

Chapter 3

Failure Cases



3. FAILURE CASES

3.1 Background

In this chapter, those steps are described which are necessary to enable a consequence analysis of plant failures to be conducted. An overview is provided of typical process plant equipment. This overview will help the analyst to identify the relevant accidental release cases of the plant. Relevant cases should include the typical (ie. most frequent) leaks and the worst cases which can be postulated in order to examine the full range of potential impacts.

As part of the release cases, the properties of the released media must be determined. This is accomplished by studying the equipment inventories under normal operation and for abnormal situations. A particular case will be to determine whether any part of the process or any reaction may release a flammable or toxic gas to a vent stack which normally does not discharge such gases. Similarly, the possibilities for reactive accidents or "run-away" exothermic reactions should be considered at the earliest possible stages in the plant.

In order to assist the analyst in these respects, event trees, which describe typical release sequences following an accident or failure, have been included in this chapter. These trees are provided to guide the analyst in the exploration of possible failure sequences and in the calculation of consequences. They provide the links to the appropriate consequence models in Chapter 4. It should be noted, however, that the figures and event trees have been included solely as a guide in identifying and analysing releases and are not intended for derivation of plant reliability and failure frequency estimates.

3.2 Release Cases

The first step in establishing a representative set of release cases is to list the components from which the plant is comprised. Only a relatively small number of different types of component are of importance in hazard analysis. Most of those components that the analyst is likely to encounter are shown in Figures 3.1 to 3.10, in which both an example of a component and a typical process flow diagram symbol are given. While there may be several variants of particular process components, the main functions are limited to the 10 generic cases which are considered here. These are expected to be the important elements in conducting a simplified hazard assessment. These 10, elements include the following:

Pipes	Figure 3.1
Flexible connections	Figure 3.2
Filters	Figure 3.3
Valves	Figure 3.4
Pressure/process vessels	Figure 3.5
Pumps	Figure 3.6
Compressors	Figure 3.7
Storage tanks (atmospheric)	Figure 3.8
Storage vessels (pressurised/refrigerated)	Figure 3.9
Flare vent stacks	Figure 3.10

Representative failures may be proposed for each component. The potential failures which should be considered are those that might lead to significant hazards. In figures 3.1 to 3.10 typical failures that might be considered are listed. The analyst should consider whether these failure modes, are appropriate to the precise design of the component in his plant. For each failure mode, a representative range of failure sizes is given. This is the minimum set of failure sizes that would usually be considered to represent the component in a hazard assessment.

3.3 Selecting the Event Sequences

Having identified the potential leak/release sources, the analyst can start to estimate the consequences of the postulated releases. In order to select the appropriate consequence models, the relevant properties of the fluid being discharged must be identified. These properties are:

- Phase (liquid, gas or two-phase)
- Pressure
- Temperature
- Flammability
- Toxicity

Once at this point, the analyst may use the "Failure Case Definition Tree" (Figure 3.11) to determine which event trees or parts of event trees he should use to guide the consequence calculations. Starting at the left and reading the tree through the relevant branches, the outcome tells the analyst which steps to take further into the analysis. If the release is both flammable and toxic, and both properties are considered to be significant, both branches of the assessment technique should be applied. In addition it should be noted that a flammable release may generate toxic products of combustion. In the case of two-phase release, the "Liquid tree" is applied. The appropriate branches of this tree feed into the "Gas trees" for calculation of gas cloud behaviour.

In this manual, the inventories have been put into the following categories:

- **Liquid at ambient pressure and temperature**
("liquid, ambient pressure")

A liquid at ambient pressure with temperature below its boiling point is treated as "liquid, ambient pressure".

- **Liquefied gas under pressure and at ambient temperature**
("liquid, pressurised")
- **Liquefied gas at ambient pressure and low temperature**
("liquid, refrigerated")

A liquefied gas may be both under pressure and at a low temperature. A release of such a fluid would lead to some initial flashing of vapour followed by a slower evaporation. For simplicity, however, such a fluid should be treated as "liquid, refrigerated" unless the pressure is considerably higher than ambient.

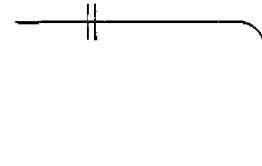
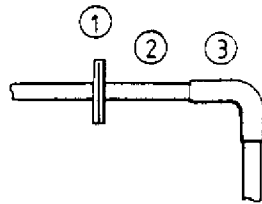
**- Gas under pressure
("gas, pressurised").**

Special note should be taken of the possibilities to produce a BLEVE (Boiling Liquid Expanding Vapour Explosion). Accidents in this category may occur when a pressurised tank with a flammable liquid is subject to a fire. The exposed steel on top of the vessel is not wetted inside by the liquid contents, so the temperature of the steel at this point can rise rapidly until the steel no longer has the strength to withstand the internal pressure. It may then stretch to such an extent that a ductile rupture occurs, releasing a great amount of gas under high pressure which is ignited immediately to form a large fireball. A BLEVE will also produce large projectiles from the ruptured vessel or communities which may cause significant damage in neighbouring plant if safety distances are too small or shielding of sensitive locations is inadequate.

Rigorous analyses of failure modes and discharge characteristics becomes less feasible if postulated releases involve mixtures of hazardous materials. Nonetheless hazard analyses involving such mixtures may be required and more approximate methods have been developed. For example, if the mixture consists mainly of one component, the physical properties of the major component may be used without the introductions of any significant inaccuracies. Similarly, if only one component of a mixture is toxic, the toxicity values adjusted for this component may be applied to the overall mixture. For example, a leak of butane with a trace of hydrogen sulphide may be treated using the physical properties of butane to calculate release rates but with the toxicity value of hydrogen sulphide applied in order to assess the overall toxic impact.

FIG 3.1

PIPE



Includes: Pipes, flanges, welds, elbows

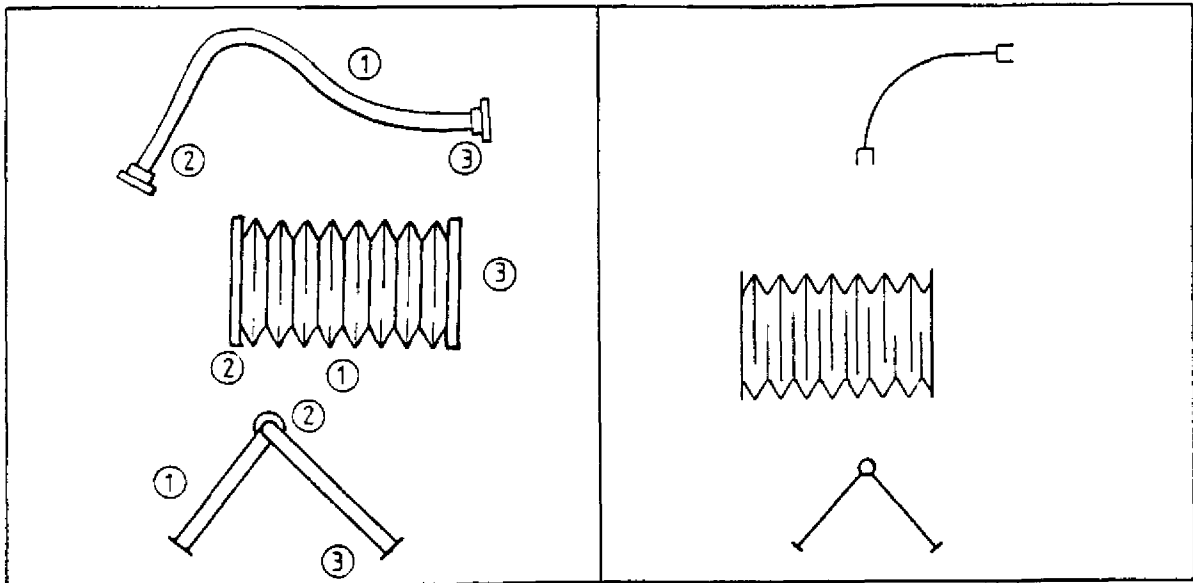
Typical failures:

Suggested failure sizes:

- | | |
|----------------|---|
| ① Flange leak | 20% pipe diameter |
| ② Pipe leak | 100% pipe diameter and
20% pipe diameter |
| ③ Weld failure | 100% pipe diameter and
20% pipe diameter |

FIG 3.2

FLEXIBLE CONNECTION



Includes: Hoses, bellows, articulated arms

Typical failures:

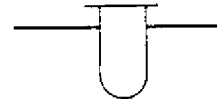
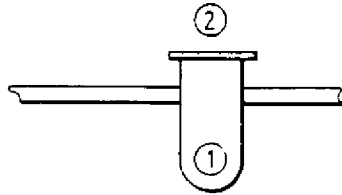
Suggested failure sizes:

- ① Rupture leak
- ② Connection leak
- ③ Connection mechanism failure

100% diameter and
20% diameter
20% diameter
100% diameter

FIG 3.3

FILTER



Includes: Filters, strainers

Typical failures:

Suggested failure sizes:

① Body leak

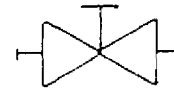
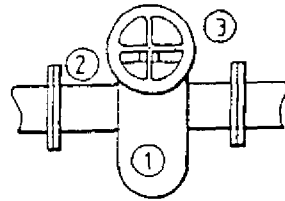
100% pipe diameter and
20% pipe diameter

② Cover leak

20% pipe diameter

FIG 3.4

VALVE



Includes: Ball, gate, globe, plug, needle, butterfly, choke, relief, ESV - valves

Typical failures:

Suggested failure sizes:

① Housing leak

100% pipe diameter and
20% pipe diameter

② Cover leak

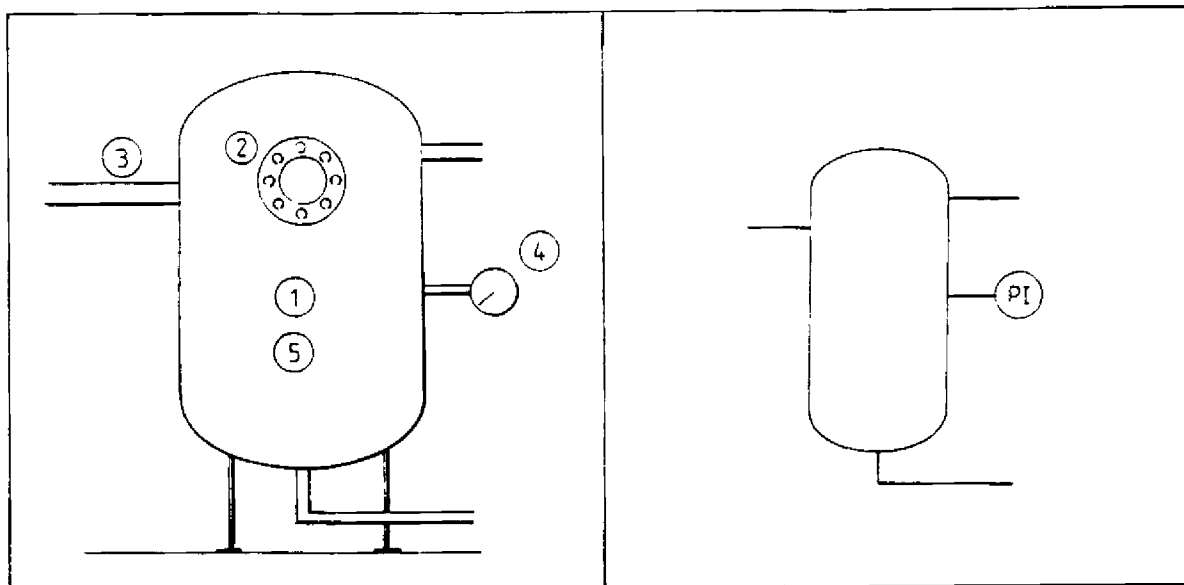
20% pipe diameter

③ Stem leak

20% pipe diameter

FIG 3.5

PRESSURE VESSEL/PROCESS VESSEL



Includes: Separators, scrubbers, contactors, reactors, heat exchangers, pig launchers/receivers, fired heaters, columns, reboilers

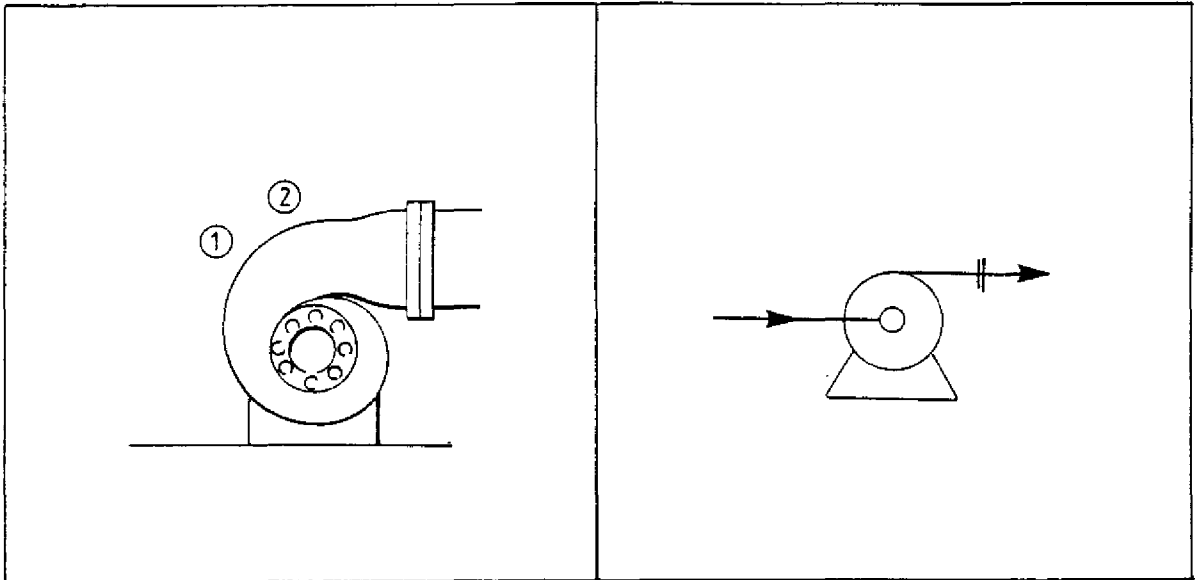
Typical failures:

Suggested failure sizes:

① Vessel rupture, leak	Total rupture, 100% pipe diameter
② Manhole cover leak	20% opening diameter
③ Nozzle failure	100% pipe diameter
④ Instrument line failure	100% line diameter and 20% line diameter
⑤ Internal explosion	Total rupture

FIG 3.6

PUMP



Includes: Centrifugal pumps, reciprocating pumps

Typical failures:

Suggested failure sizes:

① Casing failure

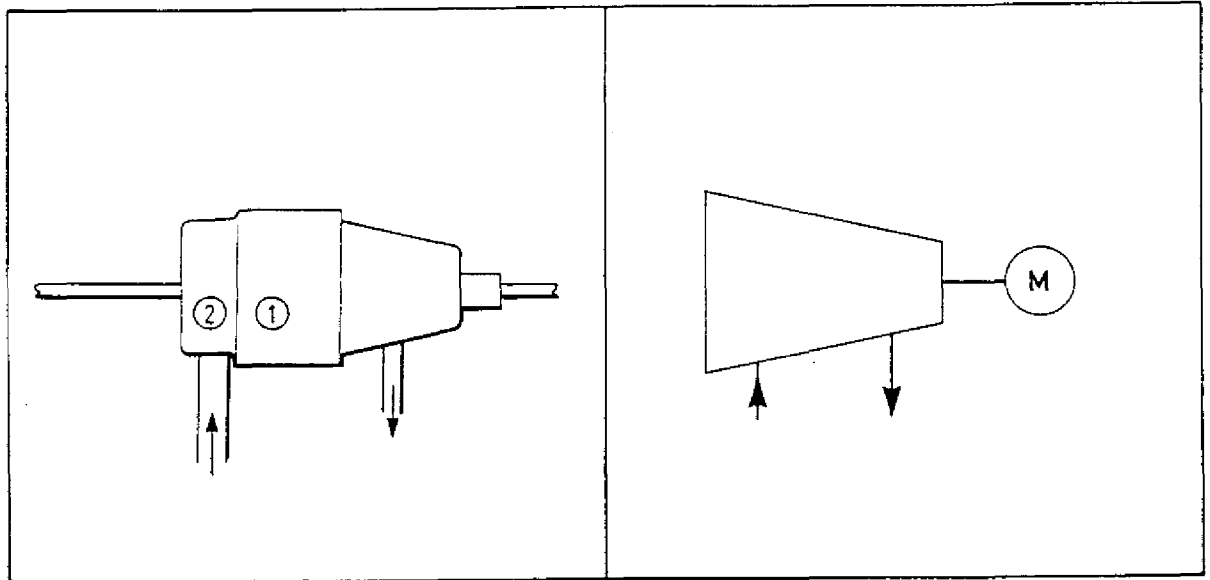
100% pipe diameter and
20% pipe diameter

② Gland leak

20% pipe diameter

FIG 3.7

COMPRESSOR



Includes: Centrifugal compressors, axial compressors, reciprocating compressors

Typical failures:

Suggested failure sizes:

① Casing failure

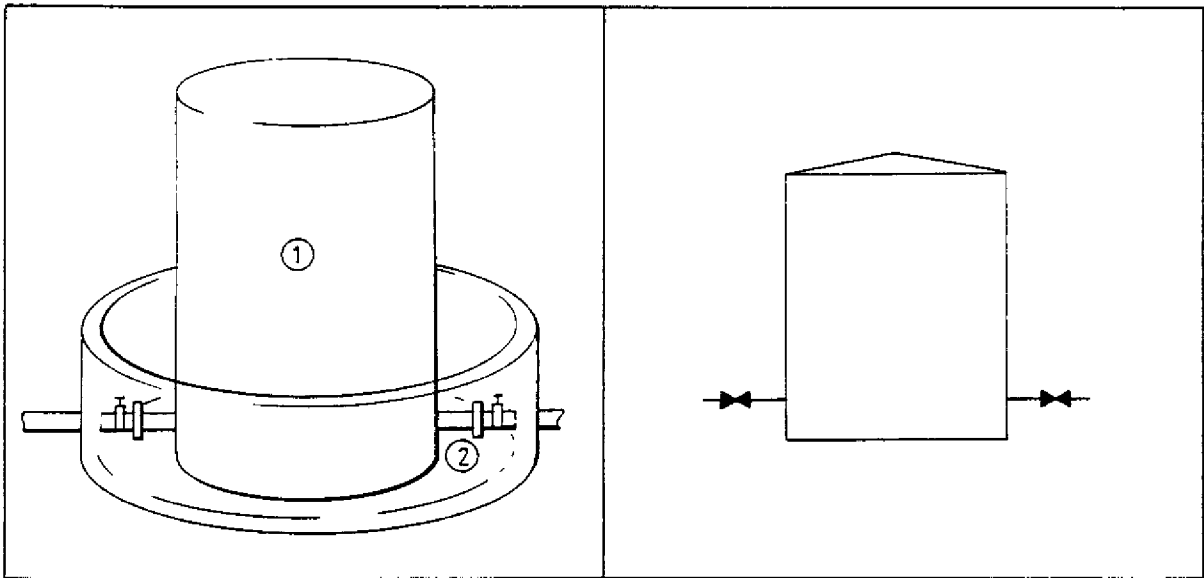
100% pipe diameter and
20% pipe diameter

② Gland leak

20% pipe diameter

FIG 3.8

STORAGE TANK (ATMOSPHERIC)



Includes: Atmospheric tanks, pipe connections,
bund wall

Typical failures:

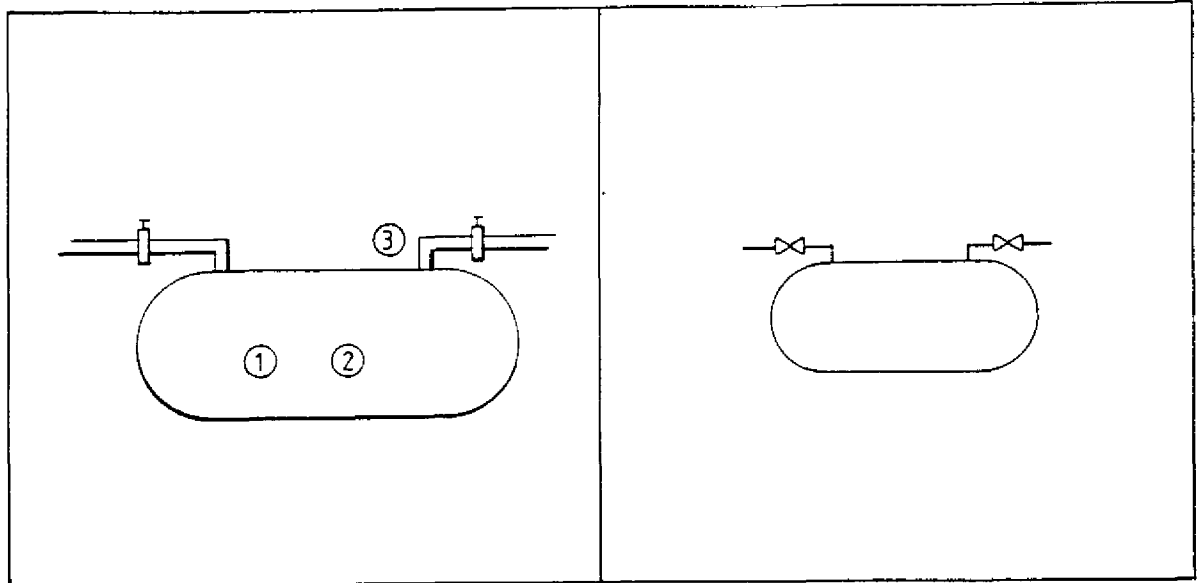
Suggested failure sizes:

- ① Vessel failure
- ② Connection leak

Total rupture
100% pipe diameter and
20% pipe diameter

FIG 3.9

STORAGE VESSEL (PRESSURISED/ REFRIGERATED)



Includes: Pressurised storage/transport vessels,
refrigerated storage/transport vessels,
buried or not buried vessels

Typical failures:

Suggested failure sizes:

① BLEVE (not buried case only)

Total rupture (ignited)

② Rupture

Total rupture

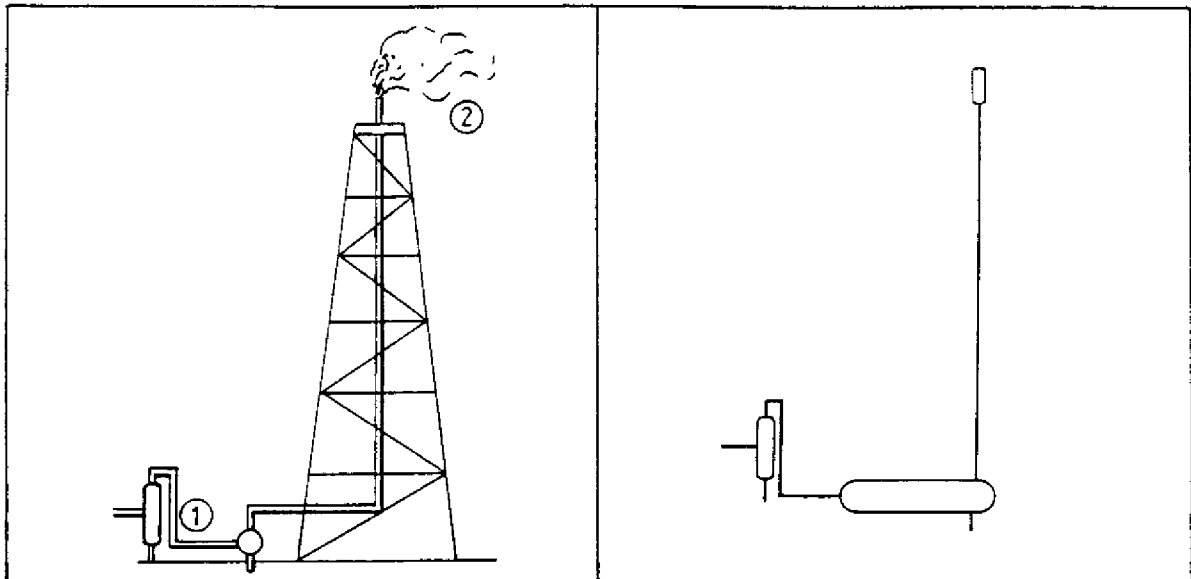
③ Connection leak

100% pipe diameter and
20% pipe diameter

Note: These storage vessels may have bund walls which should be taken into consideration in the analysis.

FIG 3.10

FLARE/VENT STACK



Includes: Manifold, vent scrubber, knock-out drum,
flare/vent stack

Typical failures:

Suggested failure sizes:

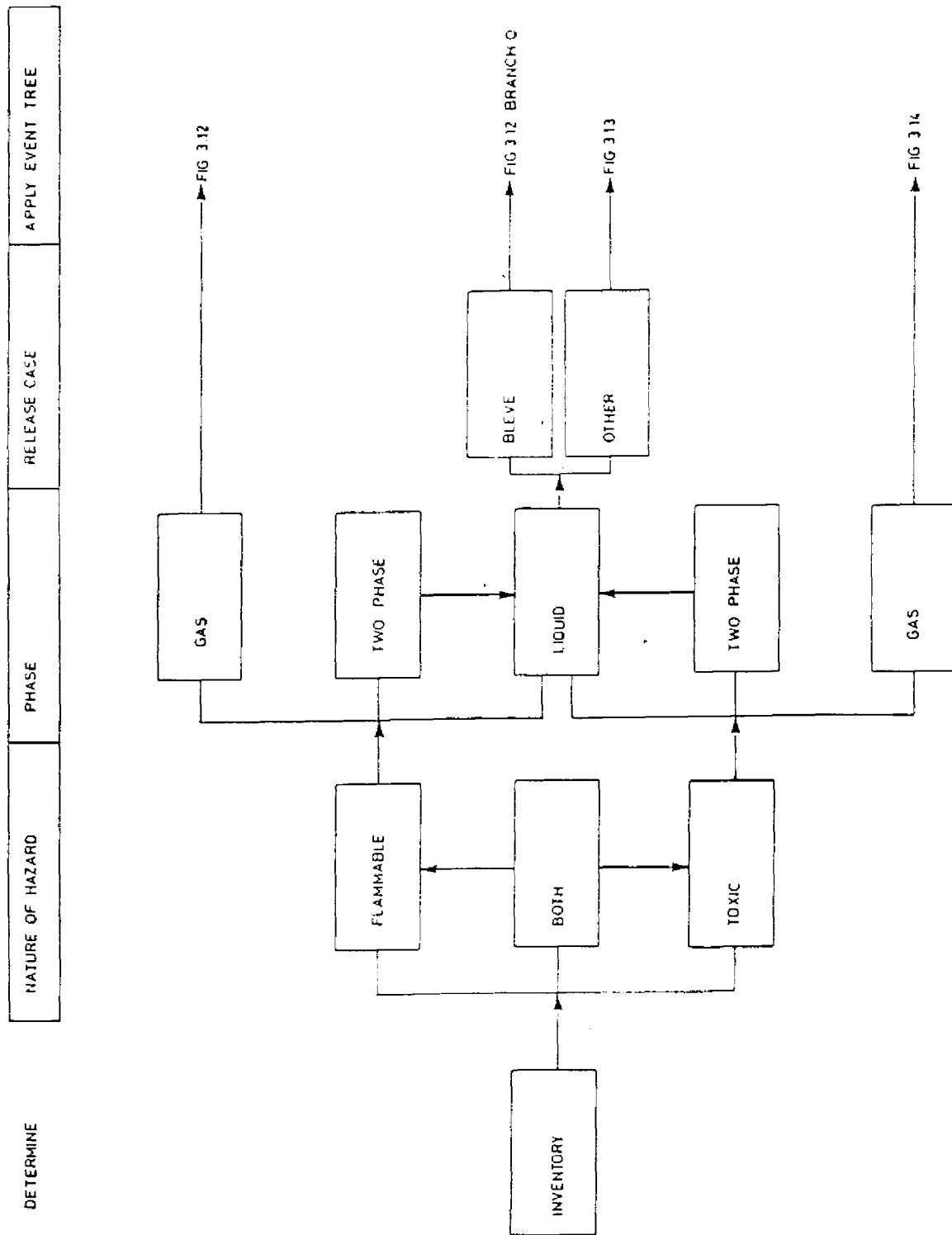
① Manifold/drum leak

100% pipe diameter and
20% pipe diameter

② Discharge beyond
specification

Should be estimated

FIGURE 311 FAILURE CASE DEFINITION



3.4 The Event Trees

There are three basic event trees which illustrate the potential accident sequences which would arise following a release:

Flammable Gas	Figure 3.12
Liquids	Figure 3.13
Toxic Gas	Figure 3.14

In the case of a toxic liquid release (non-flashing), a major cloud of material would not be formed although some toxic vapour may be produced. In these circumstances, potential impacts are not likely to cause off-site fatalities and detailed consequence modelling is probably not needed. However, the properties of the soil and the distance over which drainage to rivers, to the sea, the water reservoirs and to other sensitive areas should be evaluated. This evaluation forms a basis for the design of bund walls, the design of separate drain systems and the development of contingency plans.

Over each branching point in the event trees, there is a question which defines the sequence of events following a release. If both the "yes" and the "no" outcomes are relevant, both branches should be investigated further.

Under each branch of the event trees, an indication is given of the properties of the release which should be calculated and of the events which should be assessed. Where relevant, there is a reference to the appropriate sections in Chapter 4 which provides the details of the calculational methods. The term "Est" indicates that the analyst should make a quantitative estimate based on his knowledge of the plant.

Each tree begins with the determination of appropriate release rates. For the special case of an instantaneous release, the calculations start with the initial cloud behaviour. The jet dispersion and jet fire models are not needed for such cases. There may be, however, a jet release following an instantaneous release if another high pressure reservoir is not isolated from the ruptured vessel. These situations should be considered by the analyst in conducting the initial division of the plant into basic units.

If the release point is connected to a large reservoir of hazardous material, it is important that a realistic estimate of the time required for the isolation of the reservoir should be made so that the leak duration may be determined with some confidence. In considering the duration of a gaseous or liquid leak, the availability of shutdown will be dependent on:

- **leak detection:** the presence of gas and flame detectors near the release point or in the affected enclosure should be determined and the expected reliability of the detectors should be estimated.
- **shutdown actuation:** the presence of automatic or manual activation systems for shutdown should be determined. If the system is manual, the methods of informing the operators should be assessed including identification of the personnel responsible for decisions to activate the shutdown mechanisms. From this assessment an estimate of the duration of the response time of the systems may be made.
- **shutdown valves:** the availability or reliability of the valves should be determined and the actual closing times should be identified.

As a general rule, it is usual to assume that major ruptures and massive leaks will be detected immediately, either by instruments or by the operating personnel. For manual activation of shutdown systems, the response time depends upon the alarm design, the operating procedures and the adequacy of operator training. Response times of 3, 5 and 15 minutes may be typical, taking account of the high levels of mental stress which would be encountered during an emergency and the possibilities, therefore, for making mistakes. For automatic shutdown systems, the closing time of shutdown valves will depend upon the valve size and pressures involved. Typically, for large, high pressure valves, closing times of 30 seconds are experienced.

If the hazardous material released during an accident or failure is flammable, the ignition possibilities (immediate and delayed) must be assessed by the analyst. If the release is both flammable and toxic, it would be essential to analyse both the ignited and non-ignited events. For ignited jets or gas clouds (Figure 3.12), the calculated heat and pressure loads are used:

- directly to assess fatalities and material damage on and off site,
- indirectly to determine whether the fire/explosion may result in knock-on effects, such as those which may damage other equipment also containing hazardous materials leading to an escalation of the accident.

The analyst examining any potentially hazardous process must check that releases caused by preceding events due to knock-on effects are analysed by following the appropriate event trees in Figure 3.12 to 3.14. For the purposes of the hazard analysis, it will usually be bound that a good number of potential knock-on effects will have already been identified as potential release cases anyway. The analyst should proceed to determine the cloud density to establish if buoyant, neutral or dense cloud dispersion modes should be applied. It should be noted that the distance from the release point to a potential delayed source of ignition will form the basis for determining the flammable mass in the cloud and thus the heat and pressure loads which may be encountered in the surrounding environment.

For a flammable or toxic liquid (Figure 3.13), the release is treated as either a single phase or two-phase discharge, depending upon the thermophysical conditions under which the particular inventory is held. The latter include:

- A stabilised liquid at ambient pressure and temperature would form a pool. In the case where ignition is considered relevant, the heat loads from a pool fire may be calculated. However, if ignition is not considered to be important, any hazards to water and land pollution should be evaluated.

- A gas which is liquefied by refrigeration will initially form a pool, but, thereafter, evaporation will take place. In the case of early ignition, the fire should be treated as a pool fire. For other cases, a gas cloud would be formed, and either the flammable gas event tree and or the toxic gas event tree should be applied.
- A gas which is liquefied by pressurisation would expand immediately upon release, and thus one of the appropriate gas event tree should be applied directly.

For a toxic gas release (Figure 3.14), the cloud density governs the selection of appropriate dispersion models. In the majority of cases, emphasis will be placed on dense gas dispersion due to the low cloud temperatures which are usually encountered. Also, many gases are heavier than air and can form dense clouds even at ambient temperatures. The methods for the consequence calculations due to toxic impacts are discussed in Section 4.6.

In many plant, safe handling of discharges and upset conditions is achieved by the design and operation of adequate vent, scrubbing and flare facilities. Where reliance is placed upon such systems, the hazard analyst must take particular care to ensure that:

- if any flammable or toxic material may be discharged into the system during normal operation or during an emergency at a rate above which the system is designed, the location of overpressure and ultimate discharge is identified. A thorough check should be conducted of drain systems, of any additional pressure relief systems discharging directly to the atmosphere and of the possibilities for equipment to rupture.
- flammables may not be discharged into a cold vent system which is not designed to handle flammables.
- in the event of a flame failure at the flare stack, hazardous quantities of flammable (and possibly toxic) material may not be discharged.
- the potential for reactive or runaway reactions with the production of excess heat, toxic or flammable materials for discharge to the vent or flare system is fully examined.

- the potential for abnormal reactions to cause the discharge of hazardous materials to the vent or flare system is fully examined.

A full examination of accident sequences involving the above circumstances will require the estimation of release quantities and the estimation of potential impacts using the event sequence trees for Flammable Gas, Liquids or Toxic Gas as described above.

FIGURE 3.12 EVENT TREE FOR FLAMMABLE GAS RELEASE

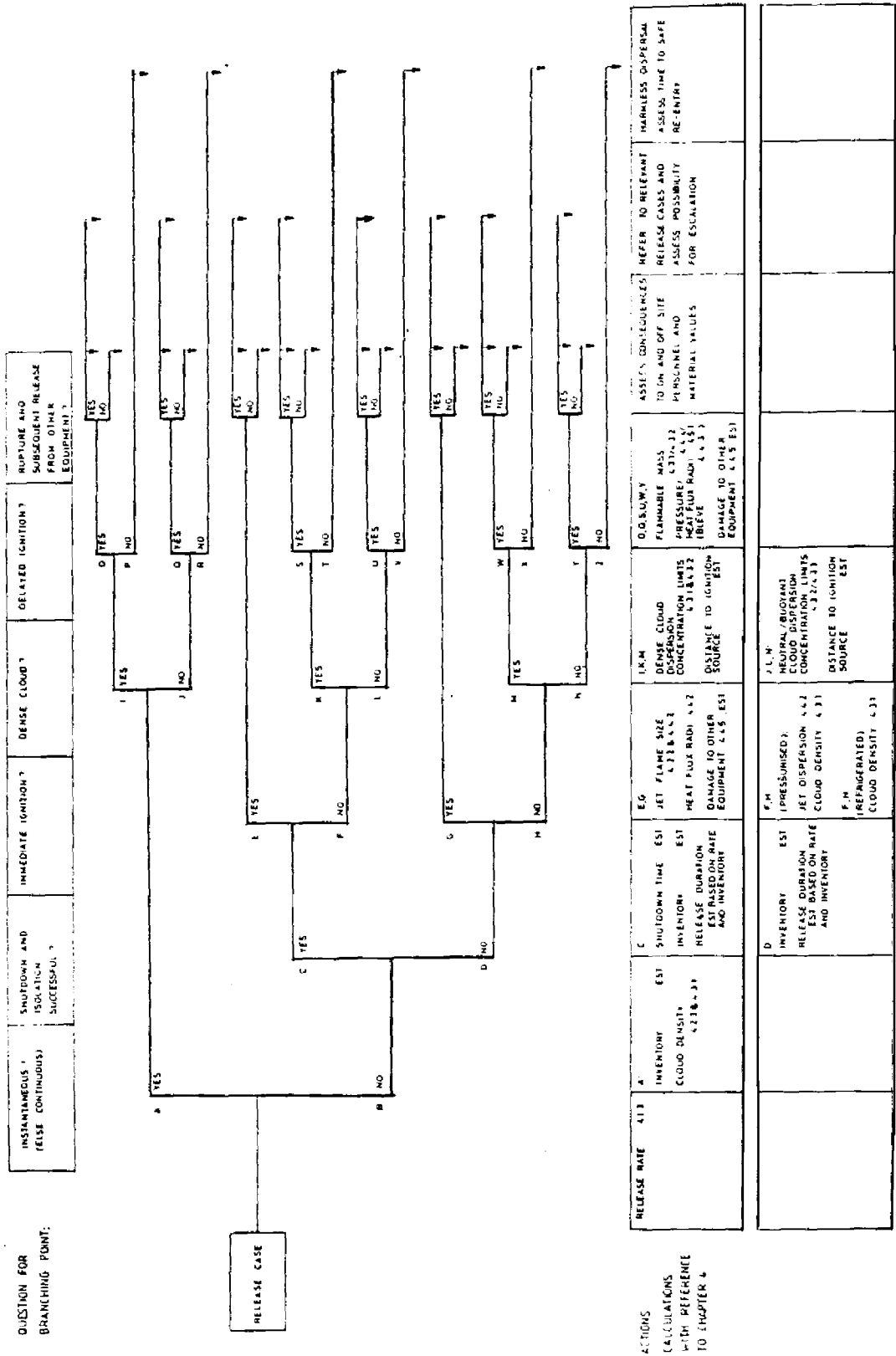


FIGURE 3.13 EVENT TREE* FOR LIQUID RELEASE; FLAMMABLE OR TOXIC.

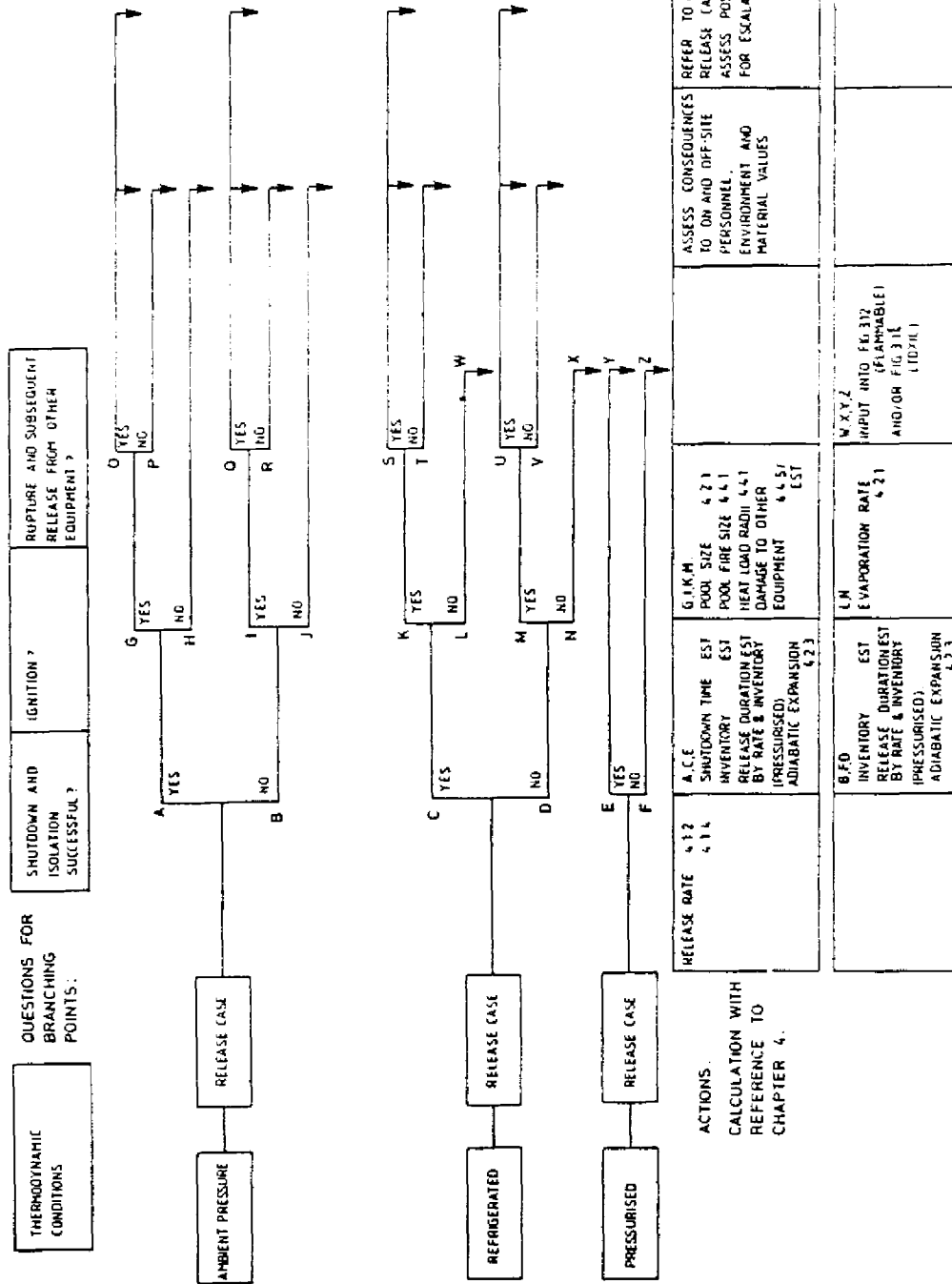


FIG 3.14. EVENT TREE FOR TOXIC GAS RELEASE

