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Application of a Quantitative Risk Assessment (QRA) in a refinery unit.

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Contents

Summary

In this study a common basic distillation unit has been chosen to perform a Quantitative Risk Analysis following the Purple Book and the OGP database. There has been an explanation of the decisions taken in order to perform this analysis. The main objective of this study is to see the differences between using those two databases particularly in terms of frequency and consequence calculation. For this to be done, there has been a selection of Initial Events situated in representative places of the process that could lead to significant accidents. The Initial Events have been the same for both databases, the only variables that changed between these two ways on analysis has been the types of leaks for each Initial Event and the frequencies used to calculate frequencies for each type of leak and final Initial Event frequency (summation of every leak present in an Initial Event). Consequences obtained with these two databases have been similar, the only significant difference between these two database in terms of consequences assessment, was the number of types of leaks in every Initial Event. When talking of frequencies assessment, these two databases had different values for final Initial Event frequency. In the majority of Initial Events, the OGP database was more conservative. When the risk values were obtained, the results following the Purple Book database were more conservative contradicting the initial hypothesis. After an analysis of the results there was seen that the Initial Event with worse consequences was also one of the few who had greater values of frequency for the Purple Book database. This higher values of frequency for this Initial Event have an explanation related to frequency values with large diameter pipelines. In the OGP databases, in case of full rupture of a large nominal diameter pipeline, the frequency of this scenario tends to zero, not being that in the case of Purple Book. Therefore, it is correct to conclude that the OGP database is more realistic in terms of frequency values but in this case, this values have given less conservative results.

Keywords: Distillation Unit, Quantitative Risk Analysis, Process Safety, Purple Book, OGP, consequences, frequencies, risk.

Resum

En aquest estudi s'ha escollit una unitat bàsica de destil·lació de cru per realitzar una anàlisi quantitativa de riscos seguint el llibre *Purple Book* i la base de dades de la OGP. Durant la realització de l'anàlisi hi ha hagut una explicació de les decisions preses. L'objectiu principal d'aquest estudi és veure les diferències entre l'ús d'aquestes dues bases de dades, sobretot en termes de freqüència i càlcul de conseqüències. Per fer-ho, s'ha dut a terme una selecció d'esdeveniments inicials situats en llocs representatius del procés que podrien provocar accidents importants. Els esdeveniments inicials han estat els mateixos per a les dues bases de dades, les úniques variables que han canviat entre aquestes dues formes d'anàlisi han estat els tipus de fuites de cada esdeveniment inicial i les freqüències utilitzades per calcular les freqüències de cada tipus de fuita i freqüències finals de cada esdeveniment inicial (sumatori de totes les fuites presents en un esdeveniment inicial). Les conseqüències obtingudes amb aquestes dues bases de dades han estat similars, l'única diferència significativa entre aquestes dues bases de dades en termes d'avaluació de conseqüències va ser el nombre de tipus de filtracions en cada esdeveniment inicial. Pel que fa a l'avaluació de freqüències, aquestes dues bases de dades tenien valors diferents per a la freqüència final de l'esdeveniment inicial. En la majoria dels esdeveniments inicials, la base de dades OGP era més conservadora, es a dir, tenia valors de freqüència més elevats. Quan es van obtenir els valors de risc, els resultats de l'anàlisi dut a terme amb la base de dades del *Purple Book* van ser més conservadors que els obtinguts amb la base de dades de la OGP, contradient la hipòtesi inicial de que els resultats del risc de l'anàlisi seguit amb la OGP serien més conservadors. Després d'una anàlisi dels resultats, es va veure que l'esdeveniment inicial amb pitjors conseqüències era també un dels pocs que tenia valors de freqüència més elevats en l'anàlisi en el que es va seguir la base de dades del *Purple Book*. Els valors més elevats de freqüència d'aquest esdeveniment inicial tenen una explicació relacionada amb els valors de freqüència amb canonades de gran diàmetre. A les bases de dades OGP, en cas de ruptura completa d'una canonada de gran diàmetre nominal, la freqüència d'aquest escenari tendeix a zero, no sent aquest el cas de la base de dades del *Purple Book*. Per tant, és correcte concloure que la base de dades OGP és més realista en termes de valors de freqüència, però en aquest estudi en concret, aquests valors han donat resultats menys conservadors

Paraules Clau: Unitat de Destil·lació, Anàlisi Quantitativa de Risc, Seguretat de Processos, Purple Book, OGP, conseqüències, freqüències, risc.

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1. INTRODUCTION

1.1 Quantitative risk analysis (QRA)

The quantitative risk analysis (QRA from now on) is one of the most useful tools for the improvement of the safety level in a chemical plant with hazardous substances. QRA, as its name indicates, allows the evaluation of the involved risk in plants operation and in the use, handling, transport and storage of dangerous substances inside a chemical plant.. An QRA consists of several parts:

- Hazard identification: The first step in QRA is the identification of hazardous areas of the plant (e.g. pressurized vessels) and hazardous substances (toxic, flammable, etc.).

- Initial events: Just after the identification of the hazardous parts and compounds, with hazardous substances there must be an identification of possible failures called Initial Events (leak in a pipe or vessel, break of a pipe, etc.). These Initial Events cover pipelines and equipment. Pipes and equipment have an associated specific failure frequency given in times per year, which will be used for the estimation of the accidents' frequencies.

- Possible accidents: From the initial events, taking into account the safety measures implemented and using techniques such as the event tree, the possible accidents that may occur are identified and their frequencies evaluated.

- Consequence analysis: This part of the study focuses on calculating the effects of the possible accidents that can be triggered after the leaks and specific events previously mentioned. Nowadays simulation programs are used to carry out these calculations, programs such as DNVGL SAFETI, GEXCON EFFECTS or RISKCURVES. For this study, the effects program will be used, which bases its calculations on an accident modelling based on the Purple Book. This consequence can be focused on the equipment, on the environment and the personnel. But normally in an QRA the consequences are focused on people working inside the plant or in the surroundings.

- Risk calculation: All chemical plants are susceptible to cause an accident, so there is always a risk associated. The risk is defined by multiplying the severity and frequency of occurrence of an accident. The severity is based in the consequences previously calculated. In order to obtain a quantitative value, it is necessary to obtain the Combined Individual Risk per Annum (CIRPA). A chemical plant has to meet minimum CIRPA values to be operational.

- Risk reduction measures: Once the risk results are obtained, a series of risk reduction measures can be carried out in the areas of the plant with a significant risk value.

1.2 QRA in the SEVESO regulations

The SEVESO regulation was first implemented in 1976, after the accident occurred in Seveso, Italy. Since then, a series of modifications have been applied up to the current Directive 2012/18/EU (SEVESO III), whose transposition into Spanish legislation has been implemented by Royal Decree 840/2015. It should be noted that any modification of the regulations includes the lessons learned from the occurred accidents. SEVSO regulation affects any company that handles hazardous substances with amounts higher than levels established by the Directive.

A large part of the chemical industry uses hazardous substances, which implies that they are affected by the SEVESO regulations. These regulations guarantee a minimum safety levels of the use, handling, transport and storage of this substances. The SEVESO regulations require quantitative risk analysis studies (QRA), in addition to other studies such as HAZOP (Hazard and operability study) and also SIL (Safety Integrity Level study) in order to cover the possible weakness points exposed in the HAZOP study, increasing safety level.

1.3 Possible accidents

As mentioned before, the programs used in this study for the consequences calculation are based on the accidents modelling. These models come from the Yellow Book and are implemented in the EFFECTS an RISKCURVES programmes. There are different kind of accidents that can occur from a LOC (Loss of containment Event from now on), and fire is one of them. To evaluate this type of accidents it will be necessary to establish an irradiation map for the risk evaluation of death and injuries in a determinate area. There are several types of fire depending on the events after the LOC and the characteristics of the accident:

- Pool Fire: It is caused by a delayed ignition of a liquid substance accumulated on a surface or on top of another substance such as water or in a tank.
- Flash Fire: It is caused by a delayed ignition of a cloud formed by a mixture of air and flammable vapour or liquid substances such as an aerosol or fine mist (all of them flammable).
- Jet Fire: This type of fire is caused by a direct ignition of a flammable liquid or gas substance after a leak in a pressure vessel or pipe.
- Fire Ball: It occurs after the sudden vaporization of a flammable liquid, for example by a vessel breakdown. If the flammable vapor cloud formed finds a source of ignition nearby, the fireball is produced.

All this type of accidents will have different consequences depending on various variables such as the amount of fuel spilled on leak, atmospheric conditions, etc. Obviously, the shape of the irradiation map will depend on the type of fire and the conditions involved.

Another kind of accidents that can occur are explosions. They are classified as:

- BLEVE: The boiling liquid expanding vapour explosion (BLEVE from now on) occurs in vessels that store pressurized liquefied gases, in which by rupture, corrosion or leakage of the tank, the liquid inside reaches its boiling point and is incorporated massively into the expanding steam. If the released steam corresponds to a flammable product, a ball of fire is also generated in expansion.

- Chemical explosions: A chemical explosion involves energy derived from a chemical reaction. Explosions of a vessel due to combustion of flammable gas, and explosion of a reactor caused by decomposition of reaction products in a runaway chemical reaction.

Other type of accidents are related to a toxic dispersion. This type of accident involves gases or vapours that can create a toxic cloud, which can produce negative effects on people. In this case, models allow to obtain the map of concentrations, which permit to determine the area where concentration of toxic compound is higher than permissible values.

2. OBJECTIVES

The main objective of this study is to compare the risk of a new crude distillation unit similar to one is already in operation using two different databases. For this to be done, a QRA will be carried out following two different databases (Purple Book and OGP). At the end, there will be a comparison of risk and final IE frequencies. There are three aspects to study during this project:

- To quantify the risk of operating a distillation unit following the Purple Book database.
- To quantify the risk of operating a distillation unit following the OGP database.
- To compare frequencies and risk results using two different databases, the OGP and the Purple Book database.

3. CONTEXT OF STUDY

A company plans to implement of a new crude distillation unit to support the unit currently in operation. The project consists in adding a new production unit very similar to the existing one. According to SEVESO regulations and the Company requirements, it is necessary to perform a risk study, in this case an QRA.

3.1 Facilities

The crude distillation unit is among the most basic and important units of an oil refinery. In this unit (see Figure 1), the feed comes directly from the refinery's crude storage tanks and goes to a pump that drives it to a group of heat exchangers and then to a desalter (C-01). The desalted crude goes to a furnace (F-01) that heats it to the necessary temperature for feeding the column and joins the bottom recirculation stream to enter the distillation column (C-02). The lighter components leave the top of the column and pass through an accumulator (C-06). From there, part is recirculated towards the distillation column (C-02) and the other part joints the fuel gas. The distillation column has 4 side extractions and a bottom outlet. From the first lateral extraction, kerosene is obtained, from the second and third, diesel oil is obtained, and from the fourth, product is obtained that is sent to another unit of the refinery. All the extractions go through a stripper and the first, third and fourth extraction go through an exchanger to lower the temperature of the stream. There is also a bottom recirculation, composed by heavy hydrocarbons, that joins with the fourth extraction and the feeding stream of the column. The atmospheric residue, containing the heaviest hydrocarbons in crude oil, leaves the bottom of the column to be treated in another unit.

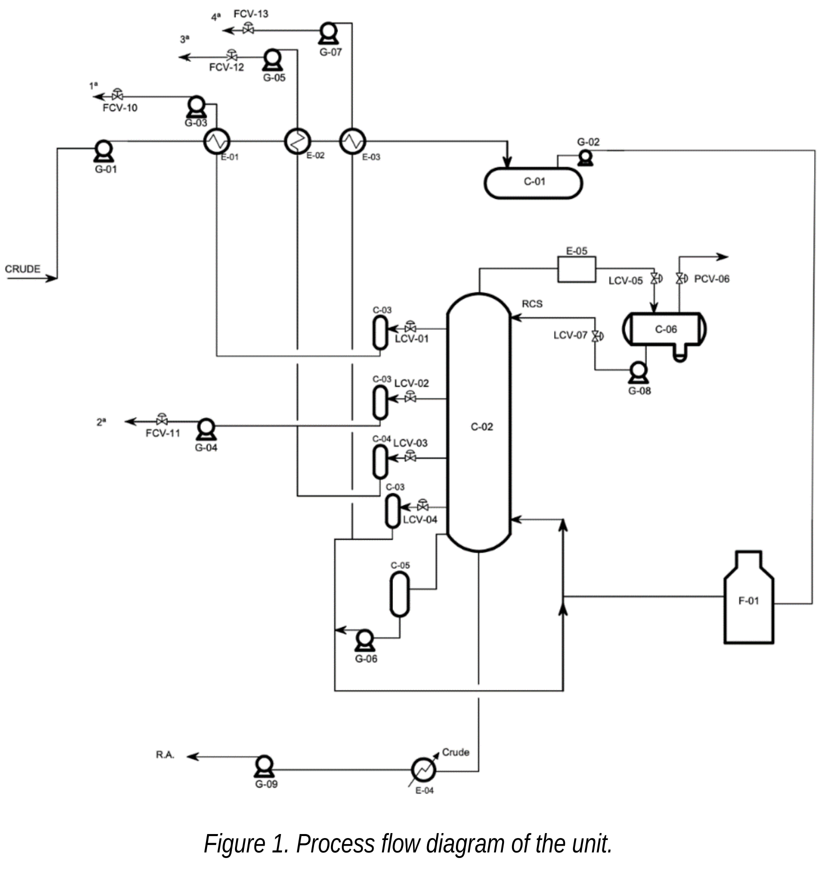

Figure 1. Process flow diagram of the unit.

3.2 Situation of the facilities

The complex is located in an area where there is no population within a radius of 10 km, so the danger to people is only for the refinery workers and people in the plant. The new crude distillation unit will be installed in the southeast area of the complex, near the main distillation unit. The Figure 2 shows where the unit is located within the complex.

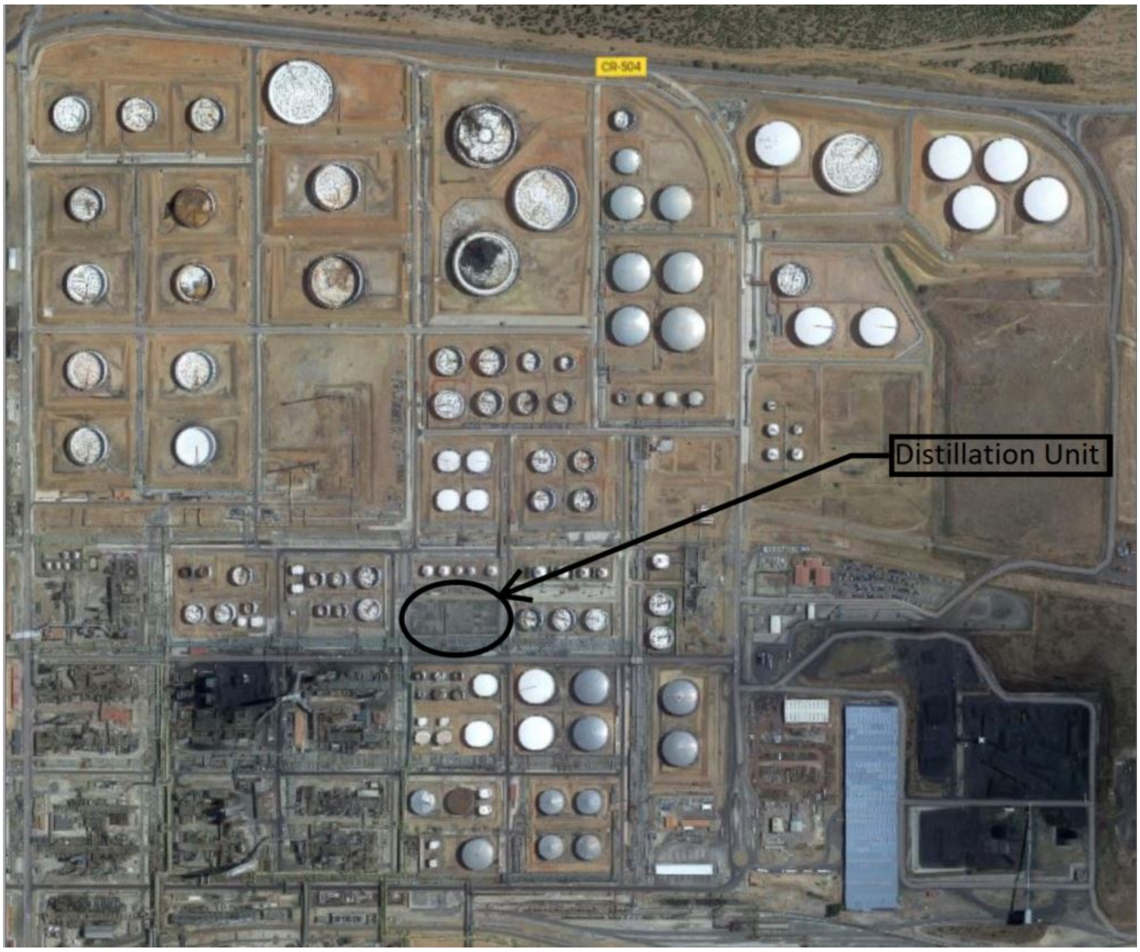

Figure 2. Unit situation within the refinery.

The distribution of the equipment in this unit is defined by the layout shown in the Figure 3.

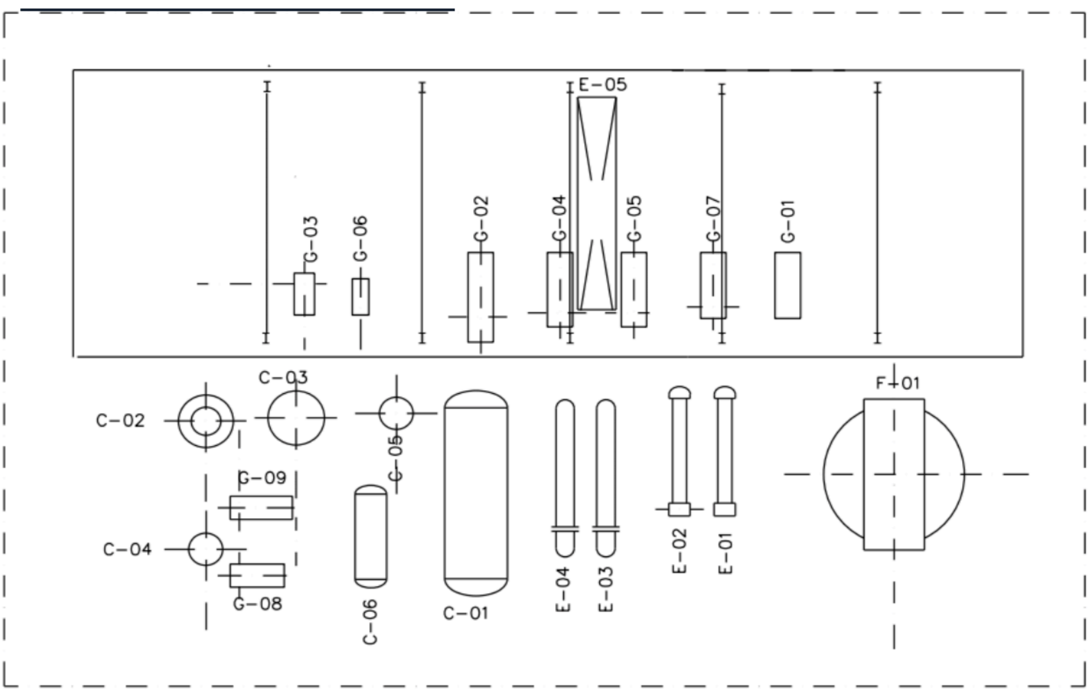

Figure 3. Layout of the distillation unit.

3.3 Equipment

This unit is composed of several types of equipment: a column, a head accumulator, a desalter, a furnace, some strippers and several heat exchangers and pumps. In the table 1 there are exposed every equipment with its name, tag and all the information necessary to calculate the consequences.

Table 1. List of equipment present in the distillation unit. ID stands for interior diameter. TAG is the designation used for every equipment in all diagrams.

EQUIPMENT	TAG	ID (mm)	VOLUME (m^3)
Heat Exchanger	E-04		
Heat Exchanger	E-01		
Heat Exchanger	E-03		
Heat Exchanger	E-02		
Crude Pump	G-01		
Desalator	C-01	3658	103,00
First extraction Pump	G-03		
Second extraction Pump	G-04		
Crude Pump	G-02		
Pump	G-07		
Third extraction Pump	G-05		
Feed Preheater	F-01		
Crude distillation tower	C-02	4300	730,79
Stripper	C-04	1300	11,61
Stripper	C-03	1200	26,91
Head Accumulator	C-06	2223	30,00
Reflux Pump	G-08		
Overflash tank	C-05	1190	3,8
Pump	G-09		
Condenser	E-05		
Pump	G-06		

3.4 Substances

As mentioned before, the QRA only includes parts of the plant that work with toxic and/or inflammable substances. In this case only flammable substances are present in operating conditions. Table 2 presents all hazard identification for substances and its respective hazard indicators and pictograms according to regulation CE num. 1272/2008 (CLP).

Table 2. Hazardous identification of the substances

Classification according to regulation CE num. 1272/2008 (CLP)		
Substance	Hazard Indicators	Pictograms
Pentane	H225, H304, H336, H411	
Hexane	H225, H304, H315, H336, H361f, H373, H411	
Heptane/Octane	H225, H304, H315, H336, H410	
Nonane	H226, H304, H315, H319, H332, H336, H410	
Undecane/Heptadecane/ Eicosane/Pentacosane	H304	
Tetradecane	H304, EUH066	

Table 3. List of mass streams present in the distillation unit

	Crude feed to column C-2 (kg/h)	Bottom C-2 (kg/h)	Top C-2 (kg/h)	First extraction (kg/h)	Second extraction (kg/h)	Third extraction (kg/h)	Fourth extraction (kg/h)	Atmospheric residue (kg/h)
Pentane	229	0	15	0	0	0	0	0
Hexane	0	0	49	0	0	0	0	0
Heptane	0	174	48	11	5	0	0	0
Octane	559	0	78	0	0	0	0	0
Nonane	0	0	6	139	10	0	0	0
Undecane	559	535	0	215	62	198	0	0
Tetradecane	237	367	0	0	119	900	4	0
Heptadecane	248	248	0	0	0	890	12	22
Eicosane	1292	1292	0	0	0	664	35	49
Pentacosane	0	0	0	0	0	106	23	1060
TOTAL	3124	2616	196	365	196	2758	74	1131

3.5 Operating conditions

As known, the process conditions are critic for QRA, because the type of accidents that can occur are strongly related to them. Figure 4 shows the process conditions (pressure and temperature).

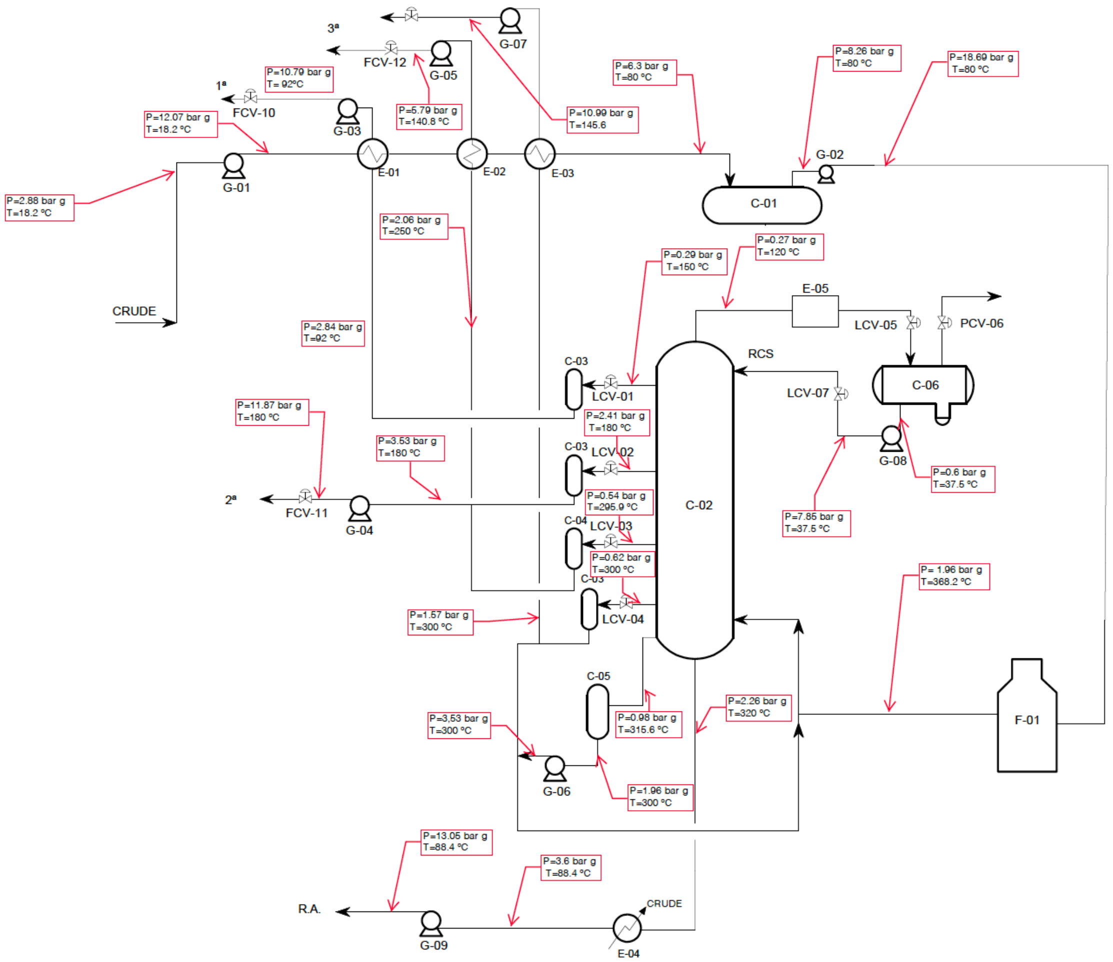

Figure 4. Process Flow Diagram with process conditions included

4. QUANTITATIVE RISK ANALYSIS

With all the information provided above, a Quantitative Risk Analysis can be done. The idea is first of all, select a series of initial events which can lead to possible accidents. The consequences of a series of leaks then must be modelled for each selected initiating event. This modelling is calculated using *EFFECTS,* software based on the Purple Book guidelines. The calculations take into account the substances, the amount of hazardous substance for each initiating event and the process conditions. After this first part is completed, in order to calculate the risk, it is necessary to include the frequency of occurrence for each type of leak for every initial event among other data such as particular accidents probabilities. Once all of this is done, while using *RISKCURVES* software, the specific individual risk values can be obtained in form of iso risk curves. It is important to bear in mind that in this study the only consequences evaluated will be damage to personnel.

4.1 Initial Events

As explained before, first of all, there must be a selection of possible initial events. These events have been located in the most critical areas of the process, being that in leaks in bottom of process equipment, (considered as pressure vessels) and in the discharge line of the pumps. In this last case, the discharge line have been chosen due to the constant leak flow rate in this part of the pipeline. This is done to cover the worst scenarios possible, where operation conditions were more unfavourable (more pressure, higher temperature) following a conservative rule. Every initial event has its own types of leaks, also called loss of containment events (LOCs). In the table 1 there are shown every initial event and its loss of containment events associated following the Purple Book Database.

Table 4. List of initial events with its description and loss of containment events associated.

INITIAL EVENT	DESCRIPTION	LOSS OF CONTAINMENT EVENTS
IE-01	Leak in discharge line of pump G-01.	G1. Full bore rupture.
		G2. Leak with an effective diameter 10% of the nominal diameter up to 50mm.
IE-02	Rupture of desalator C-01.	G1. Instantaneous release.
		G2. Pressure Vessel with a liquid release of the complete inventory in 10 min.
		G3. Pressure vessel with a liquid release from a hole of 10 mm.
IE-03		G1. Full bore rupture.

	Leak in discharge line of pump G-02	G2. Leak with an effective diameter 10% of the nominal diameter up to 50mm.
IE-04	Leak in top line of distillation column C-02 to head accumulator C-06.	G1. Full bore rupture.
		G2. Leak with an effective diameter 10% of the nominal diameter up to 50mm.
IE-05	Rupture of head accumulator C-06.	G1. Instantaneous release.
		G2. Pressure Vessel with a liquid release of the complete inventory in 10 min.
		G3. Pressure vessel with a liquid release from a hole of 10 mm.
IE-06	Leak in discharge line of pump G-08.	G1. Full bore rupture.
		G2. Leak with an effective diameter 10% of the nominal diameter up to 50mm.
IE-07	Rupture of stripper C-03A.	G1. Instantaneous release.
		G2. Pressure Vessel with a liquid release of the complete inventory in 10 min.
		G3. Pressure vessel with a liquid release from a hole of 10 mm.
IE-08	Rupture of stripper C-03B.	G1. Instantaneous release.
		G2. Pressure Vessel with a liquid release of the complete inventory in 10 min.
		G3. Pressure vessel with a liquid release from a hole of 10 mm.
IE-09	Rupture of stripper C-04.	G1. Instantaneous release.
		G2. Pressure Vessel with a liquid release of the complete inventory in 10 min.
		G3. Pressure vessel with a liquid release from a hole of 10 mm.
IE-10	Rupture of the stripper C-03C.	G1. Instantaneous release.

		G2. Pressure Vessel with a liquid release of the complete inventory in 10 min.
		G3. Pressure vessel with a liquid release from a hole of 10 mm.
IE-11	Rupture of overflash tank C-05.	G1. Instantaneous release.
		G2. Pressure Vessel with a liquid release of the complete inventory in 10 min.
		G3. Pressure vessel with a liquid release from a hole of 10 mm.
IE-12	Leak in discharge line of pump G-06.	G1. Full bore rupture.
		G2. Leak with an effective diameter 10% of the nominal diameter up to 50mm.
IE-13	Rupture of distillation tower C-02.	G1. Instantaneous release.
		G2. Pressure Vessel with a liquid release of the complete inventory in 10 min.
		G3. Pressure vessel with a liquid release from a hole of 10 mm.

Note that there is a more specific description of the reach of each initial event in frequency assumptions. All initial events exposed above are situated in PFD as it is shown in Figure 1.

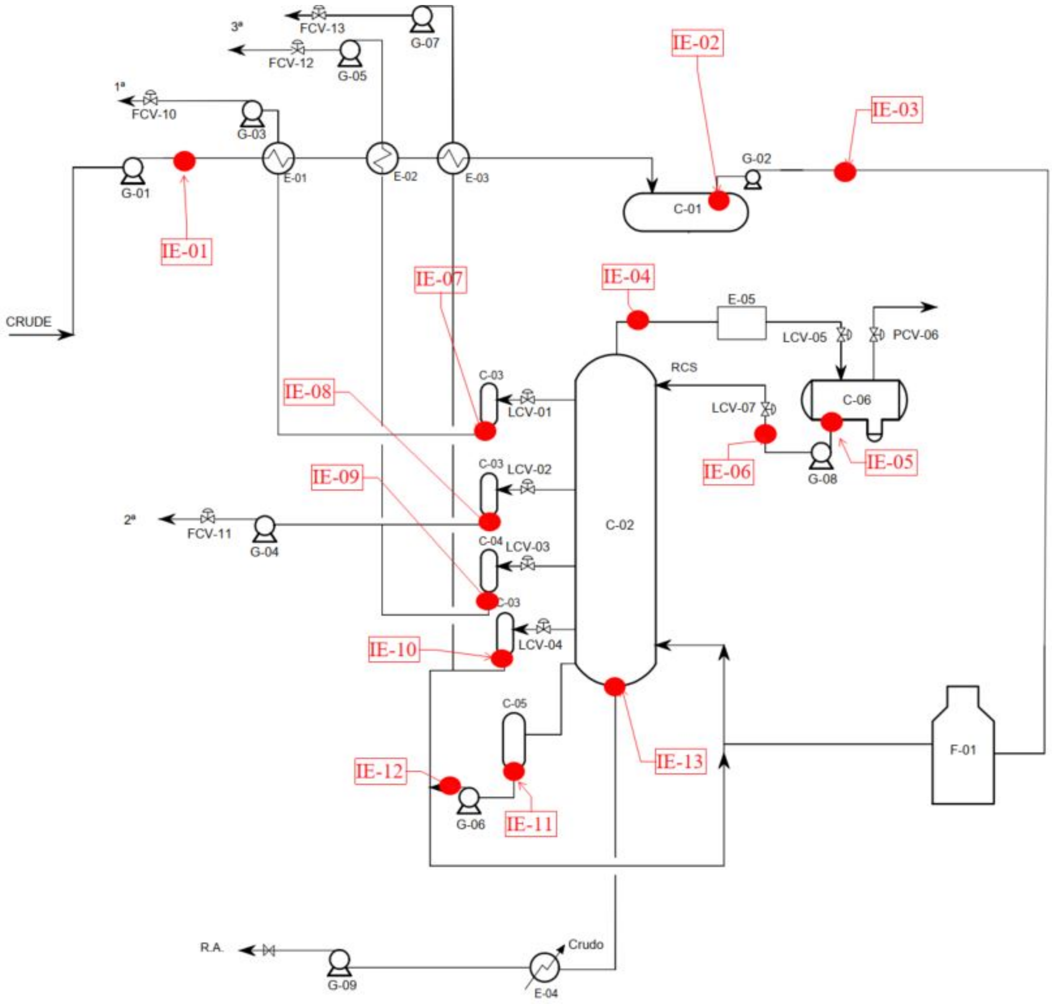

Figure 5. PFD with all IE located.

4.2 Consequence assessment assumptions

4.2.1 Consequences assessment assumptions following the Purple Book Database

The software used to model the consequences of every possible scenario in the distillation unit has been EFFECTS. This programme is based on Purple Book guidelines to do this modelling. The effects to be calculated will be overpressure related to explosive effects, gas dispersion and thermal radiation related to fire effects.

One important aspect to take into account is that this unit is working in a continuous mode of operation, therefore, there will be a continuous leak in the hole until there is action to be taken. The response time chosen has been 450 seconds (seven and a half minutes) being that a reasonable time for some operator to notice and take action.

As for the consequence calculation, it has been only considered two types of leaks or loss of containment events for initial events. One related to leaks in pipes and the other related to leaks in pressure vessels or emptying of pressure vessels:

- Related to leaks in pipes:
    - Full bore rupture of the pipeline.
    - Leak with an effective diameter of a 10% of the nominal diameter of pipeline up to 50 mm.
- Related to leaks in pressure vessel:
    - Instantaneous release of the inventory of the pressure vessel.
    - Pressure Vessel with a liquid/gas release of the complete inventory in 10 min.
    - Pressure vessel with a liquid/gas release from a hole of 10 mm.

In leaks situated in pipelines there has only been considered the amount of hazardous substance released during the time of reaction (450 seconds) because the inventory present in pipes is negligible compared to the amount released through the leak in 450 seconds. In the case of leak in the pressure vessel, it has been seen in all cases that the amount of leak during the time of detection is negligible compared to the amount of flammable substance released during the vessel emptying. Therefore, in this last case, it has only been considered the amount of substance released during the vessel emptying (vessel inventory).

The equipment present in the distillation unit that can be considered as pressure vessel are the desalator (C-01), strippers (C-03A/B/C and C-04), the over flash tank (C-05) and the head accumulator (C-06). The distillation tower (C-02) is considered as process vessel. There has only been considered gas inventory in the top of distillation tower C-02 (20% of the total volume).

All heat exchangers and the furnace have been considered as pipeline in terms of consequence calculation. In all full bore rupture cases has been considered round edges for the leak hole with a discharge coefficient of 1. And there has been considered sharp edges for any other kind of leaks with a discharge coefficient of 0,62.

The events related to the lines connecting the distillation tower C-02 and the four strippers have been set as negligible lines because they don't exceed five meter in length. Something similar happens to the IE related to discharge line of pumps G-03, G-04, G-05, G-07 and G-09, pumps are very close to battery line of unit, therefore, this sections of line can be excluded from the study and all pipeline before the pumps is covered by the IE related to the leak in upstream pressure vessel.

As for the gas dispersion calculations, it has been considered that all gases are neutral gases due to their density. All gases involved in this study are considered less dense than air. The wind direction used during the calculations and its probabilities is shown in the following figure (Figure 2). The two atmospheric stabilities (D2.8 and F1.4) present in the following figure are equally distributed.

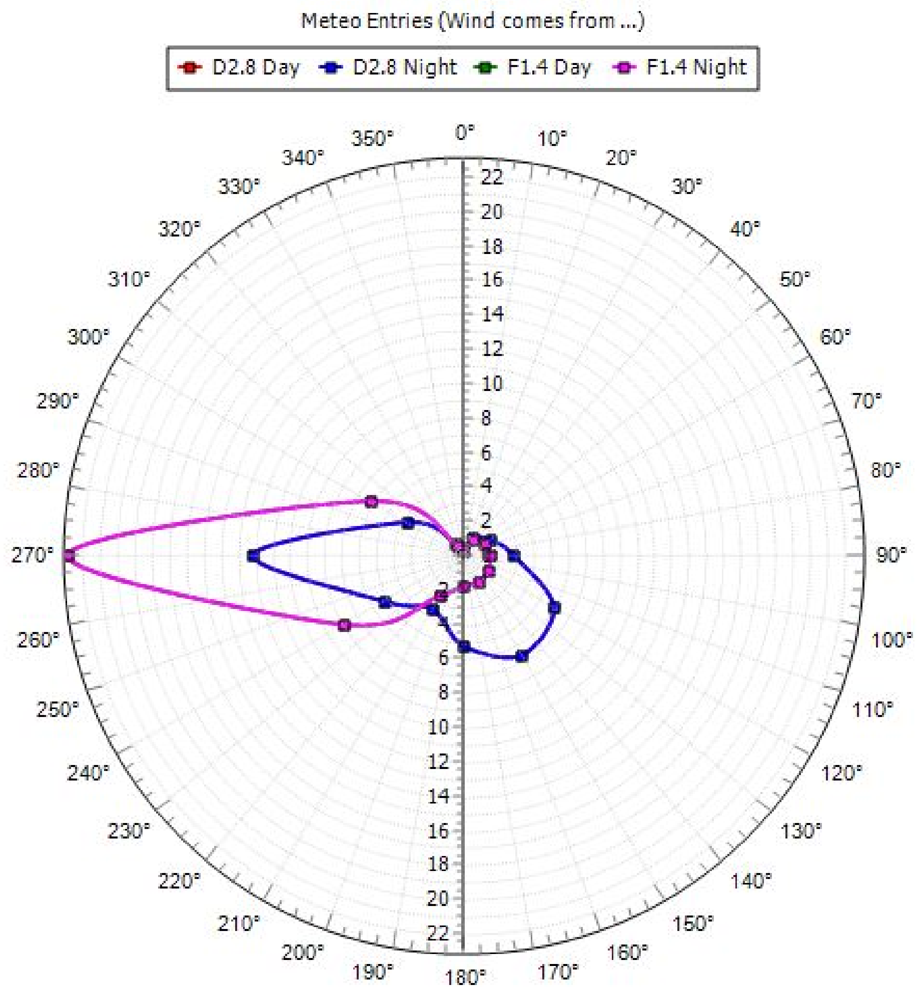

Figure 6. Wind directions used during calculations.

Another aspect to consider during the calculation of the consequences are process conditions, these parameters will determine the physical state of the stream among other consequence results.

4.2.2 Consequence assessment assumptions following the OGP Database

The only difference with the previous database will be the modes of failure evaluated during these calculations. Instead of using G1, G2, and G3, there will be used the following loss of containment events for every Initial Event in this study:

- Small leak: 5 mm diameter leak in a pipe or process equipment.
- Medium leak: 25 mm diameter leak in a pipe or process equipment.
- Big leak: 100 mm diameter leak in a pipe or process equipment.
- Catastrophic rupture: This LOC can be assimilated to the G1 of the Purple Book database.

4.3 Frequency analysis assumptions

4.3.1 Differences between OGP and Purple Book frequency Database

One of the main objectives in this study is to perform a comparison between following OGP database and Purple Book database during the frequency calculation. Both databases follow different frequency values and different procedures to obtain every initial events frequency.

OGP database is more detailed when talking of failure in process line; it has failure frequency values for manual/automatic valves, flanges, instrument connection and every item that is connected to the pipeline, apart from the frequency per meter related to the pipeline without any item attached to it. In Purple Book database there is a frequency value per meter of line with a correlative failure frequency of possible items connected to the pipeline included. So when talking to frequency calculation for a failure in process line there is no need to look at the P&ID diagram if following the Purple Book database, because all information necessary to complete the frequency count is provided by the PFD diagram. It is the opposite for the OGP database, being necessary to see the P&ID in order to count the number of elements present in the process line to add their frequency to the Initial Event. When following the Purple Book, there are only two modes of failure; full bore rupture of the pipeline and rupture of the 10% of the nominal diameter of the pipeline up to 50 mm. In the case of the OGP database, there are always four modes of rupture; small leak (<10 mm), medium leak (from 10 mm to 50 mm), big leak (from 50 mm up to 150 mm) and full rupture.

As for process equipment, there is no much difference between following one database or the other in terms of procedure, but in OGP database the equipment is more classified than the Purple Book database. For example, the Purple Book database considers all process equipment, except for pumps and heat exchangers, as pressure vessels or process vessels. And the OGP database has different frequency values for filters, separators, distillation towers, desalators, head accumulators, knock-out drums, absorbers and many other equipment. The Purple Book database has two failure databases for pumps, the same modes as in pipeline, and for heat exchangers it considers six modes of failure, being three of them exactly the same as considered in pressure vessels and other two being the same as in pipeline case. There is only one mode of failure (LOC) for pressure vessels that take into account a continuous leak, when the OGP database contemplates this scenario four different modes of failure.

4.3.2 Frequency calculation for each Initial Event following the Purple Book database

Once every initial event is defined and its loss of containment events are selected, the frequency of occurrence of each LOC can be calculated. In the case of initial events including pipeline, heat exchangers and/or pumps the frequencies from BEVI used to calculate the final LOC and IE frequencies are shown in the next table:

Table 5. Frequencies used for pipes and pumps.

Type of LOC	G1. Full bore rupture. ($m^{-1}y^{-1}$)		G2. Leak with an effective diameter of 10% of the nominal diameter, up to 50 mm. ($m^{-1}y^{-1}$)
Pipes	<75mm	1,00E-06	6,00E-06
	75mm<D<150mm	3,00E-07	2,00E-06
	>150mm	1,00E-07	5,00E-07
Pumps	1,00E-05		5,00E-04

Table 6. Frequencies used for heat exchangers.

Type of LOC	G5. Full bore rupture. ($m^{-1}y^{-1}$)	G6. Leak with an effective diameter of 10% of the nominal diameter, up to 50 mm. ($m^{-1}y^{-1}$)
Heat exchangers	5,00E-05	5,00E-05

In order to calculate the frequency of a pipeline section, it is only necessary to multiply its meters by its associated frequency. If this section also includes heat exchangers and pumps, it is also necessary to add their associated frequencies.

In the case of initial events related to a pressure vessel it is only necessary to consider the frequency of failure associated to that pressure vessel. Therefore, the frequencies used in this study are shown in the following table:

Table 7. Frequencies used for pressure vessels

	G1. Instantaneous release of the complete inventory	G2. Release of the inventory in 10 minutes	G3. Continuous release from a hole of 10mm effective diameter
Pressure Vessel	5,00E-07	5,00E-07	1,00E-05
Process Vessel (distillation column C-02)	5,00E-06	5,00E-06	5,00E-04

The process followed with the OGP database is very similar but it is necessary to consider the differences explained in the previous section. The frequencies used will not be exposed in this study because they are not from public domain.

In the following table there is the necessary information to carry out the frequency calculations for each initial event:

Table 8. Initial Event list with all necessary information to calculate frequency values.

INITIAL EVENT	INITIAL EVENT REACH	PIPE LENGTH (m)/DIAMETER (mm)
IE-01	From feed line to desalator C-01. Including pump G-01, heat exchangers E-01, E-02, E-03.	30/152
IE-02	Desalator C-01.	-
IE-03	From desalator C-01 to union line with bottom recirculation line of distillation column C-02. Including pump G-02 and furnace F-01.	14/203
IE-04	Top line from distillation column C-02 to head accumulator C-06. Including heat exchanger E-05.	10/457
IE-05	Head Accumulator C-06.	-
IE-06	Line from bottom of head accumulator C-06 to distillation tower C-02. Including pump G-08.	7/101
IE-07	Stripper C-03A	-
IE-08	Stripper C-03B	-
IE-09	Stripper C-04	-
IE-10	Stripper C-03C	-
IE-11	Overflash tank C-05	-
IE-12	Line from bottom of overflash tank C-05 to the junction with the feed line of distillation tower C-02. Including pump G-06.	16/76
IE-13	Distillation tower C-02.	-

4.3.3 Frequency calculation for each type of accident

Once the initial events frequency is calculated, it is necessary to include the probability of occurrence of an accident once there is a loss of containment. Therefore, the final frequency of an accident is defined as the product between the loss of containment event and the specific accident probability after the LOC occurs. The specific accident probability is calculated using the probability of direct and delayed ignition. The event tree of the two types of release present in this study are represented in the figures below:

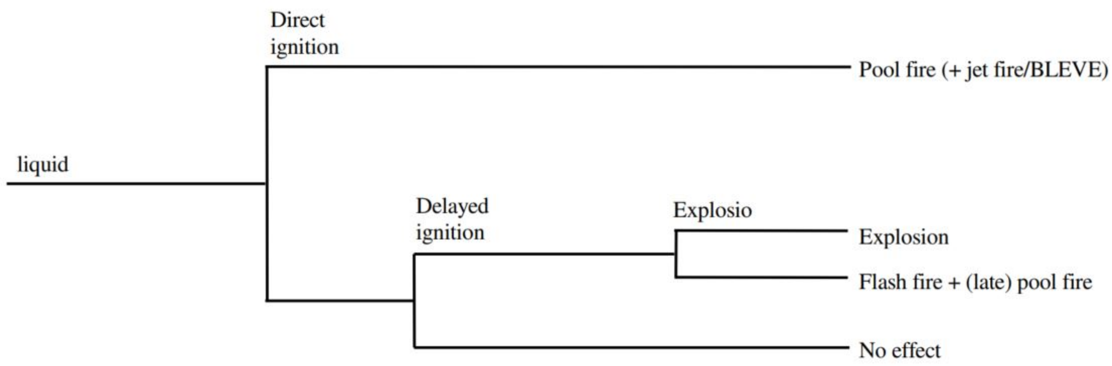

Figure 7. Event tree for a release of a flammable liquid (image from Reference Manual Bevi Risk Assessment. 3.2)

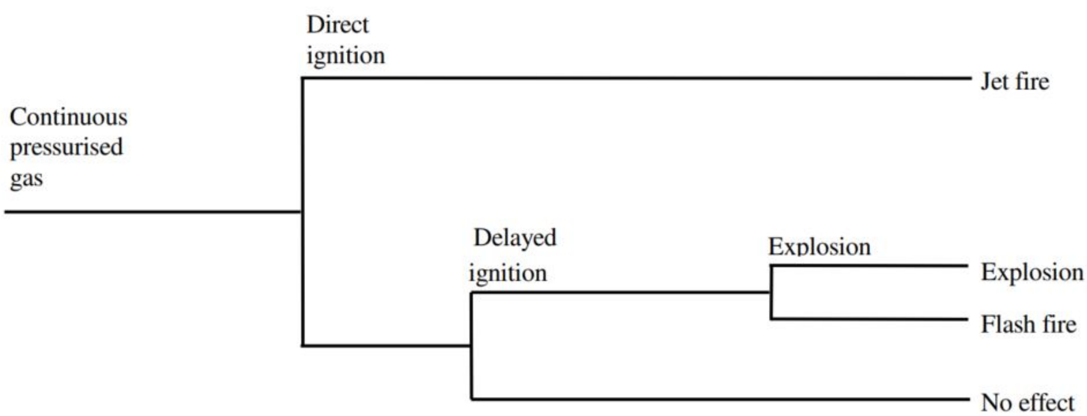

Figure 8. Event tree for a continuous release of a flammable gas (image from Reference Manual Bevi Risk Assessment. 3.2)

The probability of delayed ignition is defined as the complementary probability of the direct ignition probability. This direct ignition probability depends on the type of substance involved in the initial event. The selection of the probability for each substance has been done following the BEVI guidelines. It depends on the flash temperature and normal boiling point of the substance. With this two values it is possible to determine the inflammability of the substance and classify it in different categories (0,1, 2 ,3 and 4), being 0 the most flammable one. All substances have been classified as category 3 or 4, except for substance in top line of distillation column C-02 that have been classified as category 1. In the following table (Table 6) there are shown the ignition probabilities used for this study.

Table 9. Direct and delayed ignition probability list

Stream	$P_{Direct\ Ignition}$	$P_{Delayed\ Ignition}$
Crude	0	1
Top C-2	0,065	0,935
First extraction	0	1
Second extraction	0	1
Third extraction	0	1
Fourth extraction	0	1
Atmospheric residue	0	1

The same ignition probabilities will be used in both databases; Purple Book and OGP database.

4.3.4 Final frequencies comparison between Purple Book and OGP database

Having calculated the frequencies for each LOC in every IE with the two databases, the following results shown in the next table have been obtained.

Table 10. Frequency results for each IE and its LOCs associated

Final initial event frequency (times·year^{-1})									
	Purple Book Database				OGP Database				
IE	G1	G2	G3	TOTAL	(5mm)	(25mm)	(100mm)	FBR	TOTAL
IE-01	3,01E-03	3,05E-02	-	3,35E-02	2,04E-03	1,11E-03	3,47E-04	3,77E-04	3,88E-03
IE-02	5,00E-07	5,00E-07	1,00E-05	1,10E-05	2,03E-03	8,72E-04	2,75E-05	2,25E-05	2,95E-03
IE-03	1,01E-03	1,05E-02	-	1,15E-02	8,32E-04	5,15E-04	1,78E-04	2,20E-04	1,74E-03
IE-04	1,00E-03	1,00E-02	-	1,10E-02	3,23E-04	1,48E-04	4,12E-05	3,14E-05	5,44E-04
IE-05	5,00E-07	5,00E-07	1,00E-05	1,10E-05	1,37E-03	5,92E-04	2,75E-05	2,25E-05	2,01E-03
IE-06	1,21E-05	5,14E-04	-	5,26E-04	8,83E-04	5,55E-04	1,63E-04	2,20E-04	1,82E-03
IE-07	5,00E-07	5,00E-07	1,00E-05	1,10E-05	1,39E-03	5,97E-04	3,69E-05	2,25E-05	2,05E-03
IE-08	5,00E-07	5,00E-07	1,00E-05	1,10E-05	1,39E-03	5,97E-04	3,69E-05	2,25E-05	2,05E-03
IE-09	5,00E-07	5,00E-07	1,00E-05	1,10E-05	1,39E-03	5,97E-04	3,69E-05	2,25E-05	2,05E-03
IE-10	5,00E-07	5,00E-07	1,00E-05	1,10E-05	1,39E-03	5,97E-04	3,69E-05	2,25E-05	2,05E-03
IE-11	5,00E-07	5,00E-07	1,00E-05	1,10E-05	1,39E-03	5,97E-04	3,69E-05	2,25E-05	2,05E-03
IE-12	1,48E-05	5,32E-04	-	5,47E-04	9,59E-04	5,96E-04	1,63E-04	2,20E-04	1,94E-03
IE-13	5,00E-06	5,00E-06	1,00E-04	1,10E-04	6,14E-04	3,09E-04	4,46E-05	3,23E-05	9,99E-04

The total frequencies obtained for the OGP database are in general more conservative due to the existence of an extra mode of failure or two extra modes of failure in the cases of IE located in pipes. With all this data it is possible to think that the risk results following OGP database can be more conservative, but there are three IE located in pipeline that have bigger frequency values in the PB database, therefore this initial hypothesis could be wrong.

4.4 Risk results comparison between Purple Book and OGP database

Once both frequencies and consequence are calculated, it is possible to obtain the risk. This risk is defined as the product between frequency and consequences. In this study the results will be exposed as iso-risk curves. These curves define the specific individual risk in an area. Its units are deaths per annum. In the following figure are exposed the results following the PB database.

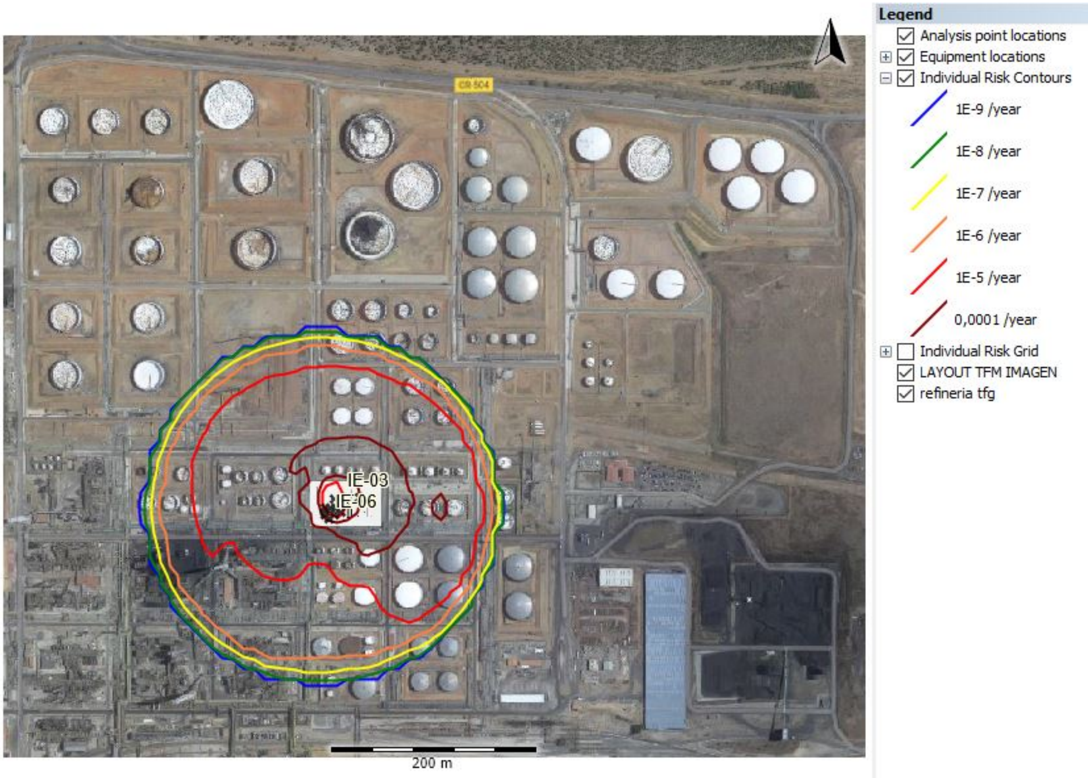

Figure 9. Results for PB database

When following the OGP database, maintain all other aspects the same, the obtained results have a significant variation. In the following figure there are shown the results obtained during the application of the OGP database.

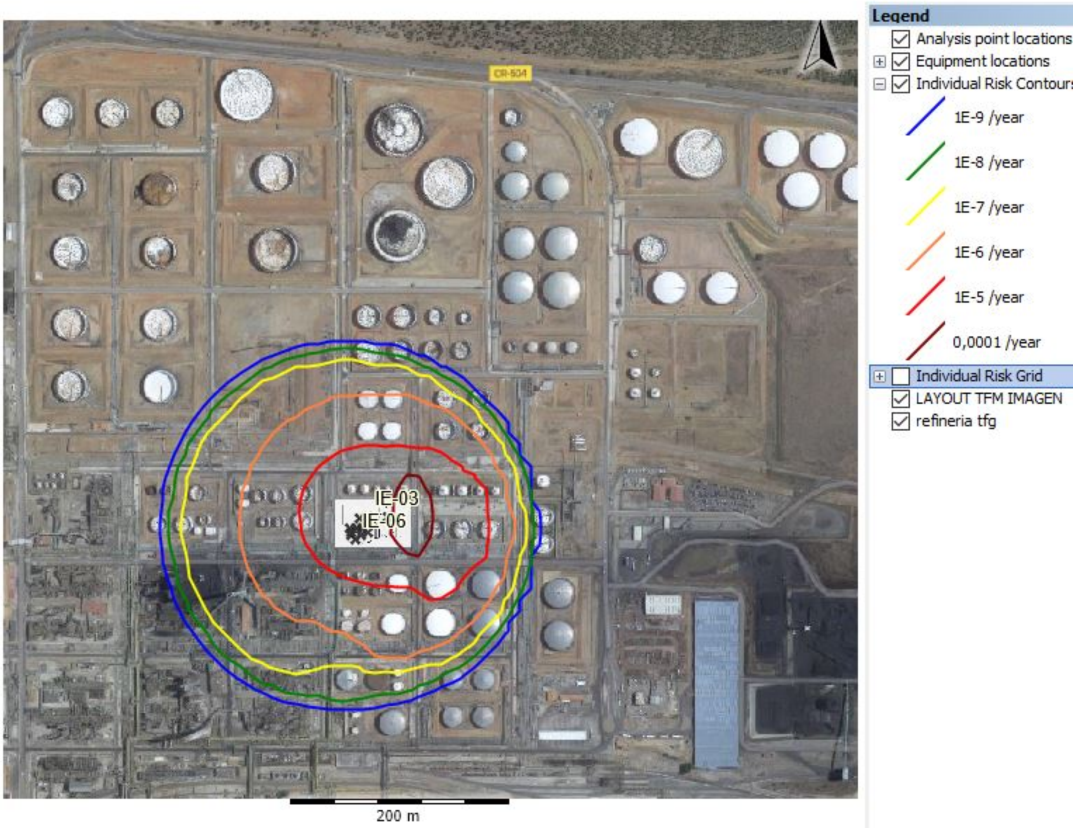

Figure 10. Results for OGP database.

Having these two databases compared, it is possible to observe that the results obtained by the PB database are more conservative. These results contradict the first hypothesis stated in the previous section, saying that the OGP database would be more conservative due to the existence of more LOCs or modes of failure for each IE and also having bigger total frequency values for most of the IE and being more detailed in terms of frequency calculations as explained in section 4.3.1. The differences between these two databases are only perceptible in the first three iso-risk curves ($1 \cdot 10^{-4}$ deaths$\cdot$year^{-1}, $1 \cdot 10^{-5}$ deaths year^{-1} and $1 \cdot 10^{-6}$ deaths$\cdot$year^{-1}), having more area in the case of PB database.

If the result sheets obtained from the RISKCURVES programme listed in the Appendix section are revised, it can be seen that the scenario with the worst consequences in the whole unit is the one represented in IE number four. This IE involves a gas leak in the top line of distillation tower C-02 that could evolve into a jet fire and gas explosion and gives the biggest 1% lethality contour. Therefore, a bigger frequency value for this scenario could give results that are more conservative.

5. CONCLUSIONS

A QRA has been carried out in order to quantify the risk of operation in a distillation unit to be implemented. It has been followed two databases to perform this QRA to compare results and see which database is more conservative in this particular unit.

The results have shown that the PB database gives more risk in this particular case, resulting in results that are more conservative. This results contradict the first hypothesis seen before risk calculations, because in the majority of IE, frequencies for OGP database are bigger than the ones in PB database.

But at the end, it has been seen that the scenario with worst consequences is also one of the scenarios with bigger frequency values for PB database, making this database give more risk values at the end of study.

After analysing the frequency values for OGP database in case of full bore rupture in large diameter pipes. It has been seen that these frequencies tend to have extremely low values. Therefore, that is the cause of having such low frequency values for IE number four. This does not mean that OGP database is less conservative than PB method, it is more realistic, because experience in field has demonstrated that pipelines with bigger nominal diameter tend to have much lower failure occurrence frequency. But in this particular case, this causes to have less conservative risk results for the OGP database case. Therefore, it is correct to conclude that the OGP database is more realistic in terms of frequency values but in this case, this values have given less conservative results.

One possible improvement for the OGP database would be simplifying frequency calculations for pipeline sections, as done in PB database. Because the model that is currently used takes into account flanges, nozzles and valves among other kind of items attached to the pipe but does not take into account for example pipe elbows and other pipe fitting that is also present but cannot be identified with the P&ID diagram.

6. REFERENCES

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7. ABBREVIATIONS

1. IE: Initial Event
2. OGP: Oil & Gas Producers
3. LOC: Loss of Containment event
4. QRA: Quantitative Risk Analysis/ Quantitative Risk Assessment
5. PB: Purple Book
6. FBR: Full Bore Rupture
7. P&ID: Plump and Instrumentation Diagram
8. PFD: Project Flow Diagram.

8. Appendix. RISKCURVES Calculation Sheets

8.1 Purple Book Database Calculation Sheets

Equipment: IE-01

Parameters	
Release Location (x;y)	45 x 26
Scenario's	
G1. Full bore rupture Set	
Frequency (/year)	3,01E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	51
G2. 10% diameter up to 50 mm Set	
Frequency (/year)	3,05E-02
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	8
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:16:20
Last Duration	9s 499ms

Equipment: IE-02(C-01)

Parameters	
Release Location (x;y)	27 x 11,5
Scenario's	
G1. Instantaneous release fo the complete inventory Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	144
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	144
Liquid LOC Scenario Leak (G3) Set	
Frequency (/year)	1,00E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	13
Liquid LOC Scenario Release in 10 min (G2) Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	89
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	89
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:17:16
Last Duration	20s 599ms

Equipment: IE-03

Parameters	
Release Location (x;y)	27,4 x 26
Scenario's	
G1. Full bore rupture Set	
Frequency (/year)	1,01E-03
Maximum Effect Distance (m)	80
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	80
G2.10% diameter up to 50mm Set	
Frequency (/year)	1,05E-02
Maximum Effect Distance (m)	45
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	45
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:15:50
Last Duration	14s 70ms

Equipment: IE-04

Parameters	
Release Location (x;y)	12 x 12

Scenario's	
G1. Full bore rupture Set	
Frequency (/year)	1,00E-03
Maximum Effect Distance (m)	182
Relevant Phenomenon	(Vapour Cloud) Explosion, Jet fire
Maximum Distance for 1% Lethality (m)	182
G2. 10% diameter up to 50 mm Set	
Frequency (/year)	1,00E-02
Maximum Effect Distance (m)	6
Relevant Phenomenon	Jet fire
Maximum Distance for 1% Lethality (m)	6

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:16:05
Last Duration	14s 552ms

Equipment: IE-05(C-06)

Parameters	
Release Location (x;y)	21 x 8,8

Scenario's	
G1. Instantaneous release fo the complete inventory Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	92
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	92
Liquid LOC Scenario Leak (G3) Set	
Frequency (/year)	1,10E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	10
Liquid LOC Scenario Release in 10 min (G2) Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	68
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	51

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:17:40
Last Duration	17s 438ms

Equipment: IE-06

Parameters	
Release Location (x;y)	16 x 6

Scenario's	
G1. Full bore rupture Set	
Frequency (/year)	1,21E-05
Maximum Effect Distance (m)	35
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	35
G2. 10% of diameter up to 50 mm Set	
Frequency (/year)	5,14E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	13

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:16:32
Last Duration	9s 528ms

Equipment: IE-07(C-03A)

Parameters	
Release Location (x;y)	16,75 x 15,4

Scenario's	
G1. Instantaneous release fo the complete inventory Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	70
Liquid LOC Scenario Leak (G3) Set	
Frequency (/year)	1,00E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	10
Liquid LOC Scenario Release in 10 min (G2) Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	34

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:35:09
Last Duration	6s 819ms

Equipment: IE-08(C-03B)

Parameters	
Release Location (x;y)	16,75 x 15,4

Scenario's	
G1. Instantaneous release fo the complete inventory Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	67
Liquid LOC Scenario Leak (G3) Set	
Frequency (/year)	1,00E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	11
Liquid LOC Scenario Release in 10 min (G2) Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	36

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:32:14
Last Duration	5s 847ms

Equipment: IE-09 (C-4)

Parameters	
Release Location (x;y)	12 x 8,8

Scenario's	
G1. Instantaneous release fo the complete inventory Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	48
Liquid LOC Scenario Leak (G3) Set	
Frequency (/year)	1,00E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	9
Liquid LOC Scenario Release in 10 min (G2) Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	23

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:18:41
Last Duration	15s 489ms

Equipment: IE-10 (C-03C)

Parameters	
Release Location (x;y)	16,75 x 15,4
Scenario's	
G1. Instantaneous release fo the complete inventory Set	
Frequency (/year)	1,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	55
Liquid LOC Scenario Leak (G3) Set	
Frequency (/year)	1,00E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	10
Liquid LOC Scenario Release in 10 min (G2) Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	38
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:19:12
Last Duration	18s 545ms

Equipment: IE-11 (C-05)

Parameters	
Release Location (x;y)	22,5 x 15,7
Scenario's	
G1. Instantaneous release fo the complete inventory Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	31
Liquid LOC Scenario Leak (G3) Set	
Frequency (/year)	1,00E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	9
Liquid LOC Scenario Release in 10 min (G2) Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	16
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:16:43
Last Duration	13s 410ms

Equipment: IE-12

Parameters	
Release Location (x;y)	20,4 x 25
Scenario's	
G1. Full bore rupture Set	
Frequency (/year)	1,48E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	20
G2. 10% of diameter up to 50mm Set	
Frequency (/year)	5,32E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	9
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:19:00
Last Duration	9s 61ms

Equipment: IE-13(C-02)

Parameters	
Release Location (x;y)	11,5 x 15,2
Scenario's	
G1. Instantaneous release fo the complete inventory Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	57
Liquid LOC Scenario Leak (G3) Set	
Frequency (/year)	1,00E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	11
Liquid LOC Scenario Release in 10 min (G2) Set	
Frequency (/year)	5,00E-07
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	60
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	10/06/2021 19:18:02
Last Duration	17s 779ms

8.2 OGP Database Calculation Sheets

Equipment: IE-01

Parameters	
Release Location (x;y)	45 x 26

Scenario's	
FG 100 mm Set	
Frequency (/year)	3,47E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	51
FM 25 mm Set	
Frequency (/year)	1,11E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	27
FP 5 mm Set	
Frequency (/year)	2,04E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	7
Full Rupture Set	
Frequency (/year)	3,77E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	51

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:02:18
Last Duration	10s 92ms

Equipment: IE-02(C-01)

Parameters	
Release Location (x;y)	27 x 11,5

Scenario's	
FG 100 mm Set	
Frequency (/year)	2,75E-05
Maximum Effect Distance (m)	115
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	115
FM 25 mm Set	
Frequency (/year)	8,72E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	26
FP 5 mm Set	
Frequency (/year)	2,03E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	8
Full Rupture Set	
Frequency (/year)	2,25E-05
Maximum Effect Distance (m)	144
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	144

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:07:33
Last Duration	8s 873ms

Equipment: IE-03

Parameters	
Release Location (x;y)	27,4 x 26

Scenario's	
FG 100 mm Set	
Frequency (/year)	1,78E-04
Maximum Effect Distance (m)	74
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	74
FM 25 mm Set	
Frequency (/year)	5,15E-04
Maximum Effect Distance (m)	41
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	41
FP 5 mm Set	
Frequency (/year)	8,32E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	7
Full Rupture Set	
Frequency (/year)	2,20E-04
Maximum Effect Distance (m)	80
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	80

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 19:58:49
Last Duration	24s 899ms

Equipment: IE-04

Parameters	
Release Location (x;y)	12 x 12

Scenario's	
FG 100 mm Set	
Frequency (/year)	4,12E-05
Maximum Effect Distance (m)	82
Relevant Phenomenon	(Vapour Cloud) Explosion, Jet fire
Maximum Distance for 1% Lethality (m)	82
FM 25 mm Set	
Frequency (/year)	1,48E-04
Maximum Effect Distance (m)	13
Relevant Phenomenon	Jet fire
Maximum Distance for 1% Lethality (m)	13
FP 5 mm Set	
Frequency (/year)	3,23E-04
Maximum Effect Distance (m)	3
Relevant Phenomenon	Jet fire
Maximum Distance for 1% Lethality (m)	3
Full Rupture Set	
Frequency (/year)	3,14E-05
Maximum Effect Distance (m)	182
Relevant Phenomenon	(Vapour Cloud) Explosion, Jet fire
Maximum Distance for 1% Lethality (m)	182

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 19:59:16
Last Duration	27s 740ms

Equipment: IE-05(C-06)

Parameters	
Release Location (x;y)	21 x 8,8
Scenario's	
FG 100 mm Set	
Frequency (/year)	2,75E-05
Maximum Effect Distance (m)	75
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	54
FM 25 mm Set	
Frequency (/year)	5,92E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	19
FP 5 mm Set	
Frequency (/year)	1,37E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	6
Full Rupture Set	
Frequency (/year)	2,25E-05
Maximum Effect Distance (m)	92
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	92
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 19:59:48
Last Duration	21s 28ms

Equipment: IE-06

Parameters	
Release Location (x;y)	16 x 6
Scenario's	
FG 100 mm Set	
Frequency (/year)	1,63E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	19
FM 25 mm Set	
Frequency (/year)	5,55E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	18
FP 5 mm Set	
Frequency (/year)	8,83E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	7
Full Rupture Set	
Frequency (/year)	2,20E-04
Maximum Effect Distance (m)	35
Relevant Phenomenon	Pool fire, (Vapour Cloud) Explosion
Maximum Distance for 1% Lethality (m)	35
Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:02:32
Last Duration	16s 411ms

Equipment: IE-07(C-03A)

Parameters	
Release Location (x;y)	16,75 x 15,4

Scenario's	
FG 100 mm Set	
Frequency (/year)	3,69E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	64
FM 25 mm Set	
Frequency (/year)	5,97E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	21
FP 5 mm Set	
Frequency (/year)	1,39E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	6
Full Rupture Set	
Frequency (/year)	2,25E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	70

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:08:30
Last Duration	6s 821ms

Equipment: IE-08(C-03B)

Parameters	
Release Location (x;y)	16,75 x 15,4

Scenario's	
FG 100 mm Set	
Frequency (/year)	3,69E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	64
FM 25 mm Set	
Frequency (/year)	5,97E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	21
FP 5 mm Set	
Frequency (/year)	1,39E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	7
Full Rupture Set	
Frequency (/year)	2,25E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	67

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:08:42
Last Duration	5s 818ms

Equipment: IE-09 (C-4)

Parameters	
Release Location (x;y)	12 x 8,8

Scenario's	
FG 100 mm Set	
Frequency (/year)	3,69E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	65
FM 25 mm Set	
Frequency (/year)	5,97E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	18
FP 5 mm Set	
Frequency (/year)	1,39E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	6
Full Rupture Set	
Frequency (/year)	2,25E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	48

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:00:13
Last Duration	19s 660ms

Equipment: IE-10 (C-03C)

Parameters	
Release Location (x;y)	16,75 x 15,4

Scenario's	
FG 100 mm Set	
Frequency (/year)	3,69E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	57
FM 25 mm Set	
Frequency (/year)	5,97E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	20
FP 5 mm Set	
Frequency (/year)	1,39E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	6
Full Rupture Set	
Frequency (/year)	2,25E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	55

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:00:36
Last Duration	24s 765ms

Equipment: IE-11 (C-05)

Parameters	
Release Location (x;y)	22,5 x 15,7

Scenario's	
FG 100 mm Set	
Frequency (/year)	3,69E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	49
FM 25 mm Set	
Frequency (/year)	5,97E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	17
FP 5 mm Set	
Frequency (/year)	1,39E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	6
Full Rupture Set	
Frequency (/year)	2,25E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	31

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:01:06
Last Duration	18s 325ms

Equipment: IE-11 (C-05)

Parameters	
Release Location (x;y)	22,5 x 15,7

Scenario's	
FG 100 mm Set	
Frequency (/year)	3,69E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	49
FM 25 mm Set	
Frequency (/year)	5,97E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	17
FP 5 mm Set	
Frequency (/year)	1,39E-03
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	6
Full Rupture Set	
Frequency (/year)	2,25E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	31

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:01:06
Last Duration	18s 325ms

Equipment: IE-12

Parameters	
Release Location (x;y)	20,4 x 25

Scenario's	
FG 100 mm Set	
Frequency (/year)	1,63E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	19
FM 25 mm Set	
Frequency (/year)	5,96E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	17
FP 5 mm Set	
Frequency (/year)	9,59E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	5
Full Rupture Set	
Frequency (/year)	2,20E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	20

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:01:29
Last Duration	16s 885ms

Equipment: IE-13(C-02)

Parameters	
Release Location (x;y)	11,5 x 15,2

Scenario's	
FG 100 mm Set	
Frequency (/year)	4,60E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	60
FM 25 mm Set	
Frequency (/year)	3,09E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	22
FP 5 mm Set	
Frequency (/year)	6,14E-04
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	6
Full Rupture Set	
Frequency (/year)	3,23E-05
Maximum Effect Distance (m)	0
Relevant Phenomenon	Pool fire
Maximum Distance for 1% Lethality (m)	57

Other Information	
Main program	RISKCURVES 11.2.1.20112
Last Calculation	11/06/2021 20:01:51
Last Duration	22s 30ms