APPENDIX 10

Generic frequencies data for the critical events

Delvosalle C., Fiévez C., Pipart A.

Faculté Polytechnique de Mons, Major Risk Research Centre (Belgium)

TABLE OF CONTENTS

Summary

This appendix tries to give information about the range of failure frequencies which can be found in the literature for the different critical events associated with the different kinds of equipment, defined according the ARAMIS typology.

First of all, chapter 0 gives information about the sources of data which have been reviewed for this study. As general remark, it should be kept in mind that most of the data published are often copied from one source to another, with implies sometimes a loss of information. The task is then difficult to have precise information about the kind of population from which the data are derived, especially regarding the state of the art (in terms of safety systems and design). Most of data date from the 70's or 80's.

From chapter 2 to chapter 17, data are summarized for each kind of equipment defined in the ARAMIS typology. For each equipment, data are given for the corresponding critical events according the matrix EQ-CE (Table 1).

		CE1 Decomposition	CE2 Explosion	CE3 Materials set in motion (entrainment by air)	CE4 Materials set in motion (entrainment by a liquid)	CE5 Start of a fire (LPI)	CE6 Breach on the shell in vapour phase	CE7 Breach on the shell in liquid phase	CE8 Leak from liquid pipe	CE9 Leak from gas pipe	CE10 Catastrophic rupture	CE11 Vessel collapse	CE12 Collapse of the roof
Mass solid storage	EQ1	X	X	X	X	X							
Storage of solid in small packages	EQ2					X					X		
Storage of fluid in small packages	EQ3					X	X	X			X		
Pressure storage	EQ4					X	X	X	X	X	X		
Padded storage	EQ5					X		X	X		X	X	
Atmospheric storage	EQ6					X		X	X		X	X	X
Cryogenic storage	EQ7					X	X	X	X	X	X	X	
Pressure transport equipment	EQ8					X	X	X	X	X	X		
Atmospheric transport equipment	EQ9					X		X	X		X	X	
Pipe	EQ10					X			X	X			
Intermediate storage equipment integrated in the process	EQ11	X	X	X	X	X	X	X	X	X	X	X	X
Equipment devoted to the physical or chemical separation of substances	EQ12					X	X	X	X	X	X		
Equipment involving chemical reactions	EQ13					X	X	X	X	X	X		
Equipment designed for energy production and supply	EQ14					X	X	X	X	X	X		
Packaging equipment	EQ15			X	X	X			X	X			
Other facilities	EQ16					X	X	X	X	X	X		

Table 1: Matrix Equipment / Critical event

Chapter 18 shows a table summarizing the ARAMIS proposals in term of frequencies of critical events. This table (Table 19) is based on the same model than the matrix EQ-CE (Table 1). For each cross in Table 1, ARAMIS tries to give a proposal of critical event frequency.

It should be reminded that the values found in this document and in the concluding table (Table 19) are only based on a synthesis of published values. No indication can be given here about the state of the art considered.

It must be kept in mind that some data are based on a large population, some other on very few equipment

Some data are derived from an homogeneous population. But it is also very probable that a large part of data are derived from a non-homogeneous population, including very different process safety design, which can thus not be defined. For example, the frequency of the critical event "BLEVE" (catastrophic rupture) for pressure storage is equal to 8 10^{-5}/year. This includes probably some storage with protective insulation of the shell, and some others without. It should then be wrong to consider that the frequency of BLEVE for a vessel with a protective insulation layer would be x times lesser because of this "additional" system. **At the moment, the published data do not allow us to describe what is an included safety system, and what is an additional one, allowing us to decrease to critical event frequency.**

Data summarized in this document should then be used cautiously. In most cases, data should not be modified according our "feeling" of the level of safety design of the equipment analysed. If the reader wants to take into account the safety system implemented on the equipment analysed, it should be more interesting to build a fault tree, to choose frequencies for the initiating events and to apply the safety barrier approach. This is the other way proposed by ARAMIS to evaluate the frequency of a critical event. This second approach is more time-consuming but allows to take prevention safety systems into account.

1. Data sources

Diverse bibliographical sources provide generic probabilities for the critical events. Most of these are issued from countries where QRA serves as a decision support for land use planning.

More than 180 references were examined by TNO (WASH-1400, Canvey, COVO (Rijnmond), Reaktorsicherheit, LPG-integral study, AMINAL study,…). As general comment, it should be noted that some authors (even in recent publications) have copied and adapted the original failure data, of which the majority was firstly presented in literature some 25 years ago. Hence the basis of the failure data is much smaller than may be expected from the large number of references and moreover the data are rather old.

It can be observed that the IPO manual is very often referred to. The reason is certainly that, for some kinds of tanks, data are only found in IPO and not elsewhere. It makes us wonder if IPO frequencies are based on real data or on expert judgement. It is rather difficult to judge the reliability of the sources.

The references used in this report are:

- The "Purple book". Data values given in this report are set by consensus following discussions between representatives from industry, the competent authorities and the central government. Data values are often based on previously made decisions using best judgement of the available information at that time (1).
- A TNO report on the failure frequencies (2).
- The RIVM used the same data than the "Purple book" (3).
- Data from "Det Norske Veritas S.A.". The estimation of the event probability is made from statistic data and/or with the help of quantitative analysis of a fault tree or an event tree.
- Data from the IPO-manual and the RE 95-1 document (4).
- Handboek Kanscijfers (5)
- Canvey report (6)
- LPG study (7)
- EDF (8)

1.1 Remark

The frequencies in the following tables are given in **frequency per year**, except for the pipes for which the frequencies are given in frequency per year and per meter. These tables give the ranges of frequencies or propositions for the different critical events associated to each equipment type.

A range of frequencies for a critical event is defined by the maximal value and the minimal value found in the literature, [max value-min value].

The set of frequencies found in the literature and used to define the ranges of frequencies, are listed in the annex C.

A vessel or tank consists of the vessel (tank) wall and the welded sumps, mounting plates and instrumentation pipes. The critical events cover the failure of the tanks and vessels and the associated instrumentation pipes. The failure of pipes (e.g. the filling pipes) connected to the vessels and tanks are considered separately.

The frequencies indicated in the following tables are the frequencies of critical events.

2. Mass solid storage (Data found in the Purple Book)

Decomposition	No data found
Explosion	1.10^{-5}
Materials set in motion (entrainment by air)	1.10^{-5}
Materials set in motion (entrainment by a liquid)	No data found
Start of fire (LPI)	1.10^{-5}

Table 2: Data found for the mass solid storage

3. Storage of solid in small packages (Data found in the Purple Book)

Start of fire (LPI)	1.10^{-5}
Catastrophic rupture	No data found

Table 3: Data found for the storage of solid in small packages

4. Storage of fluid in small packages (Data found in the Purple Book)

Start of fire (LPI)	1.10^{-5}
Breach on shell in vapour phase	No data found
Breach on shell in liquid phase	1.10^{-5}
Catastrophic rupture	1.10^{-5}

Table 4: Data found for the storage of fluid in small packages

5. Pressure storage

Start of fire	No data found
Breach on shell in vapour phase	See Note 1
Breach on shell in liquid phase	See Note 1
Leak from a liquid pipe	See Note 2
Leak from a gas pipe	See Note 2
Catastrophic rupture	1.10^{-5}-1.10^{-8} (BLEVE of a spherical tank = 8.10^{-5}/year)

Table 5: Data found for pressure storage

Remarks:

According to the Purple Book,

- The frequencies are default failure frequencies based on the situation that corrosion, fatigue due to vibrations, operating errors and external impacts are excluded.
- A lower failure frequency can be used if a tank or vessel has special provisions additional to the standard provisions. However, the frequency at which the complete inventory is released (i.e., the sum of the frequencies of the instantaneous release and the continuous release (10 min)) should never be less than 1.10^{-7} per year.
- A higher frequency should be used if standard provisions are missing or under uncommon circumstances. If external impact or operating errors cannot be excluded, an extra failure frequency of 5.10^{-6} per year should be added to the instantaneous release and an extra failure frequency of 5.10^{-6} per year should be added to the continuous release (10 min).

Note 1

Range of values in the literature	Continuous release			
	f**10 mm**	f**35 mm**	f**50 mm/10 min**	f**100 mm**
Simple tank	1.10^{-4}-4.10^{-6}	$4.4.10^{-6}$-1.10^{-6}	5.10^{-5}-5.10^{-7}	3.10^{-6}-1.10^{-6}
In-ground tank	$1.3.10^{-5}$	$4.4.10^{-6}$		3.10^{-6}
Mounded tank	$1.3.10^{-5}$	$4.4.10^{-6}$		3.10^{-6}

Data found in the LPG study

Critical events	*Probability of occurrence per year*
Stationary situation Failure of largest connection	$0.5*10^{-5}$

Table 6: some data from the LGP study

Considering that the frequency of the critical event decreases if the size of the breach increases, here is **a proposition** for the frequencies of breaches on a simple pressure tank:

Proposition	**Continuous release**			
	f**10 mm**	f**35 mm**	f**50 mm/10 min**	f**100 mm**
Simple tank	5.10^{-5}	5.10^{-6}	1.10^{-6}	5.10^{-7}
Commentaries	5.10^{-5} and 5.10^{-7}/year are considered as the maximum frequency and the minimum frequency for a breach on a simple pressure vessel. 5.10^{-5} is the frequency of a breach of 10 mm and 5.10^{-7} is the frequency of a breach of 100 mm. Between these two extreme values, the frequency of a breach of 35 mm is estimated at 5.10^{-6} (to be conservative) and the frequency of a breach of 50 mm is the intermediate value between 5.10^{-5} and 5.10^{-7}, i.e. 1.10^{-6}/year. The frequency 1.10^{-4} is not retained in our propositions. This value seems a little high compared to other data.			

Table 7: proposition for the frequencies of breaches on pressure storage

Note 2

Data found in the LPG study

Critical events	***Probability of occurrence per year***
Stationary situation	
Failure of piping system	$0.15*10^{-3}$

6. Padded storage

Start of fire	No data found
Breach on shell in liquid phase	See Note 4 (same values than for an atmospheric storage)
Leak from a liquid pipe	See paragraph 11
Catastrophic rupture	See Note 4 (same values than for an atmospheric storage) + Note 3
Vessel collapse	No data found

Table 8: Data found for padded storage

Note 3

Data from Canvey report	
Instantaneous failure	10^{-4}

This value should be compared with 5.10^{-6}/year for a single containment atmospheric tank.

7. Atmospheric storage

Start of fire	No data found
Breach on shell in liquid phase	See Note 4
Leak from a liquid pipe	See paragraph 11
Catastrophic rupture	See Note 4
Vessel collapse	No data found
Collapse of the roof	No data found

Table 9: Data found for atmospheric storage

Note 4

Range of values in the literature	f 10 mm	f 35 mm	f 50 mm / 10 min	f 100 mm	Instantaneous release
A single containment atmospheric tank	10^{-4}-$5.1.10^{-5}$	$1.8.10^{-5}$	5.10^{-6}	$1.2.10^{-5}$	5.10^{-6}
Tank with a protective outer shell	1.10^{-5}-5.10^{-6} (any release to the atmosphere for the Purple Book)	2.10^{-6}	5.10^{-7}-$2.5.10^{-7}$	1.10^{-6}	5.10^{-7}-1.10^{-7}
Double containment tank	1.10^{-5}-$1.25.10^{-7}$ (any release to the atmosphere for the Purple Book)	5.10^{-8}	$2.5.10^{-7}$-$1.25.10^{-8}$	$2.5.10^{-8}$	$2.5.10^{-8}$-$1.25.10^{-8}$
Full containment tank	1.10^{-5}-1.10^{-7} (any release to the atmosphere for the Purple Book)	4.10^{-8}	$2.5.10^{-7}$ (negligible for the Purple Book)	2.10^{-8}	1.10^{-8}
Membrane tank	The frequency of a membrane tank, determined by the strength of the secondary container, should be estimated case by case using the data on the other types of atmospheric tanks.				
In-ground tank	1.10^{-7} (any release to the atmosphere negligible for the Purple Book)	4.10^{-8}	(negligible for the Purple Book)	2.10^{-8}	1.10^{-8}
Mounded tank	1.10^{-7} (any release to the atmosphere for the Purple Book)	4.10^{-8}	(negligible for the Purple Book)	2.10^{-8}	1.10^{-8}

To be conservative and in considering that the frequency of the critical event decreases if the size of the breach increases, here is **a proposition** for the frequencies of breaches on an atmospheric storage:

Proposition	f **10 mm**	f **35 mm**	f **50 mm / 10 min**	f **100 mm**	**Instantaneous release**
A single containment atmospheric tank	10^{-4}	$1.8.10^{-5}$	5.10^{-6}	5.10^{-6}	5.10^{-6}
Commentaries	1.10^{-4} is considered to stay conservative	The only value available	The only value available	The probability to have a diameter of 100 mm can not be more probable than a diameter of 50 mm	
Tank with a protective outer shell	10^{-5}	2.10^{-6}	5.10^{-7}	5.10^{-7}	5.10^{-7}
Commentaries	1.10^{-5} is considered to stay conservative	The only value available	5.10^{-7} is considered to stay conservative	The probability to have a diameter of 100 mm can not be more probable than a diameter of 50 mm	5.10^{-7} is considered to stay conservative
Double containment tank		5.10^{-8}	$2.5.10^{-8}$	$2.5.10^{-8}$	$2.5.10^{-8}$
Commentaries	Small leaks of the primary container are assumed not to release to the atmosphere and are thus omitted.	The only value available	As the previous cases, it is considered that the probabilities to have a diameter of 50 mm, of 100 mm or an instantaneous release are the same.		

Proposition	f **10 mm**	f **35 mm**	f **50 mm / 10 min**	f **100 mm**	**Instantaneous release**
Full containment tank		4.10^{-8}	2.10^{-8}	2.10^{-8}	1.10^{-8}
Commentaries	Small leaks of the primary container are assumed not to release to the atmosphere and are thus omitted.	The only value available	The probability to have a diameter of 50 mm can not be more probable than a diameter of 35 mm. It s considered that the probabilities to have a diameter of 50 mm or of 100 mm are the same.	The only value available	The only value available
Membrane tank	The frequency of a membrane tank, determined by the strength of the secondary container, should be estimated case by case using the data on the other types of atmospheric tanks.				
In-ground tank		4.10^{-8}	2.10^{-8}	2.10^{-8}	1.10^{-8}
Commentaries	Small leaks of the primary container are assumed not to release to the atmosphere and are thus omitted.	The only value available	It s considered that the probabilities to have a diameter of 50 mm or of 100 mm are the same.	The only value available	The only value available
Mounded tank		4.10^{-8}	2.10^{-8}	2.10^{-8}	1.10^{-8}
Commentaries	Small leaks of the primary container are assumed not to release to the atmosphere and are thus omitted.	The only value available	It s considered that the probabilities to have a diameter of 50 mm or of 100 mm are the same.	The only value available	The only value available

Table 10: proposition for the frequencies of breaches on atmospheric storage

8. Cryogenic storage

Start of fire	No data found
Breach on shell in vapour phase	No data found
Breach on shell in liquid phase	See Note 4 (same values than for an atmospheric storage) + Note 5
Leak from a liquid pipe	See Note 6
Leak from a gas pipe	No data found
Catastrophic rupture	See Note 4 (same values than for an atmospheric storage) + Note 5
Vessel collapse	No data found

Table 11: Data found for cryogenic storage

Note 5

Data from EDF	
Major leak	2.10^{-5}
Rupture (internal and external tanks)	1.10^{-6}
Data from Canvey report	
Large release to bund	$5.4.10^{-4}$
Very large release, involving bund overtopping	$1.8.10^{-4}$

These data are to compare with 5.10^{-6}/year for a single containment atmospheric tank

Note 6

Data found in the LPG study

Critical events	*Probability of occurrence per year*
Stationary situation	
Failure of outlet pipe	$0.4*10^{-3}$
Failure of liquid pipe in recirculation system	$0.3*10^{-5}$

9. Pressure transport equipment

Start of fire	No data found
Breach on shell in vapour phase	See Note 7
Breach on shell in liquid phase	See Note 7
Leak from a liquid pipe	See Note 8
Leak from a gas pipe	See Note 8
Catastrophic rupture	1.10^{-5}-5.10^{-7} (BLEVE of tank truck = 8.10^{-5}/year and BLEVE of rail tankcar = 7.10^{-5}/year)

Table 12: Data found for pressure transport equipment

Note 7

Continuous release				
Continuous release size = diameter of the largest connection	**Leak of a diameter equivalent to 10 mm**	**Leak of a diameter equivalent to 35 mm**	**Leak of a diameter equivalent to 50 mm, 10min**	**Leak of a diameter equivalent to 100 mm**
5.10^{-7}(Purple Book)	1.10^{-4}(TNO)-$1.3.10^{-5}$ (Handboek Kanscijfers)	$4.4.10^{-6}$(Handboek Kanscijfers)	5.10^{-5}(TNO)	3.10^{-6}(Handboek Kanscijfers)

Note 8

Leak (*)			
Full bore rupture of the loading/unloading hose	**Leak of the loading/unloading hose (effective diameter of 10% of the nominal diameter, with a maximum of 50 mm)**	**Full bore rupture of the loading/unloading arm**	**Leak of the loading/unloading arm (effective diameter of 10% of the nominal diameter, with a maximum of 50 mm)**
4.10^{-6}/hour	4.10^{-5}/hour	3.10^{-8}/hour	3.10^{-6}-3.10^{-7}/hour

(*) An (un)loading hose is considered as a pipe pertaining to the equipment. Please note that the frequencies are given per hour.

The ***LPG study*** gives the critical events of greatest relevance during the transhipment of LPG under pressure and the probability of their occurring:

Critical events	***Probability of occurrence per year***
Transhipment to inland water way vessel from spherical tank	
Failure of liquid pipe on quay	$0.3*10^{-5}$
Failure of vapour pipe	$0.3*10^{-5}$
Transhipment to rail tank car/tank truck from spherical tank	
Failure of liquid pipe (end of pipe)	$0.6*10^{-3}$

10. Atmospheric transport equipment

Start of fire	No data found
Breach on shell in vapour phase	See Note 9
Breach on shell in liquid phase	See Note 9
Leak from a liquid pipe	See Note 10
Leak from a gas pipe	See Note 10
Catastrophic rupture	1.10^{-5}-5.10^{-6}
Vessel collapse	No data found

Table 13: Data found for atmospheric transport equipment

Note 9

Continuous release				
Continuous release size = diameter of the largest connection	**Leak of a diameter equivalent to 10 mm**	**Leak of a diameter equivalent to 35 mm**	**Leak of a diameter equivalent to 50 mm, 10min**	**Leak of a diameter equivalent to 100 mm**
$9.6.10^{-5}$(DNV)- 5.10^{-7}(Purple Book)	1.10^{-4}(TNO)- $5.1.10^{-5}$ (Handboek Kanscijfers)	$1.8.10^{-5}$(Handboek Kanscijfers)	5.10^{-6}(TNO)	$1.2.10^{-5}$(Handboek Kanscijfers)

Note 10

Leak (*)			
Full bore rupture of the loading/unloading hose	**Leak of the loading/unloading hose (effective diameter of 10% of the nominal diameter, with a maximum of 50 mm)**	**Full bore rupture of the loading/unloading arm**	**Leak of the loading/unloading arm (effective diameter of 10% of the nominal diameter, with a maximum of 50 mm)**
4.10^{-6} - $5.7.10^{-7}$/hour	4.10^{-5}/hour	3.10^{-8}/hour	3.10^{-6}-3.10^{-7}/hour

(*) An (un)loading hose is considered as a pipe pertaining to the equipment. Please note that the frequencies are given per hour.

11. Pipe

In the literature, the critical events for pipes cover all types of process pipes and inter-unit pipelines above ground of an establishment. In the MIMAH methodology, the equipment "PIPE" is defined as "Piping linking different units (for example a pipe linking an unloading unit and a storage unit, or linking a storage unit and a process unit), as well as pipes feeding the flare".

In this paragraph, the frequencies are given in frequency per year and per meter. The total failure frequency of a pipeline is determined by multiplying the failure frequency by the total length of the pipeline.

Start of fire	No data found
Leak from a liquid pipe	See Note 11
Leak from a vapour pipe	See Note 11

Table 14: Data found for pipe

Note 11

The frequency depends on the pipe diameter.

Range of values in the literature	Small leak (effective diameter of 10% of the nominal diameter)	Middle leak (effective diameter of 22% of the nominal diameter)	Large leak (effective diameter of 44% of the nominal diameter	Full bore rupture
Nominal diameter < 75 mm	5.10^{-6}-$1.85.10^{-5}$	$7.93.10^{-6}$	$3.3.10^{-6}$	1.10^{-6}-$1.45.10^{-6}$
75 mm £ nominal diameter £ 150 mm	2.10^{-6}-3.10^{-6}	$1.11.10^{-6}$	$4.62.10^{-7}$	2.10^{-7}-5.10^{-7}
Nominal diameter > 150 mm	5.10^{-7}-3.10^{-6}	$6.5.10^{-7}$	$2.7.10^{-7}$	1.10^{-7}-5.10^{-7}

To be conservative and considering that the frequency of the critical event decreases if the size of the leak increases, here is **a proposition** for the frequencies of leak from a pipe:

Proposition	Small leak (effective diameter of 10% of the nominal diameter)	Leak (effective diameter of 22% of the nominal diameter)	Leak (effective diameter of 44% of the nominal diameter (Large leak)	Full bore rupture
Nominal diameter < 75 mm	$1.18.10^{-5}$	$7.93.10^{-6}$	$3.3.10^{-6}$	$1.22.10^{-6}$
75 mm £ nominal diameter £ 150 mm	$2.5.10^{-6}$	$1.11.10^{-6}$	$4.62.10^{-7}$	$3.5.10^{-7}$
Nominal diameter > 150 mm	$1.75.10^{-6}$	$6.5.10^{-7}$	$2.7.10^{-7}$	$1.18.10^{-7}$ (value of Handboek Kanscijfers) (*)

(*) The value of Handboek Kanscijfers is considered in this case because the intermediate value is higher than the frequency of a large leak.

Table 15: Proposition for the frequencies of leak from a pipe

Remark:

According to the Purple Book, the frequencies given for the pipework failure rate are based on process pipework operating in an environment where no excessive vibration, corrosion/erosion or thermal cyclic stresses are expected. If there is a potential risk causing a significant leak, e.g. corrosion, a multiplying correction factor of 3-10 should be applied, depending on the specific situation.

According to DNV, the frequencies of failure of process pipes must be multiplied by:

- 0.768 for pipes placed on racks
- 0.809 for pipes placed on the ground
- 0.885 for inter-unit pipes

For "in-ground pipes":

Handboek Kanscijfers	Instantaneous release	Leak of a diameter equivalent to 0.1D	Leak of a diameter equivalent to 0.22D	Leak of a diameter equivalent to 0.44D
In-ground metal pipe	3.10^{-9} L/D	$5.4.10^{-8}$ L/D		$2.3.10^{-8}$ L/D

Table 16: Data found for in-ground pipes

12. Intermediate storage equipment integrated in the process

In the literature, we have not found any specific data on the failure frequencies of intermediate storage equipment integrated in the process.

13. Equipment devoted to the physical or chemical separation of substances

Start of fire	No data found
Breach on shell in vapour phase	See Note 12
Breach on shell in liquid phase	See Note 12
Leak from a liquid pipe	See paragraph 11
Leak from a gas pipe	See paragraph 11
Catastrophic rupture	1.10^{-5}-5.10^{-6}

Table 17: Data found for equipment devoted to physical or chemical separation of substances

Note 12

Continuous release	
f **10mm**	f **50mm/10min**
1.10^{-4}	5.10^{-5}-5.10^{-6}

Remark:

There are very little data in the literature on the failure frequencies of process vessels (we have found data only in the "Purple Book"). The process vessels are specific equipment with a lot of components. It should be better to use the fault tree in order to obtain the failure frequency.

14. Equipment involving chemical reactions

Start of fire	No data found
Breach on shell in vapour phase	See Note 13
Breach on shell in liquid phase	See Note 13
Leak from a liquid pipe	See paragraph 11
Leak from a gas pipe	See paragraph 11
Catastrophic rupture	1.10^{-5}-5.10^{-6}

Table 18: Data found for equipment involving chemical reactions

Remark:

According to the Purple Book, the failure frequencies of reactor vessels are 10 times higher than the failure frequencies of pressure vessels. This factor covers the hazards imposed by the chemical process, like runaway reactions unidentified in the analysis of the process.

However, there are very little data in the literature on the failure frequencies of reactor vessels (we have found data only in the "Purple Book"). The reactor vessels are equipment with specific hazards (like runaway reactions). It should be better to use the fault tree in order to obtain the failure frequency.

Note 13

Continuous release	
f **10mm**	f **50mm/10min**
1.10^{-4}	5.10^{-5}-5.10^{-6}

15. Equipment designed for energy production and supply

No data found in the literature

16. Packaging equipment

No data found in the literature

17. Other facilities

No data found in the literature

18. Conclusion

- The frequencies given in the literature have a GENERIC character; the number and nature of safety barriers included in these failure frequencies and the age of the equipment at the time of failure are not known**. The frequencies are given for a "standard" security level. However, in the literature, the "standard" security level is not specified.**
- The ranges of frequencies per critical event can vary in proportion 10 to 10000.
- If it is not possible to obtain the frequency of the critical event from the fault tree (from the frequencies of causes), the generic frequencies of critical events will be used.

Underneath, it is a summary table of data found in the literature (see Table 19).

ND means No Data found;

NSD means No Specific Data found;

The case is in green when the value is a proposition;

The case is in grey when the critical event can not be associated to the equipment.

Failure frequency(/year)		Decomposition CE1	Explosion CE2	Materials set in motion (entrainment by air) CE3	Materials set in motion (entrainment by a liquid) CE4	Start of a fire (LPI) CE5	Breach on the shell in vapour phase CE6		Breach on the shell in liquid phase CE7		Leak from liquid pipe CE8		Leak from gas pipe CE9		Catastrophic rupture CE10	Vessel collapse CE11	Collapse of the roof CE12
Mass solid storage	EQ1	ND	1.E-05	1.E-05	ND	1.E-05											
Storage of solid in small packages	EQ2					1.E-05									ND		
Storage of fluid in small packages	EQ3					1.E-05	ND		1.E-05						1.E-05		
Pressure storage	EQ4					ND	10mm	5.E-05	10mm	5.E-05	All fittings	0.15.E-3	All fittings	0.15.E-3	1.E-05 - 1E-06 (BLEVE of a spherical tank = 8.E-05/year)		
							35mm	5.E-06	35mm	5.E-06							
							50mm	1.E-06	50mm	1.E-06							
							100mm	6.E-07	100mm	6.E-07							
Padded storage	EQ5					ND			Same values than for an atmospheric storage		Same values as for a pipe				Same value as for an atmospheric storage + 1.E-04	ND	
Atmospheric storage **(single containment)**	EQ6					ND			10mm	1.E-04	Same values as for a pipe				6.E-06	ND	ND
									35mm	1.8.E-05							
									50mm	5.E-06							
									100mm	5.E-06							
Cryogenic storage	EQ7					ND	ND		Same values as for an atmospheric storage + Large release: 5.4.E-04-2.E0-5		ND		Outlet pipe	0.4.E-03	1.8.E-04 - 1.E-06	ND	
													Liquid pipe in recirculation system	0.3.E-05			
Pressure transport equipment	EQ8					ND	Largest connection	6.E-07	Largest connection	6.E-07	Full bore rupture of hose	4.E-06/hour	Full bore rupture of hose	4.E-06/hour	1.E-05 - 5E-07 (BLEVE of tank truck = 8.E-05/year and BLEVE of rail tankcar = 7.E-05/year)		
							10mm	1.1E-04-1.3.E-05	10mm	1.1E-04-1.3.E-05	10% of the nominal diameter (hose)	4.E-05/hour	10% of the nominal diameter	4.E-05/hour			
							35mm	4.4..E-06	35mm	4.4..E-06	Full bore rupture of arm	3.E-08/hour	Full bore rupture of arm	3.E-08/hour			
							50mm	5.E-05	50mm	5.E-05	10% of the nominal diameter (arm)	3.E-06 - 3.E-07/hour	10% of the nominal diameter	3.E-06 - 3.E-07/hour			
							100mm	3.E-06	100mm	3.E-06							

Failure frequency(/year)		CE1 Decomposition	CE2 Explosion	CE3 Materials set in motion (entrainment by air)	CE4 Materials set in motion (entrainment by a liquid)	CE5 Start of a fire (LPI)	CE6 Breach on the shell in vapour phase	CE7 Breach on the shell in liquid phase	CE8 Leak from liquid pipe	CE9 Leak from gas pipe	CE10 Catastrophic rupture	CE11 Vessel collapse	CE12 Collapse of the roof
Atmospheric transport equipment	EQ9					ND	Largest connection: 9.6.E-06-5.E07 10mm: 1.E-04-5.1.E-06 35mm: 1.8.E-05 50mm: 5.E-06 100mm: 1.2E-05		Full bore rupture of hose: 4.E-06 - 5.7.E-07 /hour 10% of the nominal diameter: 4.E-05/hour Full bore rupture of arm: 3.E-08/hour 10% of the nominal diameter: 3.E-06 - 3.E-07 /hour		1.E-05 - 5.E-06	ND	
Pipe	EQ10					ND			**/year and /m** — Nominal diameter <75mm 10% of the nominal diameter: 1.18E-05 22% of the nominal diameter: 7.93E-06 44% of the nominal diameter: 3.3.E-06 Full bore rupture: 1.22.E-06	75mm<nominal diameter<150mm / Nominal diameter>150mm 2.5.E-06 / 1.75.E-06 1.11E-06 / 6.5.E-07 4.62.E-07 / 2.7.E-07 3.5.E-07 / 1.18.E-07			
Intermediate storage equipment integrated in the process	EQ11	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD
Equipment devoted to the physical or chemical separation	EQ12					ND	10mm: 1.E-04 50mm: 6.E-05 - 6.E-06	10mm: 1.E-04 50mm: 6.E-05 - 6.E-06	Same values as for a pipe	Same values as for a pipe	5.E-05 - 5.E-06		
Equipment involving chemical reactions	EQ13					ND	10mm: 1.E-04 50mm: 5.E-05 - 5.E-06	10mm: 1.E-04 50mm: 5.E-05 - 5.E-06	Same values as for a pipe	Same values as for a pipe	5.E-05 - 5.E-06		
Equipment designed for energy production and supply	EQ14					ND	ND	ND	ND	ND	ND		
Packaging equipment	EQ15			ND	ND	ND			ND	ND			
Other facilities	EQ16					ND	ND	ND	ND	ND	ND		

Table 19: Summary table of data found in the literature on the frequencies of critical events

19. References

1. The "Purple book" - Committee for the Prevention of Disasters. Guidelines for quantitative risk assessment. CPR 18 E. 1999.

2. M. Th. Logtenberg, TNO-report, TNO-MEP-R 98/501, Derivation of failure frequencies for LOC cases, December 1998.

3. P.A.M. Uijt de Haag, G.M.H. Laheij, J.G. Post, B.J.M. Ale, L.J. Bellamy, RIVM Report 610066014, A method to judge the internal risk of establishments with dangerous substances, August 2001.

4. IPO A73. Handleiding voor het opstellen en beoordelen van een extern veiligheidsrapport. IPO Project A73. The Hague: IPO, 1994. Committee for the Prevention of Disasters, Risk Evaluation. Publication R-95-1; Tekstwijzigingen op de IPO A73. The Hague: Ministry of Housing, Spatial Planning and the Environment, 1996

5. Handboek Kanscijfers, Ministerie van de Vlaamse Gemeenschap, Departement Leefmilieu en Infrastructuur, AMINAL, Brussel, 1994.

6. Canvey: an investigation of potential hazards from operations in the Canvey Island/Thurrock area. Health and Safety Executive, HMSO, 1978.

7. LPG, a study. A comparative analysis of the risks inherent in the storage, transshipment, transport and use of LPG and motor spirit. Netherlands Organization for Applied Scientific research, TNO, Division of technology for Society, Apeldoorn, May 1983.

8. André Lannoy, Analyse des explosions air-hydrocarbure en milieu libre. Etudes déterministe et probabiliste du scénario d'accident prévision des effets de surpression. Electricité de France, Direction des Etudes et Recherches, 1984.

9. S. Carol, J.A. Vilchez, J. Casal, Using major hazard database systems to develop event trees for flammable materials. Universitat Politècnica de Catalunya, CERTEC, Barcelona.

10. Frank P. Lees, Loss Prevention in the Process Industries. Second Edition, 1996.

11. COVO Commission. Risk analysis of six potentially hazardous industrial objects in the Rijnmond Area, a pilot study. A report to the Rijnmond public authority Schiedam. Central Environmental Control Agency Rijnmond, 1981.