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TNO-report

Risk assessment of the use of flammable refrigerants

Final report

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EEC Contract JOU2-CT92-0060
Replacement of CFC's
Task 2: Environmentally Benign Flammable refrigerants

Part 2.2: Quantification of safety requirements for using flammable refrigerants

Intended for
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in the framework of the JOULE2 programme of the European Union

Summary

Within the framework of the JOU2-CT92-0060 project regarding the 'replacement of CFC's' (Chloro Fluoro Carbons) 5 different tasks have been defined. In this study the results are given of Task 2.1. The content of task 2 is twofold:

2.1 Collection of thermodynamic properties for potential flammable refrigerants and,
2.2 Risk assessment of the use of flammable refrigerants.
In this report the results of Task 2.2 are given.

The aim of the study is to get a deeper understanding about the risk of the use of flammables as refrigerant instead of the non-flammable normally used. This because the lack of experience about the use of flammables instead of inflammable refrigerants. Relatively small scale mobile cooling installations have been chosen as subject for this research.

The risk assessment has been carried out for two refrigerating systems: a small installation, mainly used for local transport, containing about 3 kg refrigerant and a large installation applied for international purposes with a content of about 8 kg refrigerant.

Propane has been chosen as a characteristic flammable refrigerant with a highest potential impact with regard to risks for the surroundings comparing with e.g. butane and lpg.

For the identification of the hazards use is made of different approaches and experts:
- a Hazard and Operability study,
- specific knowledge by retaining of experts with regard to refrigerating units as well as with regard to risk assessment studies,
- a firm specialised in the installation of refrigerating units and service activities has been consulted with regard to specific problems during normal conditions and during services.

This approach resulted in a number of accident scenarios (releases of flammable material) and conclusions concerning the design of the installation.

From the point of view of the design of the installation it is concluded that the design is appropriate and all safety measurements necessary, for the protection of the installation against flow, temperature and pressure deviations, are taken.
Based on the accident scenarios effect and consequences have been calculated, the frequency of occurrence is determined and both individual risk and societal risk is calculated.

Accident scenarios have been defined for three different working situations: normal working conditions, services (maintenance etc.) and accidents during transport.
The results of the individual risk calculations show that the individual risk is higher than acceptable within a distance of 2.5 meter and 3.5 meter for a small and large unit respectively. This is mainly caused by the service activities. For larger distances the individual risk is acceptable according the criteria used in several countries.

The societal risk is calculated for a number of characteristic residential areas, shopping areas, situation on a motor way and urban transport. The results show that the societal risk is negligible with regard to the criteria used.

The total impact of the consequences due to fire effects are limited to about 35 meter. In case of explosion in the cold space the consequences can be larger due to fragments of the destroyed cold space. The expected distance for a single fragment is about 300 meter. The consequences due to fragments as a result of explosions is expected to be low and are estimated as a single at a maximum.

Although the risk is acceptable according to the criteria used in different countries, a number of risk reducing measures have been defined according the As Low As Reasonable Achievable approach.
Possible risk reducing measures have been defined for the installation (including the cold space), training of driver and personal and services (non limitative). The main reducing measures are (non-limitative):

Training and education:
- training of drivers and maintenance personnel with regard to the handling of flammable gases;
- use of instruction manuals;
- special attention for specific problems during maintenance (e.g. degassification of equipment).

Maintenance:
- application of specific quick release couplings for filling up of the refrigerant, to avoid exchange with non-flammable refrigerants;
- use of specific filling up bottles with quantities comparable with the quantity of the installation;
- instruction manuals with special attention to gasfree making of the equipment;
- solder or welding activities must be applied on gasfree equipment only;
- in case of international transport, maintenance can be required at any location in any country. Therefore, adequate logistics have to be considered as well.

Installation:
- minimising of (screwed) connections;
- minimising the refrigerant content;
- application of leak detection in the cold space (if technically possible);
- application of explosion proof equipment in the cold space;
- installation of small fire extinguishing equipment;
- application of hermetic compressors.

Labelling:
- application of specific labelling on gas cylinders (for refill usage) with flammables to prevent exchanges;
- labelling on the installation itself e.g. 'filled with flammable refrigerant'.

Safety cards:
- safety cards or other information about flammables and how to handle in case of emergencies on board of the trucks.

This possible measures need further research, with regard to the effect of the reduction of the calculated risk of the individual risk reducing measures and to take care that priority is given to the most important measures. From casuistry it is known that human failures is an important cause of accidents. Therefore it is worthwhile to prevent human failures by training and education.

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1 Introduction

A risk analysis of the use of flammable refrigerants is carried out in the scope of the EC-Joule II project 'replacement of CFC's in refrigerating equipment by environmentally benign alternatives'.
This part of the study, defined as part of task 2 in the project description, contains a Quantitative Risk-Analysis (QRA) with regard to the use of flammable refrigerants.
A QRA contains an overview of possible accidental releases of, in this study, flammable material, the effects of the releases in terms of fatalities (consequences) and the frequency of the consequences. The combination of consequences and frequencies quantifies the risk.

The QRA is carried out for two different installations; a small refrigeration unit used for local transport and a large installation used for international transport. The consequences are based on the use of propane as refrigerant. The reason for this choice is the application of flammable refrigerants in relatively small and mobile installations with a low content of refrigerant and the practical experience of the use of flammables in mobile installations (e.g. LPG and gasoline). For these reasons, mobile refrigeration systems seem to be attractive for using flammable refrigerants (hydrocarbons) which are an environmentally benign alternative for common used CFC, HCFC or HFC refrigerants.
The QRA is applied for the application of flammables only. Production, bulk storage or bulktransport is not taken into account.

Three main activities have been considered:
1. normal operating conditions (cooling and defrost),
2. transport,
3. maintenance and repair.

In the QRA a detailed study has been carried out about the possible accidents with the refrigerating system and the consequences of these accidents. Consequences of the accidents can be material, economic damage and/or personal damage. In this study consequences have been defined as fatally injured people as a result of being exposed to effects concerned.

The limitation to fatalities is based on the presence of acceptability criteria for risks based on fatalities. By this approach comparison between the calculated risk and criteria are possible.

A Quantitative Risk Assessment comprises the following three main steps:
- Identification of accident scenarios: what can go wrong?
- Calculation of the possible effects of the incident and the corresponding damage or injuries;
- Determination of the frequencies or probabilities that each of the consequences occur.

The different elements are given in figure 1.1.

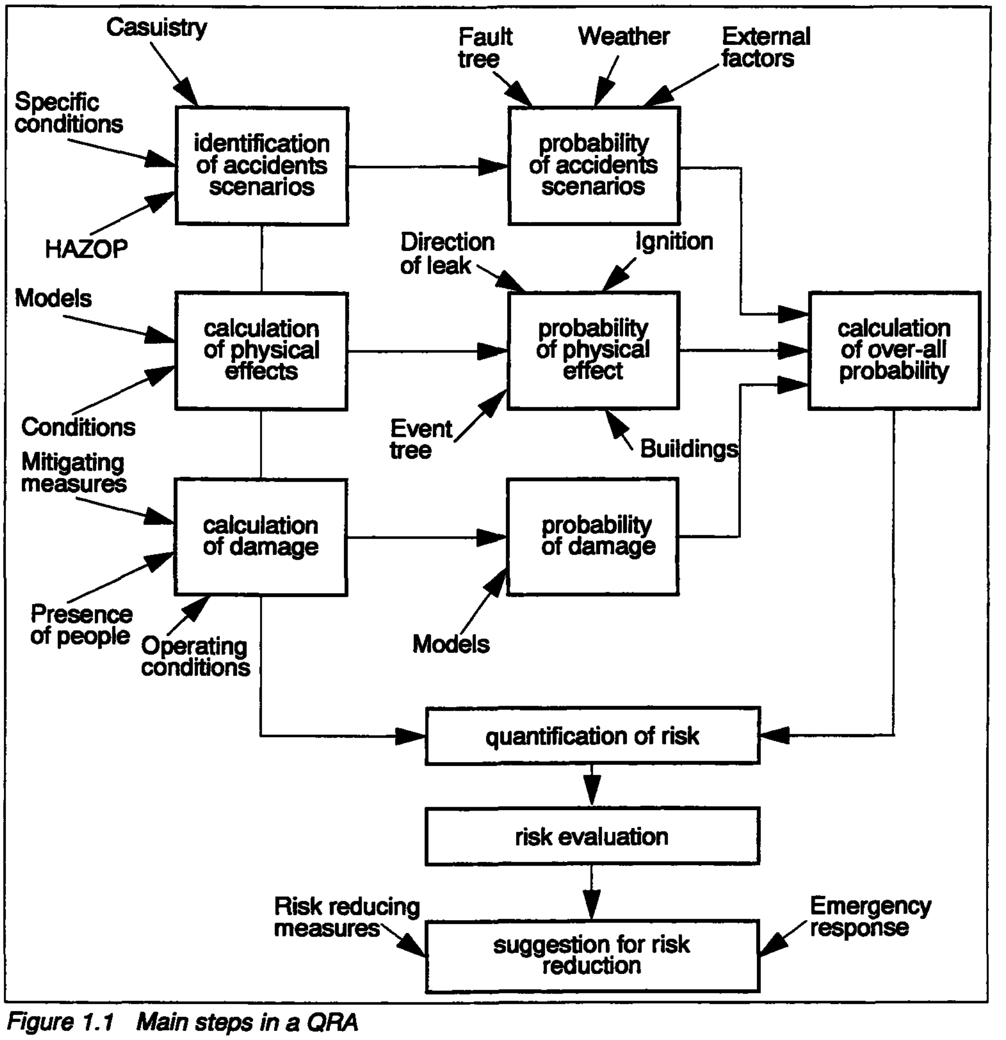

Figure 1.1 Main steps in a QRA

Risk is defined as: *'the likelihood of an adverse outcome'*

So, risk is determined by two factors: the adverse effect (consequences) of an exposure to hazard and the frequency of this exposure. In this QRA two criteria for risk are used: individual risk and societal risk.

The results of this analysis have to be considered as a quantitative contribution to the discussion about the applicability of flammable refrigerants in refrigerating systems. Readers are kindly invited to submit their comments to the authors.

In this report the following subjects are described:
- overview of the results of the literature survey (chapter 2),
- description of the cooling system considered (chapter 3),
- physical properties of flammable refrigerants (chapter 4),
- identification of accident scenario's (chapter 5),
- effect and consequence calculations (chapter 6),
- calculations and presentation of the risks (chapters 7 and 8),
- risk reducing measures (chapter 9),
- conclusions and recommendations (chapter 10).

2 Literature survey

2.1 General

The replacement of the commonly used refrigerants (which are not flammable) by flammable ones introduces the risk factor: the possibility of the occurrence of a fire or an explosion due to the release and ignition of the flammable gas.
Before starting a comprehensive risk assessment of the use of flammable refrigerants in relatively small installations a literature survey was carried out. The aim of the survey was to check the state of the art with respect to the application of flammables in refrigerating installations.
This survey was performed in co-operation with the Centre for Information and Documentation (CID) TNO. A number of keywords related to the combination: (alternative) refrigerants and safety (safety, risk, risk assessment, refrigerants) were used.
A number of databases in both Europe and the United States were selected.
The results of the retrieval are given in the next paragraphs. First specific articles and studies with respect to safety are presented and next attention have been paid to directives and standards present for refrigerating systems in general and the use of flammables as a refrigerant in particular.

2.2 Articles and studies

The retrieval has resulted in a limited number of references of articles and one specific report in which the safety of the use of flammable refrigerants was studied in more detail [15]. All references were summarised in the International Bulletin of Refrigeration, spread over several years.

A number of articles give information with respect to the subject: 'safety for people' in relation to the refrigerant used [7], [8], [9], [10], [11], [12] and [14]. In most cases the subject is mentioned but not worked out in detail. Generally the conclusion was made that from the safety point of view application of flammable refrigerants in relatively small installations will not result in dangerous situations. The main reason for this are the relatively small amount of refrigerant (mainly less than about 1 kg for domestic applications), the volume of the enclosed space and the relative high level of the lower explosion limit (about 40 $g.m^{-3}$) of the flammable used.
The overall conclusion in the articles is that it is recommended to change the standards in such a way that the use of flammable refrigerants in relatively small installations (like domestic ones and comparables) will not be restricted any more in the future.
It is noted that this conclusion is not based on a detailed risk assessment of the use of flammables as refrigerant but on the presence of limited amounts of the flammable gas and the physical properties.

In the only in-depth risk assessment of the use of flammable refrigerants for home appliances [15] it is concluded that a catastrophic leak frequency, based on a average situation, amounts $7.1.10^{-7}$ per refrigerator per year. The catastrophic leak frequency

for a worst case situation is $1.8.10^{-5}$ per refrigerator per year. The frequency of fire/ explosion inside the refrigerator is $2.7.10^{-13}$/year (on average) and $7.0.10^{-12}$/year (worst case), for the explosion outside the refrigerator the figures are respectively $2.0.10^{-8}$/year and $5.0.10^{-7}$/year.
This means that in the United States most likely 2 to 44 fires per year can occur due to the use of flammables in refrigeration equipment which are severe enough to cause fatalities.
The report concludes also that the use of a flammable refrigerant would increase the risk of a kitchen fire by 0.04%, based on the worst case assumptions.

Based on the results of the literature survey it is concluded that there is a lack of information with regard to the risk of use of flammable refrigerants for home appliances.
No information is found with respect to the risk of the use of flammables in larger installations in general and mobile refrigeration installations and industrial installations in particular.
Effect and consequences of the release of flammable refrigerants have not been calculated in detail. Also no attention is given to the probability of releases of flammables.
For a soundly based decision about the allowance of flammable refrigerants it is necessary to have insight in the effects and consequences as well as in the frequency of occurrence of the consequences. Both determine the risk of the use of flammables.

2.3 Directives and standards

In a number of articles reference was made to directives and standards. With respect to the allowance and application of flammable refrigerants the most important are:
- The British Standard BS 4434,
- DIN 8975 (UVV Kälteanlage VBG 20; DIN VDE 0165),
- EEC directive 73/23/EEC,
- (draft) prEN 378/1-13 European Standard. Safety and Environmental requirements for refrigerating systems and heat pumps.

Using the flammable refrigerant propane as representative, the standards give the following restrictions:
- The British Standard BS 4434 classifies propane as a group 3 refrigerant (Lower Explosion Limit < 3.5% by vol.) that has flammable and explosives characteristics.
  This standard prohibits the use of group 3 refrigerants in domestic occupancies, but it allows the use in commercial occupancy provided the refrigerant does not exceed 2.5 kg.
- In the German standard DIN 8975 propane is also classified as a group 3 refrigerant (like BS 4434). The use of propane is not equivocal prohibited. It is described that the use of refrigerant is acceptable if the inventory not exceeds 1 kg. But at the other hand the use of flammable refrigerants is allowed only in the circumstances of good supervision in industrial applications.
  The DIN VDE 0165 gives directives for the installation of electrical equipment in non-explosion proof spaces.

- In the draft standard prEN 378 part 1 until 13 a number of requirements have been given with respect to safety and environment:
  - part 1: basic requirements and definitions,
  - part 2: general definitions,
  - part 3: classifications of refrigerants and occupancies,
  - part 4: selection of refrigerants,
  - part 5: design, construction and materials,
  - part 6: piping,
  - part 7: testing, commissioning and site inspection,
  - part 8: installation,
  - part 9: personal,
  - part 10: documentation and instruction,
  - part 11: maintenance and repair,
  - part 12: recovery, reuse and disposal,
  - part 13: competence.

In the standard, requirements are given for flammable refrigerants. The categorisations with respect to risk to health and environment (groups L, G and O) and health and flammability (L1, L2a, L2b and L3) are the same as given in the standards BS 4434 and DIN 8975.
This European Standard is in a final stage and is re-ordered in 4 parts.

The directives and standards concern mainly the safety with regard to the use of electrical equipment, the environment (green house effect, ozone depletion) and the qualifications for different equipment applied in the installation. With respect to the risks of the use of flammable refrigerants nothing has been found.

3 Description of the cooling system

3.1 Flow diagram

In figure 1 the flow diagram of the cooling system is given for installations used in trucks both for inland transport (small installations) as well as for international transport (large installations).
An overview of dimensions, length and diameters of pipelines used etc. is given in table 3.1.
This information has been based on specifications of two commonly used commercially available transport cooling systems which are representative for this kind of cooling systems.

Table 3.1 Overview of characteristic dimensions and parts of an installation

Parts	Small units	Large units
length of lines	about 3 meter copper lines about 12 meter rubber lines	about 8 meter copper lines about 15 meter rubber lines
line diameter	6 - 12 mm	6 - 25 mm
number connections	> 4	> 10
process control	3-way valve and pressure regulator	3-way valve and pressure regulator
safety measures	pressure control valve	pressure control valve
compressor type	open compressor	open compressor
application	cooling and frost	cooling and frost
refrigerant	propane, LPG / R22	propane, LPG / R22
amount of refrigerant	3 kg	7 - 8 kg
distribution of the location [% of total numbers]	10% under the truck 90% at the front	10% under the truck 90% at the front
dimensions length, width, height [m]	1 x 0.4 x 1	1.9 x 0.6 x 2.1 m
free volume [m^3]	0.3	0.5
volume of the cold space [m^3]	25	90

Table 3.2 Settings of the safety devices (Based on R22)

Item	Setting
High pressure switch	20 - 30 bar
Low pressure switch	-37 kPa
High temperature switch	110 °C
High pressure relief valve	just above setting high pressure switch
Condenser fan switch	start: 12 bar stop: 9 bar

In figure 1 the flow diagram is given for the cooling situations, figure 2 shows the defrost situation.
The working principle is the same for the small and large installation and is described below.

Cooling situation
The cooling situation (see figure 1) means that cooling takes place of the cargo, in this case, the cargo in the cold space.
The refrigerant is pressurised by means of a compressor. The refrigerant condenses in the condenser and the liquid is collected in the receiver.
From the receiver the liquid passes a heat exchanger in which the liquid will be subcooled before it passes the expansion valve, through which a further temperature decrease is achieved and passes the evaporator coil.
The heat from the surroundings (cargo) is taken via the air passing this evaporator coil.
After the evaporator and the heat exchanger the gasflow passes an accumulator, to collect any possible liquid and (the gasified refrigerant) enters the inlet of the compressor again.

A high and low pressure switch, a high temperature switch (on the compressor outlet line), a pressure regulator and a high pressure relief valve have been installed to ensure a working situation within a prefixed pressure and temperature range (see table 5.2). Also an oil separator (in the compressor outlet line), a drier after the receiver and a check valve in the discharge line of the compressor are present.
For back up reasons also a second compressor have been installed (optionally).

Typical temperature and pressure for this kind of installations are: 12 bar and 40 °C downstream the compressor and 2-3 bar (-20 °C) upstream the compressor (R22).

Defrost situation
In the defrost situation relatively hot refrigerant gas is sent to the evaporator coil directly from the compressor without passing the condenser. This is regulated by the three way valve downstream the compressor.
See figure 2 for the flow diagram of this situation.
The figure shows (see arrows for the flow direction) that the relative 'hot' refrigerant from the outlet of the compressor passes directly to the pan heater (to prevent ice formation in the receiver) and the evaporator coil. The condenser check valve prevents the back flow of refrigerant form the receiver to the condenser.

3.2 Location of the system

The cooling system can be installed on mainly two different locations. One location is at the front side of the trailer between the truck and the trailer. The second location is under the trailer.

3.3 Services

3.3.1 Maintenance and repair

From the experience with refrigerating systems operating with CFC's it is known that maintenance and repair take place on a yearly base. The activities applied can differ from checking couplings, safety devices, expansion valve, three way valve to exchange of equipment.

3.3.2 Fill up the system

During normal operating conditions part of the installation content will be released. From working practice it is known that this amounts about 20% of the total content.
In this study it is assumed that the installation will be filled up every one year by use of small gas cylinders with a content equivalent to the total content of the installation. The fill up takes place by use of a quick release connection with the installation.

4 Physical properties of the flammable refrigerants

In the table below an overview is given of the physical properties of propane, butane and LPG. The properties are given with regard to flammable risks [19] and [20].

Table 4.1 Overview of physical properties of propane, butane and LPG (50/50)

Physical property	Propane	Butane	LPG (50/50)
refrigerant name	R 290	R 600	?
mol. weight	44.1	58	51.1
boiling point [°C]	-42.1	0.5	-21.2
pressure [bar] (at 20 °C)	8.3	2.1	5.2
liquid density [kg.m^{-3}]	500	580	541
combustion heat [Mj.kg^{-1}]	46,35	45,85	45,94
ignition temperature [°C].	468	405	400
LEL [%-vol.]	2.1	1.8	2.0
UEL [%-vol.]	9.5	8.4	9.0
critical pressure [bar]	42.5	37.97	-
critical temperature [°C]	96.8	152	124.5

5 Identification of accident scenarios

5.1 General

In the framework of this study accident scenarios are defined as abnormal conditions by which (a substantial part of) the content of the system can be released. Such abnormal situations can occur due to internal failure of the system itself or due to external causes. Internal causes are for instance leakage as a result of internal corrosion, high pressure, failure of a relief valve resulting in bursting of lines etc. Also external causes are possible, important causes for mobile installations are releases due to accidents.

The methodology for the identification of accident scenarios and the results of the application of the methodology have been given in the subsequent paragraphs.

5.2 Methodology

The identification of accident scenarios has been carried out for three characteristic activities:
1. normal operating conditions (cooling and defrost),
2. maintenance and repair,
3. transport.

For the identification of possible accident scenarios the following steps have been taken:
- study of the process and instrument diagram of the system for the two different stadia (cooling and defrosting),
- information from historical accidents with comparable systems,
- accident identification by use of the HAZOP-method [17].
  By use of the **HAZ**ard and **OP**erability method an analysis of the system by use of prefixed guidewords is carried out.
  The guidewords are applied to different sections of the installation. For this purpose the installation is divided into a number of different sections. In most cases the sections are separated by equipment (valves, compressor, heat exchanger etc.)
  In appendix I, Figure 1 and 2, the different sections for the cooling and the defrost situation are given. The guidewords are used upstream the section number.
  For every guideword (an abnormal situation of the system, e.g. no flow, high pressure, high or low temperature etc.) the possible actions of the system itself (e.g. by use of a relief valve, pressure regulators, pressure switches) are analysed. Such a method is a very detailed and structured analysis of the system with respect to the design of the system, possible abnormal situations and possible accidents. This method is described in detail in [17].

5.3 Results of the accident identification

5.3.1 Normal operating

Historical accidents
No historical accidents with regard to the use of refrigerants (others than ammonia) in both mobile and stationary installations have been found in the TNO databank FACTS. One of the main reasons for this is the application of non-flammable refrigerants on the one hand and the relative small content of the system on the other hand.
From the maintenance point of view it is known that every one year about 20% of the content of CFC-like refrigerant of the installations is released to atmosphere.
The main reason for this leakage is the use of a number of screwed connections (flares), vibrations of the system during transport and leakage through the gland of the compressor.

The HAZOP-analysis
The HAZOP-team consisted of an expert on heat and refrigeration technology, an expert on reliability of installations and an expert on risk assessment and the application of HAZOP-studies.
The analysis was carried out in four sessions. After this the results of the HAZOP were discussed in the HAZOP-team again and some unclear points were solved. Finally the results were summarised and tabulated.

The results of the HAZOP-analysis, including an explanation of the results, have been summarised in Appendix I.

The conclusions of the analysis are listed below:
- the design of the system is appropriate. Deviations of process parameters can be corrected by use of the installed instrumentation.
- Application of the HAZOP-method resulted in the identification of the following accident scenario's: leakage or failure of pipelines or pipeline connections, failure of the evaporator coil or condenser coil, failure of the accumulator or receiver and blow off via relief valves.

Five main accident scenario's are distinguished for the normal operation situation:
- leakage of pipelines.
  Two release diameters will be distinguished:
  - a full bore release with a release diameter equal to the pipeline diameter,
  - release diameter equivalent to 10% of the cross sectional area,
  - release diameter equivalent to 1% of the cross sectional area.

  The releases are situated on the location:
  - upstream the compressor,
  - at the condenser coil,
  - at the evaporator coil,
  - downstream the compressor.
- Leakage of the gland of the compressor.
- Failure of the accumulator.
- Failure of the receiver.
- Blow off via a relief valve.

5.3.2 Services

Maintenance and repair
Accidents can also occur during maintenance and repair.
The type of accidents depends partly of the activity applied. Within maintenance and repair the following activities can be distinguished:
1. replace of parts (e.g. compressor),
2. fill up the system with refrigerant.

ad 1) Before replacing parts the installation must be made free of refrigerant. During this activity it is possible that this activity is not executed correctly. The following accidents can be distinguished:
  a. the system is not completely made free of refrigerant,
  b. release of refrigerant occurred during cleaning,
  c. system blocked in by use of leaking valves,
  d. release during fill up the system (see next subject).

Fill up the installation
During fill up the system the following accidents can occur:
a. release of (part of) the refrigerant,
b. fill up the system with a wrong refrigerant.

5.3.3 Transport

Releases during transport can occur as a result of accidents or as 'spontaneous' releases.
If a release occur during the ride it is expected that the gas is diluted quickly and it is assumed that this can not result in hazardous situations.
A potential hazardous situation can occur only in case of accidents.
As a result of the accident the cooling installation can be damaged and (part) of the refrigerant can be released.
The accident scenario for the transport situation is:
- instantaneous release of the total content of the installation due to external damage due to caused by road accidents.

A more detailed description of the possible release scenarios have been mentioned below.

Leakage of pipelines
Leakage of pipelines can be caused by internal causes such as:
- internal corrosion, use of not qualified material,
- external causes (e.g accidents),
- mistakes during maintenance and repair, wrong filling procedure etc.

A leakage of pipelines can occur in different leak sizes. In risk analysis it is common to use three sizes of leakages: full bore leakage (hole equal to the pipeline diameter), leakage equivalent with 10% and 1% of the cross sectional area. By this approach all sizes relevant for a representative risk assessment are available. The release will be located at different characteristic locations of the installation, downstream as well as upstream the compressor.

Failures of equipment
Besides leakages of pipelines also failure of equipment (vessels, compressors) are credible failures.
From casuistry it is known that catastrophic failure of pressure vessels (in this study the accumulator and the receiver) can occur.
The initial cause of a failure can be the same as given for pipelines.
An accidental release can also occur as a result of spontaneous opening of a relief valve. A spontaneous relief occurs at working pressure conditions often at pressures below the setting pressure of the relief valve.

The identified accident scenarios are the bases for the effect and consequence calculations. Next the frequency of occurrence will be calculated and finally the risk of the activity is calculated (chapter 6 and 7).

6 Effect and consequence calculations

6.1 General

For effect and consequences of a release of flammable refrigerant a distinction is made between a release due to pipeline damage resulted in (semi-) continuous releases and instantaneous releases from the receiver or evaporator. Besides that also (no-accident related) relative small leakages occur.

From practice experience with the use of mobile cooling-units it is known that leakages occurred often. The most important cause of the occurrence of leakages are the vibrations of the installations during transport. It is well known that about 20% of the content of the installation is released on a yearly base. This result in a release of about 1.6 and 0.6 kg per year for respectively large and small installations.
The released amount per unit of time is negligible. Leakages of this kind will not result in a flammable gasmixture if released in the open because of the mixing up with air through by the concentration of the refrigerant stays below the lower explosion limit. Ignition of the gascloud is only possible if the concentration is between the Lower Explosion Limit (LEL) and Upper Explosion Limit (UEL).
The LEL is 38.5 $g.m^{-3}$ and the UEL is 174.2 $g.m^{-3}$ (see also chapter 4).
If the leakage takes place in a confined space of small volume a flammable mixture can occur only if accumulation of gas in the confined space can take place during a long period and without any ventilation. It is not expected that dangerous situations can occur as a result of leakages of this kind.

Immediate dangerous situations can occur in case of larger (than leakage) releases in an unconfined or (partly) confined area (under the truck or aside the truck, in the cold space). This e.g as a result of accidents, or failures due to internal causes (corrosion, defective material etc.). Instantaneous or (semi-) continuous releases can occur. An instantaneous release means that the total content of the installation (about 3 - 8 kg) is released within a few seconds. In this case a flammable gascloud is present during a certain period of time.
An instantaneous release is often caused by external forces due to accidents. In such cases an ignition source is mostly present in the form of sparks generated by the external forces, a hot exhaust etc.
In the next paragraph an overview is given of the possible effects as a result of releases of flammable refrigerants.

6.2 Description of the possible effects

A schematic overview of the possible effects and consequences in the case of a release of flammable gas is given in figure 3.

The figure shows that in case of a release in an **unconfined** area and delayed ignition a flash fire can occur. A flash fire is a fast burning gascloud. Damage will occur only in the burning cloud itself due to direct flame contact.
In case of a release in a (semi-)**confined** area (but excluding the casing of the installation) two phenomena can be distinguished: a burning gascloud like a flash fire

and the generation of a pressure wave due to high flame speeds because of the confinement. The damage in the gascloud is the same as in the case of a flash fire (in unconfined situations). The pressure wave can destroy the confined space and also buildings in the surroundings. Damage to people (outside the confined area) can occur mainly due to fragments from the confined space and, as a result of secondary damage, due to collapsed buildings (falling walls, glass fragments etc.).

The equipment of a mobile cooling-unit is constructed in a compact way inside a casing. Therefore we assumed that undisturbed releases are rare and are excluded in this study.
Release from the evaporator coil in the cold space will be diluted quickly by the evaporator fan.
Releases from the condenser coil will be quickly dispersed in the surroundings by use of the operating condenser fan. In this study the (pessimistic) assumption of a not working condenser fan is made.

A flammable gasconcentration and ignition of the gas inside the **casing** of the installation will result in an explosion which demolishing (part of) the installation. Damage in the surroundings can be expected mainly due to fragments blown away from the casing. Damage is also possible at short distances from the installation due to the burning gascloud.

6.3 Calculation of the effect and consequences

6.3.1 General

For the calculation of the effect and consequences of releases of flammable refrigerants a distinction is made between (semi-)continuous releases and instantaneous releases in a (semi-) confined space (e.g. the cold space, inside the casing) and releases in the open. Besides that the size of the installation (amount of refrigerant) is also taken into account.
In the following an overview is given of the physical effect models used for the effect calculations and the consequence models used for the calculation of the consequences for the surroundings as a result of the effects, next the results are given.
For the effect and consequence calculations two situations are distinguished, a release during transport and a release during parking.
In case of a release during transport the released gas will be dispersed quickly in case of a release inside the casing and from the condenser coil. For this situation a release from the evaporator coil inside the cold space is the only relevant release.
In the case of a release during parking all releases will be relevant.

6.3.2 Physical effect models

For the calculations of the physical effects use is made of different models. Releases are calculated by use of release models for liquids, gases or two-phase flow from [21]. The selection of the appropriate model depends on the physical state of the refrigerant at a particular section of the installation. For the calculation of the

evaporation of a liquid release it is assumed here that all released liquid will be evaporate immediate. This because the low boiling point of the refrigerant and the possibility of the formation of an aerosol as a result of a release under high pressure together with the possibility of impingement with nearby equipment. Due to the impingement the release result in an aerosol through which the evaporation rate is increased.
In case of a release in the cold space it is assumed that the released gas will be diluted homogeneous in the cold space by the applied forced ventilation.

In case of a release inside the casing it is assumed that dispersion takes place from the casing into the atmosphere.

It is assumed that the evaporated refrigerant has a density comparable with air therefore the Gaussian dispersion model for neutral gases is used [21]. The dispersion is calculated for two weather-classes:
- very stable weather (class F) and a windspeed of 2 $m.s^{-1}$ and
- neutral weather (class D) and a windspeed of 5 $m.s^{-1}$.

Ignition of a (partly) confined gascloud can result in a generation of overpressure. The overpressure is calculated by use of the Multi Energy Method [22].

6.3.3 Consequence models

For the calculation of the consequences as a result of the effects of released flammable refrigerants use is made of the consequence models from [23].
In the case of flash-fires (burning gascloud) it is assumed that all people present in the flammable gascloud will be fatally injured. In the case of an explosion (a flash-fire with generation of peak overpressure) the consequences are the same as in the case of flash-fire and in addition 1% of the people present in heavy damaged buildings will be fatally injured. Heavy damage to buildings occurred in case of peakoverpressures of at least 0.3 bar. Injuries in the surroundings are also possible by fragments of the casing or the cold space.

6.3.4 Results of the calculations

Overview of the starting points
For the calculation of the effect and consequences the following assumptions have been made with respect to the content of the different sections of the installation:

Section	Contents [kg]	
	Small unit	Large unit
evaporator coil	1.2	3.2
condenser coil	1.2	3.2
accumulator	0.15	0.4
receiver	0.15	0.4
connected lines	0.3	0.8

For the calculation of the released amounts it is assumed that the content of the section involved is released first, after that the release is calculated from the connected section(s).
In the case of release downstream the compressor it is assumed that 80% of the total content will be released in case of a working compressor.

Example of the approach of the effect calculations:
in the case of a release from the condenser coil it is assumed that the total liquid content of the condenser coil is released instantaneous first. If the compressor is not tripped, 80% of the total content of the installation will be released to a flowrate equal to the compressor capacity. In case of a compressor trip, there is still a release because there is an open connection between the condenser coil and the receiver which results in evaporation of the remaining liquid in the receiver. Evaporation takes place until the boiling point of the liquid is reached; the decrease in temperature is a result of the adiabatic evaporation of the liquid, because it is assumed that the release time is too short for a sufficient heat input from the surroundings.

The results of the effect calculations are summarised in table 6.1. In this table also the frequency of occurrence have been given. A detailed description of the frequency data and probabilities used and the applied methodology is described in chapter 7.

(The figures between brackets represents the additional flow for a situation for a working compressor.)

Table 6.1 Overview of release rates, dimensions of flares and flammable gas clouds resulted from the identified accident scenarios - small units

Accident scenario	Release rate [kg.s^{-1}] and duration [sec]				Location	Distance to LEL [m] (F-2/D-5) or concentration (inside cold space) [g.m^{-3}]	M_{ex} [kg]	Distance [m] to peakoverpressure [bar]			Frequency [yr^{-1}] (*10^{-6})	
	Gas/vapour		Liquid									
	Rate	Duration	Rate	Duration				0.3	0.1	0.03	fire	Explosion
normal operating conditions												
pipeline leakage (full bore)												
– upstream compr.	0.06 (0.06)	3 (37)	-	-	casing	negl.	-	-	-	-	-	-
– condenser coil	0.008 (0.008)	6.5 (150)	1.2	instant.	outside	22/12	1.0	5	13	36	3	0.75
– evaporator coil	- (0.02)	- (60)	1.2	instant.	cold space	99	1.2	possible lethalty after opening the door			9.6	2.4
– downstream compressor	0.02[1)]	120	-	-	casing	negl.	-	-	-	-	-	
pipeline leakage (1%/10% leakage)												
– upstream compressor	0.0006	cont.[2)]	-	-	casing	negl.	-	-	-	-	-	
	0.006	400	-	-	casing	negl.	-	-	-	-	-	
– condenser coil	0.0002 6	190	0.02	60	outside	negl.	-	-	-	-	-	
	0.0077	155	0.2	6	outside	21/12	1.2	5	13	36	10	2.5
– evaporator coil	- (0.006)	- (230)	0.0017	cont.	cold space	99	1.2	possible lethalty by opening the door			96	24
	- (0.06)	- (21)	0.017	67	cold space	99	1.2	possible lethalty after opening the door			32	8

Table 6.1 Overview of release rates, dimensions of flares and flammable gas clouds resulted from the identified accident scenarios - small units (continued)

Accident scenario	Release rate [kg.s⁻¹] and duration [sec]				Location	Distance to LEL [m] (F-2/D-5) or concentration (inside cold space) [g.m⁻³]	M_{ex} [kg]	Distance [m] to peakoverpressure [bar]			Frequency [yr⁻¹] (*10⁻⁶)	
	Gas/vapour		Liquid									
	Rate	Duration	Rate	Duration				0.3	0.1	0.03	fire	Explosion
– downstream compressor	0.002	1200	-	-	casing	negl.	-	-	-	-	-	-
	0.02	120	-	-	casing	negl.	-	-	-	-	-	-
failure of vessel												
failure of accumulator	-	-	0.15 + 1.2	instant.	casing	24/13	1.1	6.5	13	38	0.4	0.1
failure of receiver	*(+ 0.02)*	(53)	0.15 + 1.2	*instant.*	casing	24/13	1.1	6.5	13	38	0.4	0.1
failure of safety devices												
blow off relief valve	0.002 (0.004)	1200 (600)	-	-	casing	negl.	-	-	-	-	-	-
transport												
release of content			1.35	instant.	build up area	24/13	1.1	6.5	13	38	0.0052	0.0013
			1.35	instant.	motor way	24/13	1.1	6.5	13	38	0.00024	0.00006
fill up system												
release of total content			1.35	instant.	garage	r = 2.8 m[1)]	1.1	possible fatalities in the garage			800	200
repair/maintenance												
release of total content			1.35	instant.	garage	r = 2.8 m	1.1	possible fatalities in the garage			800	200

1) equal to the compressor capacity
2) means longer than 1800 seconds

Table 6.2 Overview of release rates, dimensions of flares and flammable gas clouds resulted from the identified accident scenarios - large units

Accident scenario	Release rate [kg.s^{-1}] and duration [sec]				Location	Distance to LEL [m] (F-2/D-5) or concentration (inside cold space) [g.m^{-3}]	M_{ex} [kg]	Distance [m] to peakoverpressure [bar]			Frequency [yr^{-1}] (*10^{-8})	
	Gas/vapour		Liquid									
	Rate	Duration	Rate	Duration				0.3	0.1	0.03	fire	Explosion
pipeline leakage (full bore)												
– upstream compr.	0.24 (0.24)	2 (25)	-	-	casing	negl.	-	-	-	-	-	-
– condenser coil	0.04 (0.04)	3 (77)	3.2	instant.	outside	32/17	2.2	8	17	47	7.2	1.8
– evaporator coil	- (0.06)	- (53)	3.2	instant.	cold space	70	3.2	possible fatalities after opening the door			23	5.8
– downstream compressor	0.06 [1)]	107	-	-	casing	negl.	-	-	-	-	-	-
pipeline leakage (1%/10% leakage)												
– upstream compressor	0.002	cont. [2)]	-	-	casing	negl.	-	-	-	-	-	-
	0.02	320	-	-	casing	negl.	-	-	-	-	-	-
– condenser coil	0.001 (0.003)	120 (1040)	0.09	35	outside	negl.	-	-	-	-		-
	0.01 (0.03)	12 (89)	0.9	4	outside	35/18	2.2	8	17	47	24	6
– evaporator coil	- (0.003)	- (1130)	0.0075	400	cold space	70	3.0	possible fatalities after opening the door			240	60
	- (0.03)	- (113)	0.075	40	cold space	70	3.0	possible fatalities after opening the door			80	20
– downstream compressor	0.01	640	-	-	casing	negl.	-	-	-	-	-	-
	0.10	64	-	-	casing	negl.	-	-	-	-	-	-

Table 6.2 Overview of release rates, dimensions of flares and flammable gas clouds resulted from the identified accident scenarios - large units (continued)

Accident scenario	Release rate [kg.s^{-1}] and duration [sec]				Location	Distance to LEL [m] (F-2/D-5) or concentration (inside cold space) [g.m^{-3}]	M_{ex} [kg]	Distance [m] to peakoverpressure [bar]			Frequency [yr^{-1}] (*10^{-8})	
	Gas/vapour		Liquid									
	Rate	Duration	Rate	Duration				0.3	0.1	0.03	fire	Explosion
failure of vessels												
failure of accumulator	-	-	0.4 + 3.2 kg	instant.	casing	35/18	2.2	8	17	47	0.4	0.1
failure of receiver	-	-	0.4 + 3.2 kg	instant.	casing	35/18	2.2	8	17	47	0.4	0.1
failure of safety device												
blow off relief valve	0.002	340	-	-	casing	negl.	-	-	-	-	-	-
transport												
release of content			3.6	instant.	build up area	35/18	2.2	8	17	47	0.0052	0.0013
			3.6	instant.	motor way	35/18	2.2	8	17	47	0.00024	0.00006
fill up system												
release of total content			3.6	instant.	garage	r = 3.5 m 1)		possible fatalities in the garage			800	200
repair/maintenance												
release of total content			3.6	instant.	garage	r = 3.5 m		possible fatalities in the garage			800	200

1) equal to the compressor capacity
2) means longer than 1800 seconds

The contribution of the additional flow due to a working compressor is in most cases negligible. Only in the case of a release in the cold store there is a significant contribution.

7 Risk calculations

7.1 General

Risk consist of a combination of two elements: the consequences of an accident and the frequency of occurrence of these accidents.
For the calculation and presentation of risks two criteria for risk are distinguished. risks are:

Individual risk; the frequency of fatal injury on a certain distance from the activity as a result of accidents with a refrigerating unit;

Societal risk; the frequency of a minimum number of fatalities due to an accident with a mobile refrigerating unit.

The individual risk and societal risk are used to evaluate the acceptability of risks of consequences of industrial activities.

The individual risk gives, for a certain distance, the frequency of a fatal injury.
The societal risk gives the minimum number of fatalities and the frequency of occurrence.

In this chapter the calculation of the frequency of consequences is described.
The frequency of consequences is a combination of the frequency of a release and different probabilities, such as a probability of direct ignition, delayed ignition and the probability of consequences to people.

The risk analysis scheme is given in figure 1.1 (section 1).

For the calculation of the societal risk the number of people present in the surroundings is taken into account. Because the surroundings is not known on beforehand, for the activities concerned the following population densities or number of people present have been used:
- *normal working condition:*
  - urban area with a characteristic population density of 120 persons/ha. according to [23],
  - big shopping centres, population density 1000 persons/ha (10% of the time);
- *services:*
  - number of people present in garages: 5;
- *transport:*
  - motor ways: number of people present within a radius of 100 meter: 95 (based on an occupation of 1.5 persons per car),
  - within build up area: same as the urban area 120 persons/ha.

Both the area classification and the related population densities are taken from [23].

Furthermore it is assumed that given a fire and explosion in a garage or as a result of an explosion of flammable gascloud in the cold space, regardless the population density, the probability of 1 fatal injury is 10%. In other words an accidental release resulted in a fire or an explosion results in 10% of the cases in 1 fatality.

In the next paragraphs risk criteria used in several countries are given first. Thereafter calculation of accident frequencies and probabilities of the occurrence of effects and consequences are described.

7.2 Riskcriteria

In several countries criteria have been used for risk.

An overview is given in tables 7.1 and table 7.2.

Table 7.1 Individual risk in several countries

	Individual risk criteria per year	
	Intolerable	Negligible
Ministry VROM, the Netherlands (new activities) Existing plants	10^{-6} 10^{-5}	10^{-8} 10^{-8}
Environmental Protection Authority (Western Australia (new plants)	10^{-5}	10^{-8}
Health & Safety Executive, UK (new housing near plants)	10^{-5}	10^{-6}
Hong Kong Government (new plants)	10^{-5}	not used
Department of planning New South Wales (new plants and housing)	10^{-6}	not used

Table 7.2 Societal risk criteria in several countries

Authority	FN Curve slope	societal risk (intercept with N = 1)		Limit on N
		intolerable	negligible	
Ministry VROM, the Netherlands (new plants)	-2	10^{-3}	10^{-5}	1000
Hong Kong Government (new plants)	-1	10^{-3}	-	1000
under consideration				
Health & Safety Executive, UK (existing ports)	-1	10^{-1}	10^{-4}	-

In the Netherlands there is at this moment a move to use only the level of intolerance and to make use of the ALARA (As Low As Reasonable Achievable) principle by use of risk-reducing measures. This means that the negligible level no more will be used in future.

7.3 Frequency of the release of refrigerants

A number of accident scenarios have been described in chapter 5. Most of the incidents deals with the failure of equipment such as leakage or rupture of pipelines, failure of the accumulator etc.
For the retrieval of frequencies use is made of the TNO database COMPI [24]. This database consist a number of failure frequencies of components (pipelines, valves, pumps, relief valves etc.)
Beside this database also other databases have been studied such as E&P-Forum [25] and OREDA [26]. Both databases have been developed for off-shore activities and is unimportant for small installations.
Retrieval of accident frequencies for this specific kind of refrigerating equipment is hardly available. The reason for this is the use of non-flammable and non-toxic refrigerants in this kind of mobil refrigerating units. In case of a release no dangerous situations can occur and no special attention is given to accidental releases. Therefore use is made of failure frequencies of equipment comparable with the small mobil refrigeration equipment. This means that use is made of generic failure frequencies. Engineering judgement is used to adjust the generic values to the specific units considered.

Pipeline failure frequency (full bore rupture)
The failure of a pipeline is derived from [27] and [28] and is: 3.10^{-6} $m.^{-1}.yr^{-1}$.
The construction and installation of a cooling-unit is such that a good protection has been achieved against external forces and inspection is carried out twice a year on average. For this reason the failure frequency is lowered by a factor 10.
The total length is about 15 meter for small units and 23 meter for large units.
It is assumed that the pipeline length upstream the compressor is the same as downstream.
The total pipeline length of the evaporator is 40 meter and 100 meter, the length of the pipeline of the condenser is 25 meter and 60 meter (for small and large units respectively).

This result in the following failure frequencies:

Position of the rupture	Frequency [$unit^{-1}.yr^{-1}$] * 10^{-6}	
	Large units	Small units
downstream compressor	3.45	2.25
upstream compressor	3.45	2.25
evaporator coil	30	12
condenser coil	18	7.5

Pipeline failure frequency (1% and 10% leakage)
The failure frequencies of a pipeline for a 1% and 10% leakage are derived from [27] and [28] and are: 3.10^{-5} and $1.10^{-5}.m^{-1}.yr^{-1}$ respectively.
Also in this case a reduction of a factor 10 has been applied, for the same reason as described at the full bore rupture.
This result in the following failure frequencies:

Position of the rupture	Frequency [$unit^{-1}.yr^{-1}$] * 10^{-6}			
	Large units		Small units	
	10%	1%	10%	1%
downstream compressor	11.5	34.5	7.5	22.5
upstream compressor	11.5	34.5	7.5	22.5
evaporator coil	100	300	40	120
condenser coil	60	180	25	75

Failure of pressure relief valves
The frequency of spontaneous opening of the relief valve is $4.10^{-5}.yr^{-1}$ [28].

Failure of accumulator and receiver
Both accumulator and receiver can be considered as pressure vessels, for the failure frequency use is made of data derived from pressure vessels from [28] and amounts: for a catastrophic failure: $1.10^{-6}.yr^{-1}$ [29].

Failure of a low pressure switch
The installation (compressor) is protected against low pressures by a low pressure cut out switch. In case of low pressures the compressor trips.
A failure frequency of pressure switches specific for refrigerating systems is not available therefore a failure frequency for pressure switches in general is taken from [28] and is 0.1 per demand.

7.4 Failure during transport

A failure during transport can only occur in case of accidents with a certain impact. This kind of accidents are characterised here as accidents with at least injuries.

The accident frequency is used for two situations:
1. on motor ways: accident frequency: 6.10^{-8} $veh^{-1}.km^{-1}.yr^{-1}$,
2. within build up areas: accident frequency: $1.3.10^{-6}$ $veh^{-1}.km^{-1}.yr^{-1}$.

Given an accident the probability of a release is derived from [28]. In [28] the probability of a release is given for bulktransport in tankcars and is 0.05. For the refrigerating unit this release probability is lowered by a factor 10. This because of the relative good protection of the installation and the location. This result in a release probability of 0.005 (given an accident).

The frequency of a release is expressed for a transport length of 1 km.
1. on motor ways: accident frequency: 3.10^{-10} $veh^{-1}.km^{-1}.yr^{-1}$,
2. within build up areas: accident frequency: $6.5.10^{-9}$ $veh^{-1}.km^{-1}.yr^{-1}$.

The risk of transport will be presented for a traffic density of 10,000 vehicles per year for a fictitious road length which correspondence with the consequence distance, in both urban and a non-urban areas (motor-way).

7.5 Failure during services

Fill up installation
It is assumed that a release during filling up the installation mainly occur as a result of a human failure. In [28] probabilities are given for human failures for different activities:

operator failure during transshipment: 1.10^{-4}/demand,
operator failure during control activities: 1.10^{-3}/demand.

In this study the probability is used for control activities: 1.10^{-3}/demand.

It is assumed that fill up takes place once a year; this results in a release frequency of: 1.10^{-3}/yr.

Failure during maintenance
For this situation the same probability for human failure is used as for fill up activities.

Maintenance is assumed to take place twice a year on average; the frequency of a release is: 2.10^{-3}/yr.

7.6 Probability of ignition

Ignition probabilities specific for the releases for this kind of installations are not available. An overview of ignition probabilities as a function to the release rate is given in [28] and [29]. The ignition probabilities are summarised in table 7.3.

Table 7.3 Overview of the ignition probabilities

Source strength [$kg.s^{-1}$]	Ignition probability [-]			Literature
	Immediate	Delayed	Total	
< 1 $kg.s^{-1}$			0.01	[29]
< 10 $kg.s^{-1}$	0.2	0.05	0.25	[28]
1 - 50 $kg.s^{-1}$			0.07	[29]
10 - 100 $kg.s^{-1}$	0.5	0.1	0.6	[28]
> 50 $kg.s^{-1}$	0.3		0.3	[28]
> 100 $kg.s^{-1}$	0.7	0.2	0.9	[28]

The effect calculations have shown that the release rates for the mobile refrigerating unit are, in all cases, less than 1 $kg.s^{-1}$ and < 5 kg. Because of the relative small releases the ignition probabilities for releases < 1 $kg.s^{-1}$ is used from [29]. For the distinction between immediate and delayed ignition the same ratio as valid for the figures from [28] is used. This approach results in the following ignition probabilities:

Table 7.4 Overview of the ignition probabilities used for mobil refrigeration units

Source strength	Ignition probability [-]		
	Immediate	Delayed	Total
- 1 $kg.s^{-1}$ or < 5 kg.	0.008	0.002	0.01

For a flammable gasmixture present in the cold space it is assumed that ignition occur only during of after opening the door of the cold space. A possible ignition source in this case can be a electrical switch, a burning cigarette etc.

7.7 Failure during stationary situation

As described in section 6, a release during transport would not result in hazardous situations because of the forced dispersion due to the speed. A release in the cold space (from the evaporator coil) results always in a dangerous situation.
For the calculation of the frequency of fire of explosion it is assumed that the distribution of the transport and the stationary situation is 50% (probability 0.5).

Combination of the failure frequency of pipelines or other equipment, the probability of ignition and the probability of occurrence of the stationary situation results in the frequency of the calculated effects.
An overview of the results are summarised in table 6.1 and 6.2.

8 Presentation of individual and societal risk

The consequence distances presented in section 5 and the frequency of the consequences presented in section 6 have been combined together to calculate the individual risk.
This means that for a number of locations in the surroundings the frequency of fatal injury is calculated. The number of locations depends on the consequence distance.

Additional the societal risk is calculated by taking into account the population density.

The individual riskcurve for all activities is presented in figure 4 and 5 (large and small unit).
The individual riskcurve for services is presented in figure 6 and 7 (large and small unit).
The individual riskcurve for transport, based on 10,000 trucks a year, is presented in figure 8, 9, 10 and 11 (large and small unit).

If the calculated individual risk is compared with the criteria used in The Netherlands for new activities the individual risk is higher than acceptable up to a distance of 2.5 meter (small unit) and 3.5 meter (large unit) and is defined by the service activities. The individual risk is acceptable by excluding the service activity.

Acceptability criteria for transport activities are not yet established so no conclusions can be drawn with respect to acceptability.

The societal riskcurve is given in figure 12 and 13 for both small and large units respectively.
The number of casualties is lower than 10, so there is no societal risk according to the definition used in The Netherlands.

Considering the individual risk of the different activities it is evident that the risk of the use of flammables is stated by accidents during services. The main point for risk reducing measures should be defined for services.

9 Risk reducing measures

Although the risk is acceptable according to the criteria used in different countries, a number of risk reducing measures have been defined according the As Low As Reasonable Achievable approach.
Possible risk reducing measures have been defined for the installation (including the cold space), training of driver and personal and services (non limitative).

- *Training:*
  - training of drivers and maintenance personnel with regard to the handling of flammable gases;
  - special attention must be given to the specific problems during maintenance (e.g. degassification of equipment).

- *Maintenance:*
  - application of specific quick release couplings for filling up of the refrigerant, to avoid exchange with non-flammable refrigerants,
  - use of specific filling up bottles with quantities comparable with the quantity of the installation,
  - instruction manuals with special attention to gasfree making of the equipment,
  - solder or welding activities must be applied on gasfree equipment only,
  - in case of international transport, maintenance can be required at any location in any country. Therefore, adequate logistics have to be considered as well.

- *Installation:*
  - minimising of (screwed) connections,
  - minimising the refrigerant content,
  - application of leak detection in the cold space (if technically possible),
  - application of explosion proof equipment in the cold space,
  - installation of small fire extinguishing equipment,
  - application of hermetic compressors.

- *Labelling:*
  - application of specific labelling on gas cylinders with flammables to prevent exchanges,
  - labelling on the installation itself e.g. 'filled with flammable refrigerant'.

- *Safety cards:*
  - safety cards or other information about flammables and how to handle in case of emergencies on board of the trucks.

10 Conclusions and recommendations

A risk assessment has been carried out for two refrigerating systems with flammable refrigerants. For the flammable refrigerant propane has been chosen as a characteristic one with the highest impact in the surroundings.
The aim of the study is to get a deeper understanding about the risk of the use of flammables as refrigerant instead of the non-flammables normally used. This because the lack of experience about the use of flammables instead of inflammable refrigerants in relatively small scale mobile cooling installations.

Two installations have been investigated: a large installation mainly used for local transport and a large installation applied for international purposes.

For the identification of the hazards a Hazard and Operability study (HAZOP) has been carried out. This resulted in a number of accident scenarios (releases of flammable material).
From the point of view of the design of the installation it is concluded that the design is appropriate and all safety devices to protect the installation against flow, temperature and pressure deviations necessary were taken.

The results of the individual risk calculations show that the individual risk is higher than acceptable up to 2.5 and 3.5 meter for a small and large unit respectively. By excluding the service activity the individual risk is acceptable with regard to the criteria used in several countries.

If the results of this risk assessment are compared with the risk assessment of the application of flammables in home refrigerators it is concluded that, if the service activities are excluded, the risks are in the same order of magnitude.

The societal risk is calculated for different characteristic population densities for urban areas, big shopping centres and motor ways. The results show that the societal risk is negligible for all situations concerned, this with regard to the criteria used in different countries.

The total impact of the consequences due to fire effects are limited to about 35 meter. In case of explosion in the cold space the consequences can be larger due to fragments of the destroyed cold space. The expected distance for a single fragment is estimated at about 300 meter. The consequences due to fragmentation is expected to be low and are estimated on a single fatality at a maximum.

Analysing the results of the risks of the different activities learned that the dominant consequences are defined by accidents during service activities. Therefore a number of possible safety measures with regard to risk reduction have been suggested. A non-limitative list is given below.

Training and education:
- training of maintenance personnel with regard to the handling of flammable gases
- use of instruction manuals

Maintenance:
- application of specific quick release couplings for filling up of the refrigerant, to avoid exchange with non-flammable refrigerants;
- use of specific filling up bottles with quantities comparable with the quantity of the installation;
- instruction manuals with special attention to gasfree making of the equipment;
- solder or welding activities must be applied on gasfree equipment only;

Installation:
- application of specific quick release couplings for filling up of the refrigerant, to avoid exchange with non-flammable refrigerants
- use of specific filling up bottles with quantities comparable with the quantity of the installation

Labelling:
- application of specific labelling on gas cylinders (for refill usage) with flammables to prevent exchanges.
- labelling on the installation itself e.g. 'filled with flammable refrigerant'

Based on this analysis, the application of flammable refrigerants in transport refrigeration units may be possible from a safety point of view. However, some measures, especially related to maintenance are recommended accordingly to the As Low As Reasonable Achievable approach.

11 Literature

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12 Authentication

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C.M.A. Jansen

Names of establishments to which part of the research was put out to contract
-

Date upon which, or period in which, the research took place
June 1994 - June 1995

Signature

ir. R.J.M. van Gerwen
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Approved by

ir. M. Molag
section leader

Risk assessment of the use of flammable refrigerants
Final report

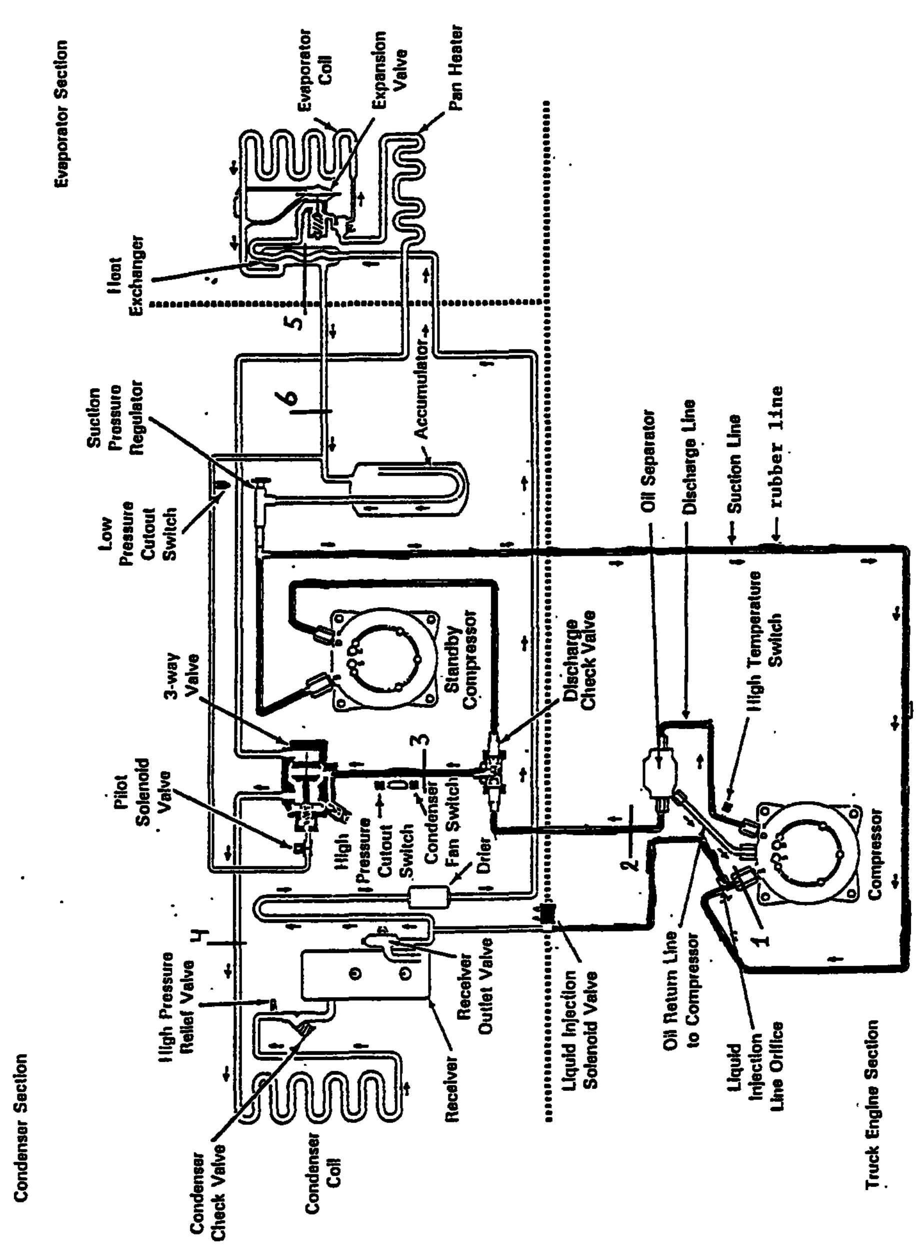


Figure 1 Flow diagram cooling situation

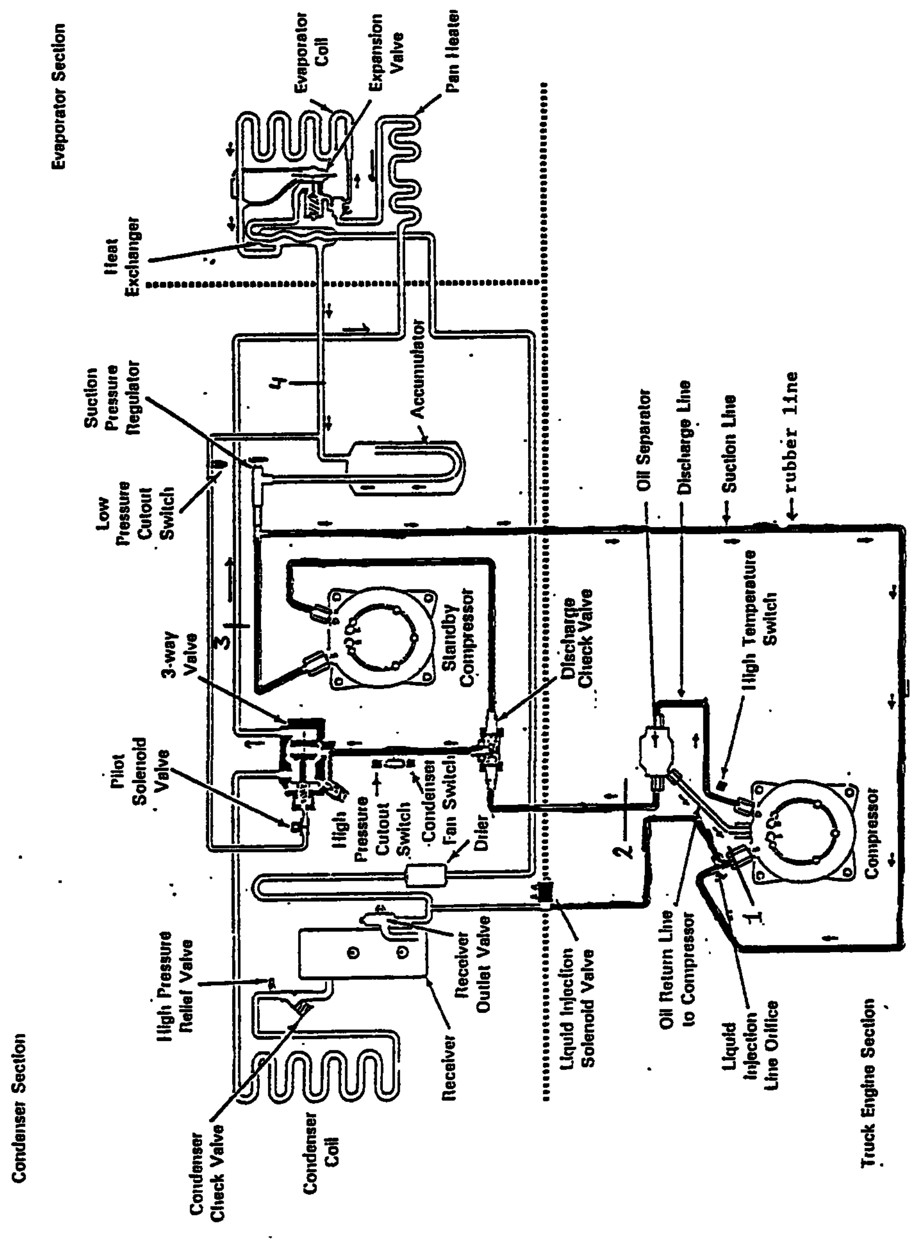


Figure 2 Flow diagram defrost situation

Risk assessment of the use of flammable refrigerants
Final report

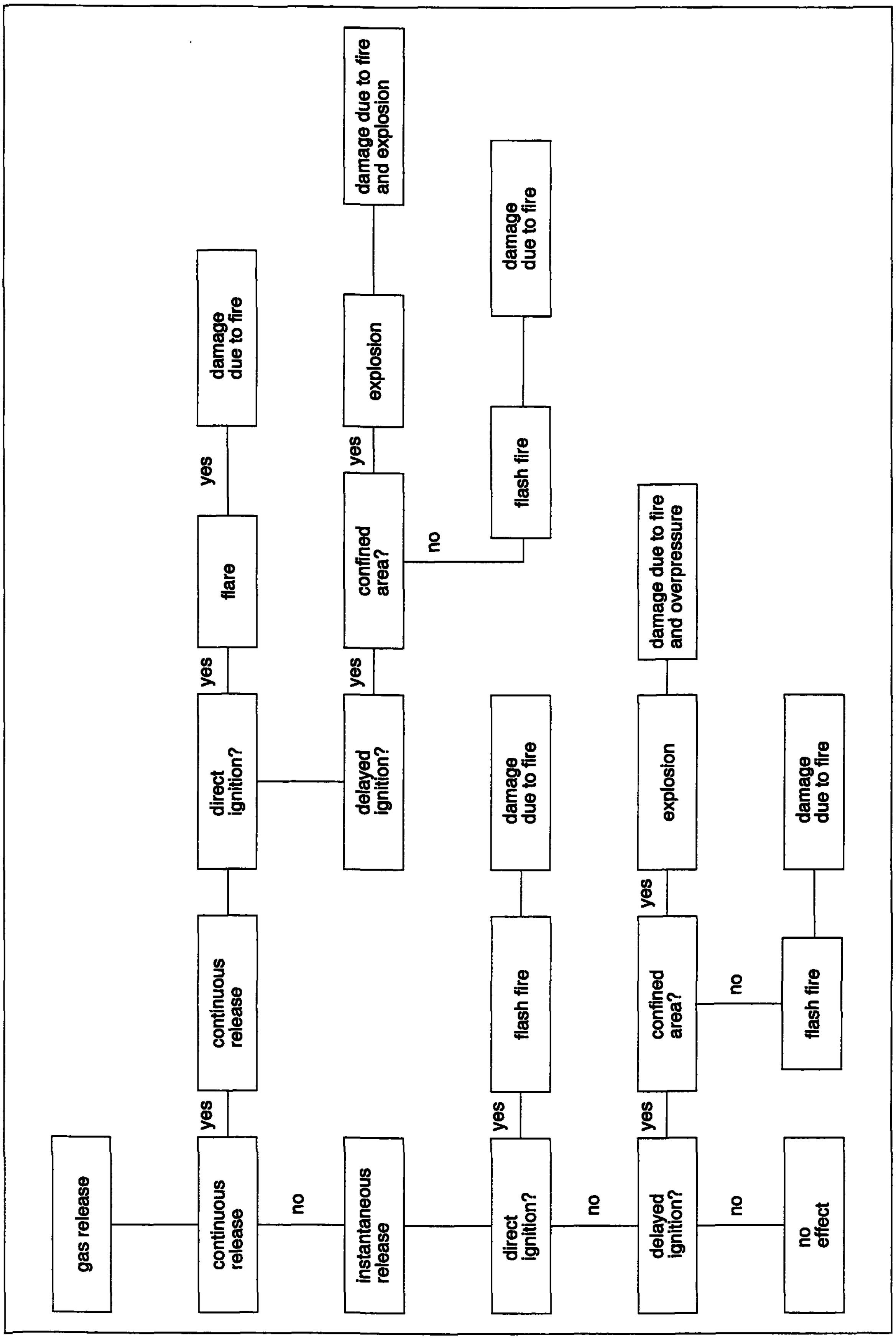
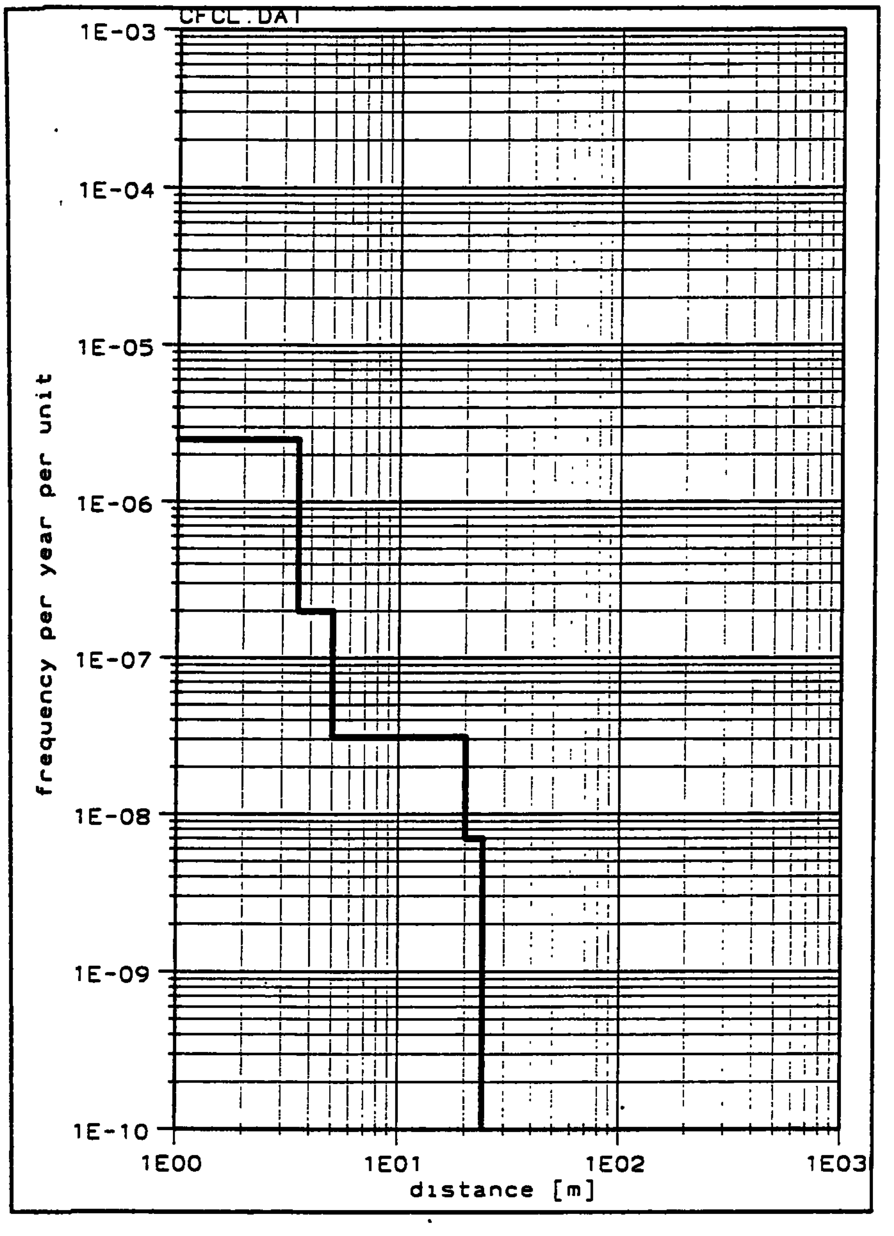
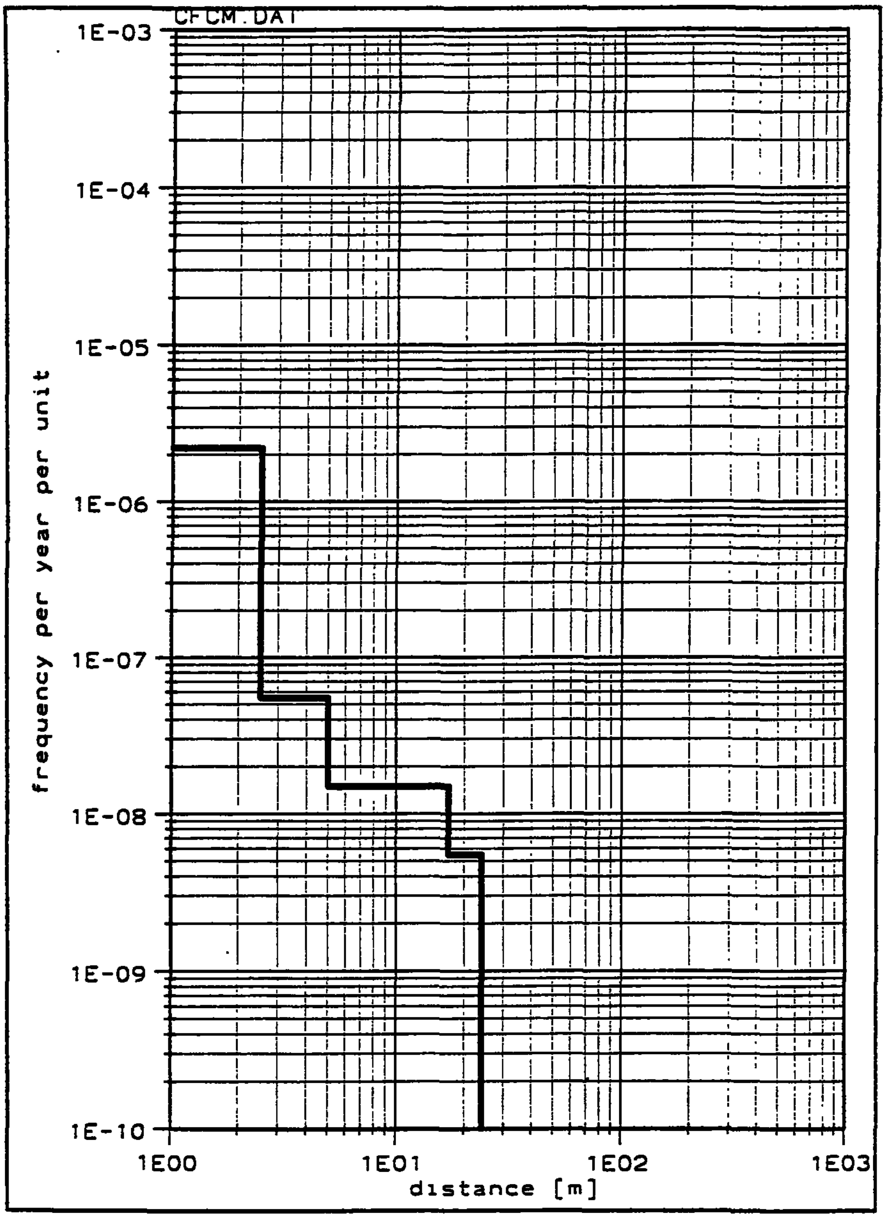


Figure 3 Overview of the possible effect and consequences

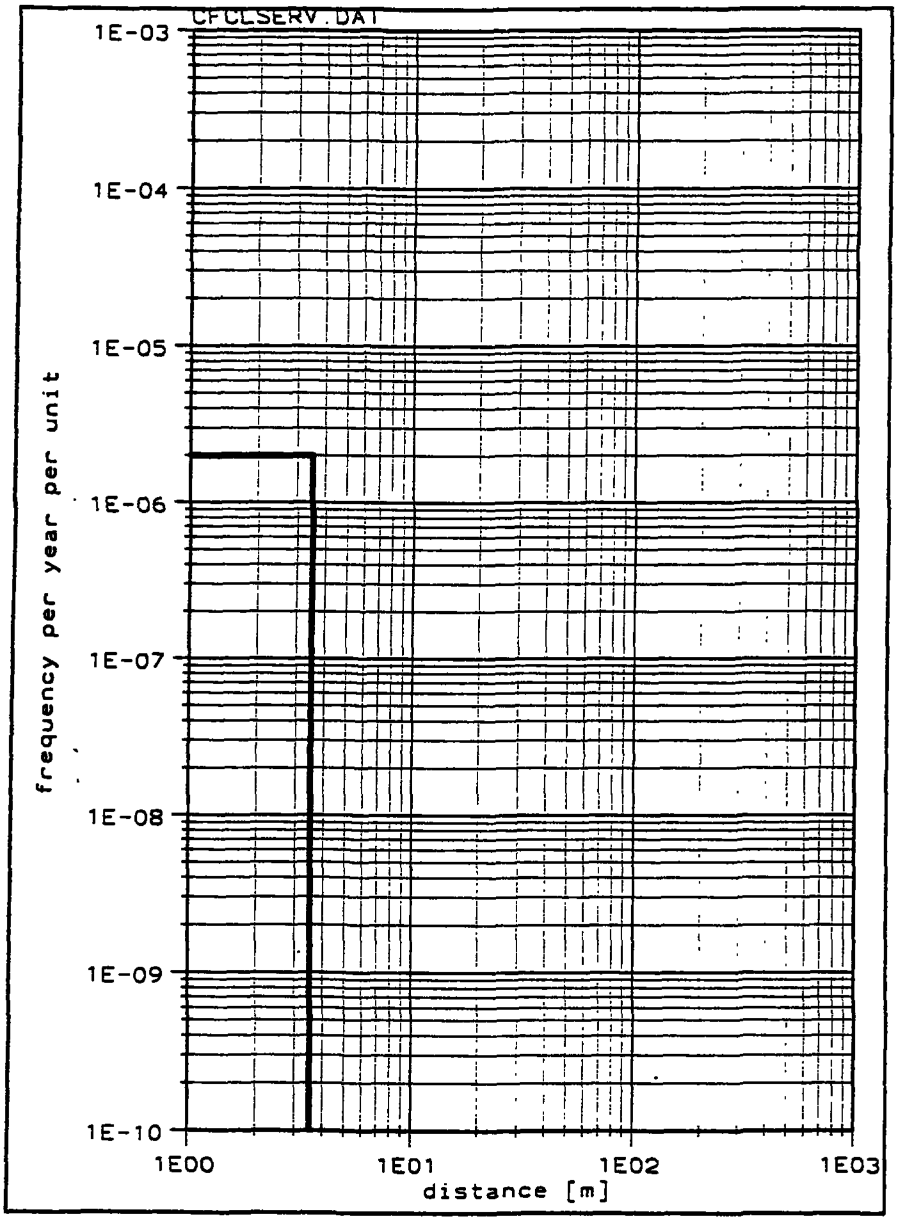


INDIVIDUAL RISK FOR ALL ACTIVITIES FOR THE LARGE UNIT	Fig. 4

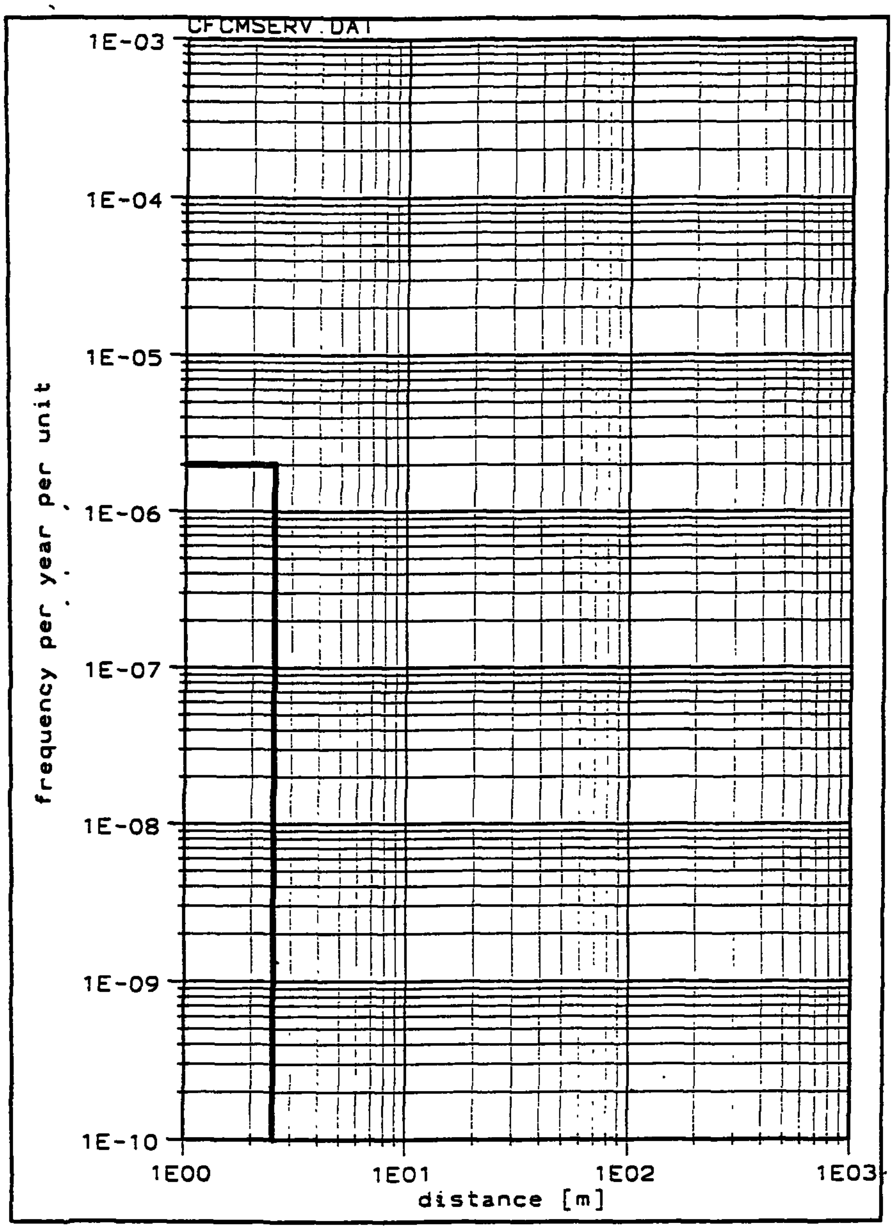


INDIVIDUAL RISK FOR ALL ACTIVITIES
FOR THE SMALL UNIT

Fig. 5

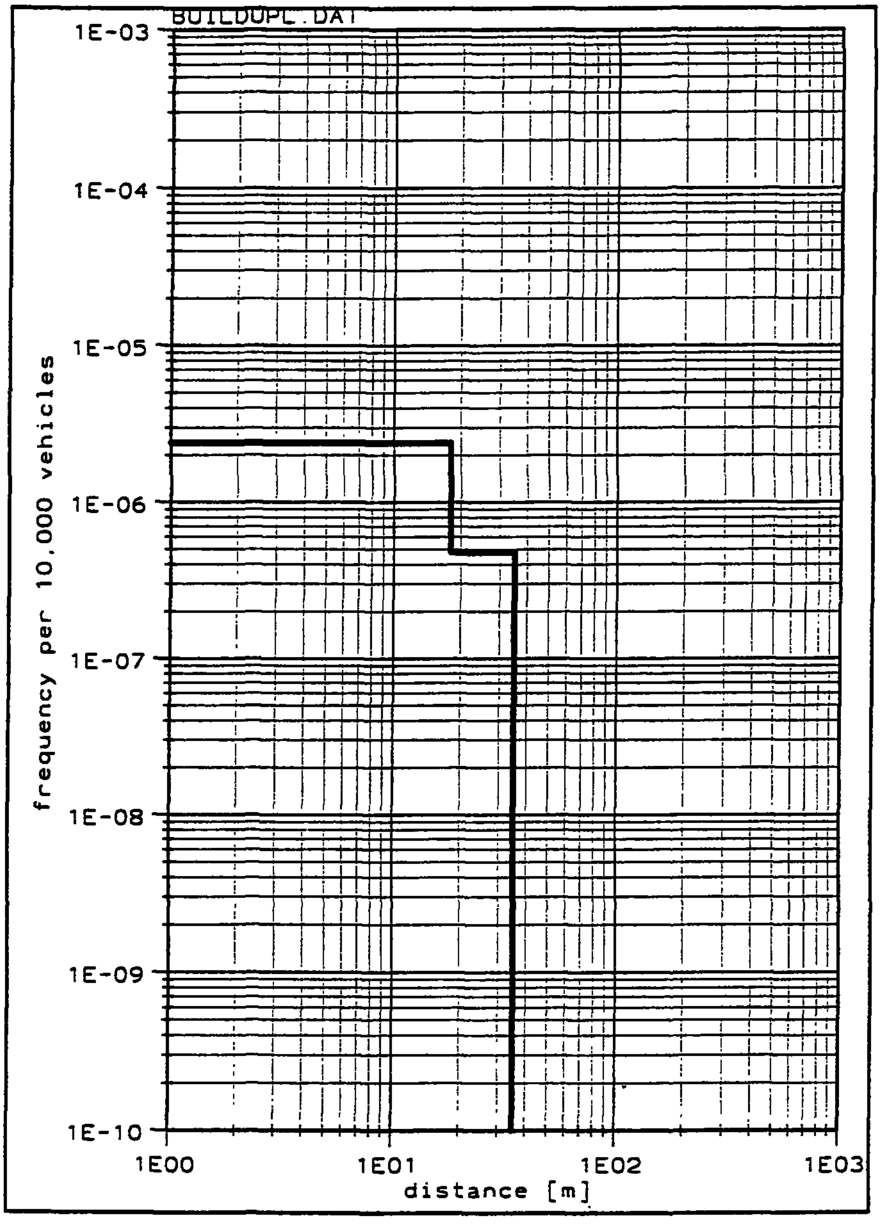


INDIVIDUAL RISK FOR SERVICES FOR THE LARGE UNIT	Fig. 6

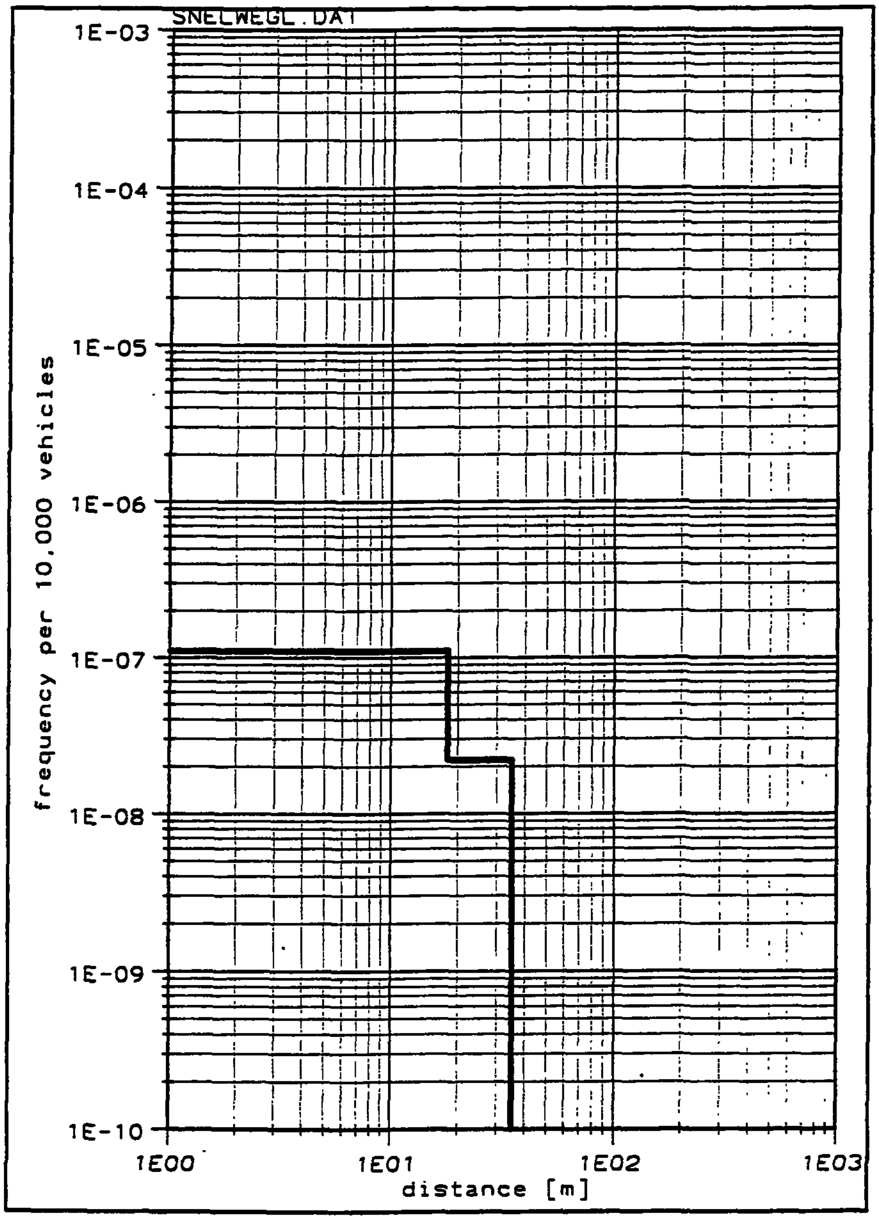


INDIVIDUAL RISK FOR SERVICES FOR THE SMALL UNIT

Fig. 7

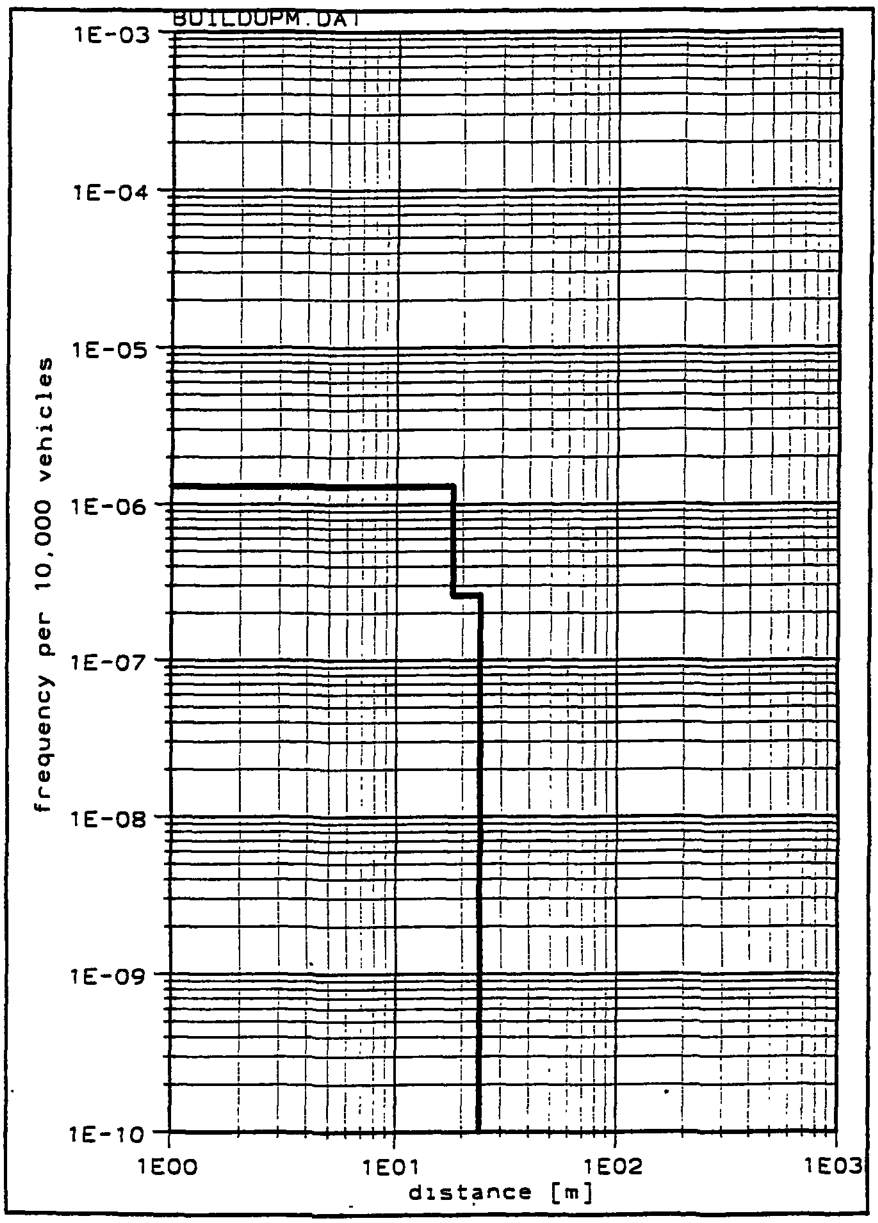


INDIVIDUAL RISK FOR TRANSPORT FOR THE LARGE UNIT (BUILD UP AREA)	Fig. 8

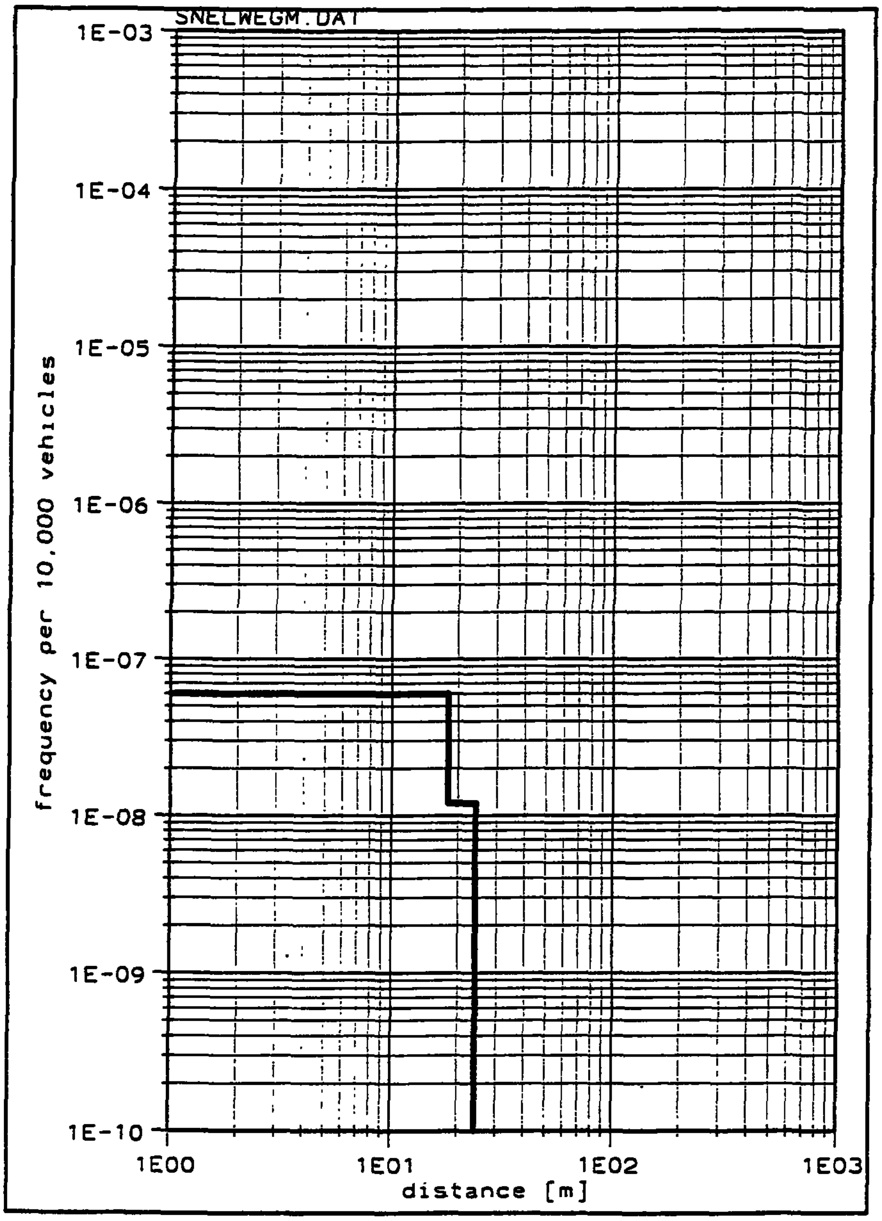


INDIVIDUAL RISK FOR TRANSPORT FOR THE LARGE UNIT (MOTOR WAY)

Fig. 9

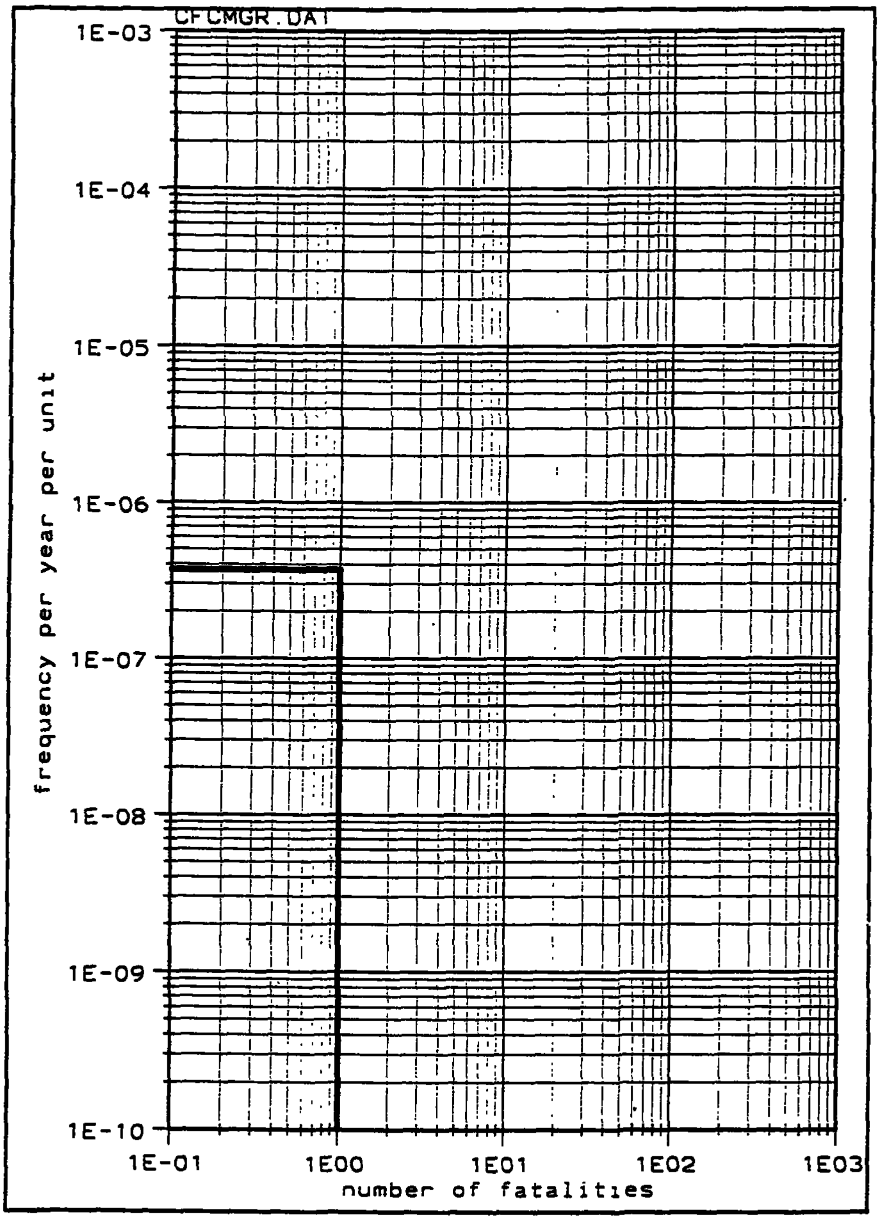


INDIVIDUAL RISK FOR TRANSPORT FOR THE SMALL UNIT (BUILD UP AREA)	Fig. 10

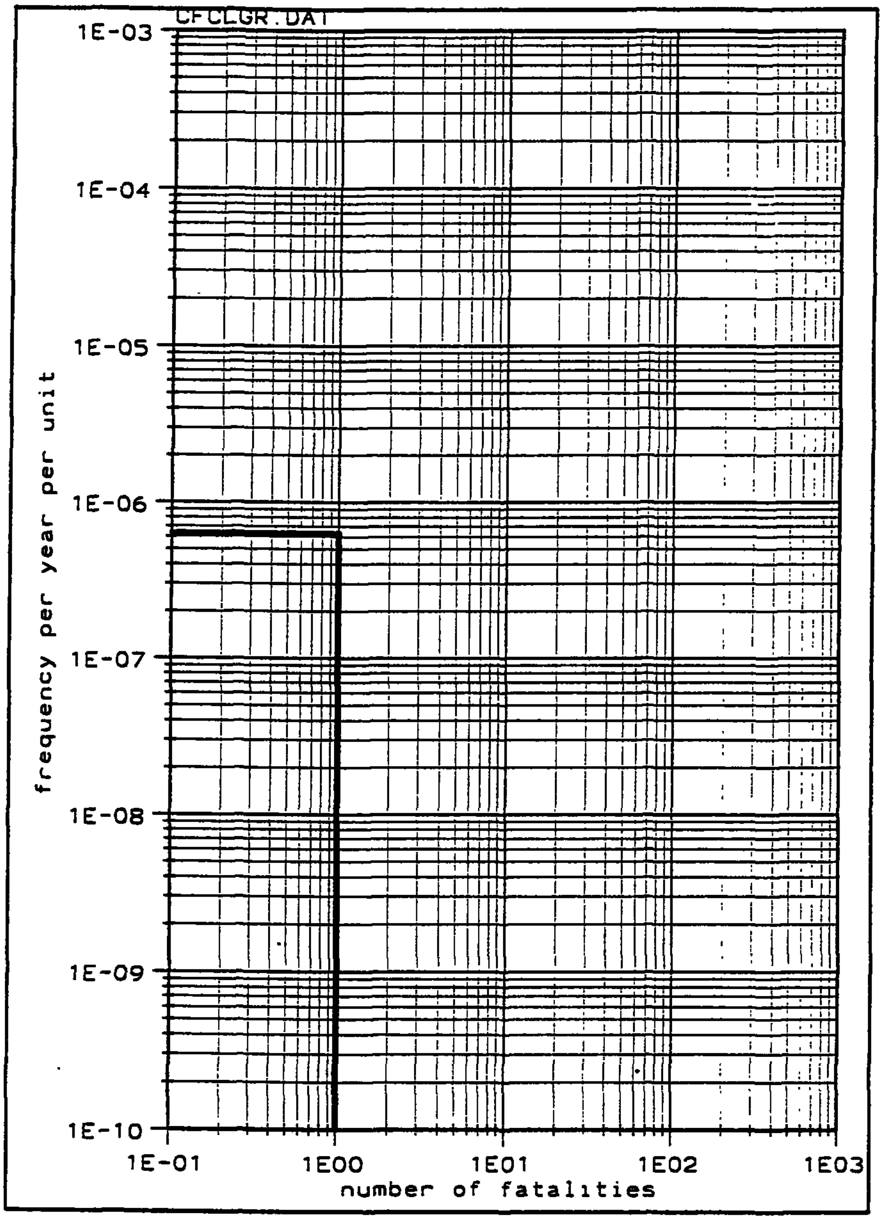


INDIVIDUAL RISK FOR TRANSPORT FOR THE SMALL UNIT (MOTOR WAY)

Fig. 11



SOCIETAL RISK FOR THE SMALL UNIT | Fig. 12



SOCIETAL RISK FOR THE LARGE UNIT	Fig. 13

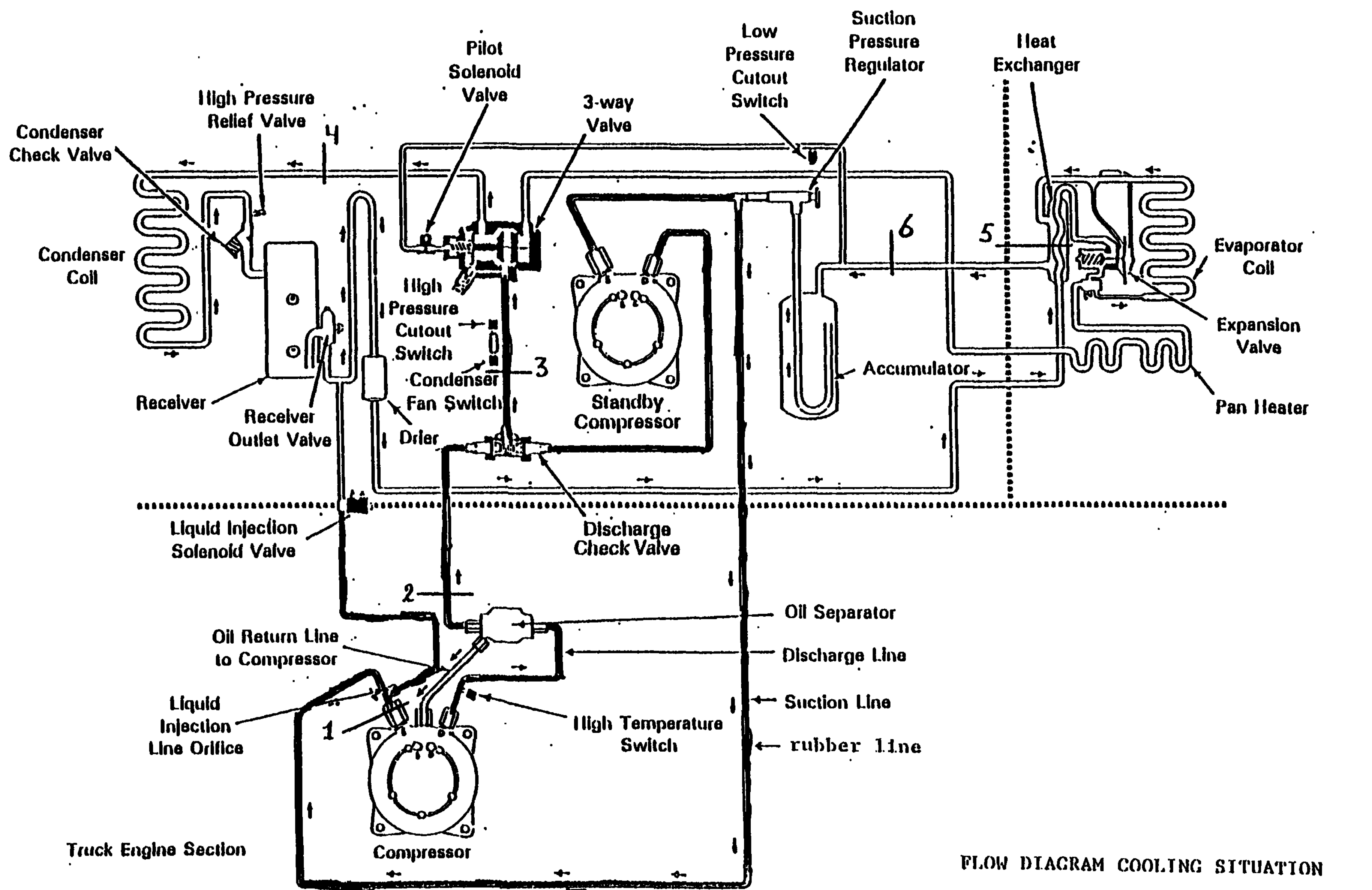
Appendix 1 Results of the HAZOP

Explanation by the worksheets

In this appendix an overview is given of the results of the Hazard and Operability study.

The results are summarised in 'worksheets'. The heading of the worksheets gives a characteristic of the situation considered.
The 'node' in the heading correspondents with a point in the installation on which the deviation of the normal conditions (the guide words: No, Less, More in column 1) have been applied.
The deviation is considered for the 'parameter' (e.g. flow, temperature, column 2).
Also the possible 'cause' of the deviation is given (column 3). In the fourth column the consequences of the deviation have been described. In the last column an overview of the possible automatic actions have been described based on the installed safety devices, such as temperature switches, pressure switches etc.

Cooling



FLOW DIAGRAM COOLING SITUATION
HAZOP SECTIONS

FIG. 1

Company: Node: 1
Facility: Page: 1

Session: 1 11-05-93 Revision: 0 11-05-93 Dwg#:
Node: 1 inlet compressor (point 1 on drawing in fig. 1)
arameter: Flow Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
No	No Flow	not relevant			
Less	Less Flow	no demand for cooling	-	-	-
		faulty compressor	less cooling,	adjustment by expansion valve; or loss of cooling capacity	
		leakage	release of gas; loss of cooling capacity, gasaccumulation		
		setting of suction pressure not correct; too low	less cooling capacity; possible air ingress	-	
More	More Flow	defective expansion valve or temp. bulb	possible liquid hammer if accumulator is filled up too high; possible damage to compressor	trip of compressor on high temp.	

Company: Node: 1
acility: Page: 1

Session: 1 11-05-93 Revision: 0 11-05-93 Dwg#:
Node: 1 inlet compressor (point 1 on drawing in fig. 1)
rameter: Temperature Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
ess	Lower Temperature	low pressure in system; LISV (partly) open	-	adjustment of expansion valve	
ore	Higher Temperature	higher pressure, failure of LISV (closed); high heat input from cold store (e.g. due to fire)	gasrelease, possibility of a flammable gascloud	initiating of high press. cut out switch and trip of compressor; relief valve opens	

Company: Node: 1
acility: Page: 1

Session: 1 11-05-93 Revision: 0 11-05-93 Dwg#:
Node: 1 inlet compressor (point 1 on drawing in fig. 1)
rameter: Composition Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
ther han	Other Than Composition	failure LISV (open)	liquid hammer; damage to compressor		

pany: Node: 2
lity: Page: 1

sion: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 2 outlet compressor (point 2/3 on drawing in fig. 1)
eter: Flow Intention:

	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
	No Flow	failure line or connection	release of flammable gas and possible flammable gascloud	-	
	Less Flow	no or less demand for cooling	-	-	
		failure of compressor	release of gas loss of cooling capacity, gasaccumulation	adjustment by expansion valve; or loss of cooling capacity	
		incorrect suction pressure	loss of cooling capacity	adjustment by expansion valve or loss of cooling capacity	
		leakage via oil separator	loss of cooling capacity	adjustment of expansion valve; or loss of cooling capacity	
e	More Flow	failue of expansion valve or temp. bulb	possible liquid hammer in compressor if accumulator filled up; possible damage of compressor	trip of the compressor	
		failure LISV (open)	possible liquid hammer in compressor; damage of compressor	trip of compressor	
		failure accumulator; mechanical or high level	liquid to compressor and possible liquid hammer; damage of the compressor	trip of the compressor	

npany: Node: 2
ility: Page: 1

ssion: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 2 outlet compressor (point 2/3 on drawing in fig. 1)
meter: Temperature Intention:

W	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
s	Lower Temperature	failure LISV (open)	liquid hammer compressor; damage of the compressor	damage to the compressor	
		failure of accumulator; (mechanical or too high level)	liquid to the compressor and liquid hammer	damage to the compressor	
		closed expansion valve	possible air ingress if pressure < atmos. and liquid injection via LISV	trip of the compressor (by high press. cut out switch)	
:e	Higher Temperature	high pressure/failure of LISV (closed)	high pressure in system; possible leakage	trip of the compressor (high temp. switch and/or high pressure switch). release via relief valve	
		high heat input from cold store	as above	as above	

Company: Node: 2
Facility: Page: 1

Session: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 2 outlet compressor (point 2/3 on drawing in fig. 1)
Parameter: Composition Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
Other Than	Other Than Composition (oil/gas)	failure working oil separator	possible damage to the compressor and decrease of cooling capacity	compressor trip on low oil pressure;	

P-PC 2.02 Worksheet Primatech Inc.

mpany: Node: 3
ility: Page: 1

ssion: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 3 outlet "3"-way valve (point 4 on drawing in fig. 1)
meter: Flow Intention:

W	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
	No Flow	pipeline failure	no cooling	-	
		system in defrost position	no cooling	-	
s	Less Flow	less cool demand			
		failure of the compressor	less cooling capacity	adjustment of expansion valve	
		line/connection leakage	lowering of cooling capacity; release of flammable gases, flammable gasmixture outside or in housing	adjustment of expansion valve	
		setting a too low suction pressure	lowering of cooling capacity	adjustment of expansion valve	
		failure of check valve	high pressure upstream check valve	LISV opens (correction of temp. increase)	
				(replace press. cut out switch, upstream check valve). Check function discharge-check valve.	
		blockage of 3-way valve	high pressure upstream check valve	switch off compr. by high pressure cut out switch.	
re	More Flow	failure of expansion valve/or temp. bulb	possible liquid hammer if high level in accumulator; damage to the compressor	trip compressor (high temp.)	

Company: Node: 3
Facility: Page: 1

Session: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 3 outlet "3"-way valve (point 4 on drawing in fig. 1)
Parameter: Temperature Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
Less	Lower Temperature	failure LISV (open)	possible liquid to the compressor and liquid hammer	trip out of compressor (high temp.)	
		failure of accumulator; (mechanical failure or too high level	as above	as above	
More	Higher Temperature	high pressure/ failure of LISV (closed)	possible leakage due to high pressure	trip compr. (high temp. switch or high pressure switch) release via relief valve	
		high heat input from cooling store	as above	as above	

Company:
acility:

Session: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 3 outlet "3"-way valve (point 4 on drawing in fig. 1)
rameter: Composition Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
ther han	Other Than Composition	failure of oil separator	possible damage to the compressor and decrease of cooling capacity	low oil pressure and compressor trip	

›mpany: Node: 4
:ility: Page: 1

›ssion: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 4 inlet expansion valve (point 5 on drawing in fig. 1)
ımeter: Flow Intention:

›W	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
	No Flow	pipeline or-connection failure	no cooling; release of flammable gas; possible flammable gasmixture in and outside casing	alarm on high temp. in cold store	
		freezing of drier	no cooling		
		blockage of check valve of the condensor	as above	trip compr. on high pressure	
		system in defrost position	no cooling		
ss	Less Flow	less cool demand			
		failure of the compressor	less cool capacity	adjustment of expansion valve	
		line/connection leakage	lowering of cooling capacity; release of flammable gas; flammable gasmixture in casing or outside	as above	
		setting a too low suction pressure	lowering cooling capacity	adjustment of expansion valve	
		partly blockage due to freezing the line	lowering cooling capacity	trip compressor (high press. cut out)	
		see also "less flow" point 4			
›re	More Flow	failure expansion valve or temp. bulb	possible liquid hammer if high level in accumulator and damage to the compressor	trip compressor (high temp.)	

Company: Node: 4
acility: Page: 1

Session: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 4 inlet expansion valve (point 5 on drawing in fig. 1)
rameter: Composition Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
ther han	Other Than Composition (liquid/gas	unsufficient coolant in system	decrease of cooling capacity	adjustment of expansion valve	
		blocked drier (working is in this case the same as the expansion valve)	as above	as above	

Company: Node: 4
acility: Page: 1

Session: 1 11-05-93 Revision: 0 11-10-93 Dwg#:
Node: 4 inlet expansion valve (point 5 on drawing in fig. 1)
rameter: Temperature Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
ess	Lower Temperature	fan not switched off	too high use of energy		
		failure LISV (open)	possibly liquid to the compressor and liquid hammer	damage to the compressor	
		failure of accumulator (mechanic or high level)	as above	as above	
ore	Higher Temperature	higher pressure/ failure of LISV (closed)	possible leakage due to high pressure	trip compressor (high temp. or high pressure)	
		high heat input from cold store	as above	as above	
		leakage 3-way valve	decrease of cooling capacity possible leakage due to high pressure	adjustment of expansion valve	

Company: Node: 5
acility: Page: 1

Session: 1 11-05-93 Revision: 0 11-19-93 Dwg#:
Node: 5 inlet accumulator (point 6 on the drawing in fig. 1)
rameter: Flow Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
o	No Flow	expansion valve	low pressure after compressure; no cooling	trip compressor by low pressure cut out switch	
		pipeline failure	no cooling; release of flammable gas	as above	
		froozen drier	no cooling; low pressure after compressor	as above	
		blockage of check valve condensor	as above	compressor trip by high pressure cut out switch	
ess	Less Flow	pipeline leakages	less cooling; release of flammable gas		
		less cool demand	-		
		failure of the compressor	decrease of cooling capacity	adjustment by expansion valve	
		incorrect suction pressure setting	as above; possible air ingress	-	
		partly froozen drier	decrease of cooling capacity	adjustment by expansion valve	
ore	More Flow	expansion valve completely open	accumulator filled up with liquid	-	
		leakage of 3-way valve	high pressure in system	compr. trip by high pressure cut out switch	
		leakage of heatexchanger (liquid to vapour side)	liquid accumulation in accumulator	-	

Company: Node: 5
acility: Page: 1

Session: 1 11-05-93 Revision: 0 11-19-93 Dwg#:
Node: 5 inlet accumulator (point 6 on the drawing in fig. 1)
rameter: Temperature Intention:

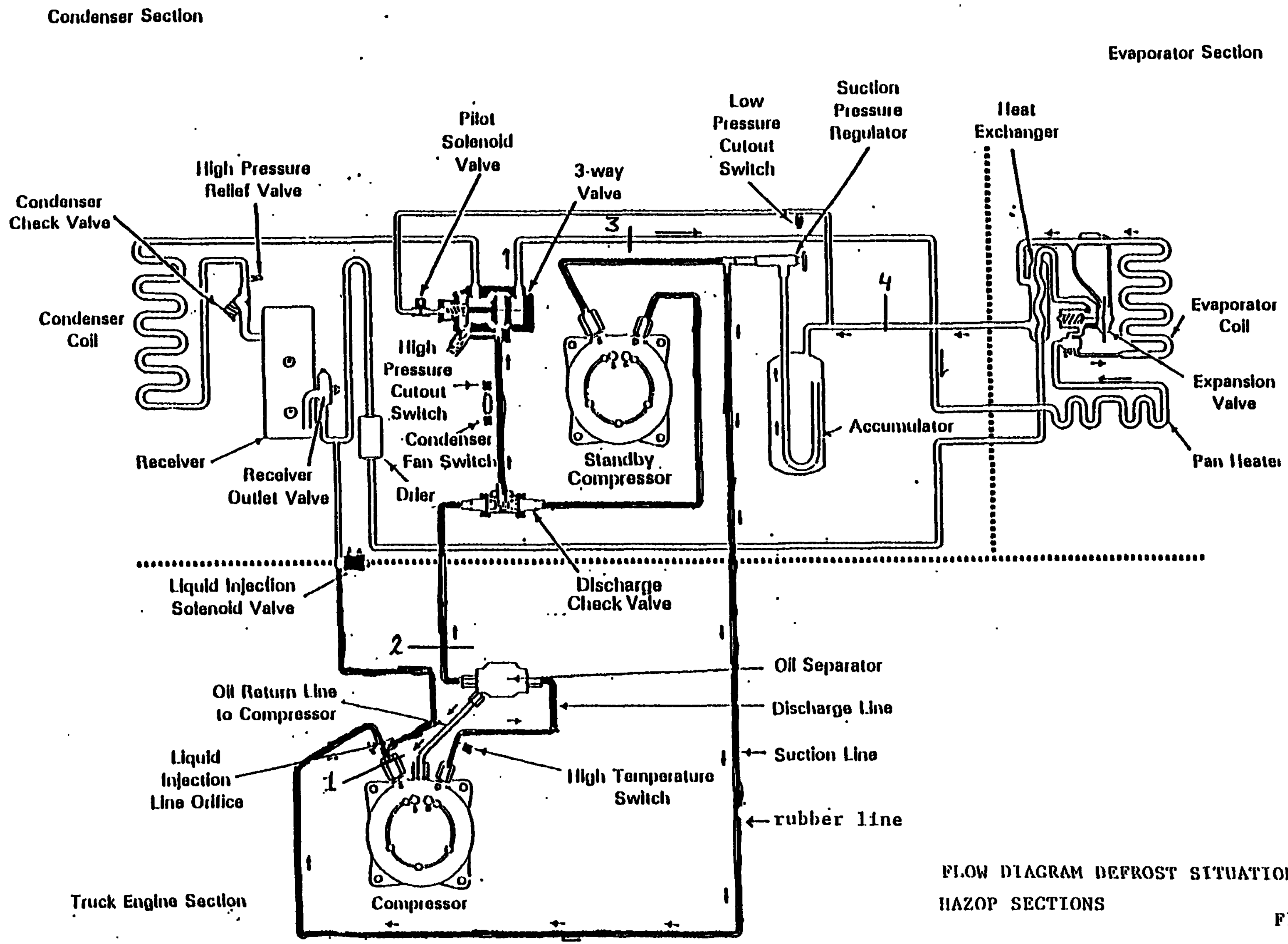
GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
ess	Lower Temperature	-	-	-	
ore	Higher Temperature	leakage 3-way valve	higher suction pressure and outlet pressure	trip compressor by high pressure cut out switch	
		failure of expansion valve (too far open)	liquid accumulation in accumulator	-	
		failure of LISV (closed)	higher pressure	trip by high temp. or high pressure cut out switch	
		high heat input from cold store	as above	as above	

Company: Node: 5
Facility: Page: 1

Session: 1 11-05-93 Revision: 0 11-19-93 Dwg#:
Node: 5 inlet accumulator (point 6 on the drawing in fig. 1)
Parameter: Composition Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	AUTOMATIC ACTION	BY
Other Than	Other Than Composition (liquid/vapour)	failure LISV (open)	more liquid to the compressor and possible liquid hammer	damage to the compressor	
		failure accumulator	liquid to compressor possible liquid hammer	as above	
	(gas/air)	low pressure due to closed expansion valve	if press. < atmos possible air ingress	trip compressor by low pressure cut out switch	

Defrost



FLOW DIAGRAM DEFROST SITUATION
HAZOP SECTIONS

FIG. 2

Company: Node: 1
'acility: Page: 1

Session: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 1 inlet compressor (point 1 on drawing in fig. 2)
.rameter: Flow Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
'o	No Flow	-	-	-	
,ess	Less Flow	no (or less) watersupply to the cooling coil of the accumulator	decrease of cooling capacity	-	
		leakage	release of gas, possibility of flammable mixture	-	
		leakage via expansion valve	closure of check valve receiver		
[ore	More Flow	leakage LISV	liquid hammer in the compressor	damage to the compressor	
		liquid flow from the accumulator	as above	as above	

:ompany: Node: 1
ıcility: Page: 1

;ession: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 1 inlet compressor (point 1 on drawing in fig. 2)
:ameter: Temperature Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
ɜss	Lower Temperature	-	-	-	
ɔre	Higher Temperature	failure of LISV	possible switch of by high pressure cut out switch	-	
		delayed starting of cooling	no cooling		

P-PC 2.02 Worksheet Primatech Inc.

mpany: Node: 2
:ility: Page: 1

ssion: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 2 outlet compressor, after oil separator (point 2 in fig. 2)
meter: Flow Intention:

W	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
	No Flow	-	-	-	
ss	Less Flow	no or less watersupply	decrease of capacity	-	
		leakage	release of gas, possible flammable mixture	-	
		leakage via expansion valve		closure of check valve receiver	
		leakage oil separator	decrease of capacity		
re	More Flow	leakage LISV	possibility of liquid hammer	damage to the compressor	
		liquid entrance via accumulator	as above	as above	

Company: Node: 1
'acility: Page: 1

Session: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 1 inlet compressor (point 1 on drawing in fig. 2)
.rameter: Composition Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
'ther 'han	Other Than Composition (liquid/vapour)	leakage of LISV	liquid to the compressor and possible liquid hammer	damage to the compressor	

Company: Node: 2
Facility: Page: 1

Session: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 2 outlet compressor, after oil separator (point 2 in fig. 2)
arameter: Temperature Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
More	Higher Temperature	see point 2 cooling situation			
Less	Lower Temperature	as above			

Company: Node: 2
Facility: Page: 1

Session: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 2 outlet compressor, after oil separator (point 2 in fig. 2)
Parameter: Composition Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
No	No Composition	not applicable			
Other Than	Other Than Composition	see point 2 cooling situation			

ıpany: Node: 3
ılity: Page: 1

ssion: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 3 downstream 3-way valve (point 3 on drawing in fig. 2)
ıeter: Flow Intention:

N	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
	No Flow	3-way valve not in defrost position	no defrost	-	
s	Less Flow	leakage 3-way valve	no defrost and no cooling		
		failure of oil separator	decrease of capacity		
		leakage (pipeline or connection)	release of flammable gas	possible flammable gasmixture	
e	More Flow	leakage of LISV	possible liquid hammer	damage to compressor	

AZOP-PC 2.02 Worksheet Primatech Inc.

Company: Node: 3
Facility: Page: 1

Session: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 3 downstream 3-way valve (point 3 on drawing in fig. 2)
arameter: Temperature Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
Less	Lower Temperature	failure LISV (open)	possible liquid hammer compressor	damage to the compressor	
		failure of accumulator	as above	as above	
More	Higher Temperature	heat input from cold store	higher pressure	possible trip by high pressure cut out switch	
		end of defrost period	return to cooling sitution		

Company: Node: 3
acility: Page: 1

Session: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 3 downstream 3-way valve (point 3 on drawing in fig. 2)
rameter: Composition Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
ther han	Other Than Composition (oil/gas)	failure of oil separator	oil contamination of the system		

ɔP-PC 2.02	Worksheet	Primatech Inc.

ɔmpany:
ːility:

Node: 4
Page: 1

ession: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 4 between evaporator and accumulator (point 4 in fig. 2)
ameter: Flow Intention:

ːW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
	No Flow	-	-	-	
ss	Less Flow	leakage 3-way valve	no cooling/no defrost	switch to cooling possible because of lower suction pressure	
		failure of oil separator	oil contamination of the system, less lubricating of compressor	possible damage to the compressor	
		leakage of pipeline/connection	release of flammable gas; possible flammable gasmixture		
ːe	More Flow	leakage via heatexchanger	possible overfill accumulator and liquid hammer	damage to the compressor	

Company: Node: 4
acility: Page: 1

Session: 1 11-22-93 Revision: 0 11-22-93 Dwg#:
Node: 4 between evaporator and accumulator (point 4 in fig. 2)
rameter: Temperature Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	RECOMMENDATIONS	BY
ess	Lower Temperature	leakage 3-way valve	fill up accumulator possible liquid to compressor	-	
			no defrost nor cooling	possible switch to cooling; low suction pressure	
		failure of the oil separator	loss of defrost capacity		
		leakage 3-way valve	loss of defrost capacity		
ore	Higher Temperature	see point 1 high temperature			