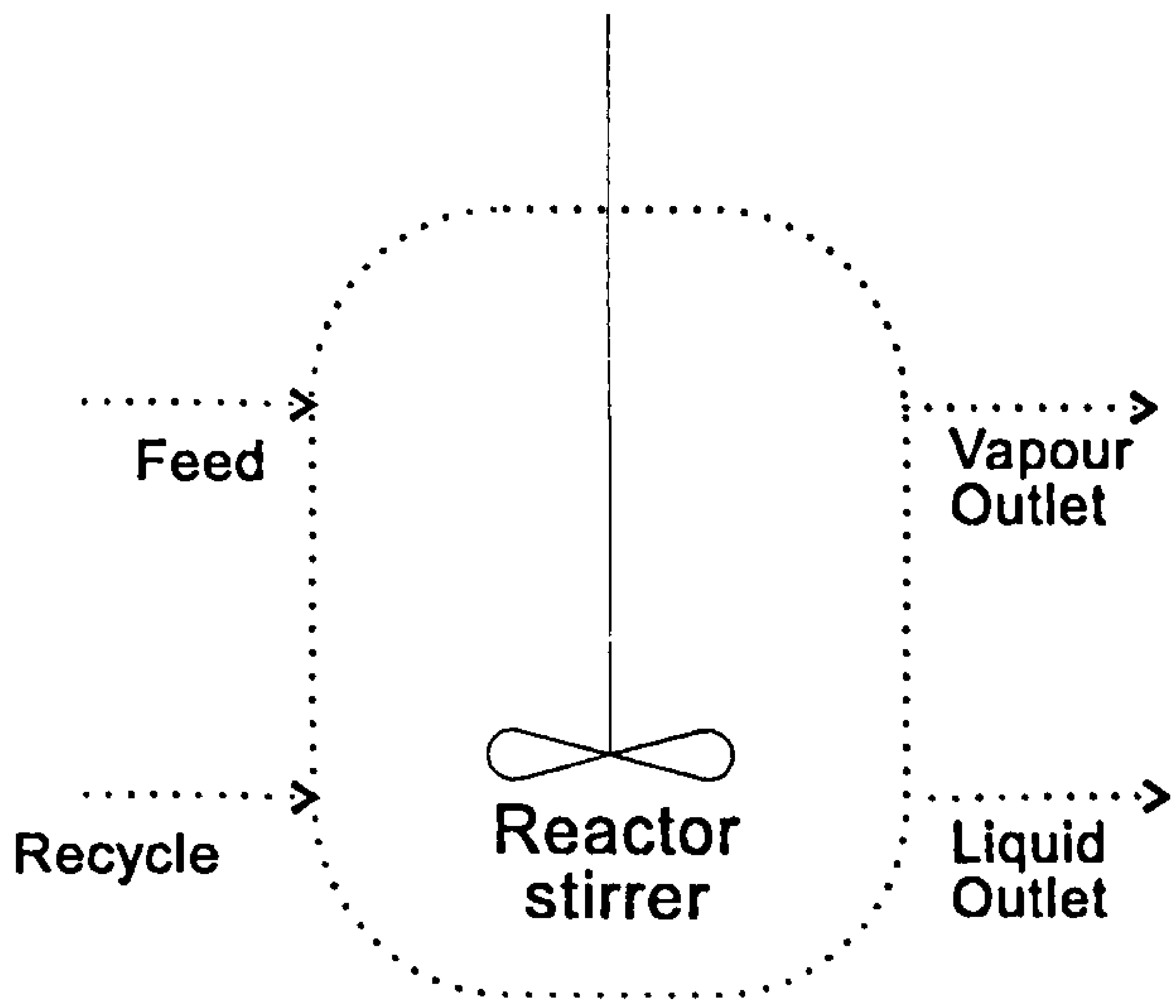


Figure A3.8 – Reactor sub-module – stirrer.

A3.2.4.7 Catalyst

Use the following node:

- Fixed solid catalyst bed.

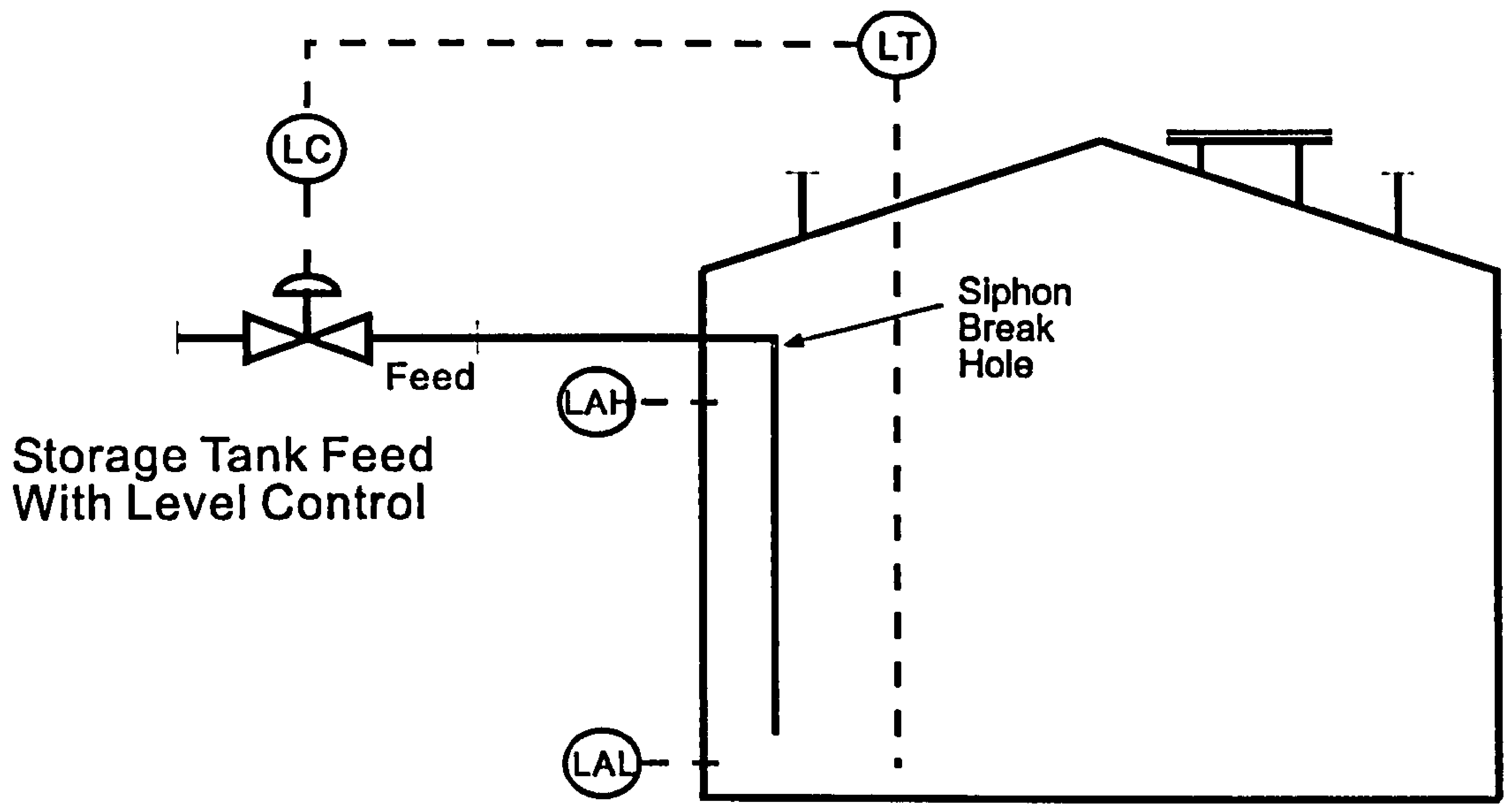


Figure A3.9 – Storage tank sub-modules - feed with level control.

A3.3 Atmospheric Storage Tank Module

A3.3.1 Required sub-modules

- Storage tank vessel.
- Storage tank feed(s).
- Storage tank outlet.
- Storage tank vent system.
- Storage tank overflow.

A3.3.2 Additional sub-modules

None.

A3.3.3 Available Specific Sub-Modules

A3.3.3.4 Storage Tank Vessel

Use the following node:

- Storage tank vessel. (Node 5)

A3.3.3.5 Storage Tank Feed

The following nodes may be used. Use as many as are required to represent different reactor feeds.

- Storage tank feed with flow control. (
- Storage tank feed with level control. (Figure A3.9) (Node 1)
- Storage tank feed without control valve. (Figure A3.10) (Node 13)

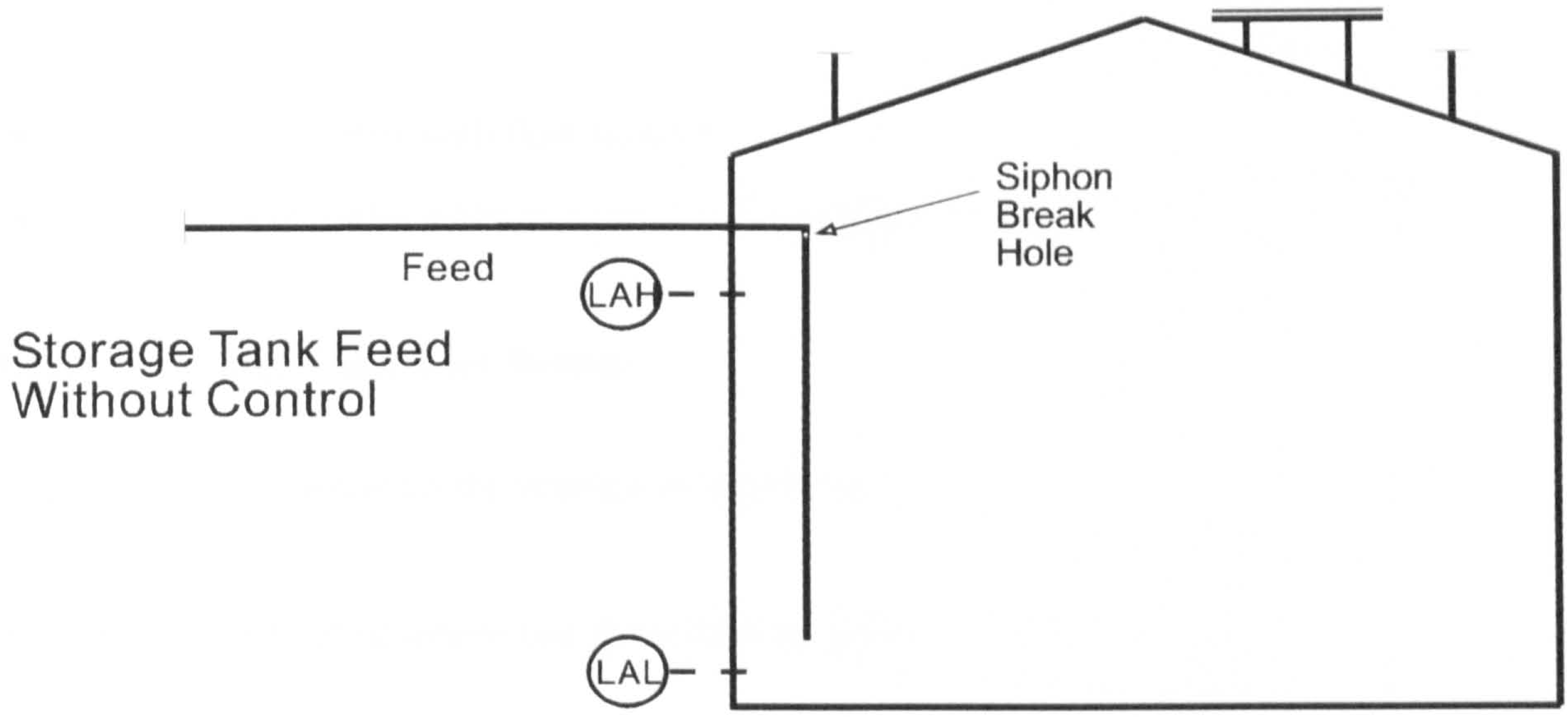


Figure A3.10 – Storage tank sub-module – feed without control.

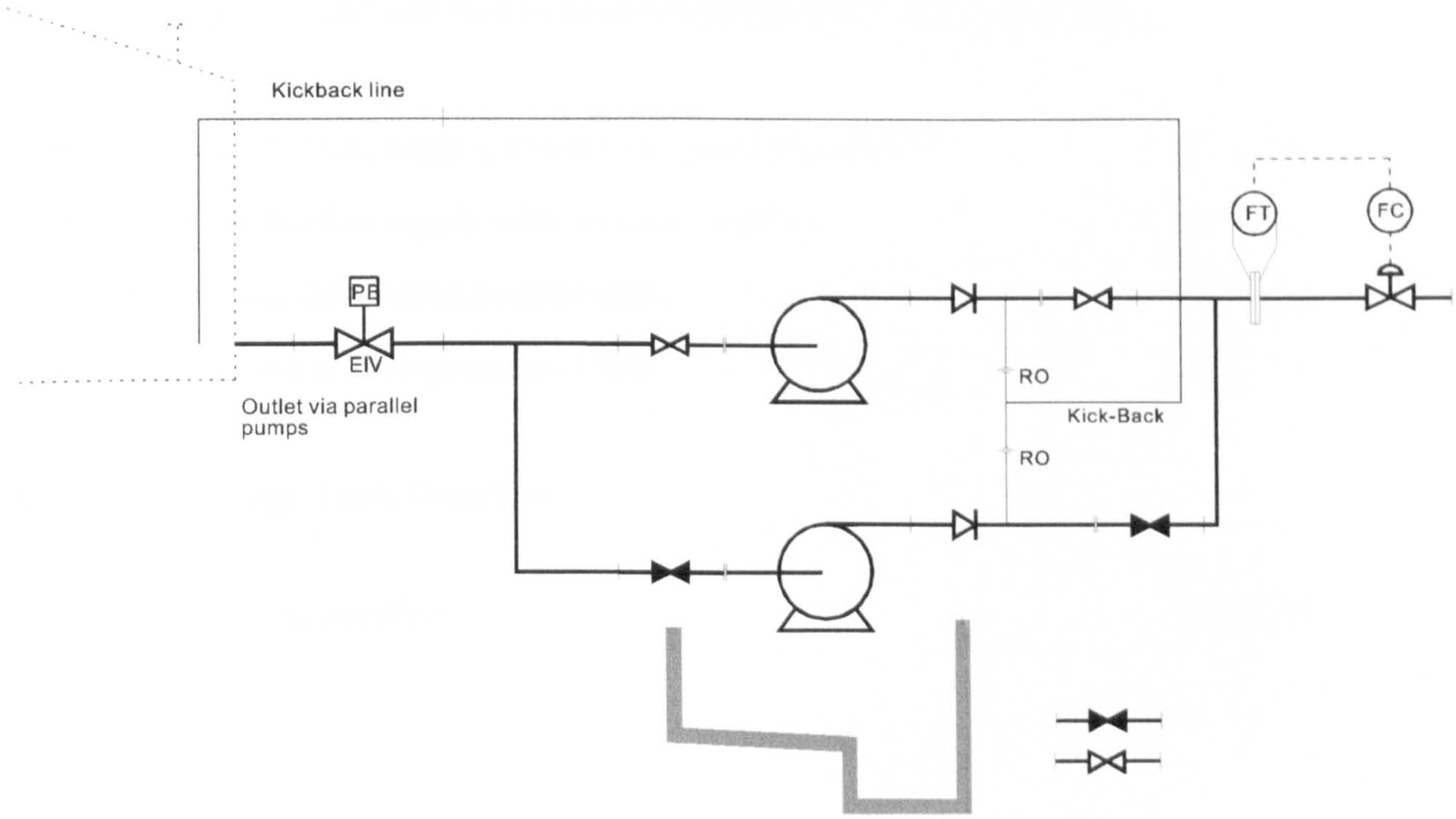


Figure A3.11 – Storage tank sub-module – outlet via parallel pumps.

A3.3.3.6 Storage Tank Outlet

Use one of the following nodes:

- Storage tank outlet with flow control. (
- Storage tank outlet without control valve. (Figure A3.11) (Node 4)

A3.3.3.7 Storage Tank Vent System

Choice of nodes depends on the venting arrangement.

For a simple vent to atmosphere use the following node:

- Storage tank vent to atmosphere. (Node 2)

For a nitrogen blanketed vent system, such as that illustrated in figure A3.12, use one blanket supply node and one vent to header node from the following nodes:

- Nitrogen blanket supply, continuous feed through RO. (Node 6)
- Nitrogen blanket supply with pressure control (Node 7)
- Vent to header without control valve (Node 8)
- Vent to header with pressure control (Node 9)

A3.3.3.8 Storage Tank Overflow

- Storage tank overflow (Node 3)

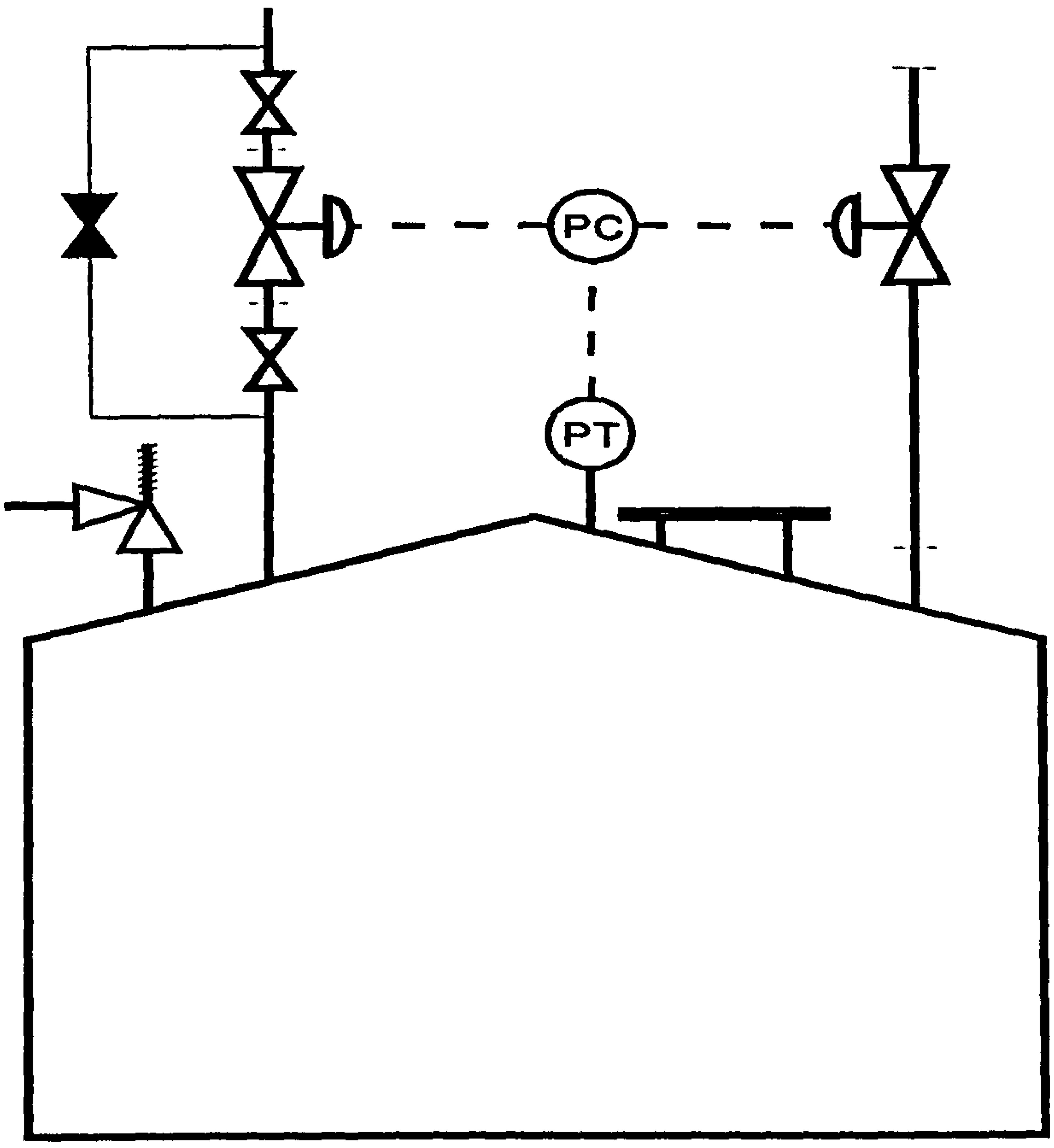


Figure A3.12 – Nitrogen blanket system.

TEXT BOUND INTO

THE SPINE

BLANK IN ORIGINAL

Worksheet

Company: MODHAZ
Facility: Cooling Water System

Page: 1

Revision: 0 12 Dec 95
Node: 1 Water top up - single supply, single pump and float valve.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow	1.1. Inline filter blocked. Float valve fails shut. Pump failure.	IC	1.1.1. Level in cold well cannot be maintained. Cooling water supply may be restricted.	EE				
	1.2. NO FLOW FROM UPSTREAM SUPPLY	VUL	1.2.1. Level in cold well cannot be maintained. Cooling water supply may be restricted.	EE			1.2.1.1. If the supply is unreliable consider the need for a backup supply. See appropriate node.	
2. More Flow	2.1. Float valve fails open.	IC	2.1.1. Cold well overflows. Contamination due to dosing chemicals.	EE	2.1.1.1. Suitable overflow to drain.			

Revision: 0 12 Dec 95
Node: 1 Water top up - single supply, single pump and float valve.
Parameter: Temperature

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Higher Temperature								
2. Lower Temperature	2.1. Low ambient temperature leads to freezing, particularly as there may be no flow for long periods of time.	IC	2.1.1. Prolonged cold weather may reduce availability of cooling water.					

Table A3.1 – Cooling water system sub-modules – preHAZOPed results.

Company: MODHAZ
Facility: Cooling Water System

Revision: 0 6 Feb 96
Node: 2 Cooling water return to tower.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Less Flow	1.1. Purge to drain valve left open or fails open. Spray nozzles become blocked.	IC	1.1.1. Cooling water tower performance falls off. Cooling water supply may be restricted during periods of high deamand.	EE	1.1.1.1. Regualr inspection.			

Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Worksheet

Company: MODHAZ
Facility: Cooling Water System

Page: 3

Revision: 0   6 Feb 96
Node: 3 Cooling water supply main - single pump.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow	1.1. Pump failure.	IC	1.1.1. NO FLOW TO DOWNSTREAM UNITS	DPE	1.1.1.1. Low flow alarm.		1.1.1.1. If cooling water supply must be maintained at all times	

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Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Company: MODHAZ
Facility: Cooling Water System

Revision: 0 6 Feb 96
Node: 5 Cooling water supply main - 2 or more pumps.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Less Flow	1.1. Pump failure.	IC	1.1.1. LESS FLOW TO DOWNSTREAM UNITS. Only likely to be a problem during periods of high demand.	DPE	1.1.1.1. Appropriate alarms on pumps. 1.1.1.2. Low flow alarm on supply main.			
More/Dev	HIGH FLOW DOWNSTREAM UNIT	VUL						
2. Reverse Flow	2.1. Pump not running	IC	2.1.1. Reverse flow through pump back into cooling water pond.	EE	2.1.1.1. Separate non-return valves on all pump discharges.			

Revision: 0 20 Feb 96
Node: 5 Cooling water supply main - 2 or more pumps.
Parameter: Maintenance

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Part Of Maintenance	1.1. High cooling water demand e.g. due to hot weather.	IC	1.1.1. Unable to meet demand due to pump down for maintenance. Unable to carry out maintenance due to high cooling water demand.	EE			1.1.1.1. Planned maintenance should be scheduled for periods of low cooling water demand.	

Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Worksheet

Company: MODHAZ
Facility: Cooling Water System

Revision: 0 6 Feb 96
Node: 5 Cooling water supply main - 2 or more pumps.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Less Flow More flow	1.1. Pump failure. HIGH FLOW DOWNSTREAM UNIT	IC UU	1.1.1. LESS FLOW TO DOWNSTREAM UNITS. Only likely to be a problem during periods of high demand.	DPE	1.1.1.1. Appropriate alarms on pumps. 1.1.1.2. Low flow alarm on supply main.			
2. Reverse Flow	2.1. Pump not running	IC	2.1.1. Reverse flow through pump back into cooling water pond.	EE	2.1.1.1. Separate non-return valves on all pump discharges.			

Revision: 0 20 Feb 96
Node: 5 Cooling water supply main - 2 or more pumps.
Parameter: Maintenance

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Part Of Maintenanc e	1.1. High cooling water demand e.g. due to hot weather.	IC	1.1.1. Unable to meet demand due to pump down for maintenance. Unable to carry out maintenance due to high cooling water demand.	EE			1.1.1.1. Planned maintenance should be scheduled for periods of low cooling water demand.	

Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Worksheet

Company: MODHAZ
Facility: Cooling Water System

Page: 6

Revision: 0 6 Feb 96
Node: 6 NALCO A.Z.LITE 98 dosing - scale and corrosion inhibition. Feed by automatic dosing control.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow								
2. Less Flow	2.1. Automatic dosing control fails, delivering less chemical than required. Dosing chemical supply exhausted.	IC	2.1.1. Rapid corrosion of steel piping and vessels.	EE	2.1.1.1. Routine and regular testing. 2.1.1.2. Low level alarm.			
3. Other Than Flow	3.1. NALCO A.Z.LITE 98 is not sutable for use with aluminium.	IC	3.1.1. INCOMPATIBILITY WITH ALUMINIUM	SPE				

Revision: 0 6 Feb 96
Node: 6 NALCO A.Z.LITE 98 dosing - scale and corrosion inhibition. Feed by automatic dosing control.
Parameter: Maintenance

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Part Of Maintenance	1.1. Spillage of dosing chemical during refilling or changing of drums.	IC	1.1.1. Dosing chemical is strongly acidic.	EE	1.1.1.1. Personnel to wear suitable protective equipment.			
			1.1.2. Environmental contamination.	EE	1.1.2.1. Drums to be situated in an area where spillages can be contained and dealt with appropriately to minimise the effects of spillages.			
	1.2. Incorrect storage of dosing chemical	IC	1.2.1. Dosing chemical should not be stored in steel tanks/drums.	EE			1.2.1.1. Storage and application equipment used for NALCO A.Z.LITE 98 should be made from polypropylene, polyethylene, PVC, Neoprene,Viton, Hypalon, PTFE or acrylic resin. Do not use carbon steel, stainless steel, copper, brass, aluminium or cast iron in contact with the neat product.	

Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Company: MODHAZ
Facility: Cooling Water System

Revision: 0 6 Feb 96
Node: 6 NALCO A.Z.LITE 98 dosing - scale and corrosion inhibition. Feed by automatic dosing control.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow								
2. Less Flow	2.1. Automatic dosing control fails, delivering less chemical than required. Dosing chemical supply exhausted.	IC	2.1.1. Rapid corrosion of steel piping and vessels.	EE	2.1.1.1. Routine and regular testing. 2.1.1.2. Low level alarm.			
3. Other Than Flow	3.1. NALCO A.Z.LITE 98 is not sutable for use with aluminium.	IC	3.1.1. INCOMPATIBILITY WITH ALUMINIUM	SPE				

Revision: 0 6 Feb 96
Node: 6 NALCO A.Z.LITE 98 dosing - scale and corrosion inhibition. Feed by automatic dosing control.
Parameter: Maintenance

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Part Of Maintenance	1.1. Spillage of dosing chemical during refilling or changing of drums.	IC	1.1.1. Dosing chemical is strongly acidic.	EE	1.1.1.1. Personnel to wear suitable protective equipment.			
			1.1.2. Environmental contamination.	EE	1.1.2.1. Drums to be situated in an area where spillages can be contained and dealt with appropriately to minimise the effects of spillages.			
	1.2. Incorrect storage of dosing chemical	IC	1.2.1. Dosing chemical should not be stored in steel tanks/drums.	EE			1.2.1.1. Storage and application equipment used for NALCO A.Z.LITE 98 should be made from polypropylene, polyethylene, PVC, Neoprene,Viton, Hypalon, PTFE or acrylic resin. Do not use carbon steel, stainless steel, copper, brass, aluminium or cast iron in contact with the neat product.	

Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Company: MODHAZ
Facility: Cooling Water System

Revision: 0 6 Feb 96
Node: 7 NALCO A.Z.LITE 98 dosing - sacle and corrosion inhibition. Manually controlled feed.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Less Flow	1.1. Monitoring of chemical concentration fails, resulting in delivery of less chemical than required. Dosing chemical supply exhausted.	IC	1.1.1. Rapid corrosion of steel piping and vessels.	EE	1.1.1.1. Routine and regular testing. 1.1.1.2. Level indication.		1.1.1.1. Ensure storage of dosing chemical is sufficent that it will never be in short supply. Bear in mind more dosing chemicals will be used in hotter weather.	
	1.2. Incorrect dosing routine. Dosing should be continuous.	IC	1.2.1. Rapid corrosion of steel piping and vessles.	EE	1.2.1.1. Operating instructions.		1.2.1.1. Slug dosing should not be used.	
2. Other Than Flow	2.1. NALCO A.Z.LITE 98 is not sutable for use with aluminium.	IC	2.1.1. INCOMPATIBILITY WITH ALUMINIUM					

Revision: 0 6 Feb 96
Node: 7 NALCO A.Z.LITE 98 dosing - sacle and corrosion inhibition. Manually controlled feed.
Parameter: Maintenance

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Part Of Maintenance	1.1. Spillage of dosing chemical during refilling or changing of drums.	IC	1.1.1. Dosing chemical is strongly acidic.	EE	1.1.1.1. Personnel to wear suitable protective equipment.			
			1.1.2. Environmental contamination.	EE	Drums to 1.1.2.1. be situated in an area where spillages can be contained and dealt with appropriately to minimise the effects of spillages.			
	1.2. Incorrect storage of dosing chemical	IC	1.2.1. Hydrogen may be released if neat chemical is in contact with many metals.	EE			1.2.1.1. Storage and application equipment used for NALCO A.Z.LITE 98 should be made from polypropylene, polyethylene, PVC, Neoprene, Viton, Hypalon, PTFE or acrylic resin. Do not use carbon steel, stainless steel, copper, brass, aluminium or cast iron in contact with the neat product.	

Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Worksheet

Company: MODHAZ
Facility: Cooling Water System

Revision: 0   6 Feb 96
Node: 8 Purge to drain - controlled by automatic dosing control.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. More Flow	1.1. Automatic dosing control fails opening control valve.	IC	1.1.1. Wastage of cooling water and dosing chemicals.	EE	1.1.1.1. Orifice plate to minimise maximum possible flow rate.			
2. Less Flow	2.1. Automatic dosing control fails closing control valve.	IC	2.1.1. Increased scaling, general solids deposition, and fouling problems.	EE				

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Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Company: MODHAZ
Facility: Cooling Water System

Revision: 0 6 Feb 96
Node: 9 Purge to drain - manually adjusted.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. More Flow	1.1. Chemical concentration monitoring fails requiring purge valve to be opened more than necessary. Purge valve inadvertantly left further open than required.	IC	1.1.1. Wastage of cooling water and dosing chemicals.	EE	1.1.1.1. Orifice plate to minimise maximum possible flow rate.			
2. Less Flow	2.1. Purge valve insufficiently open.	IC	2.1.1. Increased scaling, general solids deposition, and fouling problems.	EE				

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Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Worksheet

Company: MODHAZ
Facility: Cooling Water System

Revision: 0   6 Feb 96
Node: 10   Water top up - single supply via header tank.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow	1.1. Float valve fails shut.	IC	1.1.1. Level in cold well cannot be maintained. Cooling water supply may be restricted.	EE				
2. More Flow	2.1. Float valve fails open.	IC	2.1.1. Cold well overflows. Contamination due to dosing chemicals.	EE	2.1.1.1. Suitable overflow to drain.			
			2.1.2. Starvation of header tank.	EE	2.1.2.1. Orifice plate may be required to minimise maximum possible flowrate.			

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Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Company: MODHAZ
Facility: Cooling Water System

Revision: 0 6 Feb 96
Node: 11 Acid dosing - automatically controlled.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Less Flow	1.1. Automatic dosing control fails, delivering less acid than required. Acid supply exhausted.	IC	1.1.1. pH should be maintained between pH7-8 to maintain non-scaling, non-corrosive conditions in the system.	EE	1.1.1.1. Routine and regular testing. 1.1.1.2. Low level alarm.			
2. More Flow	2.1. Automatic dosing control fails, delivering more acid than required. Acid supply exhausted.	IC	2.1.1. pH should be maintained between pH7-8 to maintain non-scaling, non-corrosive conditions in the system.	EE	2.1.1.1. Routine and regular testing.			

Table A3.1 (cont.) – Cooling water system sub-modules – preHAZOPed results.

Company:
Facility: Exothermic Reactor

Revision: 0 24 Mar 95
Node: 1 Reactor liquid feed with flow control
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Feed line blocked. Control valve fails shut.	IC	1.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	1.1.1.1. Low flow alarm		
			1.1.2. NO FLOW FROM UPSTREAM UNITS	DPE	1.1.2.1. Low flow alarm		
2. More Flow	2.1. Control valve fails open	IC	2.1.1. Incomplete conversion of reactants	EE			
			2.1.2. HIGH FLOW TO UNIT DOWNSTREAM OF REACTOR OUTLET	IPE			
			2.1.3. HIGH FLOW FROM UPSTREAM UNITS	DPE			
3. Less Flow	3.1. Feed line partially blocked	IC	3.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	3.1.1.1. Flow control		
			3.1.2. LESS FLOW TO UNIT DOWNSTREAM OF REACTOR OUTLET	IPE	3.1.2.1. Flow control		
			3.1.3. LESS FLOW FROM UPSTREAM UNITS	DPE	3.1.3.1. Flow control		
	3.2. Control valve fails insufficiently open	IC	3.2.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	3.2.1.1. Flow control		
			3.2.2. LESS FLOW TO UNIT DOWNSTREAM OF REACTOR OUTLET	IPE	3.2.2.1. FLow control		
			3.2.3. LESS FLOW FROM UPSTREAM UNIT	DPE	3.2.3.1. Flow control		

Revision: 0 24 Mar 95
Node: 1 Reactor liquid feed with flow control
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
2. Lower Pressure	2.2. Feed line leaking.	IC	2.2.1. Reactionn does not proceed as required. Poor conversion, side reactions etc.	EE	2.2.1.1. Pressure control 2.2.1.2. FLow control		
			2.2.2. Environmental damage.	EE			

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Table A3.2 – Exothermic reactor sub-modules – preHAZOPed results (IC filtered).

Company:
Facility: Exothermic Reactor

Revision: 0 24 Mar 95
Node: 2 Vapour Out
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Vapour out line blocked. Control valve fails shut.	IC	1.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	1.1.1.1. Low flow alarm		
			1.1.2. NO FLOW AT UNITS UPSTREAM OF REACTOR FEED	IPE	1.1.2.1. Low flow alram		
			1.1.3. NO FLOW TO DOWNSTREAM UNITS	DPE	1.1.3.1. Low flow alarm		
2. More Flow	2.1. Control valve fails open	IC	2.1.1. Insufficient conversion of reactants.	EE	2.1.1.1. High flow alarm		
			2.1.2. MORE FLOW FROM UNITS UPSTREAM OF REACTOR FEED	IPE	2.1.2.1. High flow alarm		
			2.1.3. MORE FLOW TO DOWNSTREAM UNITS	DPE	2.1.3.1. High flow alarm		
3. Less Flow	3.1. Vapour outlet line partially blocked	IC	3.1.1. Reaction does not proceed as required. Poor conversion, side reactions, etc.	EE	3.1.1.1. Flow control 3.1.1.2. Low flow alarm		
			3.1.2. LOW FLOW TO DOWNSTREAM UNITS	DPE	3.1.2.1. Flow control 3.1.2.2. Low flow alarm		
			3.1.3. LOW FLOW FROM UNITS UPSTREAM OF REACTOR FEED	IPE	3.1.3.1. Flow control 3.1.3.2. Low flow alarm		
	3.2. Control valve fails insufficiently open	IC	3.2.1. Reaction does not procedd as required. Poor conversion, side reactions etc.	EE	3.2.1.1. Low flow alarm		
			3.2.2. LOW FLOW TO DOWNSTREAM UNITS	DPE	3.2.2.1. Low flow alarm		
			3.2.3. LOW FLOW FROM UNITS UPSTREAM OF REACTOR FEED	IPE	3.2.3.1. Low flow alarm		

Revision: 0 24 Mar 95
Node: 2 Vapour Out
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
2. Lower Pressure	2.1. Vapour out line leaks to atmosphere	IC	2.1.1. Environmental damage	EE			
			2.1.2. Reaction does not proceed as required. Poor conversion, side reactions, etc.	EE			

HAZOP-PC 3.02 by Primatech Inc.

Table A3.2 (cont.) – Exothermic reactor sub-modules – preHAZOPed results (IC filtered).

Company:
Facility: Exothermic Reactor

Revision: 0 24 Mar 95
Node: 3 Reactor liquid outlet with flow control
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flowz	1.1. Outlet line blocked	IC	1.1.1. Reactor overflows	EE	1.1.1.1. Low flow alram 1.1.1.2. High level alarm		
			1.1.2. Reaction does not proceed as required. Poor conversion, side effects, etc.	EE	1.1.2.1. Low flow alarm		
			1.1.3. NO FLOW FROM UNITS UPSTREAM OF REACTOR FEED	IPE	1.1.3.1. Low flow alarm		

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Table A3.2 (cont.) – Exothermic reactor sub-modules – preHAZOPed results (IC filtered).

Company:
Facility: Exothermic Reactor

Revision: 0 4 Sep 95
Node: 10 Reactor vessel self
Parameter: Maintenance

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Catalyst Removal Maintenance	1.1. Incorrect procedures.	IC	1.1.1. Toxic dust hazard. Reactor improperly isolated. Spent catalyst disposed of incorrectly.	EE	1.1.1.1. Permit to work. 1.1.1.2. Vessel isolated by slip plates and removable spools /elbows.		1.1.1.1. Ensure reaction vessel can be isolated and cleaned prior to personnel enetering vessel. Ensure personnel entering vessel have all necessary protective equipment and are trained in its use. Ensure correct equipment is available for safe removal of spent catalyst. Ensure spent catalyst can be disposed of safely and in accordance with statutory requirements.

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Table A3.2 (cont.) – Exothermic reactor sub-modules – preHAZOPed results (IC filtered).

Company:
Facility: Exothermic Reactor

Revision: 0 24 Mar 95
Node: 1 Reactor liquid feed with flow control
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.2. NO FLOW FROM UPSTREAM UNITS	VUL	1.2.1. Reaction does not proceed as required.	EE	1.2.1.1. Low flow alarm		
			1.2.2. NO FLOW TO UNITS DOWNSTREAM OF REACTOR OUTLET	IPE	1.2.2.1. Low flow alarm		
2. More Flow	2.2. HIGH FLOW FROM UPSTREAM UNITS	VUL	2.2.1. Incomplete conversion of reactants	EE	2.2.1.1. Flow control		
			2.2.2. HIGH FLOW TO UNIT DOWNSTREAM OF REACTOR OUTLET	IPE	2.2.2.1. Flow control		
3. Less Flow	3.3. LESS FLOW FROM UPSTREAM UNITS	VUL	3.3.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	3.3.1.1. Flow control		
			3.3.2. LESS FLOW TO UNIT DOWNSTREAM OF REACTOR OUTLET	IPE	3.3.2.1. Flow control		

Revision: 0 24 Mar 95
Node: 1 Reactor liquid feed with flow control
Parameter: Temperature

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Temperature	1.1. HIGH TEMPERATURE FROM UPSTREAM UNITS	VUL	1.1.1. Reaction begins to runaway. Possible explosion.	EE	1.1.1.1. Temperature control. 1.1.1.2. Relief valve required.		
			1.1.2. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	1.1.2.1. Temperature control		
2. Lower Temperature	2.1. LOW TEMPERATURE FROM UPSTREAM UNITS	VUL	2.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	2.1.1.1. Temperature control		
			2.1.2. Reaction does not proceed at required rate.	EE	2.1.2.1. Temperature control		

Revision: 0 24 Mar 95
Node: 1 Reactor liquid feed with flow control
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. HIGH PRESSURE FROM UPSTREAM UNITS	VUL	1.1.1. Reaction does not proceed as required. Poor conversion, side reactions, etc.	EE	1.1.1.1. Pressure control		
2. Lower Pressure	2.1. LOW PRESSURE FROM UPSTREAM UNITS	VUL	2.1.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	2.1.1.1. Pressure control		

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Table A3.3 – Exothermic reactor sub-modules – preHAZOPed results (VUL filtered).

Company:
Facility: Exothermic Reactor

Revision: 0 24 Mar 95
Node: 2 Vapour Out
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.2. NO FLOW TO DOWNSTREAM UNITS	VUL	1.2.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	1.2.1.1. Low flow alarm		
			1.2.2. NO FLOW AT UNITS UPSTREAM OF REACTOR FEED	IPE	1.2.2.1. Low flow alarm		
2. More Flow	2.2. HIGH FLOW TO DOWNSTREAM UNITS	VUL	2.2.1. Insufficient conversion of reactants	EE	2.2.1.1. High flow alarm. 2.2.1.2. Flow control		
			2.2.2. MORE FLOW FROM UNITS UPSTREAM OF REACTOR FEED	IPE	2.2.2.1. High flow alarm 2.2.2.2. Flow control		
3. Less Flow	3.3. LOW FLOW AT DOWNSTREAM UNITS	VUL	3.3.1. Reaction does not proceed as required. Poor conversion, side reactions etc.	EE	3.3.1.1. Low flow alarm		
			3.3.2. LOW FLOW FROM UNITS UPSTREAM OF REACTOR FEED	IPE	3.3.2.1. Low flow alarm.		

Revision: 0 24 Mar 95
Node: 2 Vapour Out
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. HIGH PRESSURE AT DOWNSTREAM UNIT	VUL	1.1.1. Reaction does not proceed as required. Poor conversion, side reactions, etc.	EE			
2. Lower Pressure	2.2. LOW PRESSURE AT DOWNSTREAM UNIT	VUL	2.2.1. Reaction does not proceed as required	EE			

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Table A3.3 (cont.) – Exothermic reactor sub-modules – preHAZOPed results (VUL filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 1 Inlet to tanker, controlled by batch meter (tanker loading operations)
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
2. More Flow	2.2. Batch meter control valve fails open. Operator enters wrong amount into batch meter control.	IC	2.2.1. Tanker overfilled	LOC	2.2.1.1. Overfilling alarm 2.2.1.2. Pressure trip		
	2.3. Hose ruptured.	IC	2.3.1. Leak to environment.	LOC			2.3.1.1. Ensure hoses are stored correctly, inspected frequently and changed regularly.
	2.4. Tanker moves off while loading operation still in progress. Driver drives off, tanker not parked securely, or tanker in conflict with other traffic.	IC	2.4.1. Leak to environment.	LOC	2.4.1.1. Dry break couplings. 2.4.1.2. Tanker immobilisation interlock.		2.4.1.1. Loading bay to be on level ground. Ensure tanker can be parked securely in bay at a reasonable distance from other traffic.

Revision: 0 12 Jun 95
Node: 1 Inlet to tanker, controlled by batch meter (tanker loading operations)
Parameter: Composition

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Other Than Compositio n	1.1. Wrong tanker connected	IC	1.1.1. Material incompatibility.	LOC			1.1.1.1. Use different connectors where material incompatibilty is a problem to so wrong tanker cannot be connected easily.
	1.2. Wrong material in tanker	IC	1.2.1. 1.2.1. Material incompatibility.	LOC			1.2.1.1. Check tanker contents before unloading if material incompatibility is a problem.

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Table A3.4 – Road tanker sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 12 Jun 95
Node: 2 Pumped outlet from tanker, no control (tanker offloading operations)
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Tanker outlet line blocked.	IC	1.1.1. Tanker not emptied as required.	LOC			
			1.1.2. NO FLOW TO DOWNSTREAM UNIT	PE			
2. More Flow	2.1. Hose ruptured.	IC	2.1.1. Leak to environment.	LOC			2.1.1.1. Ensure hoses are stored correctly, inspected frequently and changed regularly.
	2.2. Tanker moves off while offloading operation still in progress. Driver drives off, tanker not parked securely, or tanker in conflict with other traffic.	IC	2.2.1. Leak to environment.	LOC	2.2.1.1. Dry break couplings. 2.2.1.2. Tanker immobilisation interlock.		2.2.1.1. Loading bay to be on level ground. Ensure tanker can be parked securely in bay at a reasonable distance from other traffic.
3. Less Flow	3.1. Tanker outlet line partially blocked.	IC	3.1.1. Tanker takes longer to empty than normal	LOC			
			3.1.2. LESS FLOW TO DOWNSTREAM UNIT	PE			
4. Reverse Flow	4.1. Discharge pump fails	IC	4.1.1. REVERSE FLOW AT DOWNSTREAM UNIT	PE	4.1.1.1. Non-return valve		

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Table A3.4 (cont.) – Road tanker sub-modules – preHAZOPed results (IC filtered).

Worksheet

Company:
Facility:

Revision: 0 2 Jun 95
Node: 1 Inlet to tanker, controlled by batch meter (tanker loading operations)
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. NO FLOW FROM UPSTREAM UNIT	VUL	1.1.1. Tanker not filled as required.	LOC			
2. More Flow	2.1. MORE FLOW FROM UPSTREAM UNIT	VUL					
3. Less Flow	3.1. LESS FLOW FROM UPSTREAM UNIT	VUL	3.1.1. Tanker takes longer to fill than normal.	LOC	3.1.1.1. Overdue filling alarm.		

Revision: 0 12 Jun 95
Node: 1 Inlet to tanker, controlled by batch meter (tanker loading operations)
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. HIGH PRESSURE FROM UPSTREAM UNIT	VUL	1.1.1. Tanker overpressure rupture.	LOC	1.1.1.1. Relief valve		
2. Lower Pressure	2.1. LOW PRESSURE FROM UPSTREAM UNIT	VUL	2.1.1. Vessel takes longer to fill than normal	LOC			

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Table A3.5 – Road tanker sub-modules – preHAZOPed results (VUL filtered).

Company:
Facility:

Revision: 0 12 Jun 95
Node: 2 Pumped outlet from tanker, no control (tanker offloading operations)
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.2. NO FLOW AT DOWNSTREAM UNIT	VUL	1.2.1. Tanker not emptied as required	LOC			
3. Less Flow	3.2. LESS FLOW TO DOWNSTREAM UNIT	VUL	3.2.1. Tanker takes longer to empty than normal	LOC			
4. Reverse Flow	4.2. REVERSE FLOW FROM DOWNSTREAM UNIT	VUL	4.2.1. Tanker overfills. Environmental damage.	LOC			

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Table A3.5 (cont.) – Road tanker sub-modules – preHAZOPed results (VUL filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 1 Storage tank feed inlet with level control on tank.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Feed line blocked. Level control valve fails shut.	IC	1.1.1. Possible inability to continue process at normal production rates	EE			
			1.1.2. Low tank level leading to outlet pump cavitation.	EE	1.1.2.1. Low level alarm	CON	
					1.1.2.2. Level indicator	CON	
			1.1.3. NO FLOW AT UPSTREAM UNITS	DPE			
2. More Flow	2.1. Control valve fails open	IC	2.1.1. Inadequate venting. Vessel overpressure rupture.	EE	2.1.1.1. Relief valve.		2.1.1.1. Size vent adequately
			2.1.2. Static build up.	EE	2.1.2.1. Dip tubes for filling.		2.1.2.1. Flammable fluids only. If filling is not done via dip tubes check design assumptions.
			2.1.3. MORE FLOW AT UPSTREAM UNITS	DPE			
3. Less Flow	3.1. Feed line partially blocked. Control valve fails insufficiently open.	IC	3.1.1. Vessel takes longer to fill than normal	EE	3.1.1.1. Level indicator.	CON	
			3.1.2. LOW FLOW AT UPSTREAM UNIT	DPE	3.1.2.1. Level indicator.	CAU	

Revision: 0 2 Jun 95
Node: 1 Storage tank feed inlet with level control on tank.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.2. Feed line isolated.	IC	1.2.1. Expansion of locked in fluid causes hydraulic overpressure rupture of line.	EE	1.2.1.1. Hydraulic pressure relief	CON	1.2.1.1. Ensure operating instructions preclude deliberate isolation of line without having first drained line.
							1.2.1.2. Ensure design minimises opportunites for isolation in error due to control valves failing etc.
	1.3. Level control valve closes quickly. Manual valve on storage tank inlet closes quickly.	IC	1.3.1. LIQUID HAMMER. HIGH PRESSURE TO UPSTREAM UNITS.	DPE			1.3.1.1. Only a problem for long pipelines. Ensure closing time on control valves and manual valves is long enough to avoid liquid hammer.

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Table A3.6 – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 2 Storage tank vent to atmosphere
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No/Less Flow	1.1. Vent line blocked or partially blocked	IC	1.1.1. Tank overpressure rupture on filling	EE	1.1.1.1. Relief valve	CON	1.1.1.1. Minimise opportunities for vent blockage
							1.1.1.2. Ensure flame arrestor is maintained correctly.
			1.1.2. Tank vacuum collapse on discharge	EE	1.1.2.1. Vacuum relief valve.	CON	1.1.2.1. Minimise opportunities for vent blockage.
							1.1.2.2. Ensure flame arrestor is maintained correctly

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Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 3 Storage tank overflow
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No/Less Flow	1.1. Overflow blocked or partially blocked	IC	1.1.1. No/partial tank overflow available. Possible tank rupture on overfilling	EE	1.1.1.1. Level control 1.1.1.2. Level indicator 1.1.1.3. High level alarm	CON CON CON	1.1.1.1. Ensure opportunities for overflow blocking are minimised.

HAZOP-PC 3.02 by Primatech Inc.

Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 4 Storage tank outlet
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Outlet line blocked between tank and pump. Pump fails.	IC	1.1.1. NO FLOW TO DOWNSTREAM UNIT	DPE	1.1.1.1. Low flow alarm	CAU	
	1.2. Flow control valve fails shut. Outlet line blocked downstream of pump.	IC	1.2.1. NO FLOW TO DOWNSTREAM UNIT	DPE	1.2.1.1. Low flow alarm	CAU	
			1.2.2. Full head pump pressure developed. High pressure rupture risk to outlet line. Pump overheats, seals damaged, possible leak.	EE	1.2.2.1. Kick back line. 1.2.2.2. Low flow alarm.		1.2.2.1. Consider designing equipment to withstand maximum pump delivery pressure.
2. More Flow	2.1. Control valve fails open	IC	2.1.1. HIGH FLOW TO DOWNSTREAM UNIT	DPE			
	2.2. Spare pump running in error	IC	2.2.1. HIGH FLOW TO DOWNSTREAM UNIT	DPE	2.2.1.1. Flow control	CON	2.2.1.1. Ensure operating and maintenance instructions preclude running parallel pumps incorrectly.
	2.3. Outlet line ruptured	IC	2.3.1. Tank contents lost to environment	EE	2.3.1.1. Emergency isolation valve	CON	2.3.1.1. Ensure tank is adequately bunded. 2.3.1.2. Locate isolation valve as near as possible to tank. 2.3.1.3. Consider need for remote operation of isolation valve.
	2.4. Pump seals fail.	IC	2.4.1. Environmental contamination	EE	2.4.1.1. Emergency isolation valve.	CON	2.4.1.1. Use canned or seal-less pump if appropriate. 2.4.1.2. Pump to be adequately bunded. 2.4.1.3. Consider need for remote operation of isolation valve.
3. Less Flow	3.1. Outlet line partially blocked. Pump running incorrectly.	IC	3.1.1. LESS FLOW TO DOWNSTREAM UNIT	DPE	3.1.1.1. Flow control 3.1.1.2. Low flow alarm	CON CON	
	3.2. Control valve fails insufficiently open.	IC	3.2.1. LESS FLOW TO DOWNSTREAM UNIT	DPE	3.2.1.1. Low flow alarm.		
4. As Well As Flow	4.1. Contamination of tank contents	IC	4.1.1. CONTAMINATION OF DOWNSTREAM UNIT	DPE			
5. Reverse Flow	5.2. Outlet line ruptured.	IC	5.2.1. REVERSE FLO W FROM DOWNSTREAM UNIT	DPE			

Revision: 0 2 Jun 95
Node: 4 Storage tank outlet
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
2. Lower Pressure	2.1. Storage tank inlet line blocked. Level control valve fails shut.	IC	2.1.1. Low tank level leading to LOW PRESSURE AT DOWNSTREAM UNIT	DPE	2.1.1.1. Low flow alarm 2.1.1.2. Low level alarm 2.1.1.3. Level indicator	CAU CON CON	

Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 5 Storage tank self
Parameter: Temperature

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Temperature	1.1. Fire	IC	1.1.1. Rapid evaporation of tank contents.	EE	1.1.1.1. Emergency fire relief valve.	CON	
			1.1.2. Structural weakening of tank.	EE			1.1.2.1. Ensure adequate fire relief equipment exists.
	1.2. High ambient temperature	IC	1.2.1. Rapid evaporation of tank contents	EE	1.2.1.1. Temperature indicator	CAU	1.2.1.1. Lag tank to protect against high ambient temperature if necessary.
			1.2.2. Possible pump cavitation	EE	1.2.2.1. Temperature indicator.		
2. Lower Temperature	2.1. Cold weather	IC	2.1.1. Possible freezing of contents	EE	2.1.1.1. Temperature indicator	CAU	2.1.1.1. Lag tank to protect against cold ambient temperature if necessary. 2.1.1.2. Install trace heating if necessary.
			2.1.2. Rapid condensation of vapour. Possible vacuum collapse.	EE	2.1.2.1. Install vacuum relief. 2.1.2.2. Temperature indicator	CON CAU	
			2.1.3. Condensation of vapour draws air into tank.	EE	2.1.3.1. Temperature indicator	CAU	2.1.3.1. Use inert blanket if necessary. See blanket in and vent out nodes.
			2.1.4. Pump seals damaged	EE	2.1.4.1. Temperature indicator	CAU	

Revision: 0 2 Jun 95
Node: 5 Storage tank self
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. Fluid for hydraulic test is denser than fluid tank designed for	IC	1.1.1. Tank overpressure rupture	EE			1.1.1.1. Design tank to contain all appropriate fluids.

Revision: 0 2 Jun 95
Node: 5 Storage tank self
Parameter: Level

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Level	1.1. Level control fails Wrong level sensed due to tank being filled with less dense material than anticipated.	IC	1.1.1. Tank contents lost to environment	EE	1.1.1.1. Overflow 1.1.1.2. High level alarm 1.1.1.3. Level indicator	CON CAU CAU	1.1.1.1. Overflow to be below tank roof. 1.1.1.2. Tank to be adequately bunded.

Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 6 Storage tank vent in from inert blanket supply.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Vent in line blocked	IC	1.1.1. Tank vacuum collapse	EE	1.1.1.1. Vacuum relief valve	CON	1.1.1.1. Minimise opportunities for line blockage.
3. Less Flow	3.1. Vent in line partially blocked	IC	3.1.1. Tank vacuum collapse	EE	3.1.1.1. Vacuum relief valve	CON	3.1.1.1. Minimise opportunities for line blockage

Revision: 0 2 Jun 95
Node: 6 Storage tank vent in from inert blanket supply.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. Pressure control failure of blanket	IC	1.1.1. Tank overpressure rupture	EE	1.1.1.1. Install relief valve		
2. Lower Pressure	2.1. Vent in line blocked or partially blocked	IC	2.1.1. Vacuum collapse	EE	2.1.1.1. Ensure vent in line is not prone to blocking 2.1.1.2. Install vacuum relief		

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Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 7 Storage tank vent out to vent header
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Vent out line blocked	IC	1.1.1. Tank overpresssure rupture	EE	1.1.1.1. Ensure vent out line is not prone to blocking 1.1.1.2. Install relief valve		
2. More Flow	2.1. Vent out line open in error	IC	2.1.1. Rapid evaporation of tank contents	EE			
3. Less Flow	3.1. Vent out line partially blocked	IC	3.1.1. Tank overpressure rupture	EE	3.1.1.1. Ensure vent out line is not prone to blocking 3.1.1.2. Install relief valve		

Revision: 0 2 Jun 95
Node: 7 Storage tank vent out to vent header
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. Vent out line blocked or partially blocked	IC	1.1.1. Overpressure rupture	EE	1.1.1.1. Install relief valve		

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Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Revision: 0 26 Jun 95
Node: 8 Storage tank outlet via batch meter to tanker
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Outlet line blocked between pump and tanker. BaEEh meter control valve fails closed.	IC	1.1.1. Tanker not filled as required.	EE			
			1.1.2. Full head pump pressure developed. Pump overheats, seals damaged, possible leak.	EE	1.1.2.1. Kick back line		
	1.2. Pump fails. Outlet line blocked between storage tank and pump.	IC	1.2.1. Tanker not filled as required.	EE			
2. More Flow	2.1. Outlet line ruptures. Tanker filling hose ruptured.	IC	2.1.1. Tank contents lost to environment.	EE	2.1.1.1. Emergency isolation valve		2.1.1.1. Ensure tank is adequately bunded. 2.1.1.2. Locate isolation valve as near as possible to tank. 2.1.1.3. Consider need for remote operation of isolation valve. 2.1.1.4. Ensure tanker filling hoses are stored correctly, inspected frequently and changed regularly.
	2.2. Batch meter control valve fails open. Operator enters wrong amount into batch meter control. Tanker smaller than expected. Tanker already partially filled.	IC	2.2.1. Tanker overfilled	EE	2.2.1.1. Overfilling alarm 2.2.1.2. Pressure trip		2.2.1.1. Consider effects a change in size of standard tanker will have on tanker loading operations.
	2.3. Tanker moves off while loading operation still in progress. Driver drives off, tanker not parked securely, or tanker in conflict with other traffic.	IC	2.3.1. Leak to environment.	EE	2.3.1.1. Dry break couplings. 2.3.1.2. Tanker immobilisation interlock.		2.3.1.1. Loading bay to be on level ground. Ensure tanker can be parked securely in bay at a reasonable distance from other traffic.
3. Less Flow	3.1. Outlet line partially blocked. Batch meter control valve fails insufficiently open. Pump running incorrectly.	IC	3.1.1. Tanker takes longer to fill than normal.	EE	3.1.1.1. Overdue filling alarm.		3.1.1.1. Ensure operators do not rely solely on time taken to fill tanker as an indicator as to when to disconnect filling hose.

Revision: 0 26 Jun 95
Node: 8 Storage tank outlet via batch meter to tanker
Parameter: Composition

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Other Than Compositio n	1.1. Wrong tanker connected	IC	1.1.1. Material incompatibility.	EE			1.1.1.1. Use different connectors where material incompatibilty is a problem to so wrong tanker cannot be connected easily.
	1.2. Wrong material in tanker	IC	1.2.1. Material incompatibility.	EE			1.2.1.1. Check tanker contents before unloading if material incompatibility is a problem.

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Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 26 Jun 95
Node: 9 Storage tank inlet from tanker
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Tanker outlet line blocked.	IC	1.1.1. Possible inability to continue process at normal production rates.	EE			
			1.1.2. Low tank level leading to outlet pump cavitation	EE			
2. More Flow	2.1. Hose ruptured.	IC	2.1.1. Leak to environment.	EE			2.1.1.1. Ensure hoses are stored correctly, inspected frequently and changed regularly.
	2.2. Tanker moves off while offloading operation still in progress. Driver drives off, tanker not parked securely, or tanker in conflict with other traffic.	IC	2.2.1. Leak to environment.	EE	2.2.1.1. Dry break couplings. 2.2.1.2. Tanker immobilisation interlock.		2.2.1.1. Loading bay to be on level ground. Ensure tanker can be parked securely in bay at a reasonable distance from other traffic.
	2.3. Larger tanker than expected.	IC	2.3.1. Possible inability to offload tanker completely without overfilling storage tank.	EE	2.3.1.1. Consider effects change in standard size of tank will have on tanker offloading operations.		
3. Less Flow	3.1. Tanker outlet line partially blocked.	IC	3.1.1. Tank takes longer to fill than normal.	EE	3.1.1.1. Ensure operators do not rely solely on time taken to empty tanker as an indicator as to when to disconnect hose.		
4. Reverse Flow	4.1. Discharge pump fails	IC	4.1.1. Reverse flow from storage tank. Tanker overfilling.	EE	4.1.1.1. Non-return valve 4.1.1.2. Siphon break on dip tubes.		

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Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 21 Jul 95
Node: 11 Storage tank feed inlet without control valve.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Feed line blocked.	IC	1.1.1. Possible inability to continue process at normal production rates	EE			
			1.1.2. Low tank level leading to outlet pump cavitation.	EE	1.1.2.1. Low level alarm	CON	
					1.1.2.2. Level indicator	CON	
			1.1.3. NO FLOW AT UPSTREAM UNITS	DPE			
3. Less Flow	3.1. Feed line partially blocked.	IC	3.1.1. Vessel takes longer to fill than normal	EE	3.1.1.1. Level indicator.	CON	
			3.1.2. LOW FLOW FROM UPSTREAM UNIT	DPE	3.1.2.1. Level indicator.	CAU	

Revision: 0 21 Jul 95
Node: 11 Storage tank feed inlet without control valve.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.2. Feed line isolated.	IC	1.2.1. Expansion of locked in fluid causes hydraulic overpressure rupture of line.	IC	1.2.1.1. Hydraulic pressure relief		1.2.1.1. Ensure operating instructions preclude deliberate isolation of line without having first drained line.
							1.2.1.2. Ensure design minimises opportunites for isolation in error due to control valves failing etc.
	1.3. Manual valve on storage tank inlet closes quickly.	IC	1.3.1. LIQUID HAMMER. HIGH PRESSURE TO UPSTREAM UNITS.				1.3.1.1. Only a problem for long pipelines. Ensure closing time on control valves and manual valves is long enough to avoid liquid hammer.

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Table A3.6 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company: MODHAZ
Facility: Thermal Oxidiser

Revision: 0 21 Feb 96
Node: 1 Fuel Gas In
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow	1.1. NO FLOW FROM UPSTREAM UNIT	VUL	1.1.1. Burners will require re-igniting. Possible explosion risk on re-ignition if fuel loss is temporary.	EE			① Procedure for re-ignition Flow trip to prevent self re start	
			1.1.2. Process waste is not oxidised. Toxic and flammable chemicals released to atmosphere. Environmental contamination.	EE				
	1.2. Burner control fails shut	IC	1.2.1. Burners will require re-igniting. Possible explosion risk on re-ignition if fuel loss is temporary.	EE				
			1.2.2. Process waste is not oxidised. Toxic and flammable chemicals released to atmosphere. Environmental contamination.	EE				
2. More Flow	2.1. Burner control fails open	IC	2.1.1. Refactory lining breaks down.	EE				
	2.2. HIGH FLOW FROM UPSTREAM UNITS	VUL	2.2.1. Refractory lining breaks down.	EE	2.2.1.1. Burner control system.			
	2.3. Burners fail to ignite	IC	2.3.1. Explosion risk	EE	2.3.1.1. Explosion doors			
					2.3.1.2. Burner control system.			
3. Less Flow	3.1. LESS FLOW FROM UPSTREAM UNIT	VUL	3.1.1. Flame fails. Explosive atmosphere develops. Burners will require re-igniting. Possible explosion risk on re-ignition.	EE	3.1.1.1. Burner control system.			
					3.1.1.2. Explosion doors.			
	3.2. Burner control fails to open control valve sufficiently.	IC	3.2.1. Flame fails. Explosive atmosphere develops.	EE	3.2.1.1. Explosion doors.			

HAZOP-PC 3.02 by Primatech Inc.

Table A3.7 – Thermal oxidiser sub-modules – preHAZOPed results.

Worksheet

Company: MODHAZ
Facility: Thermal Oxidiser

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DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
			Burners will require re-igniting. Possible explosion risk on re-ignition.					

Revision: 0 21 Feb 96
Node: 1 Fuel Gas In
Parameter: Temperature

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Higher Temperatur e								

Revision: 0 21 Feb 96
Node: 1 Fuel Gas In
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Higher Pressure	1.1. HIGH PRESSURE FROM UPSTREAM UNIT	VUL	1.1.1. Refractory lining breaks down	EE	1.1.1.1. Burner control system.			
2. Lower Pressure	2.1. Burners partially blocked. Burner control fails to open fuel gas supply valve sufficiently.	IC	2.1.1. Insufficient oxidation of process waste. Toxic and flammable chemicals released to atmosphere.	EE				
	2.2. LESS PRESSURE FROM UPSTREAM UNIT	VUL	2.2.1. Insufficient oxidation of process waste. Toxic and flammable chemicals released to atmosphere.	EE				

Table A3.7 (cont.) – Thermal oxidiser sub-modules – preHAZOPed results.

Worksheet

Company: MODHAZ
Facility: Thermal Oxidiser

Revision: 0 21 Feb 96
Node: 2 Stack
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow	1.1. Stack blocked or damper fails shut	IC	1.1.1. Flame fails. Explosive atmosphere develops. Burners require re-igniting. Possible explosion risk on re-ignition.	EE	1.1.1.1. Explosion doors. 1.1.1.2. Burner control system.		1.1.1.1. Chimney should be designed so that there is plenty of space around damper to avoidage blockage.	
			1.1.2. High pressure in furnace. Explosion doors open. Possibility of fire from opening.	EE	1.1.2.1. Burner control system.		1.1.2.1. Chimney should be designed so that there is plenty of space around damper to avoidage blockage.	
2. Less Flow	2.1. Stack partially blocked or damper fails to open sufficiently.	IC	2.1.1. Temperature of furnace falls. Waste not oxidised correctly. Toxic chemical discharged to atmosphere.	EE	2.1.1.1. Stack emission monitoring.			

Revision: 0 21 Feb 96
Node: 2 Stack
Parameter: Temperature

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Higher Temperatur e								

Table A3.7 (cont.) – Thermal oxidiser sub-modules – preHAZOPed results.

Company: MODHAZ
Facility: Thermal Oxidiser

Revision: 0 21 Feb 96
Node: 3 Process waste feed
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow	1.1. Feed line blocked	IC	1.1.1. NO FLOW AT DOWNSTREAM UNIT	DPE				
	1.2. NO FLOW FROM UPSTREAM UNIT	VUL	~~1.2.1. Furnace tubes overheat, Possible tube failure~~	EE	1.2.1.1. High temperature alarm 1.2.1.2. Low flow alarm			
2. More Flow	2.1. MORE FLOW FROM UPSTREAM UNIT	VUL	2.1.1. Insufficient air to oxidise all process waste. Toxic and flammable chemicals lost to atmosphere. Environmental contamination.	EE	2.1.1.1. High flow alarm.			
			2.1.2. Fuel gas supply may cut out if there are sufficient flammables in process waste. Possible explosion risk when fuel gas supply is re-established.	EE				
3. Reverse Flow	3.1. REVERSE FLOW AT UPSTREAM UNIT	VUL	3.1.1. CONTAMINATION AT UPSTREAM UNIT. TOXIC AND FLAMMABLE CHEMICALS RELEASED AT REMOTE POINTS OF PLANT.					

Revision: 0 21 Feb 96
Node: 3 Process waste feed
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. Higher Pressure	1.1. HIGH PRESSURE AT UPSTREAM UNIT	VUL	1.1.1. REVERSE FLOW AT OTHER WASTE FEEDS TO THERMAL OXIDISER	IPE			1.1.1.1. Tubes should be designed to withstand all expected pressure deviations	
2. Lower Pressure	2.1. LOW PRESSURE AT UPSTREAM UNIT	VUL	2.1.1. REVERSE FLOW AT UPSTREAM UNIT. TOXIC AND FLAMMABLE CHEMICALS RELEASED AT REMOTE POINTS OF PLANT.	DPE				

– ble A3.7 (cont.) – Thermal oxidiser sub-modules – preHAZOPed results.

Company: MODHAZ
Facility: Thermal Oxidiser

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
			2.1.2. CONTAMINATION AT UPSTREAM UNIT. TOXIC AND FLAMMABLE CHEMICALS RELEASED AR REMOTE POINTS OF PLANTS.					

Table A3.7 (cont.) – Thermal oxidiser sub-modules – preHAZOPed results.

Worksheet

Company: MODHAZ
Facility: Thermal Oxidiser

Revision: 0 21 Feb 96
Node: 4 Air supply
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS	REMARKS
1. No Flow								
2. More Flow								

Table A3.7 (cont.) – Thermal oxidiser sub-modules – preHAZOPed results.

Worksheet

Company:
Facility:

Page: 1

Revision: 0 2 Jun 95
Node: 1 Storage tank feed inlet with level control on tank.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Feed line blocked. Level control valve fails shut.	IC	1.1.1. Possible inability to continue process at normal production rates	EE			
			1.1.2. Low tank level leading to outlet pump cavitation.	EE	1.1.2.1. Low level alarm	CON	
					1.1.2.2. Level indicator	CON	
			1.1.3. NO FLOW AT UPSTREAM UNITS	DPE			
2. More Flow	2.1. Control valve fails open	IC	2.1.1. Inadequate venting. Vessel overpressure rupture.	EE	2.1.1.1. Relief valve.		2.1.1.1. Size vent adequately
			2.1.2. Static build up.	EE	2.1.2.1. Dip tubes for filling.		2.1.2.1. Flammable fluids only. If filling is not done via dip tubes check design assumptions.
			2.1.3. MORE FLOW AT UPSTREAM UNITS	DPE			
3. Less Flow	3.1. Feed line partially blocked. Control valve fails insufficiently open.	IC	3.1.1. Vessel takes longer to fill than normal	EE	3.1.1.1. Level indicator.	CON	
			3.1.2. LOW FLOW AT UPSTREAM UNIT	DPE	3.1.2.1. Level indicator.	CAU	

Revision: 0 2 Jun 95
Node: 1 Storage tank feed inlet with level control on tank.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.2. Feed line isolated.	IC	1.2.1. Expansion of locked in fluid causes hydraulic overpressure rupture of line.	EE	1.2.1.1. Hydraulic pressure relief	CON	1.2.1.1. Ensure operating instructions preclude deliberate isolation of line without having first drained line.
							1.2.1.2. Ensure design minimises opportunites for isolation in error due to control valves failing etc.
	1.3. Level control valve closes quickly. Manual valve on storage tank inlet closes quickly.	IC	1.3.1. LIQUID HAMMER. HIGH PRESSURE TO UPSTREAM UNITS.	DPE			1.3.1.1. Only a problem for long pipelines. Ensure closing time on control valves and manual valves is long enough to avoid liquid hammer.

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Table A3.8 – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 2 Storage tank vent to atmosphere
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No/Less Flow	1.1. Vent line blocked or partially blocked	IC	1.1.1. Tank overpressure rupture on filling	EE	1.1.1.1. Relief valve	CON	1.1.1.1. Minimise opportunities for vent blockage 1.1.1.2. Ensure flame arrestor is maintained correctly.
			1.1.2. Tank vacuum collapse on discharge	EE	1.1.2.1. Vacuum relief valve.	CON	1.1.2.1. Minimise opportunities for vent blockage. 1.1.2.2. Ensure flame arrestor is maintained correctly

HAZOP-PC 3.02 by Primatech Inc.

Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Worksheet

Company:
Facility:

Revision: 0 2 Jun 95
Node: 3 Storage tank overflow
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No/Less Flow	1.1. Overflow blocked or partially blocked	IC	1.1.1. No/partial tank overflow available. Possible tank rupture on overfilling	EE	1.1.1.1. Level control 1.1.1.2. Level indicator 1.1.1.3. High level alarm	CON CON CON	1.1.1.1. Ensure opportunities for overflow blocking are minimised.

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Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 4 Storage tank outlet
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Outlet line blocked between tank and pump. Pump fails.	IC	1.1.1. NO FLOW TO DOWNSTREAM UNIT	DPE	1.1.1.1. Low flow alarm	CAU	
	1.2. Flow control valve fails shut. Outlet line blocked downstream of pump.	IC	1.2.1. NO FLOW TO DOWNSTREAM UNIT	DPE	1.2.1.1. Low flow alarm	CAU	
			1.2.2. Full head pump pressure developed. High pressure rupture risk to outlet line. Pump overheats, seals damaged, possible leak.	EE	1.2.2.1. Kick back line. 1.2.2.2. Low flow alarm.		1.2.2.1. Consider designing equipment to withstand maximum pump delivery pressure.
2. More Flow	2.1. Control valve fails open	IC	2.1.1. HIGH FLOW TO DOWNSTREAM UNIT	DPE			
	2.2. Spare pump running in error	IC	2.2.1. HIGH FLOW TO DOWNSTREAM UNIT	DPE	2.2.1.1. Flow control	CON	2.2.1.1. Ensure operating and maintenance instructions preclude running parallel pumps incorrectly.
	2.3. Outlet line ruptured	IC	2.3.1. Tank contents lost to environment	EE	2.3.1.1. Emergency isolation valve	CON	2.3.1.1. Ensure tank is adequately bunded. 2.3.1.2. Locate isolation valve as near as possible to tank. 2.3.1.3. Consider need for remote operation of isolation valve.
	2.4. Pump seals fail.	IC	2.4.1. Environmental contamination	EE	2.4.1.1. Emergency isolation valve.	CON	2.4.1.1. Use canned or seal-less pump if appropriate. 2.4.1.2. Pump to be adequately bunded. 2.4.1.3. Consider need for remote operation of isolation valve.
3. Less Flow	3.1. Outlet line partially blocked. Pump running incorrectly.	IC	3.1.1. LESS FLOW TO DOWNSTREAM UNIT	DPE	3.1.1.1. Flow control 3.1.1.2. Low flow alarm	CON CON	
	3.2. Control valve fails insufficiently open.	IC	3.2.1. LESS FLOW TO DOWNSTREAM UNIT	DPE	3.2.1.1. Low flow alarm.		
4. As Well As Flow	4.1. Contamination of tank contents	IC	4.1.1. CONTAMINATION OF DOWNSTREAM UNIT	DPE			
5. Reverse Flow	5.2. Outlet line ruptured.	IC	5.2.1. REVERSE FLO W FROM DOWNSTREAM UNIT	DPE			

Revision: 0 2 Jun 95
Node: 4 Storage tank outlet
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
2. Lower Pressure	2.1. Storage tank inlet line blocked. Level control valve fails shut.	IC	2.1.1. Low tank level leading to LOW PRESSURE AT DOWNSTREAM UNIT	DPE	2.1.1.1. Low flow alarm 2.1.1.2. Low level alarm 2.1.1.3. Level indicator	CAU CON CON	

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Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 5 Storage tank self
Parameter: Temperature

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Temperature	1.1. Fire	IC	1.1.1. Rapid evaporation of tank contents.	EE	1.1.1.1. Emergency fire relief valve.	CON	
			1.1.2. Structural weakening of tank.	EE			1.1.2.1. Ensure adequate fire relief equipment exists.
	1.2. High ambient temperature	IC	1.2.1. Rapid evaporation of tank contents	EE	1.2.1.1. Temperature indicator	CAU	1.2.1.1. Lag tank to protect against high ambient temperature if necessary.
			1.2.2. Possible pump cavitation	EE	1.2.2.1. Temperature indicator.		
2. Lower Temperature	2.1. Cold weather	IC	2.1.1. Possible freezing of contents	EE	2.1.1.1. Temperature indicator	CAU	2.1.1.1. Lag tank to protect against cold ambient temperature if necessary. 2.1.1.2. Install trace heating if necessary.
			2.1.2. Rapid condensation of vapour. Possible vacuum collapse.	EE	2.1.2.1. Install vacuum relief.	CON	
					2.1.2.2. Temperature indicator	CAU	
			2.1.3. Condensation of vapour draws air into tank.	EE	2.1.3.1. Temperature indicator	CAU	2.1.3.1. Use inert blanket if necessary. See blanket in and vent out nodes.
			2.1.4. Pump seals damaged	EE	2.1.4.1. Temperature indicator	CAU	

Revision: 0 2 Jun 95
Node: 5 Storage tank self
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. Fluid for hydraulic test is denser than fluid tank designed for	IC	1.1.1. Tank overpressure rupture	EE			1.1.1.1. Design tank to contain all appropriate fluids.

Revision: 0 2 Jun 95
Node: 5 Storage tank self
Parameter: Level

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Level	1.1. Level control fails Wrong level sensed due to tank being filled with less dense material than anticipated.	IC	1.1.1. Tank contents lost to environment	EE	1.1.1.1. Overflow	CON	1.1.1.1. Overflow to be below tank roof.
					1.1.1.2. High level alarm	CAU	1.1.1.2. Tank to be adequately bunded.
					1.1.1.3. Level indicator	CAU	

HAZOP-PC 3.02 by Primatech Inc.

Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 6 Storage tank vent in from inert blanket supply.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Vent in line blocked	IC	1.1.1. Tank vacuum collapse	EE	1.1.1.1. Vacuum relief valve	CON	1.1.1.1. Minimise opportunities for line blockage.
3. Less Flow	3.1. Vent in line partially blocked	IC	3.1.1. Tank vacuum collapse	EE	3.1.1.1. Vacuum relief valve	CON	3.1.1.1. Minimise opportunities for line blockage

Revision: 0 2 Jun 95
Node: 6 Storage tank vent in from inert blanket supply.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. Pressure control failure of blanket	IC	1.1.1. Tank overpressure rupture	EE	1.1.1.1. Install relief valve		
2. Lower Pressure	2.1. Vent in line blocked or partially blocked	IC	2.1.1. Vacuum collapse	EE	2.1.1.1. Ensure vent in line is not prone to blocking 2.1.1.2. Install vacuum relief		

HAZOP-PC 3.02 by Primatech Inc.

Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 7 Storage tank vent out to vent header
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Vent out line blocked	IC	1.1.1. Tank overpressure rupture	EE	1.1.1.1. Ensure vent out line is not prone to blocking 1.1.1.2. Install relief valve		
2. More Flow	2.1. Vent out line open in error	IC	2.1.1. Rapid evaporation of tank contents	EE			
3. Less Flow	3.1. Vent out line partially blocked	IC	3.1.1. Tank overpressure rupture	EE	3.1.1.1. Ensure vent out line is not prone to blocking 3.1.1.2. Install relief valve		

Revision: 0 2 Jun 95
Node: 7 Storage tank vent out to vent header
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. Vent out line blocked or partially blocked	IC	1.1.1. Overpressure rupture	EE	1.1.1.1. Install relief valve		

Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 26 Jun 95
Node: 8 Storage tank outlet via batch meter to tanker
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Outlet line blocked between pump and tanker. BaEEh meter control valve fails closed.	IC	1.1.1. Tanker not filled as required.	EE			
			1.1.2. Full head pump pressure developed. Pump overheats, seals damaged, possible leak.	EE	1.1.2.1. Kick back line		
	1.2. Pump fails. Outlet line blocked between storage tank and pump.	IC	1.2.1. Tanker not filled as required.	EE			
2. More Flow	2.1. Outlet line ruptures. Tanker filling hose ruptured.	IC	2.1.1. Tank contents lost to environment.	EE	2.1.1.1. Emergency isolation valve		2.1.1.1. Ensure tank is adequately bunded. 2.1.1.2. Locate isolation valve as near as possible to tank. 2.1.1.3. Consider need for remote operation of isolation valve. 2.1.1.4. Ensure tanker filling hoses are stored correctly, inspected frequently and changed regularly.
	2.2. Batch meter control valve fails open. Operator enters wrong amount into batch meter control. Tanker smaller than expected. Tanker already partially filled.	IC	2.2.1. Tanker overfilled	EE	2.2.1.1. Overfilling alarm 2.2.1.2. Pressure trip		2.2.1.1. Consider effects a change in size of standard tanker will have on tanker loading operations.
	2.3. Tanker moves off while loading operation still in progress. Driver drives off, tanker not parked securely, or tanker in conflict with other traffic.	IC	2.3.1. Leak to environment.	EE	2.3.1.1. Dry break couplings. 2.3.1.2. Tanker immobilisation interlock.		2.3.1.1. Loading bay to be on level ground. Ensure tanker can be parked securely in bay at a reasonable distance from other traffic.
3. Less Flow	3.1. Outlet line partially blocked. Batch meter control valve fails insufficiently open. Pump running incorrectly.	IC	3.1.1. Tanker takes longer to fill than normal.	EE	3.1.1.1. Overdue filling alarm.		3.1.1.1. Ensure operators do not rely solely on time taken to fill tanker as an indicator as to when to disconnect filling hose.

Revision: 0 26 Jun 95
Node: 8 Storage tank outlet via batch meter to tanker
Parameter: Composition

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Other Than Composition	1.1. Wrong tanker connected	IC	1.1.1. Material incompatibility.	EE			1.1.1.1. Use different connectors where material incompatibilty is a problem to so wrong tanker cannot be connected easily.
	1.2. Wrong material in tanker	IC	1.2.1. Material incompatibility.	EE			1.2.1.1. Check tanker contents before unloading if material incompatibility is a problem.

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Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 26 Jun 95
Node: 9 Storage tank inlet from tanker
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Tanker outlet line blocked.	IC	1.1.1. Possible inability to continue process at normal production rates.	EE			
			1.1.2. Low tank level leading to outlet pump cavitation	EE			
2. More Flow	2.1. Hose ruptured.	IC	2.1.1. Leak to environment.	EE			2.1.1.1. Ensure hoses are stored correctly, inspected frequently and changed regularly.
	2.2. Tanker moves off while offloading operation still in progress. Driver drives off, tanker not parked securely, or tanker in conflict with other traffic.	IC	2.2.1. Leak to environment.	EE	2.2.1.1. Dry break couplings. 2.2.1.2. Tanker immobilisation interlock.		2.2.1.1. Loading bay to be on level ground. Ensure tanker can be parked securely in bay at a reasonable distance from other traffic.
	2.3. Larger tanker than expected.	IC	2.3.1. Possible inability to offload tanker completely without overfilling storage tank.	EE	2.3.1.1. Consider effects change in standard size of tank will have on tanker offloading operations.		
3. Less Flow	3.1. Tanker outlet line partially blocked.	IC	3.1.1. Tank takes longer to fill than normal.	EE	3.1.1.1. Ensure operators do not rely solely on time taken to empty tanker as an indicator as to when to disconnect hose.		
4. Reverse Flow	4.1. Discharge pump fails	IC	4.1.1. Reverse flow from storage tank. Tanker overfilling.	EE	4.1.1.1. Non-return valve 4.1.1.2. Siphon break on dip tubes.		

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Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Company:
Facility:

Revision: 0 21 Jul 95
Node: 11 Storage tank feed inlet without control valve.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.1. Feed line blocked.	IC	1.1.1. Possible inability to continue process at normal production rates	EE			
			1.1.2. Low tank level leading to outlet pump cavitation.	EE	1.1.2.1. Low level alarm	CON	
					1.1.2.2. Level indicator	CON	
			1.1.3. NO FLOW AT UPSTREAM UNITS	DPE			
3. Less Flow	3.1. Feed line partially blocked.	IC	3.1.1. Vessel takes longer to fill than normal	EE	3.1.1.1. Level indicator.	CON	
			3.1.2. LOW FLOW FROM UPSTREAM UNIT	DPE	3.1.2.1. Level indicator.	CAU	

Revision: 0 21 Jul 95
Node: 11 Storage tank feed inlet without control valve.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.2. Feed line isolated.	IC	1.2.1. Expansion of locked in fluid causes hydraulic overpressure rupture of line.	IC	1.2.1.1. Hydraulic pressure relief		1.2.1.1. Ensure operating instructions preclude deliberate isolation of line without having first drained line.
							1.2.1.2. Ensure design minimises opportunites for isolation in error due to control valves failing etc.
	1.3. Manual valve on storage tank inlet closes quickly.	IC	1.3.1. LIQUID HAMMER. HIGH PRESSURE TO UPSTREAM UNITS.				1.3.1.1. Only a problem for long pipelines. Ensure closing time on control valves and manual valves is long enough to avoid liquid hammer.

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Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (IC filtered).

Worksheet

Company:
Facility:

Page: 1

Revision: 0 2 Jun 95
Node: 1 Storage tank feed inlet with level control on tank.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.2. NO FLOW FROM SOURCE	VUL	1.2.1. Possible inability to continue process at normal production rates	EE			
			1.2.2. Low tank level leading to outlet pump cavitation.	EE	1.2.2.1. Low level alarm 1.2.2.2. Level indicator		
2. More Flow	2.2. HIGH FLOW FROM UPSTREAM UNIT	VUL	2.2.1. Inadequate venting. Vessel overpressure rupture.	EE	2.2.1.1. Relief valve.		
			2.2.2. Static build up.	EE	2.2.2.1. Dip tubes for filling.		2.2.2.1. Flammable fluids only. If filling is not done via dip tubes check design assumptions.
3. Less Flow	3.2. LOW FLOW FROM UPSTREAM UNIT	VUL	3.2.1. Vessel takes longer to fill than normal.	EE	3.2.1.1. Level indicator.		
4. As Well As Flow	4.1. WRONG MATERIAL FROM UPSTREAM UNIT	VUL	4.1.1. Material incompatability	EE			4.1.1.1. Ensure appropriate measures exist to check incoming material.
	4.2. CONTAMINATED MATERIAL FROM UPSTREAM UNIT	VUL	4.2.1. As above				
5. Reverse Flow	5.1. REVERSE FLOW AT UPSTREAM UNIT	VUL	5.1.1. Liquid siphoned out of tank.	EE	5.1.1.1. Siphon break on dip tubes. 5.1.1.2. Non-return valve	CON CAU	

Revision: 0 2 Jun 95
Node: 1 Storage tank feed inlet with level control on tank.
Parameter: Temperature

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Temperature	1.1. HIGH TEMPERATURE FROM UPSTREAM UNIT	VUL	1.1.1. Rapid evaporation of tank contents.	EE	1.1.1.1. Temperature indicator 1.1.1.2. High temperature alarm	CAU CAU	1.1.1.1. For system with vent header system, can system cope with increase in venting due to hot weather acting on several tanks?
			1.1.2. Increased vapour concentration around tank, possibly rising to a hazardous level.	EE	1.1.2.1. Temperature indicator. 1.1.2.2. High temperature alarm.		1.1.2.1. Only a problem for tanks with open vent. Consider installing appropriate gas detection equipment if appropriate.

Revision: 0 2 Jun 95
Node: 1 Storage tank feed inlet with level control on tank.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. HIGH PRESSURE AT UPSTREAM UNIT	VUL	1.1.1. Vessel overpressure rupture	EE	1.1.1.1. Relief valve. 1.1.1.2. Pressure indicator.	CON CAU	1.1.1.1. Ensure adequate venting.

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Table A3.8 – Storage tank sub-modules – preHAZOPed results (VUL filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 4 Storage tank outlet
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.3. NO FLOW AT DOWNSTREAM UNITS	VUL	1.3.1. Full head pump pressure developed. High pressure rupture risk to downstream equipment. Pump overheats, seals damaged, possible leak.	EE	1.3.1.1. High pressure/low flow pump cut out switches. 1.3.1.2. Kick back line 1.3.1.3. Integral pump high pressure relief valve 1.3.1.4. Pressure indicator 1.3.1.5. Low flow alarm	CON CON CON CON CON	1.3.1.1. Design equipment to withstand maximum pump delivery pressure.
	1.4. NO FLOW AT DOWNSTREAM UNITS	VUL	1.4.1. Full head pump pressure developed. HIGH PRESSURE TO DOWNSTREAM UNITS	LPE	1.4.1.1. Kick back line. 1.4.1.2. Low flow alarm.		1.4.1.1. Consider designing equipment to withstand maximum pump delivery pressure.
2. More Flow	2.5. LESS PRESSURE AT DOWNSTREAM UNIT	VUL	2.5.1. HIGH FLOW TO DOWNSTREAM UNIT	LPE	2.5.1.1. Flow control	CON	
3. Less Flow	3.3. HIGH PRESSURE AT DOWNSTREAM UNIT	VUL	3.3.1. LOW FLOW TO DOWNSTREAM UNIT	LPE	3.3.1.1. Flow control	CON	
5. Reverse Flow	5.1. Pump failure and REVERSE FLOW FROM DOWNSTREAM UNIT.	VUL	5.1.1. Material incompatability	EE	5.1.1.1. Non-return valve.	CAU	

Revision: 0 2 Jun 95
Node: 4 Storage tank outlet
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. NO FLOW AT DOWNSTREAM UNIT	VUL	1.1.1. Full head pump pressure developed. HIGH PRESSURE TO DOWNSTREAM UNIT	LPE	1.1.1.1. Kick back line. 1.1.1.2. Low flow alarm.		1.1.1.1. Consider designing equipment to withstand maximum pump delivery pressure.
2. Lower Pressure	2.2. LESS FLOW AT DOWNSTREAM UNIT	VUL	2.2.1. HIGH PRESSURE AT DOWNSTREAM UNIT	LPE	2.2.1.1. Flow control 2.2.1.2. Low flow alarm 2.2.1.3. Pressure indicator	CAU CAU CON	
	2.3. HIGH FLOW AT DOWNSTREAM UNITS	VUL	2.3.1. LOW PRESSURE AT DOWNSTREAM UNITS	LPE	2.3.1.1. Flow control	CAU	

Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (VUL filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 6 Storage tank vent in from inert blanket supply.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.2. NO FLOW FROM VENT IN SOURCE	VUL	1.2.1. Tank vacuum collapse	EE	1.2.1.1. Vacuum relief valve	CON	1.2.1.1. Ensure source is sufficiently reliable.
2. More Flow	2.1. HIGH FLOW FROM VENT IN SOURCE	VUL	2.1.1. Rapid evaporation of tank contents	EE			
3. Less Flow	3.2. LOW FLOW FROM VENT IN SOURCE	VUL	3.2.1. Tank vacuum collapse	EE	3.2.1.1. Vacuum relief valve		
4. As Well As Flow	4.1. WRONG MATERIAL FROM VENT IN SOURCE	VUL	4.1.1. Material incompatability	EE			4.1.1.1. Ensure risk of wrong material in source is sufficiently small.
			4.1.2. Possible explosion risk	EE			
	4.2. CONTAMINATION OF VENT IN SOURCE	VUL	4.2.1. Material incompatability	EE			
5. Reverse Flow	5.1. LOW PRESSURE AT UPSTREAM UNIT	VUL	5.1.1. CONTAMINATION OF VENT IN SOURCE	LPE	5.1.1.1. Install non-return valve		

Revision: 0 2 Jun 95
Node: 6 Storage tank vent in from inert blanket supply.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
2. Lower Pressure	2.2. LOW PRESSURE FROM VENT IN SOURCE	VUL	2.2.1. Vacuum collapse	EE	2.2.1.1. Check reliability of vent in source 2.2.1.2. Install vacuum relief		

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Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (VUL filtered).

Company:
Facility:

Revision: 0 2 Jun 95
Node: 7 Storage tank vent out to vent header
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
3. Less Flow	3.2. LOW FLOW TO DOWNSTREAM UNIT	VUL	3.2.1. Tank overpressure rupture	EE	3.2.1.1. Install relief valve		
4. Reverse Flow	4.1. HIGH PRESSURE AT DOWNSTREAM UNIT	VUL	4.1.1. Material incompatability	EE			
			4.1.2. Explosion risk	EE			

Revision: 0 2 Jun 95
Node: 7 Storage tank vent out to vent header
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.2. NO FLOW AT DOWNSTREAM UNIT. LESS FLOW AT DOWNSTREAM UNIT.	VUL	1.2.1. Overpressure rupture	EE	1.2.1.1. Install relief valve		

HAZOP-PC 3.02 by Primatech Inc.

Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (VUL filtered).

Company:
Facility:

Revision: 0 21 Jul 95
Node: 11 Storage tank feed inlet without control valve.
Parameter: Flow

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. No Flow	1.2. NO FLOW FROM UPSTREAM UNIT	VUL	1.2.1. Possible inability to continue process at normal production rates	EE			
			1.2.2. Low tank level leading to outlet pump cavitation.	EE	1.2.2.1. Low level alarm 1.2.2.2. Level indicator		
2. More Flow	2.1. HIGH FLOW FROM UPSTREAM UNIT	VUL	2.1.1. Inadequate venting. Vessel overpressure rupture.	EE	2.1.1.1. Relief valve.		
			2.1.2. Static build up.	EE	2.1.2.1. Dip tubes for filling.		2.1.2.1. Flammable fluids only. If filling is not done via dip tubes check design assumptions.
3. Less Flow	3.2. LOW FLOW FROM SOURCE	VUL	3.2.1. Vessel takes longer to fill than normal.	EE	3.2.1.1. Level indicator.		
4. As Well As Flow	4.1. WRONG MATERIAL AT SOURCE	VUL	4.1.1. Material incompatability	EE			4.1.1.1. Ensure appropriate measures exist to check incoming material.
		VUL	As above				
	4.2. CONTAMINATION OF MATERIAL AT SOURCE	VUL	4.2.1. Material incompatibility	EE			
5. Reverse Flow	5.1. REVERSE FLOW AT SOURCE	VUL	5.1.1. Liquid siphoned out of tank.	EE	5.1.1.1. Siphon break on dip tubes.	CON	
					5.1.1.2. Non-return valve	CAU	

Revision: 0 21 Jul 95
Node: 11 Storage tank feed inlet without control valve.
Parameter: Temperature

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Temperature	1.1. HIGH TEMPERATURE FROM UPSTREAM UNIT	VUL	1.1.1. Rapid evaporation of tank contents.	EE	1.1.1.1. Temperature indicator 1.1.1.2. High temperature alarm	CAU	1.1.1.1. For system with vent header system, can system cope with increase in venting due to hot weather acting on several tanks?
			1.1.2. Increased vapour concentration around tank, possibly rising to a hazardous level.	EE	1.1.2.1. Temperature indicator. 1.1.2.2. High temperature alarm.		1.1.2.1. Only a problem for tanks with open vent. Consider installing appropriate gas detection equipment if appropriate.

Revision: 0 21 Jul 95
Node: 11 Storage tank feed inlet without control valve.
Parameter: Pressure

DEVIATION	CAUSES	CAT	CONSEQUENCES	CAT	SAFEGUARDS	CAT	RECOMMENDATIONS
1. Higher Pressure	1.1. HIGH PRESSURE FROM SOURCE	VUL	1.1.1. Vessel overpressure rupture	EE	1.1.1.1. Relief valve.	CON	1.1.1.1. Ensure adequate venting.
					1.1.1.2. Pressure indicator.	CAU	

Table A3.8 (cont.) – Storage tank sub-modules – preHAZOPed results (VUL filtered).