Chlorine storage unit design and application of risk mitigation measures

ME&S *Engineering*

TFG-214102

Ana Guinea Alier

Date: 21/05/2014

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1. INTRODUCTION

Project title	Chlorine storage unit design and application of risk mitigations measures.
Project number	214103
Project authors	Sara Callau Mendoza
	Ana Guinea Alier
Date	21/05/2014
Location	URV (Tarragona)

ME&S Engineering is a company that was created on January 28th, 2014 in the academic framework of development of the Chemical Engineering Final Project, in Rovira i Virgili University, with the final aim of elaborating the TFG 214103 *Chlorine storage unit design and application of risk mitigations measures*.

The members of *ME&S Engineering* are Ana Guinea Alier as team leader and responsible of the project; Sara Callau Mendoza as responsible of the engineering.

The project selected is based on the execution of the design of a chlorine storage unit to determine whether it is possible or not to implement in an already existing factory as a possible future investment. Once the design is finished, a Quantitative Risk Assessment of the installation will be done. Also, alternative ways of design and safeguard will be studied and considered in order to diminish all possible risks.

The final documents will be handed in to the secretary of the ETSEQ (Tarragona) on May 21st, 2014.

- Responsible of the project: Ana Guinea Alier
- Responsible of engineering: Sara Callau Mendoza

1.1. <u>Agraïments</u>

Aquest treball de fi de grau o projecte final de carrera no hagués estat possible sense totes les persones que ens han ajudat i ens han recolzat, tant a la universitat com a casa.

A tots ells, volem dedicar-los aquest treball i, sobretot, agrair tot el que han fet per nosaltres.

En primer lloc, a Josep Basco que, ens ha donat suport des del primer moment. Gràcies per haver-nos donat la confiança necessària per tirar endavant aquest projecte. Sabem que la seva agenda no és fàcil i que li ha tocat treballar més hores del compte, però sempre ens ha rebut amb noves idees, amb crítiques constructives, amb consells i sobretot, amb ganes d'ajudar-nos. Gràcies per la seva paciència i les seves correccions, per les bones estones que hem compartit a les reunions, per ensenyar-nos alguna cosa nova cada dia, per animar-nos quan semblava que el treball no avancés i per exigir-nos més, fins l'últim moment. Sense la seva ajuda aquest projecte no hauria estat possible.

També volem donar les gràcies al Doctor Christophe Bengoa per oferir-nos la possibilitat de realitzar aquest projecte, arrel de la nostra feina amb ell a l'*Entitat Avaluadora del Risc*. Gràcies, per tot el que hem après durant aquests mesos, per facilitar-nos els programes informàtics necessaris per a la realització dels càlculs, per brindar-nos llibertat a l'hora de prendre decisions i per la confiança que ha dipositat en nosaltres.

Un agraïment molt especial a la Maria Miñana, per la seva paciència a l'hora d'explicar-nos procediments, pels seus consells i la seva predisposició a ajudar-nos des del primer moment. Volem agrair tot el que ens ha ensenyat i pels bons moments que hem compartit, no només durant la realització del projecte, sinó des del primer dia que vam començar a treballar amb ella.

També volem mostrar el nostre agraïment a Javier Abarca, per les seves ganes d'ajudar-nos, per tota la informació que ens ha facilitat, per rebre'ns sempre amb un somriure i per brindar-nos l'oportunitat de poder veure una zona d'emmagatzematge de clor liquat real.

També volem donar les gràcies a tots aquells professors que, d'una manera o una altra, ens han dedicat el seu temps per resoldre els nostres dubtes, donar-nos consells o facilitar-nos informació.

Ja per acabar, volem dedicar aquest treball a totes aquelles persones properes, que ens han donat suport, que han tingut paciència en els nostres moments d'estrès, que ens han animat a tirar endavant i que han cregut en nosaltres, moltes gràcies per ser-hi sempre.

2. PRELIMINAR STAGE

2.1. Project description

The purpose of the project is to do the design as complete as possible of the chlorine storage installations of *Chlorite* Company.

Such storage unit will enable *Chlorite* to increase production during the low energy cost time-slots and decrease it during the high cost ones. In this way, the excess of what is produced during low cost time-slots could be stored and supplied when necessary to clients by rack. This will decrease the production during high cost time-slots and still be able to provide the clients with the product.

Taking into account that the substance to be stored is chlorine and according to Real Decret 1254/1999 (ref. 1) it is a substance classified as highly toxic (risk phrase R12). Once the unit is designed, a Quantitative Risk Assessment (hereinafter referred to as QRA) is done. Through that study Iso-Risc curves are obtained, which permit to visualize the risk associated to the installation and the effects to population. For this reason, one of the objectives of the project is to get the minimization of this risk. In order to get it, many design alternatives for the chlorine storage has been contemplated, as well as mitigation measures for the possible release cases.

Finally, taking into account that the reason why the storage unit will be designed is economical, it is necessary to guarantee, with an economical study, that the design done is viable and will provide earnings to *Chlorite*.

2.2. Scope

The project is based on the design of a chlorine storage installation and its battery limits (hereinafter referred to as BL) include from the chlorine supply, which comes from *Chlorite* production plant, until sales lines, by rack and road tanker, and chlorine absorption system.

The project consists of the following sections:

- Design of the principal equipment: a chlorine storage tank, three centrifugal pumps (with chlorine, carbon tetrachloride and caustic soda), a tank refrigeration system (tube and shell heat exchangers and air cooler), an absorption column with chemical reaction, a caustic soda storage tank and a plate heat exchanger.
- Design of the necessary instrumentation to guarantee the installation safety: rupture discs, safety valves, etc.

- Design of the piping of the storage and absorption installations.
- Development of the Quantitative Risk Assessment according to current legislation (ref.1)
- Study of design and safety alternatives.

The establishment will have installed two bottles as refrigeration for the pumps and a safety bottle as a safety measure. Nevertheless, these bottles are not going to be designed due to the fact that they are not included in the scope of the project.

Once all the installations are designed, the QRA will be done, which will provide isorisk curves. Mitigation systems will be implemented on the plant to dismiss the consequences of the accidents that can occur and, moreover, a possible reduction of the risk for the alternatives of the design will be evaluated, focusing on safety and economy.

Also operation and maintenance manuals of the chlorine storage unit will be elaborated.

Then, an environmental study will be done in order to know the impact of the installations, as well as an economic study to know the viability of the project and the different alternatives.

Finally, once all these studies are carried out, the comparative relating to safety and economic will be done.

2.3. Process contextualization

To contextualize the project, following there is a brief description of the chlorine production process which takes place at *Chlorite* Company. It is a short description due to the fact that the important issue of the project is the tank T-101, which is described in detail in section 4.2.3.1 of this document.

Chlorine production is based on chlor-alkali electrolysis by membrane cell process, in which the anolyte and catholyte are separated by a cation-exchange membrane, which selectively transmits sodium ions but suppresses the migration of hydroxyl ions from the catholyte into the anolyte.

The process comprises brine purification, electrolysis and product treatment. The block diagram of the process is shown in diagram 1 (section 4.1)

2.3.1. Brine purification

The source brine is treated in a two-stage purification to ensure good performance of the membrane. The primary purification involves conventional precipitation and sedimentation, while secondary purification is accomplished by the absorption of impurities, such as calcium and magnesium ions. Thus, a saturated brine of NaCl is obtained without impurities.

This is necessary because the membrane comes into contact with a highly concentrated NaOH solution, and the impurities that the brine contains (Ca^{+2} and Mg^{+2}) can react with OH^- within the membrane to form insoluble hydroxides, which then precipitate inside the membrane. This causes serious problems, such as an increase in cell voltage and a reduction in current efficiency.

2.3.2. Electrolysis (ref. 39)

The overall reaction of the process is following shown, which takes place in two parts; at the anode and at the cathode.

$$2NaCl+2H_2O \rightarrow Cl_2+H_2+2NaOH \qquad 2.3.1$$

The evolution of chlorine takes place at the anode:

$$2Cl^- \rightarrow 2Cl+2e^- \rightarrow Cl_2+2e^- \qquad 2.3.2$$

In the cathode, hydrogen and hydroxyl ions are generated by reaction:

$$2H_2O+2e^- \rightarrow 2H+2OH^- \rightarrow H_2+2OH^- \qquad 2.3.3$$

In a membrane cell, a cation-exchange membrane separates the anolyte and catholyte. Saturated brine is fed into the anode compartment, where chlorine gas is evolved at the anode and sodium ions migrate into the catholyte through the membrane. Depleted brine is discharged from the cell.

In the cathode compartment, hydrogen is evolved at the cathode, leaving hydroxyl ions, which together with the permeating sodium ions constitute the caustic soda. Pure water is added to the catholyte to control the concentration of the caustic soda.

Chloride ions in the anolyte are excluded by the cation-exchange membrane so that the rate of diffusion of chloride from the anolyte to the catholyte is extremely low. As a result, a strong caustic with low salt content is obtained as the catholyte effluent.

Since the catholyte is a strong caustic, there is some back migration of hydroxyl ions from the catholyte into the anolyte, even with the use of a high-performance cation-exchange membrane. This causes a loss of current efficiency of 3-5 % in caustic production.

The membrane is made of perfluoro polymers containing ion-exchange groups. The carboxylate type is indispensable for obtaining a high current efficiency.
The basic flow sheet of the process is shown in diagram 2 (section 4.1.)

2.3.3. Product treatment

2.3.3.1. Hydrogen

The hydrogen produced is cooled as it leaves the cathode compartment and is carried to a safety seal. A demister ensures that the gas is free of droplets. The hydrogen is compressed before it passes through coolers on its way to the consuming plants.

2.3.3.2. Sodium hydroxide solution

The caustic soda solution from the electrolyzer can be used as is, or a 50 wt% NaOH can be obtained by concentrating the catholyte effluent in a double-effect evaporator.

2.3.3.3. Chlorine

The chlorine gas is firstly cooled in a tower, where water is sprayed inside and flows countercurrent to the chlorine. This treatment thoroughly washes the chlorine and wastewater is dechlorinated.
The wet chlorine gas is passed through a demister, which is a filter that removes the water droplets and impurities of the stream. It passes between wire electrodes in vertical tubes. The particles and droplets in the chlorine become charged and collect on the tube walls. The resultant liquid is fed back into the brine system or chemically treated before disposal.
The purified chlorine gas is dried, in a packed tower, with concentrated sulfuric acid (96-98 wt%) in a two-stage process. The acid, which is first cooled, and chlorine flow countercurrently. The heat liberated on dilution of the circulating acid in the first stage is removed by heat exchangers and the weak acid is dechlorinated chemically or by blowing air.
After drying, the chlorine gas is passed through a demister to remove sulfuric acid mist.
Then, it is got into a cooling and scrubbing column, where also liquid chlorine injection is used for cooling. The fluid goes to a 3-stage compressor and the heat of compression of each stage is removed by heat exchangers.

2.4. <u>Design of alternatives</u>

The design of the storage area of *Chlorite* has been done considering a chlorine storage tank (T-101), a centrifugal pump to impulse the fluid (P-101A/B), two heat exchangers to refrigerate the tank in case of overheating (E-102 and E-103) and a system to treat the chlorine feed in case of leak. This system is compound by an absorption column (C-101), a sodium hydroxide storage tank (T-102), a centrifugal pump (P-103A/B) and a heat exchanger (E-104) to refrigerate the absorption column. The main product, chlorine, is sent to sell by two ways. On one hand, it can be transported by a road tanker, which occasionally works, and on the other hand, chlorine can be send by pipe network.

As an alternative of this design, some of these systems can be replaced by others. This section includes the explanation of these alternatives, which are design alternatives and safety alternatives in case of a release of the product, in order to minimize the possible accidents occurred and its consequences in the chlorine storage area.

Section 6 includes the efficiency study of the mitigation measures and section 10 includes the economic study of some of these alternatives in order to determine which ones would be more profitable.

2.4.1. Design alternatives

Referring to the refrigeration system of the storage tank T-101, there are three alternatives that can be implemented.

- <u>1st alternative</u>: Installation of two heat exchangers (E-102 and E-103)

  This is the option installed in the establishment. It consists of two tube and shell exchangers that refrigerate the chlorine coming from the tank T-101. Both exchangers work together; the first one (E-102) directly refrigerates the liquid chlorine, which is inside the tubs and is refrigerated by carbon tetrachloride in the shell. Since the hot product in the exchanger is chlorine, it is not possible to have water as cooler because in case of little leak in the equipment, there would be hydrochloric acid formation and all installation would be destroyed by corrosion, releasing toxic substances and damaging population.

  The second heat exchanger (E-103) consists of the water going inside the tubs as the cooling product in order to refrigerate the carbon tetrachloride heated in the first exchanger.

With this system, chlorine is not in contact with water, which makes more secure the refrigeration system of the tank T-101. To have more details, P&ID diagram can be viewed at diagram 6 (section 4.1)

- 2nd alternative: Double tube in a tube and shell exchanger.

  This option consists of the design of one tube and shell exchanger which is provided with a double tub system. In the inside tubes there would be chlorine, while the outside tubes would contain carbon tetrachloride. Finally, the shell of the exchanger would contain water to refrigerate the carbon tetrachloride, which would refrigerate the chlorine. In this way, chlorine would be insulated of water by this third product.

  Despite the fact this is a good option due to its characteristics (simply construction, easy maintenance, high pressure applications), this alternative has been dismissed because in case of a failure in the chlorine tube, it would be more difficult to detect than if it happens in the system formed by two tube and shell exchangers, which means that the consequences would be worst and more dangerous.

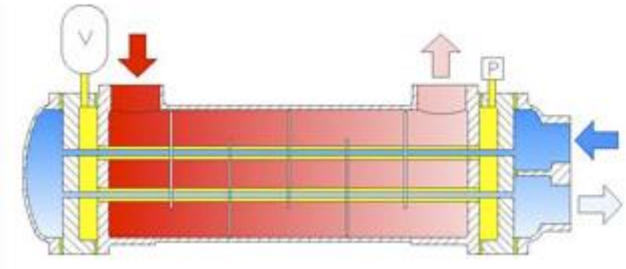


Figure 2.4.1. Double tube in a tube and shell exchanger (ref. 2)

- 3rd alternative: Installation of an industrial air cooler.

  This is a good alternative for the heat exchangers due to the fact that it does not contain any other substance, which completely avoids any corrosion risk caused by the hydrochloric acid formation.

2.4.2. Safety alternatives

To contemplate alternatives related to safety, it is important to take into account the lethal dispersion that could be caused in case of product release. For this reason, to reduce the distance that the toxic dispersion could reach, it is necessary to reduce the substance released to the environment in case of failure of the tank.

This section includes the analysis of different alternatives of the chlorine storage area, in order to determine which one could cause less damage to the environment and population in case of chlorine release from the tank T-101.

- 1st alternative: Installation of one tank of 82 m^3 (T-101)

  This is the system installed in *Chlorite* and consists of an only storage tank of 82 m^3 of capacity with a filled level of 90 %. This tank is designed to be able to storage the chlorine produced in the process area before it is send to sell.

  Section 10 shows this economic study of this alternative in order to determine if it is profitable.

- 2nd alternative: Replacement of the 82 m^3 tank by two tanks with less capacity (41 m^3)

  According to safety, this design offers a reduction of lethal dispersion in case of rupture of the tank because the quantity stored is fewer.

  It has not been considered the option of divide the initial tank (82 m^3) in more than 2 tanks because the installation, maintenance and loading and unloading operation costs would be excessive.

  Section 6 shows this study related to the lethal dispersion in case of release and section 10 contains the economic study.

- 3rd alternative: Underground storage tank.

  Underground tanks are more secure than aboveground because in case of release the substance would be hold in the grave where the tank is located, which would avoid its dispersion to the outside because the evaporation of the substance would be less. Moreover, it is an economical option due to the fact that it presents low maintenance costs.

  According to legislation ITC MIE APQ-3 “Almacenamiento de cloro” (ref. 3), it is not possible to storage chlorine in underground tanks, so this alternative is dismissed.

- 4th alternative: Double-wall tank of the same capacity (82 m^3)

  Replacement of the ordinary tank by a double-wall tank of the same capacity reduces the probability of accident since, if the first wall have a leak, the chlorine released will be retained into the second wall.

  The economic viability of this option is studied in section 10.

- 5th alternative: Installation of a dome that covers the storage tank T-101.

  The installation of a dome covering the tank is an option that makes an increase in the safety of the area due to the fact that, in case of release, the substance would stay inside the dome, which would avoid its dispersion to the outside.

  It is necessary to take into account that pressure inside the dome has to be less than atmospheric pressure in order to maintain the leak inside the dome in case of release.

- 6th alternative: Installation of a *Faltenbag* in the tank.

This kind of measure could be installed as an alternative of the absorption system, which would work in case of an overpressure in the tank. Instead of sending the gas to the absorption column, it would be stored in the balloon, which would be installed in the outlet of the pressure relief valve.

This alternative has not been applied due to the huge quantity of chlorine gas that it would have to store, as can be seen in the design of the absorption column, on section 4.

- 7th alternative: Plantation of trees around the storage area.

  The storage area of *Chlorite* is wrapped with tall and leafy trees because this mitigation measure helps to reduce the dispersion of the toxic cloud formed after the release from any equipment of the area.

- 8th alternative: Installation of water curtains in all the equipment.

  All the equipment of the storage area that involves chlorine have installed deluge water systems, which consist of water curtains that create provisional protective barriers to protect people near there in case of release.

  This installation provide a high safety level because this measure is very effective, as can be seen in section 6, where a study of the water curtains installation have been done. This study is done in order to analyze the effect of water curtains comparing the lethal dispersion distances obtained when several accidents take place in the storage area.

- 9th alternative: Installation of bund around the tank.

  A bund consists of a contained horizontal area around a tank for the purpose of limiting the spread of a pool of liquid. By installing the bund, the lethal dispersion effect would be reduced due to the accumulation of the liquid and, moreover, to the high walls of the bund, as it is explained in section 5.1.6.

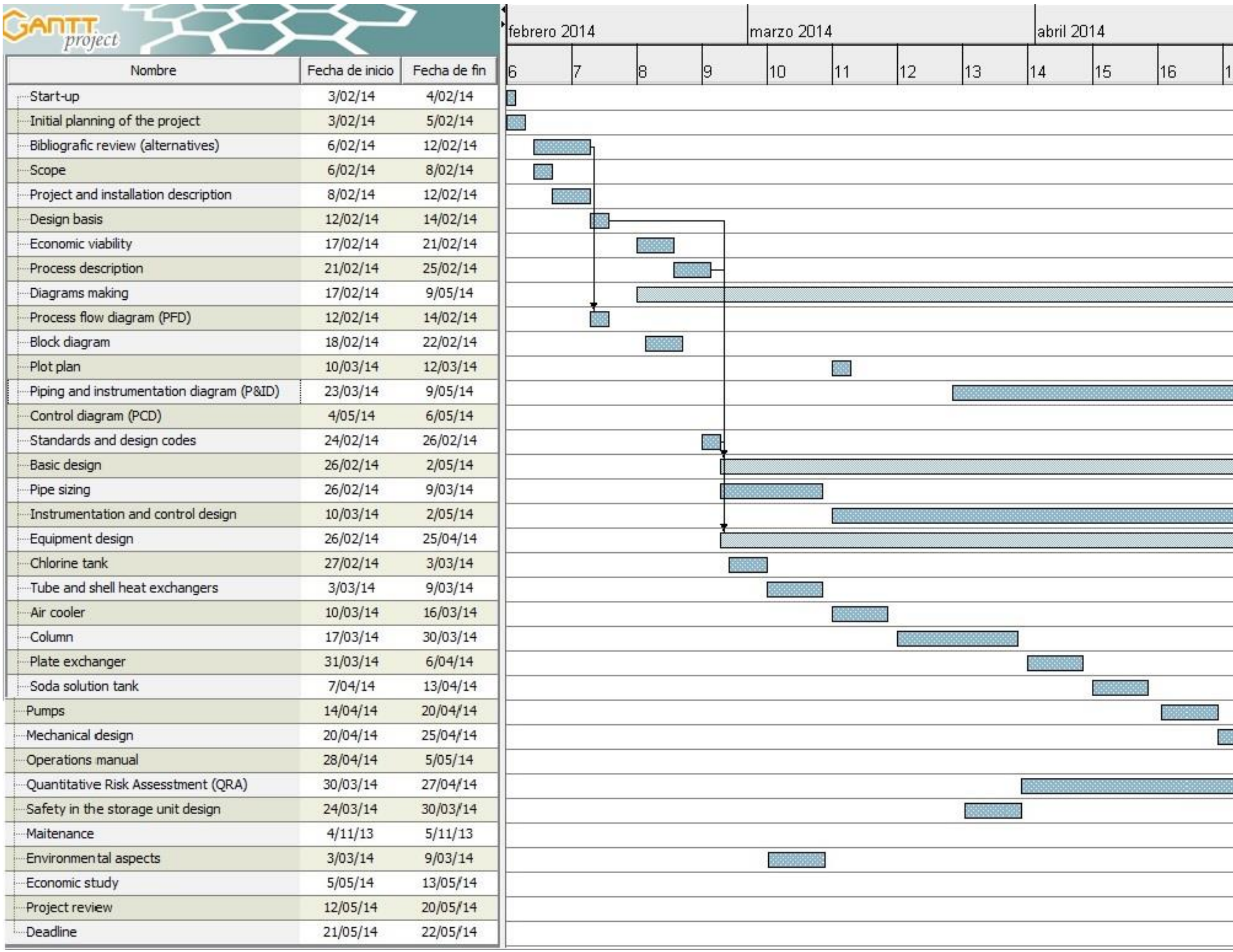
  The effectiveness of this mitigation measure is analyzed in section 6, where a comparison of the distances obtained applying and not applying the bunds is done.

- 10th alternative: Installation of switch valves.

  Possible accidents related with very large pipes are extremely dangerous due to the fact that all product contained over the entire length of pipe would be released. In order to reduce product release, several switch valves could be installed in the largest pipes every 20 meters, approximately.

2.5. Initial planning of the project

Following the Gantt diagram is shown, which includes the initial planning of the project.



Nombre	Fecha de inicio	Fecha de fin
Start-up	3/02/14	4/02/14
Initial planning of the project	3/02/14	5/02/14
Bibliografic review (alternatives)	6/02/14	12/02/14
Scope	6/02/14	8/02/14
Project and installation description	8/02/14	12/02/14
Design basis	12/02/14	14/02/14
Economic viability	17/02/14	21/02/14
Process description	21/02/14	25/02/14
Diagrams making	17/02/14	9/05/14
Process flow diagram (PFD)	12/02/14	14/02/14
Block diagram	18/02/14	22/02/14
Plot plan	10/03/14	12/03/14
Piping and instrumentation diagram (P&ID)	23/03/14	9/05/14
Control diagram (PCD)	4/05/14	6/05/14
Standards and design codes	24/02/14	26/02/14
Basic design	26/02/14	2/05/14
Pipe sizing	26/02/14	9/03/14
Instrumentation and control design	10/03/14	2/05/14
Equipment design	26/02/14	25/04/14
Chlorine tank	27/02/14	3/03/14
Tube and shell heat exchangers	3/03/14	9/03/14
Air cooler	10/03/14	16/03/14
Column	17/03/14	30/03/14
Plate exchanger	31/03/14	6/04/14
Soda solution tank	7/04/14	13/04/14
Pumps	14/04/14	20/04/14
Mechanical design	20/04/14	25/04/14
Operations manual	28/04/14	5/05/14
Quantitative Risk Assesstment (QRA)	30/03/14	27/04/14
Safety in the storage unit design	24/03/14	30/03/14
Maitenance	4/11/13	5/11/13
Environmental aspects	3/03/14	9/03/14
Economic study	5/05/14	13/05/14
Project review	12/05/14	20/05/14
Deadline	21/05/14	22/05/14

3. BASIS FOR THE DEVELOPMENT OF THE PROJECT

3.1. Design basis

In this section the parameters set by the customer are described in advance. These parameters have been used in the design of the storage unit.

3.1.1. Supply specifications

The supply of the storage unit, coming from *Chlorite* plant, is a pure chlorine flow of 21,5 m^3/h.

Table 3.1.1. Chlorine supply specification.

Parameter	Value
Flow [m^3/h]	21,5
Temperature [ºC]	15,0
Pressure [barg]	4,88
Chlorine purity [%]	100

3.1.2. Capacity, Operational Flexibility and Service Factor

The capacity and the operational flexibility of the unit have been fixed depending on the chlorine demand. In order to make sure that all costumers get their required products, chlorine gas is liquefied and stored in one tank of 82m^3.

Chlorine is supplied to nearby plants and external customers. The supply can be done by pipe rack or by 35 m^3 road tankers. The service factor is 8.760 h/year.

3.1.3. Products' specification

In order to test the quality of the *Chlorite* industry, it is essential to ensure that the product supplied to costumers meet the stipulated requirements. Find the main specifications in the following table.

Table 3.1.2. Outlet product specification.

Parameter	Value
Flow [m^3/h]	21,5
Temperature [ºC]	15,0
Pressure [barg]	4,88
Chlorine purity [%]	100

3.1.4. Terms of raw materials and products in the BL

Raw materials and products conditions in the designed chlorine storage area are specified in the above tables 3.1.1 and 3.1.2.

3.1.5. Design standards to be applied

In order to design the chlorine tank, instructions from ITC MIE APQ-3 (ref. 3) have been followed.

3.2. Basic information for the development of engineering

3.2.1. Available utilities

The utilities available at the chlorine storage area are: water, nitrogen and air. Electricity is used to supply pumps motors and illumination.

3.2.1.1. Electric energy: Tension levels and uses

The energy administered to the plant will be a three-phase one, have a voltage of 6.000 V, 609 V and 380 V, and a frequency of 50 Hz. The mains supply will be of 2.500 V and it will be basically used for the pumps' supply and illumination.

Table 3.2.1. Electricity specification.

Service	Power (kW)	Voltage (V)	Phases
Pump motor	45 >45 & <400 4000	400 690 6000	3
Illumination	-	230	1
Instrumentation	-	24 DC 230 AC	1

3.2.1.2. Water: type, uses and quality

The water used for cooling the shell and tube heat exchanger E-102 and the plate heat exchanger E-104 comes from the cooling tower. This water is also used for cooling the double seal of the pumps.

Table 3.2.2. Water specification.

Inlet temperature [ºC]	Outlet temperature [ºC]	Design temperature [ºC]	Operation pressure [bar]	Design pressure [bar]	Pressure drop [bar]
27	37	80	5,0	8,0	0,7

Moreover, water supplied by AITASA, a company set in Tarragona, will be used for cleaning equipment.

3.2.1.3. Air: Specifications and applications

Air used in the installations, which will be used for the instrumentation, will have the following characteristics:

Table 3.2.3. Air specifications.

Inlet temperature [ºC]	Dew temperature [ºC]	Operation pressure [bar]
20	-40	5,0

To ensure the air supply to instrumentation in case of failure of the air pipe, the system is provided with an emergency tank air.

3.2.1.4. Nitrogen: Specifications and applications.

The required nitrogen is used as an inert gas for depressurizing and blanketing the chloride storage tank and the tanker truck that will deliver the product to the client.

Table 3.2.4. Nitrogen specifications.

Temperature [ºC]	Design temp. [ºC]	Pressure [bar]	Design pressure [bar]
20	50	12	15

3.2.2. Energy prices

In the following table, it appears the utilities price used in the chlorine storage unit.

Table 3.2.5. Energy prices.

Utility	Price
Industrial water [€/m^3]	1,97
Demineralized water [€/m^3]	23,7
Compressed air [€/1.000m^3]	12,23
Electricity [€/1.000Keh]	81,16
Nitrogen [€/1.000m^3]	54,40

3.2.3. Location

Chlorite industry is located in Tarragona's region, specifically in the industrial state "Polígon Industrial Gran Indústria de Tarragona".

Territory, demography and climate of the area are listed below, which are essential for the analysis of the damage that an accident with a chlorine tank could generate.

3.2.3.1. Description of the area

As it has been mentioned, *Chlorite* is set in "Polígon Industrial Gran Indústria de Tarragona", and takes up approximately to 5.000 m^2.

The strategic location offers a developed road network in order to provide the industry with cheaper, decent and close connections with airports, train stations and seaports. In this way, *Chlorite* not only has facilities to successfully take products to their costumers but it might also provide other industries with raw materials easily.

Moreover, the vast majority of enterprises located in Tarragona Industrial State form part of AEQT (Chemical Business Association of Tarragona), association whose aim is to promote chemical safety and to enhance competitiveness between all industries.

Another important benefit with location is the proximity of two important enterprises which are involved in the storage and transport of products. In this way *Chlorite* could minimize its movements of toxic products, diminishing the dangerous related with logistic activities.

Figure 3.2.1. Specific location of *Chlorite*.

3.2.3.2 Territory structure

To be able to evaluate and assess the risk produced by an undesired situation related to the chlorine tank, it is necessary to have a clear idea about the urban centres which could result affected by this dangerous situation.

In order to evaluate the risk in each town and the neighboring towns, next table shows the distance between these places and the origin point of the accident.

Table 3.2.6. Distance from *Chlorite* emplacement and neighboring towns affected.

Town	**Distance from *Chlorite* [m]**
La Canonja	600
Bonavista	900
Camp Clar	1.900
Torreforta	2.700
Vila-seca	2.700
Tarragona	5.100

There also have to be taken into account the industrial relevant establishments near *Chlorite*, such as REPSOL PETRÓLEO, BASF, SHELL, IQA, DOW BAYER, BASELL POLIOLEOFINAS I and CELANESE, which could also be affected by an incident occurred in *Chlorite*.

Finally, the highway Tarragona – Salou, Barcelona’s road and two railways which connect Tarragona to Valencia and Lleida constitute four lines which are usually busy. In case of an emergency situation it could be necessary to regulate their traffic (even block it) in order to ensure drivers’ safety.

3.2.3.3 Climatic, rain gauge and seismology

In general terms, the climate of Catalonia is characterized by the Mediterranean influence which results in irregular seasonal rainfall. Wet winters characterized by mild temperatures are typical in coastal areas; however, summers are usually very hot and dry.

Nevertheless, Catalonia is divided into different climatic zones with slight variations between them, specifically, Tarragona belongs to South Mediterranean influence.

The nearest meteorological station to *Chlorite* is “Tarragona – Complex Educatiu”, which belongs to the Tarragones region. The specific coordinates of the meteorological site are 349.027, 4.552.053 and it is located 10 m above sea level.

The following data have been obtained from the website of the DEMO study IQS:

Table 3.2.7. Meteorological data from Tarragona.

Meteorological parameter	Value
Average temperature [ºC]	17,4
Average temperature of the land [ºC]	17,4
Relative humidity [%]	76,0
Wind speed [m/s]	4,05D & 1,46F
Prevailing direction of the wind	West (D) & North (F)
Type of land	-
Roughness [cm]	10,0

Thanks to these data the climate of the municipality could be characterized by mild temperatures which range between 12,4 ºC and 21,4 ºC, being the average temperature 17,4ºC. Finally, the average annual rainfall in Tarragona is between 500 and 550 mm. See figure 3.2.2.

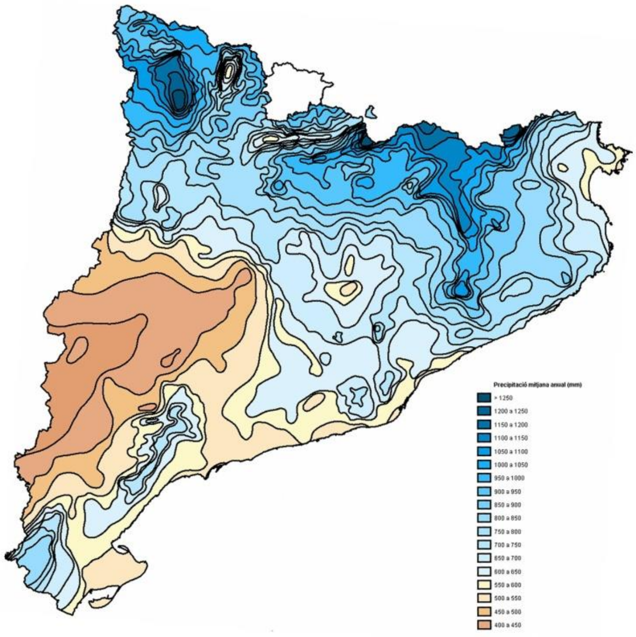


Figure 3.2.2. Average annual precipitation (mm) in Catalonia.

This territory does not have any kind of seismic movements which could damage the installation, as it is shown in figure 3.2.3.

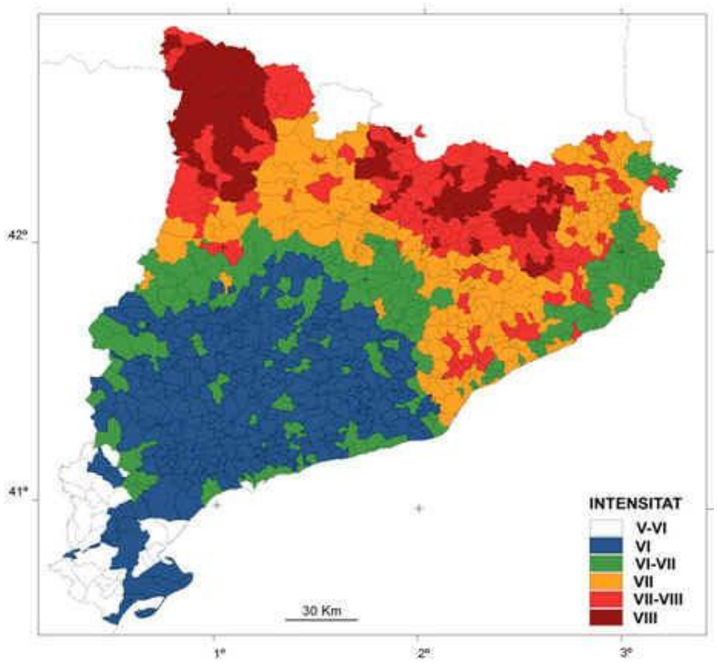


Figure 3.2.3. Seismic zones in Catalonia.

3.2.3.4 Structure and elevation of land

The location corresponds to a flat territory over 70 m of sea level.

3.2.4. Standards and design codes

In order to obtain a proper design of the equipment required, the design codes which have been used are exposed on table 3.2.8.

Table 3.2.8. Codes used for each equipment design.

Item	Code
Chlorine storage (T-101)	ASME Section VIII division 1; ITC MIE APQ-3 "Alamacenamiento de cloro"
Pumps (P-101A/B, P-102, P-103)	DIN25256; ISO2858
Heat exchanger (E-102, E-103)	TEMA; ASME Section VIII División 1
Absorption column (C-101)	ASME Section VIII División 1
Soda storage (T-102)	ASME Section VIII División 1
Air cooler	API 661
Piping	ASME B31.3
Plate heat exchanger (E-104)	API 662
Pressure relieve valves (PSV)	API RP 520, API RP 521
Rupture disk (RD)	ASME section VIII
Control valves	Document "Manual de Cálculo de válvulas de Control. Masoneilan"

4. DEVELOPMENT OF THE BASIC ENGINEERING

4.1. Diagrams

4.1.1. Contextualization of storage unit

As it has been mentioned, the required storage unit will be implemented, as a possible future investment, in an existing chemical industry. Taking into account that the storage unit will be used for the storage of the final product of *Chlorite* industry, it is important to get a general idea about the process used. For this reason, the following diagrams have been performed:

- Block diagram of chlorine of process of chlorine obtantion.
- Process flow diagram (chlorine obtantion)

The remaining diagrams have been performed only including the chlorine storage unit.

4.1.2. Process flow diagram (PFD)

4.1.3. Control diagram (PCD)

4.1.4. Plot plan

4.1.5. Piping and instrumentation diagram (P&ID)

Piping and instrumentation diagram includes not only the control of the storage unit, but also all protective systems as rupture disks or pressure relief valves, strategically installed to protect pressure equipment.

Moreover, in order to facilitate maintenance and reparation operations of all the equipment many gate valves, have been installed. In this way, the equipment would be disconnected and taken out of the pipe if necessary. Drainage systems have also been situated where it is required. Finally, each pump have a check valve situated in its impulsion to avoid liquid hammering and cavitation.

Identification code for pipes follows the next pattern:

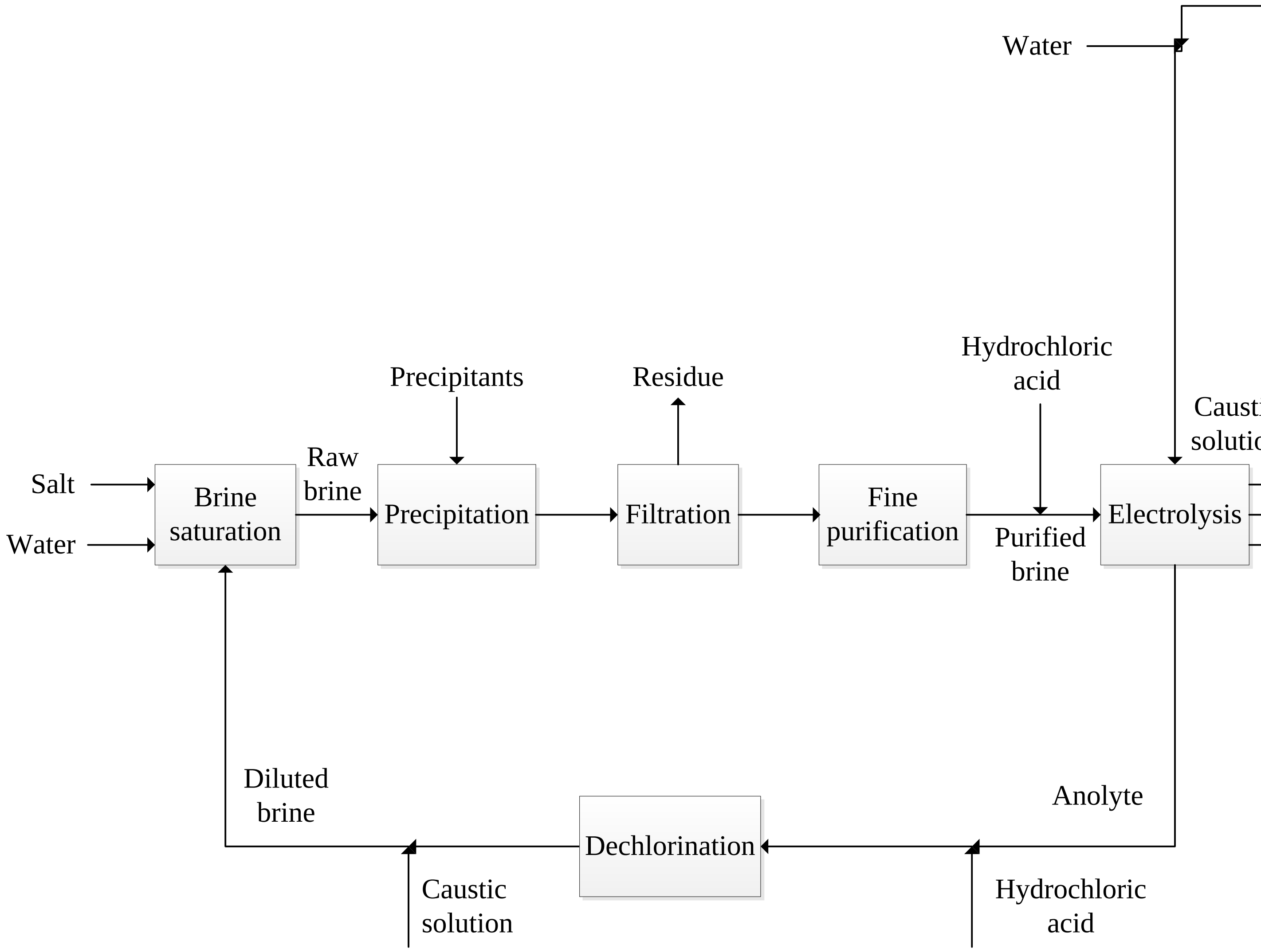
DN" – Material – Product – Pipe number.

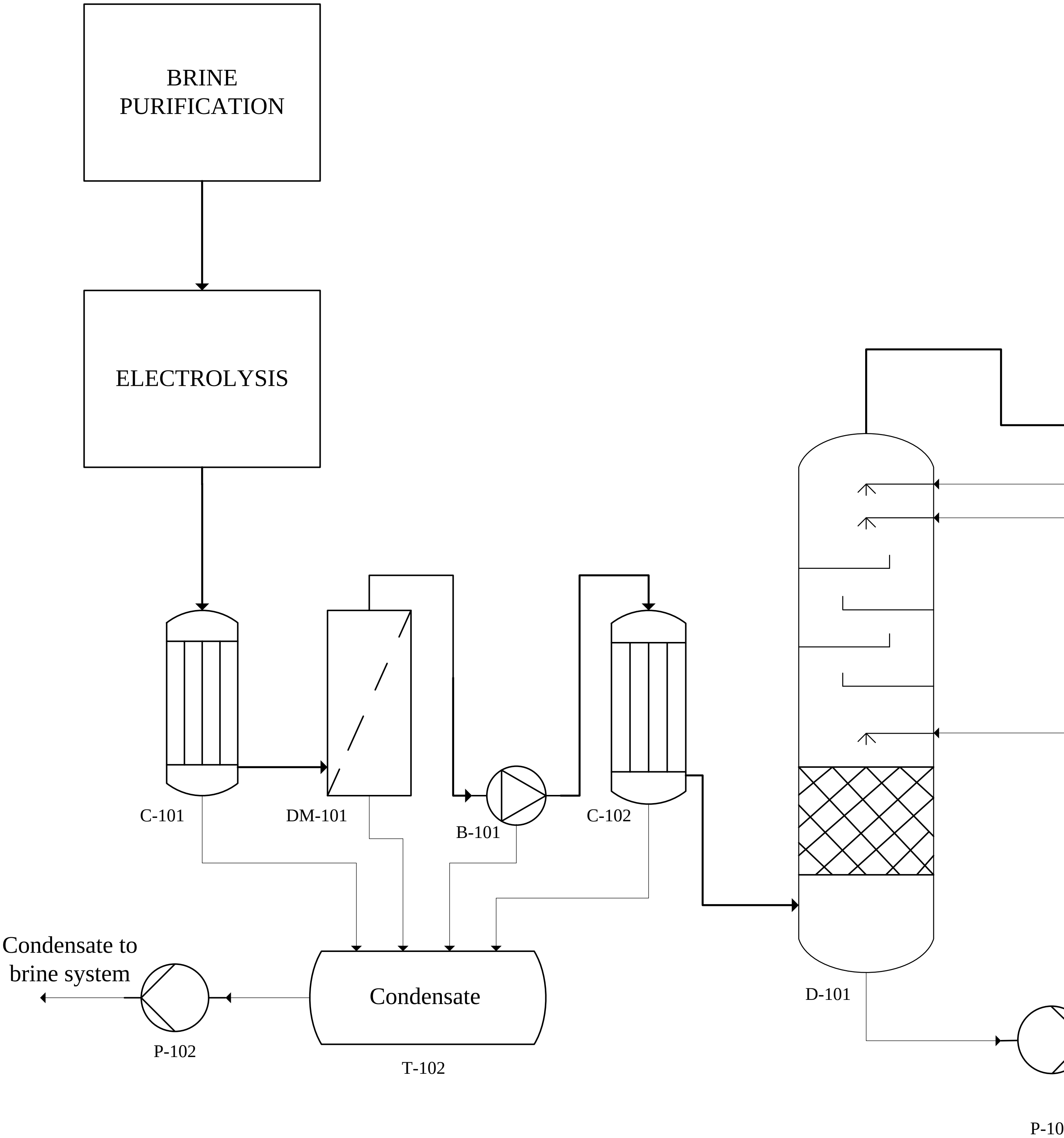
Where:

CS	ASTM A-516 Grade 70
FG	Reinforced fiberglass polyester

4.1.6. Isometric sketch

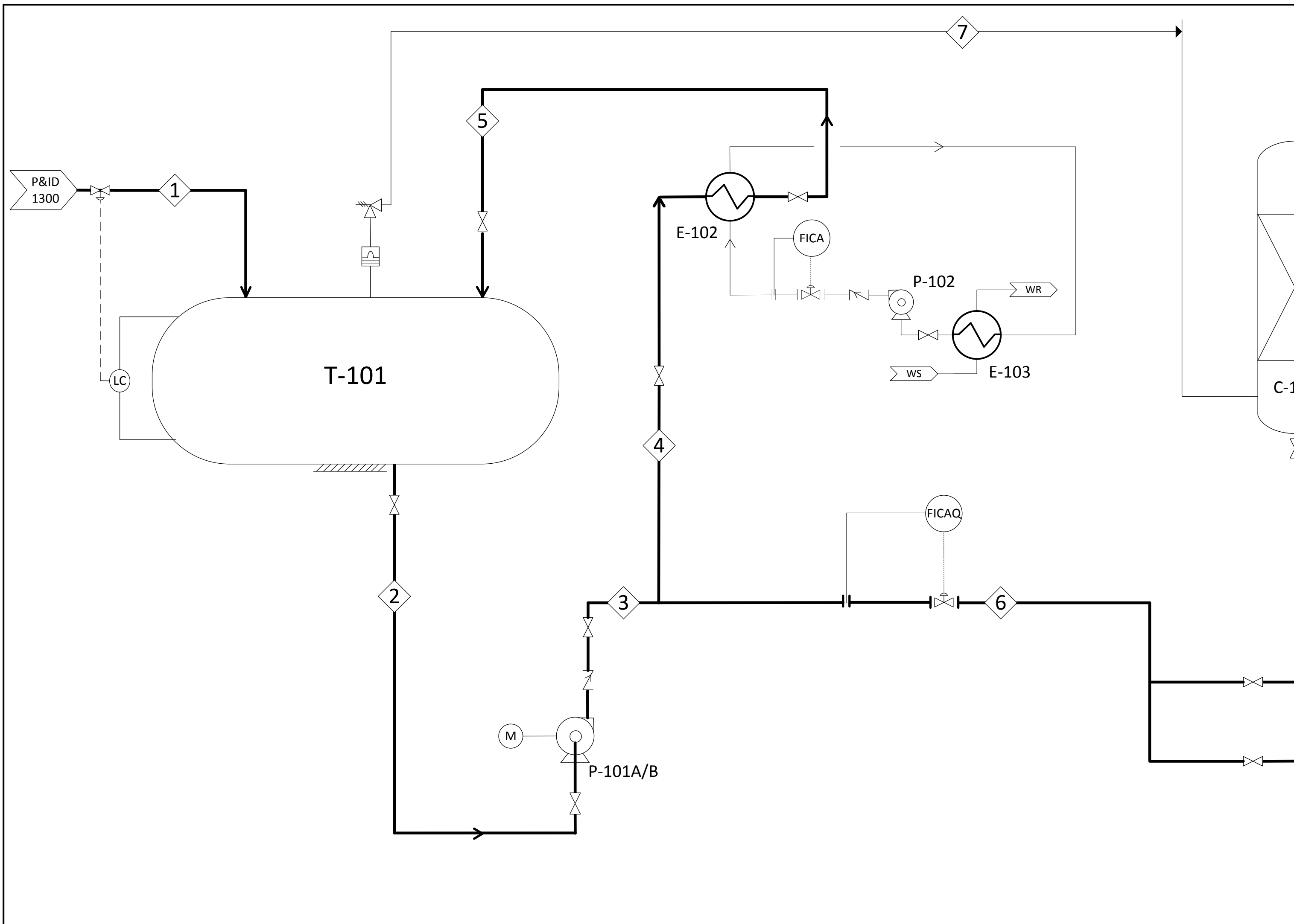
The Isometric sketch done corresponds to the pipes that connect pump P-101A/B, (3”-CS-Cl_2-3 and 3”-CS-Cl_2-3a) and heat exchanger E-102 (11/4”-CS-Cl_2-4)


Water
Hydrochloric acid
Precipitants
Residue
Salt
Water
Brine saturation
Raw brine
Precipitation
Filtration
Fine purification
Purified brine
Electrolysis
Diluted brine
Dechlorination
Anolyte
Caustic solution
Hydrochloric acid



C	Cooler
DM	Demister
B	Blower
T	Tank
P	Pump
D	Dryer
S	Separator
CSC	Cooling and Scrubbing Column
CM	Compressor
L	Liquefier
V	Vessel

NOTES:
(1) Scope of the project



Flow number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Temperature [ºC]	15	15	15	15	15	15	20	72	60	60	42	30	20	60
Pressure [bar]	5,8	5,8	5,8	5,8	5,8	5,8	1	1	1	2	1	1	1	1
Mass flow [t/h]	31	36	36	5,7	5,7	36	7,9	52	43	43	43	$7{,}7\cdot10^{-5}$	72	36
Chlorine, wt%	100	100	100	100	100	100	100	0,00	0,00	0,00	0,00	1,00	0,00	0,00
Water, wt%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	94,8	80,0	80,0	80,0	0,00	80,0	50,00
Caustic soda, wt%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	20,0	20,0	20,0	0,00	20,00	30,00
NaClO, wt%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,59	0,00	0,00	0,00	0,00	0,00	11,00
NaCl, wt%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,59	0,00	0,00	0,00	0,00	0,00	9,00
Air, wt%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	99,00	0,00	0,00

	DATE	NAME
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CHECKED	2014	Ana G.
APPROVED	2014	Cristina N.
SCALE		

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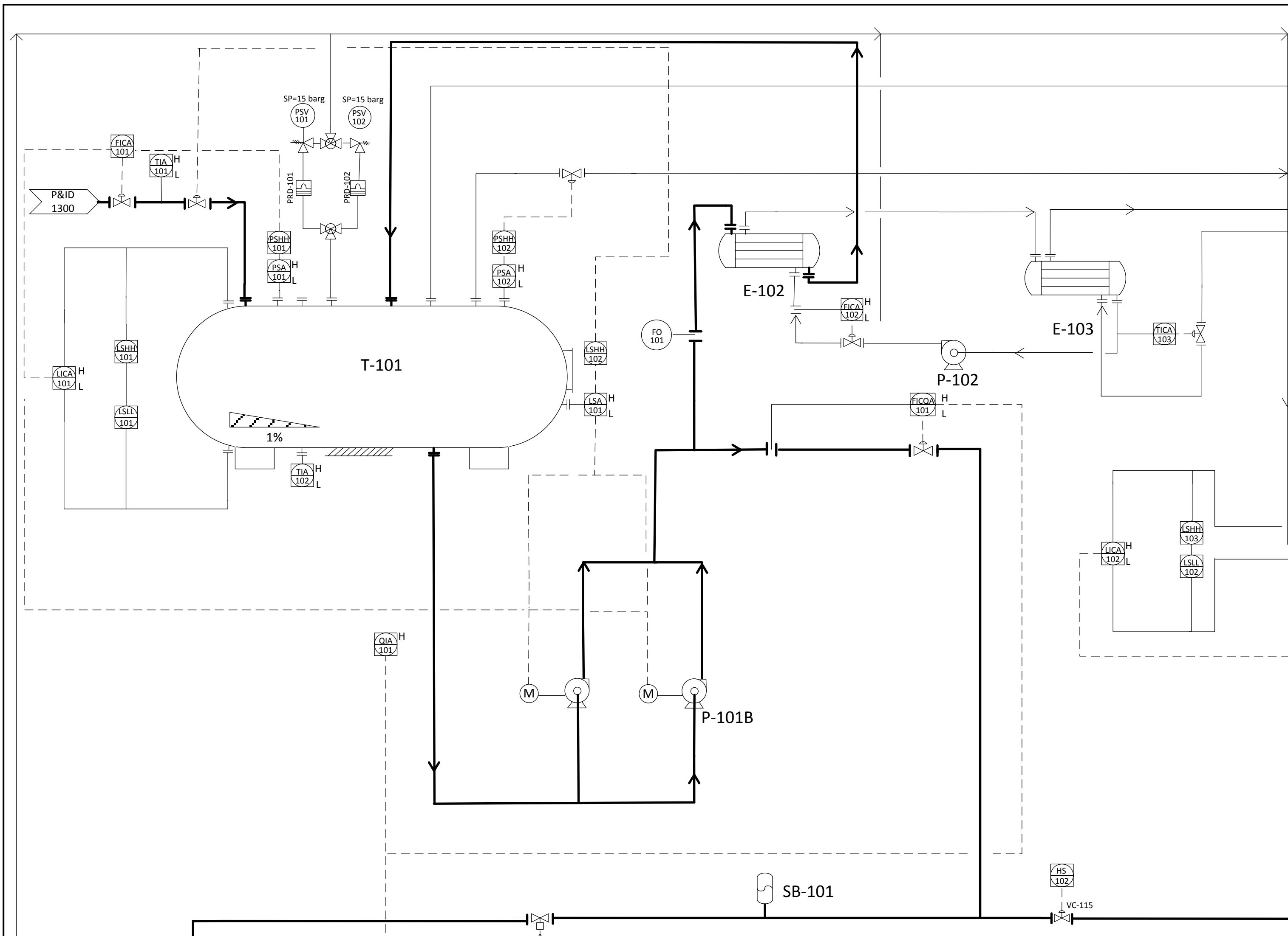

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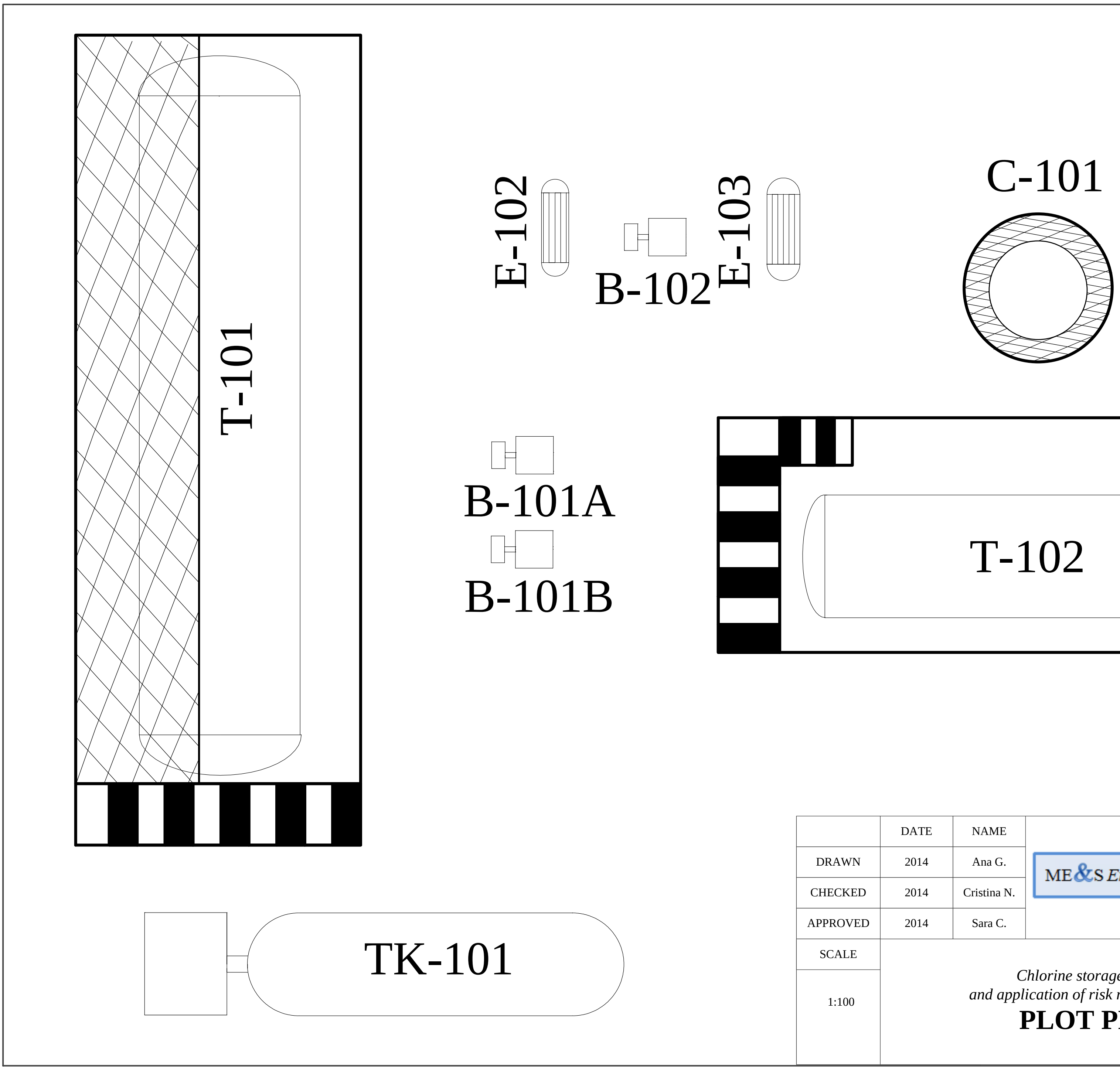

T-101
E-102
B-102
E-103
C-101
B-101A
B-101B
T-102
TK-101
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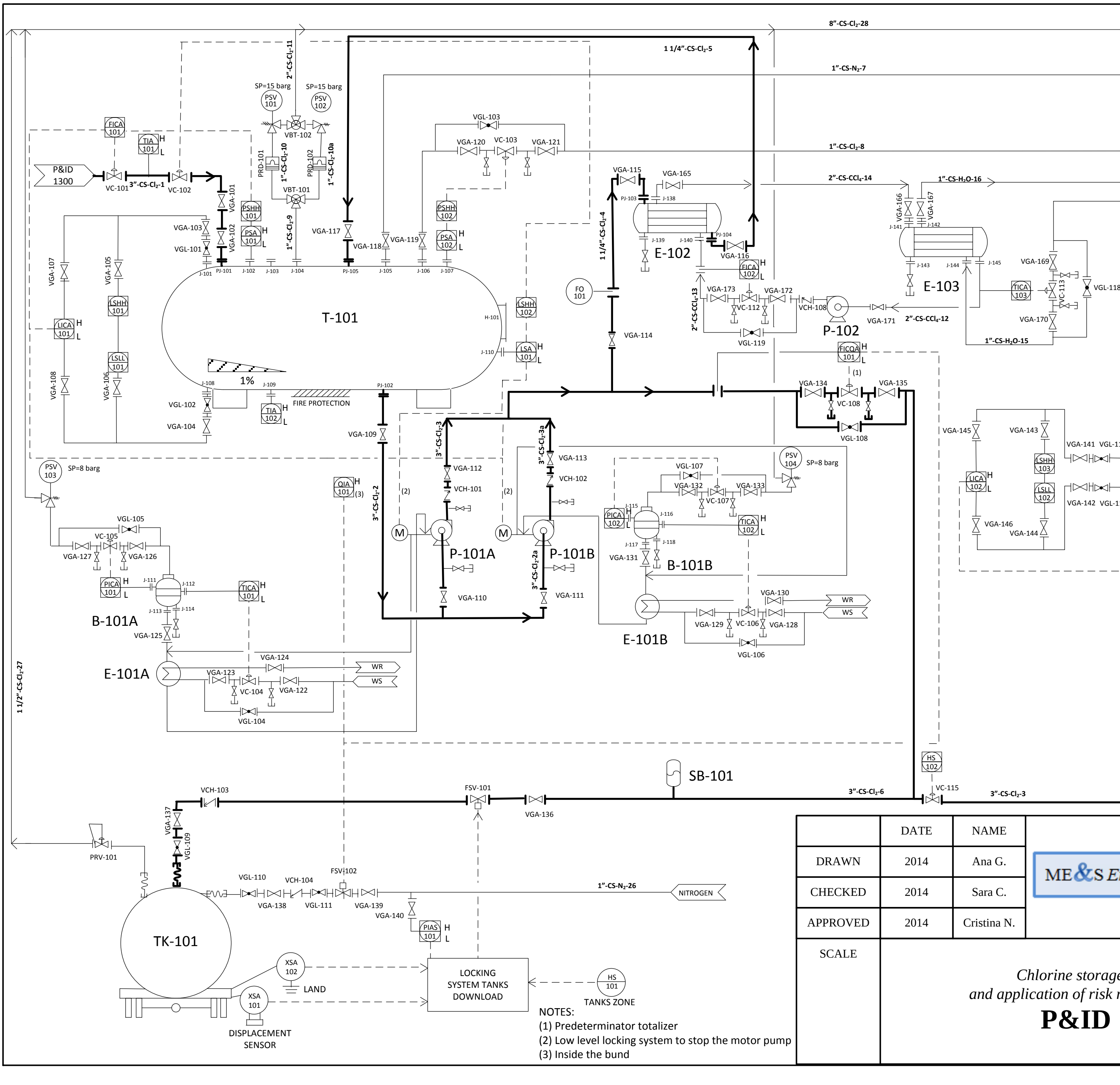
Chlorine storage
and application of risk
PLOT P



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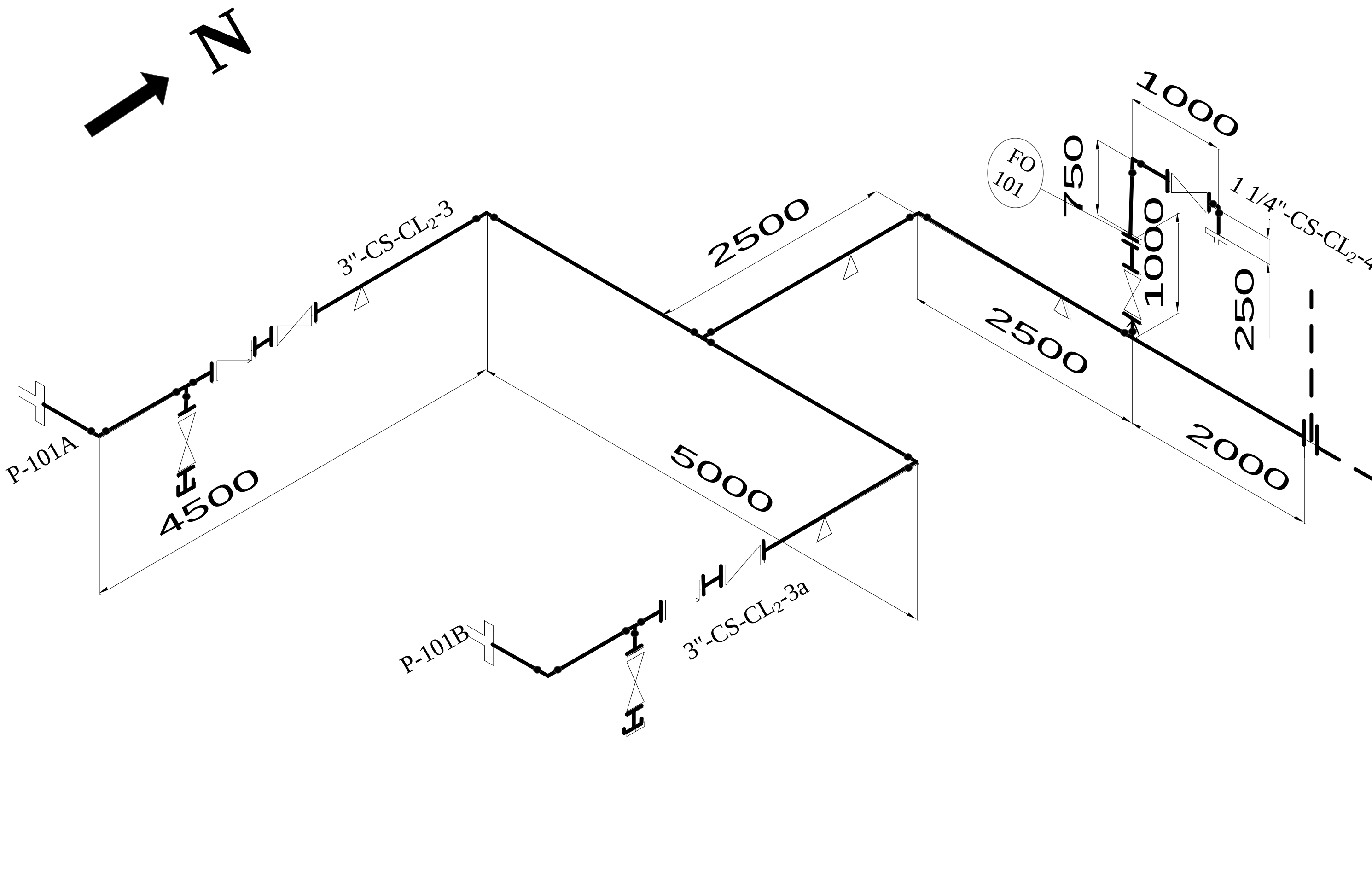

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APPROVED	2014	Sara C.
SCALE		

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ISOMETIC

4.2. <u>Basic design</u>

4.2.1. Pipe sizing

The design of pipes of the storage area consists in determining the nominal pipe size and friction head losses. All process pipes are made of carbon steel with Schedule 40 and have no insulation. Pipes which belong to absorption system are made of reinforced fiberglass polyester and are insulated with glass wool.

The complete explanation of the design procedure can be found at Annex A.1.1.

Table 4.2.1. Pipe specification.

Pipe	**DN**	**Sch**	**PIPES ENDS**		**OPERATING COND**	
			From	**To**	**Q [m^3/h]**	**T [ºC]**
3”-CS-Cl_2-1	3	40	Process	T-101	21,5	15
3”-CS-Cl_2-2	3	40	T-101	P-101A	25,5	15
3”-CS-Cl_2-2a	3	40	Pipe union 2	P-101B	25,5	15
3”-CS-Cl_2-3	3	40	P-101A	Chlorine rack	25,5	15
3”-CS-Cl_2-3a	3	40	P-101B	Pipe union 3	25,5	15
1 ¼”-CS-Cl_2-4	1 1/4	40	Pipe union 3	E-102	4,00	15
1 ¼”-CS-Cl_2-5	1 1/4	40	E-101	T-101	4,00	15
3”-CS-Cl_2-6	3	40	Pipe union 3	Road tanker	21,5	15
1"-CS-N_2-7	1	40	Nitrogen supply	T-101	15,0	20
1”-CS-Cl_2-8	1	40	T-101	Pipe 32	4,00	20
1”-CS-Cl_2-9	1	40	T-101	VBT-101	2.525	50
1”-CS-Cl_2-10	1	40	VBT-101	VBT-102	2.525	50
1”-CS-Cl_2-10a	1	40	VBT-101	VBT-102	2.525	50
2”-CS-Cl_2-11	2	40	VBT-102	Pipe union 32	2.525	20
2”-CS-CCl_4-12	2	40	E-103	P-102	9,46	38
2”-CS-CCl_4-13	2	40	P-102	E-102	9,46	38
2”-CS-CCl_4-14	2	40	E-102	E-103	9,51	42
1”-CS-H_2O-15	1	40	Refrigeration tower	E-103	0,44	27
1”-CS-H_2O-16	1	40	E-103	Refrigeration tower	0,44	35
4”-FG-NaOH-17	4	40	Absorption column	T-102	43,3	72
3 ½ ”-FG-NaOH-18	3 1/2	40	T-102	P-103A	35,5	60
3 ½ ”-FG-NaOH-18a	3 1/2	40	Pipe union 18	P-103B	35,5	60
3 ½ ”-FG-NaOH-19	3 1/2	40	P-103A	E-104	35,5	60
3 ½ ”-FG-NaOH-19a	3 1/2	40	P-103B	Pipe union 19	35,5	60

Pipe	DN	Sch	PIPES ENDS		OPERATING COND	
			From	To	Q [m^3/h]	T [ºC]
5"-CS-H_2O-20	5	40	Refrigeration tower	E-104	78,1	27
5"-CS-H_2O-21	5	40	E-104	Refrigeration tower	78,3	37
3 ½"-FG-NaOH-22	3 1/2	40	E-104	Absorption column	35,5	42
1"-CS-Air-23	1	40	Absorption column	Atmosphere	0,01	30
5"-FG-NaOH-24	5	40	Caustic soda supply	T-102	60,0	20
3 ½"-FG-NaOH-25	3 1/2	40	T-102	To sell	30,0	60
1"-CS-N_2-26	1	40	Nitrogen supply	Road tanker	15,0	20
1 ½"-CS-Cl_2-27	1	40	Road tanker	Pipe union 28	89,3	20
8"-CS-Cl_2-28	8	40	Pipe union 11	Absorption column	2.615	20
1"-CS-Air-29	1	40	Air supply	T-102	10,0	20
3"-FG-NaOH-30	3	40	T-102	Atmosphere	5.630	110

4.2.2. Instrumentation and control design

The control of the storage area is detailed below, including measuring, transmissions and controlling elements. All values of process parameters, proportioned by transmitters or controllers, are indicated in control room where they are registered.

4.2.2.1. Characterization of the control strategies

4.2.2.1.1. Storage chlorine tank T-101

- Level control

Level control is applied by the level controller LICA 101, which sends the signal to the control valve VC-101 which adjusts the flow. This cascade control loop has low and high level alarms and very low and very high level alarms (LSLL 101 and LSHH 101). In case of low level, LICA 101 will switch off power and insulate from mains voltage P-101A/B.

This tank also contains a high and low alarm (LSA 101) in case the main control loop fails. This system has an indicator level and high locking system (LSHH 102) that sends the signal to the control valve VC-102. In case of low level, LSA 101 will also switch off power and insulate from mains voltage P-101A/B.

- Pressure control

The main pressure control loop is PSA 101, which contains a high and low alarm and a locking system (PSHH 101) for very high pressure that acts on control valve VC-101.

There is another pressure controller in case of VC-101 failure. The second one contains a pressure switch alarm for high pressure (PSA 102). The pressure controller has a very high interlock system (PSHH 102) that relieve the chlorine to the absorption system by control valve VC-103.

In case of fire, tank has installed two rupture disks (PRD 101/102) followed by two pressure safety valves (PSV 101/102). One pair of safety elements (PRD and PSV) is on standby, while the other pair works by relieving the tank pressure sending the product to the absorption column C-101.

- Flow control

Flux controller FICA 101 works on selective conditions with LICA 101 and PSA 101, despite it usually works depending on the level control loop.

- Temperature control

In pipe 3”-CS-Cl_2-1 a temperature indicator alarm (TIA 101) is installed for high and low temperature in order to know the temperature of the inlet flows from the process area.

At the bottom of the tank T-101 a temperature indicator alarm for high and low temperature (TIA 102) is installed. When the temperature grows significantly, it sends a signal to the control room and the operator remotely activates the refrigeration system of the tank, which consists of two heat exchangers (E-102 and E-103)

- Composition control

A composition indicator alarm (QIA 101) is installed in the bund of the storage tank T-101 in order to activate the mitigation deluge system in case of toxic dispersion due to accidental leaks of chlorine. Moreover, in case of chlorine release, QIA 101 sends a signal to FICQA 101 and the controller closes immediately.

4.2.2.1.2. Pumps P-101A/B

As it has been mentioned, to ensure the pumps work correctly and in order to avoid cavitation, pumps motors are connected to the level regulator control alarm LICA 101, which in case of low level, will switch off power and insulate from mains voltage P-101A/B. In case the first loop fails, there is a secondary control system which acts by the same way using VC-102 from the low alarm (LSA 101)

Despite bottle are not included in the design scope, each pump has a temperature indicator controller (TICA 101/102), which is regulated by the control valve VC-104/106 (installed in refrigeration pipe of the heat exchanger of the pump) and a pressure indicator controller (PICA 101/102), which is regulated by the control valve VC-105/107. Pressure safety valves PSV 103/104 are installed in order to relieve the pressure in bottles in emergency situations, which sends the product to the absorption column C-101.

4.2.2.1.3. Heat exchangers E-102 and E-103

To maintain the desired temperature inside the chlorine tank there are two exchangers which refrigerate the recirculation (see 4.2.3 Exchangers design to more details)

The exchanger E-103 has a control loop to guarantee that the hot fluid (intermediate fluid between exchangers) gets the required temperature to refrigerate the process liquid in the first exchanger (E-102). The temperature of the 2”-CS-H_2O-15 flow is measured by the temperature indicator controller (TICA 103) and the refrigerating flow is regulated by VC-113 valve. If the temperature of the intermediate liquid goes up, the valve will increase its opening degree to introduce more refrigerating fluid.

Moreover, it is necessary to control the inlet of intermediate fluid flow at E-102, which is acting as refrigerating fluid in this exchanger. For this reason, there is a feedback control between two exchangers (after pump P-102). The real flow is measured in the orifice plate by FICA 102, which contains high and low level alarms and acts on the control valve VC-112.

Finally, the recirculation process pipe has a restriction plate (FO 101) before the exchanger E-102 to secure a minimum recirculation to the tank; specifically, the plate allows a 4 m^3/h flow.

4.2.2.1.4. Absorption column C-101

To control the liquid level on the absorption column there is a level controller (LICA 102), that sends the signal to the control valve VC-109, which is installed in the outlet pipe of the absorption column. This valve will increase or decrease its opening degree depending on the signal sent by LICA 102 (cascade control). This control loop has low and high level alarms (LSLL 102) and very low and very high level alarms (LSHH 103)

To regulate the flow of caustic soda that enters the absorption column, the real flow is measured in the orifice plate by FICA 104 which acts on the control valve VC-111.

A high composition indicator alarm QIA 102 is installed at the top of the absorption column, which indicates the chlorine composition released to the atmosphere.

4.2.2.1.5. Tank T-102

Caustic soda tank contains a level switch alarm (LSA 102) that has a locking system for very high liquid level (LSHH 104), which regulates the inlet flow of soda by pipe 5”-FG-NaOH-24 using the control valve VC-114.

In case of fire, pressure safety valve (PSV 105) has been installed in order to relive the tank containment to the atmosphere.

4.2.2.1.6. Plate heat exchanger E-104

The refrigeration system of this heat exchanger is regulated by the control valve VC-110, which works according to the temperature of the indicator controller (TICA 104). TICA 104 measures the temperature of the outlet caustic soda flow and sends the signal to the valve. If the temperature of the intermediate liquid goes up, the valve will increase its opening degree to introduce more refrigerating fluid.

This indicator controller has a high alarm system which is installed in order to prevent chlorine bad absorption.

4.2.2.1.7. Road tanker

Nitrogen inlet to road tanker (TK-101) has a high and low pressure alarm (PIAS 101) which acts on the emergency blocking system.

In case of QIA 101 detects toxic atmosphere, due to a leak in the storage area, while loading operation, a locking system will open nitrogen inlet in the tanker and will also close chlorine supply. This system is activated by a high composition indicator alarm (QIA 101) located in the bund of the storage tank T-101, it also will send the signal to FICQA 101 and the controller will close the valve VC-108 immediately.

4.2.2.1.8. Pipe 3”-CS-Cl_2-3

Chlorine supply to costumers by rack is done by a control valve VC-115, remotely acted by hand switcher HS 102.

4.2.2.2. Instrumentation and control design

Chlorite industry uses a distributed control system (DCS) hardware to perform the site control. New chlorine storage unit will be added to the same control system.

DCS is a kind of control system where the elements are not specifically located, but are distributed throughout the system with each component or sub-system controlled by one or more controllers. All components of the system are connected through networking, communication and monitoring.

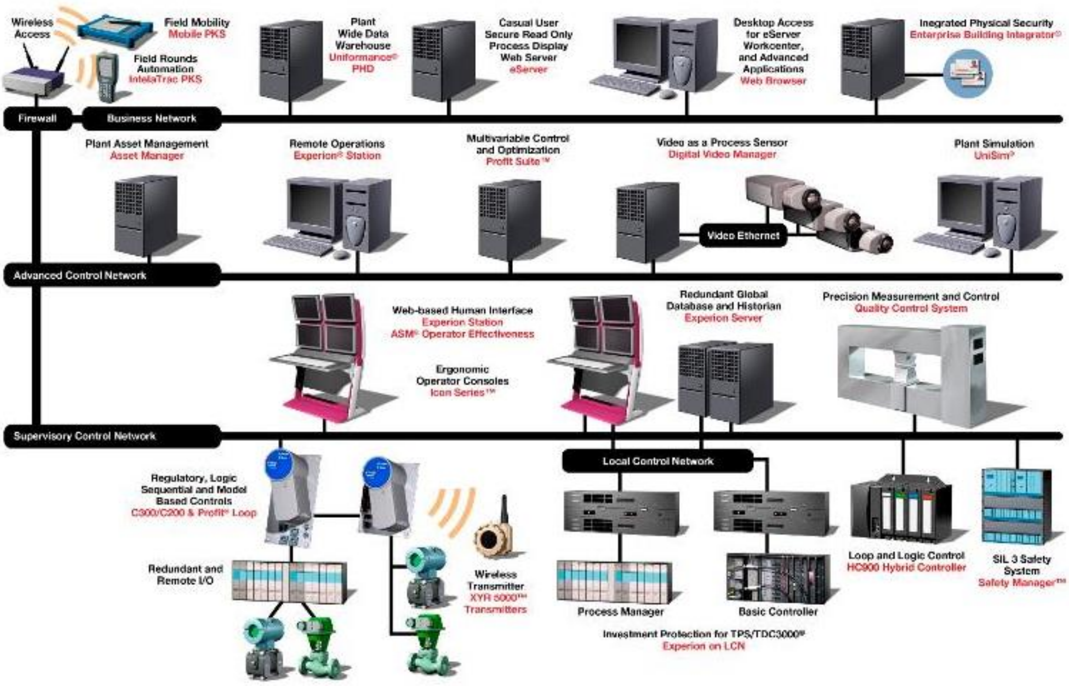

Figure 4.2.1. Example of distributed control system DCS (ref. 4)

4.2.2.2.1. Control valves design

This section presents the design of all the control valves installed in the storage area of *Chlorite*. Annex 1.2 shows the whole explanation of the design procedure.

Following table shows the specification of the mentioned valves. Control valves of pumps bottles have not been designed because it does not take part of the scope of the project.

Table 4.2.1. Control valve specifications.

Valve	Pipe	Flow phase [3]	Normal flow [m^3/h]	Maximum flow [m^3/h]	ΔP [barg]	Cv calc.[1]	Cv selec. [2]	Body Size [mm]	Valve Travel [mm]	DN ["]	R cha
VC-101	3"-CS-Cl_2-1	L	21,50	26,9	0,7	44,6	47	47	32	1 1/2"	
VC-102	3"-CS-Cl_2-1	L	21,50	26,9	0,7	44,6	47	47	32	1 1/2"	
VC-103	1"-CS-Cl_2-5	G	4,00	5	0,7	0,08	0,12	4	32	1/2"	Equ
VC-108	3"-CS-Cl_2-3	L	21,50	26,9	0,7	44,6	47	50	32	2"	Equ
VC-109	4”-FG-NaOH-17	L	43,30	54,1	0,7	79,4	82	65	32	3"	
VC-110	5"-CS-H_2O-20	L	78,30	97,9	0,7	136	140	95	32	3"	Equ
VC-111	3 1/2"-FG-NaOH-22	L	35,50	44,4	0,7	65,1	70	65	32	2"	Equ
VC-112	2"-CS-CCl_4-13	L	9,50	11,9	0,7	20,5	23,3	30	32	2"	
VC-113	1"-CS-H_2O-15	L	0,45	0,56	0,7	0,77	1,1	6	32	1/2"	
VC-114	5”-FG-NaOH-24	L	60,00	75	0,7	110,1	129	80	32	3"	
VC-115	3"-CS-Cl_2-3	L	21,50	26,9	0,7	44,6	47	50	32	2"	Equ

[1] calc.: calculated.
[2] selec.: selected.
[3] L: liquid and G: gas.

4.2.2.2.2. Orifice plate design

In order to control the volume flow rate guided to chlorine costumer enterprises, it has been designed a flow controller (FICQA-101). The measurement of the flow rate is performed through an orifice plate, which consists of a perforated plate installed in the proper pipe, where two points (one before the plate, the other after it) captures the pressure drop. To ensure it fits properly, the plate has been calculated taking into account the properties of the shipped liquid and the desired pressure at pipe.

Moreover, two more orifice plates are required in chlorine unit in order to install two more flow controllers. One of them will be installed in the cold water inlet pipe (2”-CS-CCl_4-13) to secure a proper operation of E-102 and E-103 to refrigerate the chlorine recirculation. The last one will be installed in soda solution inlet on the absorption column (C-101) to supply the equipment with the optimum absorbent liquid.

The results for all orifice plates are:

Table 4.2.2. Characteristics of the orifice plate.

Orifice plate	Mass flow [kg/s]	Inside pipe diameter [mm]	Pressure drop [bar]	β [Relation between ϕ]	d [mm] Orifice plate ϕ
FICQA-101	8,52	75,2	0,6	0,5	37
FICA-102	4,09	50,6	0,7	0,5	24
FICA-104	12,02	86,9	0,4	0,6	51

The measurement of the pressure drop is executed by flange taps, installed at 1” (before and after) of the orifice plate and drilled at the flanges supporting the plate.

The complete explanation of the design procedure can be viewed at Annex 1.3 and the specification sheet of the orifice plates is also available in 4.2.2.5.

4.2.2.2.3. Restriction orifice design

The recirculation to the chlorine storage tank is controlled through a restriction orifice. In the Annex A.1.4 appears the detailed calculation procedure. The results for FO-101 are:

Table 4.2.3. Restriction orifice.

Item	$K\cdot\beta^2$[-]	Re[-]	β[-]	d [in]
FO-101	0,043	80.600	0,27	0,83

To get more details, see the specification sheet available in 4.2.2.5.

4.2.2.3. Control instruments relation

ME&S Engineering has made a control instrumentation list which contains the basic information about all these items presents in the chlorine storage unit.

Table 4.2.4. Control instruments relation.

TAG	Service/ Localization	Type
FICA 101	Pipe 1	Flow indicator controller alarm
TIA 101	Pipe 1	Temperature indicator alarm
PSA 101	Tank T-101	Pressure switch alarm
PSHH 101	Tank T-101	Very high pressure
LSHH 101	Tank T-101	Very high level
LSLL 101	Tank T-101	Very low level
LICA 101	Tank T-101	Level indicator controller alarm
TIA102	Tank T-101	Temperature indicator alarm
PSHH 102	Tank T-101	Very high pressure
PSA 102	Tank T-101	Pressure switch alarm
LSA 101	Tank T-101	Level switch alarm
LSHH 102	Tank T-101	Very high level
PSV 101	Pipe 10	Pressure Safety Valve
PSV 102	Pipe 10a	Pressure Safety Valve
PRD-101	Pipe 10	Pressure Disc
PRD-102	Pipe 10a	Pressure Disc
QIA 101	Tank T-101 bund	Composition indicator alarm
PICA 101	Bottle B-101A	Pressure indicator controller alarm
TICA 101	Bottle B-101A	Temperature indicator controller alarm
PSV 103	Bottle B-101A	Pressure Safety Valve
PICA 102	Bottle B-101B	Pressure indicator controller alarm
TICA 102	Bottle B-101B	Temperature indicator controller alarm
PSV 104	Bottle B-101B	Pressure Safety Valve
FICAQ 101	Pipe 3	Totalizer flow indicator controller alarm
FO 101	Pipe 4	Restriction orifice
FICA 102	Pipe 13	Flow indicator controller alarm
TICA 103	Pipe 15	Temperature indicator controller alarm
LSHH 103	Absorption column C-101	Very high level
LSLL 102	Absorption column C-101	Very low level
LICA 102	Absorption column C-101	Level indicator controller alarm
FICA 103	Absorption column C-101	Flow indicator controller alarm
PSV 105	Pipe 30	Pressure Safety Valve
LSHH 104	Tank T-102	Very high level
LSA 102	Tank T-102	Level switch alarm

TAG	Service/ Localization	Type
TICA 104	Pipe 20	Temperature indicator controller alarm
FICA 104	Pipe 22	Flow indicator controller alarm
QIA 102	Pipe 23	Composition indicator alarm
PIAS-101	Pipe 26	Pressure indicator alarm switch
XSA 101	Road tanker	Displacement sensor
XSA 102	Road tanker	Earth electrode
HS 101	Tanks zone	Hand switch
HS 102	Pipe 3	Hand switch
PRV 101	Pipe 27	Pressure relief valve
FSV 101	Pipe 6	Flow switch valve
FSV 102	Pipe 26	Flow switch valve
VGA-101	Pipe 1	Gate Valve
VGA-102	Pipe 1	Gate Valve
VGA-103	Tank T-101	Gate Valve
VGA-104	Tank T-102	Gate Valve
VGA-105	Tank T-103	Gate Valve
VGA-106	Tank T-104	Gate Valve
VGA-107	Tank T-105	Gate Valve
VGA-108	Tank T-106	Gate Valve
VGA-109	Pipe 2	Gate Valve
VGA-110	Pipe 2	Gate Valve
VGA-111	Pipe 2b	Gate Valve
VGA-112	Pipe 3	Gate Valve
VGA-113	Pipe 3a	Gate Valve
VGA-114	Pipe 3	Gate Valve
VGA-115	Pipe 4	Gate Valve
VGA-116	Pipe 5	Gate Valve
VGA-117	Pipe 5	Gate Valve
VGA-118	Pipe 7	Gate Valve
VGA-119	Pipe 8	Gate Valve
VGA-120	Pipe 8	Gate Valve
VGA-121	Pipe 8	Gate Valve
VGA-122	Bottle B-101A	Gate Valve
VGA-123	Bottle B-101A	Gate Valve
VGA-124	Bottle B-101A	Gate Valve
VGA-125	Bottle B-101A	Gate Valve
VGA-126	Bottle B-101A	Gate Valve
VGA-127	Bottle B-101A	Gate Valve
VGA-128	Bottle B-101B	Gate Valve

TAG	Service/ Localization	Type
VGA-129	Bottle B-101B	Gate Valve
VGA-130	Bottle B-101B	Gate Valve
VGA-131	Bottle B-101B	Gate Valve
VGA-132	Bottle B-101B	Gate Valve
VGA-133	Bottle B-101B	Gate Valve
VGA-134	Pipe 3	Gate Valve
VGA-135	Pipe 3	Gate Valve
VGA-136	Pipe 6	Gate Valve
VGA-137	Pipe 6	Gate Valve
VGA-138	Pipe 26	Gate Valve
VGA-139	Pipe 26	Gate Valve
VGA-140	Pipe 26	Gate Valve
VGA-141	Absorption column C-101	Gate Valve
VGA-142	Absorption column C-101	Gate Valve
VGA-143	Absorption column C-101	Gate Valve
VGA-144	Absorption column C-101	Gate Valve
VGA-145	Absorption column C-101	Gate Valve
VGA-146	Absorption column C-101	Gate Valve
VGA-147	Pipe 17	Gate Valve
VGA-148	Pipe 17	Gate Valve
VGA-149	Pipe 24	Gate Valve
VGA-150	Pipe 24	Gate Valve
VGA-151	Pipe 24	Gate Valve
VGA-152	Pipe 29	Gate Valve
VGA-153	Pipe 25	Gate Valve
VGA-154	Pipe 18	Gate Valve
VGA-155	Pipe 18	Gate Valve
VGA-156	Pipe 18a	Gate Valve
VGA-157	Pipe 19	Gate Valve
VGA-158	Pipe 19a	Gate Valve
VGA-159	Pipe 20	Gate Valve
VGA-160	Pipe 20	Gate Valve
VGA-161	Pipe 21	Gate Valve
VGA-162	Pipe 22	Gate Valve
VGA-163	Pipe 22	Gate Valve
VGA-164	Pipe 23	Gate Valve
VGA-165	Pipe 14	Gate Valve
VGA-166	Pipe 14	Gate Valve
VGA-167	Pipe 16	Gate Valve

TAG	Service/ Localization	Type
VGA-168	Pipe 16	Gate Valve
VGA-169	Pipe 15	Gate Valve
VGA-170	Pipe 15	Gate Valve
VGA-171	Pipe 12	Gate Valve
VGA-172	Pipe 13	Gate Valve
VGA-173	Pipe 13	Gate Valve
VGL-101	Tank T-101	Glove Valve
VGL-102	Tank T-101	Glove Valve
VGL-103	By-pass pipe 8	Glove Valve
VGL-104	Bottle B-101A	Glove Valve
VGL-105	Bottle B-101A	Glove Valve
VGL-106	Bottle B-101B	Glove Valve
VGL-107	Bottle B-101B	Glove Valve
VGL-108	By-pass pipe 3	Glove Valve
VGL-109	Pipe 6	Glove Valve
VGL-110	Pipe 26	Glove Valve
VGL-111	Pipe 26	Glove Valve
VGL-112	Tank T-102	Glove Valve
VGL-113	Tank T-102	Glove Valve
VGL-114	By-pass pipe 17	Glove Valve
VGL-115	By-pass pipe 24	Glove Valve
VGL-116	By-pass pipe 20	Glove Valve
VGL-117	By-pass pipe 22	Glove Valve
VGL-118	By-pass pipe 15	Glove Valve
VGL-119	By-pass pipe 13	Glove Valve
VCH-101	Pipe 3	Check Valve
VCH-102	Pipe 3a	Check Valve
VCH-103	Pipe 6	Check Valve
VCH-104	Pipe 26	Check Valve
VCH-105	Pipe 18	Check Valve
VCH-106	Pipe 18a	Check Valve
VCH-107	Pipe 22	Check Valve
VCH-108	Pipe 13	Check Valve
VBT-101	Pipe 9 &10 & 10a	Butterfly Valve
VBT-102	Pipe 10 &10a & 11	Butterfly Valve
VC-101	Pipe 1	Control Valve
VC-102	Pipe 1	Control Valve
VC-103	Pipe 8	Control Valve
VC-104	Bottle B-101A	Control Valve

TAG	Service/ Localization	Type
VC-105	Bottle B-101A	Control Valve
VC-106	Bottle B-101B	Control Valve
VC-107	Bottle B-101B	Control Valve
VC-108	Pipe 3	Control Valve
VC-109	Pipe 17	Control Valve
VC-110	Pipe 20	Control Valve
VC-111	Pipe 22	Control Valve
VC-112	Pipe 13	Control Valve
VC-113	Pipe 15	Control Valve
VC-114	Pipe 24	Control Valve

4.2.2.4. Interlock systems

In order to protect the storage tank T-101, two locking systems have been installed in the main control level system (LICA 101) which acts on VC-101; one of them for very high level and the other one for very low level, LSHH 101 and LSLL 101, respectively. Just in case of failure of both locking systems, a redundant locking system (LSHH 102) has been installed but it acts on a different valve (VC-102)

In order to protect the tank T-101 in case of overpressure, the selective controller FICA 101, besides the first two locking systems explained above, has another one locking system acting in case of overpressure (PSHH 101). Just in case of failure of this system, another locking system for very high pressure (PSHH 102) has been installed, which will open VC-103 to relieve product to the absorption column.

Regarding the column absorption, it has two locking systems; one for very high level (LSHH 103) and another for very low level (LSLL 102), which acts on VC-109 by the same way as those of the tank.

Soda caustic storage tank has a very high level locking system (LSHH 104), which acts closing VC-114 in case the tank suffers an overfilled.

The road tanker TK-101 has a pressure gauge (PIAS 101) with high and low pressure alarms installed in nitrogen pipe 1”-CS-N_2-26. In case of shooting due to high pressure, the supply valve FSV-101 will close and FSV-102 will open to allow the nitrogen entrance.

A pressure relieve valve (PRV-101) has also been installed, which is a mechanical valve that acts relieving the product to the absorption column C-101 in case of overpressure.

4.2.2.5. Specification sheets of control elements

Specification sheets of the designed restriction orifice and all the orifice plates can be viewed in the following pages.

ORIFICE PLATE

1	**GENERAL**	Manufacturer	-		P&ID No:	1
2		Type	Orifice Plate		Service	Liquid
3		Vendor	-		Range limits	-
4		Purchase order number	-		Diff. Pressure	-
5						
6	**OPERATING DATA**			**FICQA-101**	**FICA-102**	**FICA-104**
7		Line/App. No:		3"-CS-CL_2-3	2"-CS-CCl_4-13	3 1/2"-FG-NaOH-22
8		Flow	kg/s	8,5	4,1	12
9		Oper. Press.	bar	8,8	4,5	1
10		Oper. Temp.	ºC	15	38	40
11		Density @ op. Cond.	kg/m^3	1427	1550	1220
12		Molecular weight	g/mol	70,9	153,8	40,0
13						
14						
15	**DESIGN**	Type of construction		Orifice plate		
16		Flange (pipe)	Rating	150		
17			Material	ASTM A-516 Grade 70		
18			Facings	Racing face		
19			Line internal diameter, mm	75,2	50,6	86,9
20		Orifice Plate	Orifice bore diameter, mm	37,2	24,3	50,9
21			Outside diameter	75,2	50,6	86,9
23			Plate thickness	-	-	-
24			Pressure drop (bar)	0,5	0,7	0,4
25			Material	ASTM A-516 Grade 70		
26			Vent or drain hole diameter	-	-	-
27			Beta = d/D	0,5	0,5	0,6

28	**Notes:**				ME&S Engineering
29					
30					UNIVERSITAT ROVIRA I VIRGILI Escola Tècnica Superior d'Enginyeria Química Departament d'Enginyeria Química
31			Sara C.	Cristina N.	
32	*REV.*	*DATE*	*PREP.*	*APPR.*	

RESTRICTION ORIFICE

1	GENERAL	Manufacturer					Tag No:	FO 101		
2		Type								
3		Vendor					Service:	Liquid		
4		Purchase order number					Renge limits:			
5		Line/App. No:	1 1/4”-CS-Cl_2-4				Diff. press@ max Range:			
6		P&ID No:	Location:							
7	OPERATING DATA	Medium					State	Liquid		
8		Corrosive Matters					Density @ op. Cond.	kg/m^3	1308	
9				min.	norm.	max.	Viscosity @op. Cond.	mPa s	0,295	
10		Flow	kg/h			4,0	Molecular weight	kg/kmol	70,9	
11		Oper. Press.	bar			7,7	Compressibility	Zn/Z1		
12							Pour point	ºC		
13		Oper. Temp.	ºC			55,0	Crystallization Point	ºC		
14										
15										

16	DESIGN	Type of construction		Restriction orifice
17		Flange (pipe)	Pipe-class	
18			Rating	150
19			Material	ASTM A-516 Grade 70
20			Facings	RF (1)
21			Line internal diameter mm	77,93
23		Orificce Plate	Orifice bore diameter mm	21,04
24			Outside diameter	77,93
25			Plate thikness	
26			Material	
27			Vent or drain hole diameter	
28			Beta = d/D	0,27
30		Impulse line connection	NPS	
31			Material	
32				
33		Acessories	Material	
34			Sealing liuid	
35			Density	
37		Meter run	Ends	
38			Up stream straing length	
39			Total length	
40			Material	
41			Bolts material	
42			Nuts material	
44		Certificate		

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4.2.3. Equipment design

All equipment required on the new chlorine storage unit have been designed following the appropriated methods and regulations. The main results for each equipment are detailed below and all specification sheets can be viewed in section 4.2.3.5. *Equipment specification sheets*.

4.2.3.1. Chlorine tank design

Proper and safe chlorine storage is the aim of this project. In order to prevent accidents related with this highly toxic substance, the tank has been designed following the instruction ITC MIE APQ-3 (ref. 3). It has been provided with safety elements, most of them to prevent the accidents (as pressure relieves valves) and others to minimize the damage if the accident is impossible to prevent (as the absorption column).

The pressure equipment has been designed according to the following requirements:

Table 4.2.1. Design basis for the storage equipment.

Characteristic	Value
Stored product	Pure chlorine
Physical state	Liquid
Working pressure [barg]	8,0
Working temperature [ºC]	15
Required volume [m^3]	82
Filling degree [%]	90
Construction material	ASTM A-516 Grade 70

Once all the design conditions are known, it is possible to determinate the essential characteristics of the pressure tank, the optimum geometry is that formed by cylindrical shell with ellipsoidal heads because of its working pressure. Moreover, the most efficient position is horizontal since its volume is not too large.

The design of the tank includes its measures, the required thicknesses, the stresses due to the support of saddles and, finally, its foundation footings. Diameters and thicknesses for nozzles have also been calculated. The results obtained are shown in the following tables.

Table 4.2.2. Geometric measures and thicknesses of T-101.

Parameter	Value
Design pressure [barg]	15
Design temperature [ºC]	75
Diameter [m]	2,90
Body length [m]	11,5
L/D relation	4,00

Parameter	Value
Ellipsoidal relation [D/h]	2:1 (h = 0.73m)
Volume [m^3]	82
Filling degree [%]	90
Body thickness [mm]	25 (1)
Heads thickness [mm]	24 (1)

(1) The minimum required thicknesses have one extra millimetre due to possible corrosion.

Table 4.2.3. Designed nozzles of T-101.

Nozzle	Diameter [“]	Thickness [“]
PJ-101	3 1/2	0,32
J-104	1 1/2	0,40
PJ-105	1 1/2	0.40
J-105	1 1/2	0,20
J-106	1 1/2	0,40
H-101	30,0	0,37
PJ-102	3 1/2	0,32

Table 4.2.4. Results of efforts on the saddles of T-101.

Equipment	S_1	S_2	S_3	S_4	S_5	S_6	S_7
	[Psi]						
T-101	59	1.211	2.356	2.375	1.082	-4.737	18.860

Where S_1 is stress at saddles; S_2, stress at midspan; S_3, tangential shear stress in shell; S_4, tangential shear stress in head; S_5, additional stress in shell; S_6, circumferential stress at horn of saddle, and S_7 is circumferential stress at the bottom of the shell.

Finally, the foundations to support the equipment have been designed as two rectangles, one for each saddle. To obtain the correct design, it is important to secure that, on one hand, foundations will have enough capacity to support the full equipment weight and, on the other hand, total ground pressure that does not exceed the value of 20000 kg/m^2. In next table there are shown the characteristics of foundations; both of them have the same properties.

Table 4.2.5.Characteristics of foundations for the equipment T-101.

Parameter	Value
Weight to support (each foundation) [kg]	75.600
Pedestal height [m]	1,2
Pedestal length [m]	3,0
Pedestal width [m]	0,4
Foundation thickness [m]	0,6
Foundation length [m]	3.0
Foundation width [m]	1.5
Total ground pressure [kg/m^2]	16.900

The results for geometric, measures and characteristics of saddles and foundations are represented in the following picture.

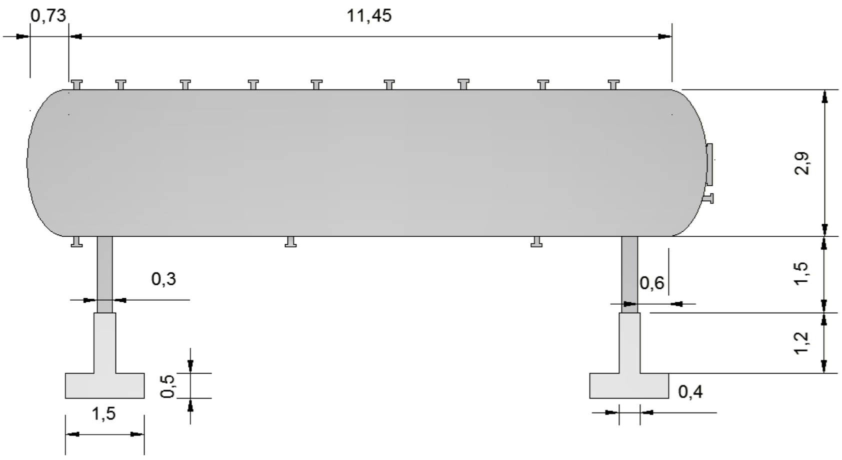


Figure 4.2.1. Chlorine tank measures (in meters).

The complete explanation of the design procedure can be viewed in Annex 1.5 of the same document and the specification sheet of the chlorine vessel is also available in 4.2.3.5 of the report.

4.2.3.2. Pump design

There are installed several pumps in the storage area of Chlorite. The first one, P-101A/B, is installed in the outlet pipe of the tank T-101 to impulse the fluid to the heat exchangers and to chlorine buyer enterprises. The pump selected is CPK/HPK 50-315 (1.450 rpm) from KSB company.

Second pump is P-102, installed in pipe 2”-CS-CCl_4-12 and is located between heat exchangers E-102 and E-103. The pump selected is CPK/HPK 40-200 (1.450 rpm) from KSB brand.

One of the important things to take into account when selecting pumps is the limitation of a possible release of the liquid pumped. If the substance is toxic and is pressurized, it is necessary the installation of a double seal pump. The advantages of the double seal are its sealed precision; the extremely low possibility of release, and the low maintenance required. All this allow a periodic revision to detect liquid releases, which will indicate when the seal needs to be replaced.

According to these conditions and taking into account that chlorine and carbon tetrachloride are toxic substances, pumps P-101A/B and P-102 are centrifugal pumps with double seal, according to API Plan 52.

Referring to pump P-103A/B, according to its properties and conditions, the selected seal applies API Plan 21.

The design has been done properly to ensure the pumps are able to achieve the height and the pressure required. The calculation procedure and the specification sheet are exposed in annex 1.6.

The following table show the results of the design of the pumps.

Table 4.2.6. Results of the pumps design.

Description [units]	**P-101 A/B**	**P-102**
Flow [m^3/h]	25,5	9,45
Total head [m]	32,6	10,7
Impeller diameter [mm]	310	184
Pump efficiency [%]	49,5	51,0
Suction pressure [barg]	5,00	3,63
Discharge pressure [barg]	9,57	5,26
$NPSH_R$ [m]	0,50	0,90
$NPSH_A$ [m]	0,84	29,7
Pump input [kW]	6,86	0,84

4.2.3.3. Refrigeration system design

To maintain de desired temperature inside the chlorine tank, it is necessary to have installed a refrigerated recirculation. As it has been mentioned, since the hot product in the exchanger is chlorine, it is not possible to use water as the cool product because in case of little leak in the equipment, there will be hydrochloric acid formation and so outside all installation would be destroyed by corrosion, releasing toxic substances and damaging population.

For this reason, two alternatives have been studied:

- The use of an intermediate cool product (carbon tetrachloride). The installation will have two tube and shell exchanger, the first one will refrigerate carbon tetrachloride with cool water, and the second one will use that cool carbon tetrachloride to refrigerate the chlorine recirculation. With this system chlorine will be not in contact with water.

- The use of an industrial air cooler to refrigerate the chlorine recirculation. As with the previously mentioned system, with this equipment will not be any corrosion risk due to the fact that there is no any hydrochloric acid formation.

4.2.3.3.1. Exchangers design

As the first design alternative there has been designed two tube and shell heat exchangers.

The method that has been followed to the thermal design of the equipment has been the KERN method (see Annex 1.7), which allows the using main data of the fluids flowing through it. Then, these results have been compared with ASPEN. Next table shows both results of thermal design.

Table 4.2.7. Results for the operating conditions of tube and shell heat exchangers.

Parameters	**E-102**		**E-103**	
	Tube side	**Shell side**	**Tube side**	**Shell side**
Input temperature, Ti, [ºC]	55	38	42	27
Output temperature, To, [ºC]	45	42	38	35
Flow, m, [kg/s]	1,44	4,07	4,07	0,44
Heat exchanged, Q, [kW]	14,7	14,7	14,8	14,8

The results obtained from the thermal design of the shell and tube exchangers are:

Table 4.2.8. Comparison results for KERN and ASPEN tube and shell heat exchanger E-102.

Parameters	**E-102 KERN**		**E-102 ASPEN**	
	Tube side	**Shell side**	**Tube side**	**Shell side**
Number of tubes	170		158	
Tube length [m]	1,25		1,25	
Required Area [m^2]	17,9		14,6	
Global heat coefficient [$W/m^{2\,o}C$]	95,2		111,8	
Pressure drop [bar]	0,001	0,02	0,02	0,18

Table 4.2.9. Comparison results for KERN and ASPEN tube and shell heat exchanger E-103.

Parameters	E-103 KERN		E-103 ASPEN	
	Tube side	Shell side	Tube side	Shell side
Number of tubes	215		240	
Tube length [m]	1,25		1,25	
Required Area [m^2]	21,4		22,2	
Global heat coefficient [W/m^2ºC]	79,5		75,2	
Pressure drop [bar]	0,010	0,005	0,050	0,020

The parameters to be implemented in the heat exchanger design are those obtained from the software ASPEN, due to the fact that this methodology is more accurate than Kern method because it involves more parameters during the calculations, which provides more precision to the obtained results. In order to see more specifications see section 4.2.3.5.

4.2.3.3.2. Aircooler design

As an alternative, an industrial air cooler has been designed in order to refrigerate chlorine in case of high increment of the operating temperature in tank T-101.

The main results for the thermal air cooler design are specified in the following table.

Table 4.2.10. Air cooler operating conditions.

Characteristic	Tube side	Air side
Product	Chlorine	Air
Total flow [kg/h]	5.184	7.150
Inlet/Outlet temperature[ºC]	55/45	32/47
Pressure [kg/cm^2 g]	8	Atmospheric
Heat exchanged [kcal/h]	23.390	23.390

Taking into account operation conditions, tubs will be have a triangular layout and will be provided with fins to obtain better heat transfer. The air cooler have been selected from Alpha Naval Catalogue, specifically Alpha Blue BDM model (ref. 5) The main specifications are listed below.

Table 4.2.11. Design results for required air cooler.

Design pressure [bar]	Design temperature [Cº]	Tubes, Nº
15	60	56
Tubes length [m]	**Fins, Nº/in**	**Rows, Nº**
2,0	11	7

Passes, Nº	Nozzles, ºN/Fans, Nº	Fan diameter [m]
1	**2/2**	0,8

The complete explanation of the design procedure can be viewed at Annex 1.8 and the specification sheet of the chlorine vessel is also available in 4.2.3.5 of the report.

4.2.3.4. Absorption system design

In order to protect equipment from fire situation there have been designed rupture disks and pressure relief valves that release chlorine to the absorption system. Since chlorine is a high toxic substance its projection to the atmosphere could affect people and the environment. For these reason, absorption system has been designed.

The absorption system includes: absorption column C-101; storage tank T-102 which contains caustic soda and the products obtained in chemical reaction (absorption); and pumps P-103A/B, which sends the product from T-102 to plate heat exchanger E-104. The plate heat exchanger makes sure that the caustic soda dilution comes into the column with the proper temperature in order to achieve a good absorption.

The absorption system will work as a batch process, which means that, first of all, tank T-102 will be filled with soda solution 20%. While the system will be working, soda solution will be entering constantly to the column and liquid bottom product will be returned to T-102. System will keep working until the tank contains a soda solution less than 2% in mass. In that moment, system will be stopped, the wasted solution will be removed and T-102 will be filled with new 20% soda solution.

Design specifications of each equipment are shown below.

4.2.3.4.1. Absorption column design

The packed absorption column has been designed according to ASME code, in order to achieve good absorption of chlorine realised by all PSV of the storage unit. The column has been designed to be able to neutralize the worst scenario, it means to absorb all chlorine released from T-101 in case of 20 minutes fire.

Operating temperature should be in 30-60 ºC range and the chemical reaction inside the absorption column is:

$$Cl_2+2\cdot NaOH \rightarrow NaCl+NaClO+H_2O \quad (3.2.1)$$

Following diagram shows the operating conditions when chlorine is relieved from T-101 and the absorption column, C-101, is activated.

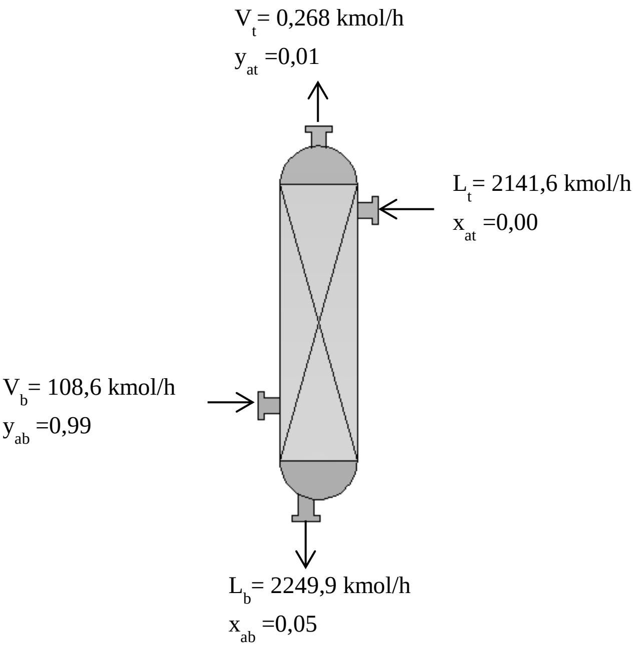


Figure 4.2.2. Column parameters.

In order to achieve maximum effectiveness, the absorption column will be a packing column filled with Ceramic Pall rings. The results obtained for this are shown in table 4.2.12.

Table 4.2.12. Design results of the designed absorption column C-101.

Column C-101 parameters	**Value**
Pressure drop, [in]	1,18
G_y , packing flood [kg/m^{2}s]	2,99
Column area, [m^2]	0,71
Absorption column diameter, [m]	0,95
$U_{v,flood}$, flood velocity inundation, [m/s]	1,38
H_{oy}, height of the packing absorption, [m]	0,47
N_{oy}, theoretical number of stages [m]	7,10
Z, total absorption column height, [m]	3,37
HETP, equivalent height of theoretical stage, [m]	0,56

The design of the column includes its measures, required thicknesses, stresses due to wind and weight and its foundation footings. Diameters and thicknesses for nozzles have also been calculated. Find attached the results in the following tables.

Table 4.2.13.Geometric measures and thickness for T-102.

Parameter	Value
Design pressure [barg]	2,00
Design temperature [ºC]	100
Diameter [m]	0,95
Body length [m]	3,40
Body thickness due to internal pressure [mm]	1,34
Head thickness due to internal pressure [mm]	1,15
Head thickness due to internal pressure [mm]	1,17
Thickness due to wind [mm]	6,03

Total thickness of each part will be the sum of individual thickness due to internal pressure and general thickness due to wind.

Table 4.2.14.Designed nozzles for T-102.

Nozzle	Diameter [m]	Thickness [mm]
J-125	1 1/4	0,191
J-124	4	0,337
J-122	5	0,375
J-120	2 1/2	0,276

Total height, weight and diameter of the column have been taking into account to design the skirt support and the anchor bolts. The skirt diameter will be the same as the column. The number of anchor bolts must be in multiple of four, preferred to use minimum of eight bolts. Finally, the spacing of anchor bolts should be equal or higher than about 10 in.

Table 4.2.15.Geometric measures and thickness for T-102.

Parameter	Value
Total weight (full of water) [kg]	3.100
Skirt diameter [m]	0,95
Skirt height [m]	1,20
Skirt thickness (for wind + for weight) [mm]	9,10
Number of anchor bolts	8
Bolt size [“]	1/2

Finally, the foundation to support the equipment has also been designed as an octagonal foundation. To obtain correct design, it is important to secure that, on one hand, foundation will have enough capacity to support the full equipment weight and, on the other hand, total ground pressure do not exceed 20.000 kg/m^2. Find in next table the characteristics of the foundations, both of them have the same properties.

Table 2.4.16.Characteristics of foundations of T-102.

Parameter	Value
Weight to support [kg]	7.200
Pedestal height [m]	1,20
Pedestal side [m]	1,20
Foundation thickness [m]	0,20
Foundation side [m]	1,30
Total ground pressure [kg/m^2]	6.500

The full explanation of this design can be viewed in Annex 1.9 and the specification sheet of the chlorine vessel is also available in 4.2.3.5.

4.2.3.4.2. Soda solution tank design

As it has been mentioned, the absorption system works as a batch process and it is provided with a tank. At the beginning of the process, the tank contains enough caustic soda solution (20%) to absorb 30 minutes of discharge of PSV-101/102 (C-101 has been designed with absorption capacity to endure the worst situation, 20 minutes of fire), in this way, the tank supply C-101.

Moreover, it is important to considerer that de bottom absorption product will return to the same tank. So, by the end of the absorption, the tank will contain a different solution, its flow and density will be different too.

Taking into account this information, the tank has been designed as following:

Table 4.2.17.Design basis for the storage equipment.

Parameter	Value
Stored product at the beginning	Caustic soda solution
Physical state	Liquid
Working pressure [barg]	1,00
Working temperature [ºC]	20-60
Required volume [m^3]	30,0
Filling degree [%]	80,0

Once all design conditions are known, is possible to determine the essential characteristics of the pressure tank. The optimum geometry is cylindrical shell with korbogen heads because of its working pressure, and, the most efficient position is horizontal since the volume is not too large.

The design of the tank includes its dimensions, required thicknesses, stresses due to the support of saddles and its foundation footings. Diameters and thicknesses of nozzles have also been calculated. Find the results in the following tables.

Table 4.2.18.Geometric measures and thickness for T-102.

Parameter	Value
Design pressure [barg]	2,00
Design temperature [ºC]	80,0
Diameter [m]	2,20
Body length [m]	7,20
L/D relation	3,20
Head relation (Korbbogen) [r1/r2]	5,20
Volume [m^3]	30,0
Filling degree [%]	80,0
Body thickness [mm]	1,75
Heads thickness [mm]	1,80

Table 4.2.19. Designed nozzles for T-102.

Nozzle	Diameter [m]	Thickness [mm]
J-126	5	0,26
J-127	3 1/2	0,23
J-128	1 1/2	0,15
J-129	6	0,28
H-102	26	0,25
J-132	4	0,24
J-133	4	0,24

Table 4.2.20. Results of efforts on the saddles of T-102.

Equipment	S_1	S_2	S_3	S_4	S_5	S_6	S_7
				[Psi]			
T-102	476	4.560	12.090	11.800	5.380	-217.350	-30.820

Where:

where S_1 is stress at saddles; S_2, stress at midspan; S_3, tangential shear stress in shell; S_4, tangential shear stress in head; S_5, additional stress in shell; S_6, circumferential stress at horn of saddle, and S_7 is circumferential stress at the bottom of the shell.

Finally, the foundations to support the equipment have been designed as two rectangle, one for each saddle. To obtain correct design, it is important to secure that, on one hand, foundations will have enough capacity to support the full equipment weight and, on the other hand, the total ground pressure does not exceed 20000 kg/m^2. Find, at next table the, characteristics of the foundations (both of them have the same properties)

Table 2.4.21.Characteristics of foundations for the equipment T-102.

Parameter	Value
Weight to support (each foundation) [kg]	20.440
Pedestal height [m]	1,20
Pedestal length [m]	2,20
Pedestal width [m]	0,40
Foundation thickness [m]	0,30
Foundation length [m]	2,20
Foundation width [m]	0,60
Total ground pressure [kg/m^2]	15.600

The results of geometric, dimensions and characteristics of saddles and foundations are presented in the following picture.

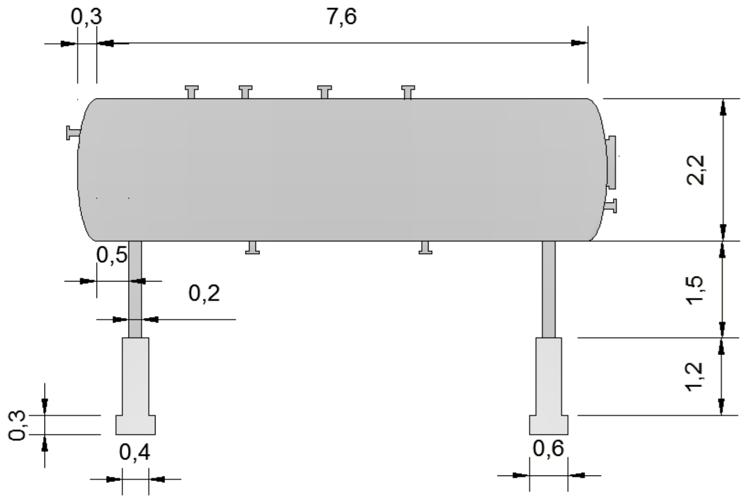


Figure 2.4.3. Soda solution tank measures (in meters)

The full explanation of the design procedure can be viewed in Annex 1.10 and the specification sheet of the chlorine vessel is also available in 4.2.3.5.

4.2.3.4.3. Pump design

The third pump installed in the chlorine storage area is P-103A/B, in pipe 3½"-CS-NaOH-19a/19b, and impulses fluid from the tank T-102 to the heat exchanger E-104. The pump selected is CPK/HPK 50-200 (1.450 rpm) from KSB brand.

The design has been done properly to ensure the pump is able to achieve the height and the pressure required. The calculation procedure and the specification sheet are exposed in Annex 1.11.

The following table shows the results of the design of the pumps.

Table 2.4.22. Results of the pumps design.

Description [units]	**P-103 A/B**
Flow [m^3/h]	35,5
Total head [m]	10,9
Impeller diameter [mm]	200
Pump efficiency [%]	71,0
Suction pressure [barg]	2,15
Discharge pressure [barg]	3,45
$NPSH_R$ [m]	1,10
$NPSH_A$ [m]	9,65
Pump input [kW]	3,00

4.2.3.4.4. Plate heat exchanger design

The absorption system has a plate heat exchanger installed to reach the required soda mixture temperature and achieve the total absorption of chlorine gas.

M10-Plate Heat Exchanger of Alfa Laval catalogue (ref.6) has been chosen according to design specifications.

In Annex A.1.12 appears a detailed calculation indicating the equations followed to determine the main parameters.

Table 2.4.23. Results of the geometrical dimensions.

Surface exchange, A, [m^2]	60,0
Effective surface of the plate, Ap, [m^2]	0,332
Total number of plates, n, [-]	180
Height, h, [m]	1,18
Length, L, [m]	1,689

Table 2.4.124 Results of plate heat exchanger.

Characteristic	**Hot**	**Cold**
Flow, M, [kg/s]	12,03	21,65
Input temperature, Ti, [ºC]	60	27
Output temperature, To, [ºC]	42	37
Heat, Q, [kJ/s]	905,1	905,1

Characteristic	Hot	Cold
Mass rate in the canal, m, [kg/s m^2]	56,69	102,0
Heat transfer coefficient, h, [W/m^2 ºC]	429	1.665
Global heat transfer, U, [W/m^2 ºC]	264	264
Canal pressure drop, ΔP_C, [Pa]	$1,52 \cdot 10^4$	$2,781 \cdot 10^4$
Gate fluid velocity, V_P, [m/s]	0,239	0,526
Total pressure drop, ΔP, [bar]	0,153	0,280

The specification sheet of the plate heat exchanger is also available in 4.2.3.5.

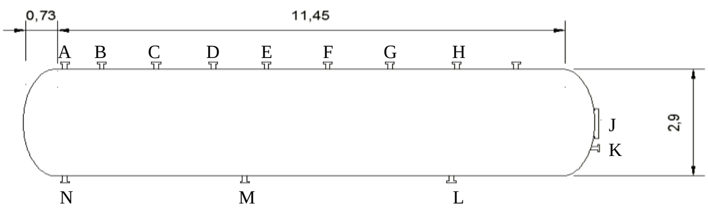
4.2.3.5. Equipment specification sheets

Specification sheets of the designed equipment are shown in the following pages.

DRUM DATA SHEET

1	GENERAL	Manufacturer: -				
2		Item: T-101				
3		Description: Storage of liquid chlorine		Position:	X Horiz.	Vertical

4	OPERATING	Product:	Chlorine	
5		Operating Pressure (eff.)	5,8	barg
6		Operating Temperature	15	ºC
7		Liquid Density	1427,4	kg/m^3
8	DESIGN DATA	Design Pressure (eff.)	15	barg
9		Design Temperature	55	ºC
10		Hidrostatic Test (eff.)	21,45	kg/cm2g
11		Corr. Allow. Shell / Heads	1	mm
12		Joint Eff. Shell / Heads	1	
13		Code:	ASME VIII	
14		Radiograph:	Total	
15		Stress Relieve:	Yes X	No
16		Seismic:	Yes	No X
17		Wind Load:	130	km/h



18	MATERIALS		Thickness	Mat´l Class
19		Shell	25 mm	ASTM A-516 Grade 70
20		Heads	24 mm	ASTM A-516 Grade 70
21		Lining	- mm	
22		Nozzle Necks		ASTM A-516 Grade 70
23		Flanges		Tongue and groove -

24	CONSTRUCTION		Dia.	L / D	Material
25		Shell	2,9 m	4	ASTM A-516 Grade 70
26		Heads	-1	-	ASTM A-516 Grade 70
27		Insulation:		Yes	No X
28		Fireproofing:		Yes	No X
29		Sandblast:		Yes X	No
30		Paint:		Yes X	No
31		Wt. Empty:	16750	kg	
32		Wt. Full Chlorine:	133780	kg	

		Service	Mark	Joint name	Size (")	Rating
33	NOZZLE SCHEDULE	Service	Mark	Joint name	Size (")	Rating
34		High level indicator	A	J-101	-	300 #
35		Product entrance	B	PJ-101	3 1/2	300 #
36		Pressure indicator	C	J-102	-	300 #
37		Blind flange	D	J-103	-	300 #
38		Pressure Relieve System	E	J-104	1 1/2	300 #
39		Recirculation inlet	F	PJ-105	1 1/2	300 #
40		Nitrogen entrance	G	J-105	1 1/2	300 #
41		Ventilation to absorber	H	J-106	1 1/2	300 #
42		Pressure indicator	I	J-107	-	300 #
43		Manhole	J	H-101	30	300 #
44		Level indicator	K	J-110	-	300 #
45		Product outlet	L	PJ-102	3 1/2	300 #
46		Temperature indicator	M	J-109	-	300 #
47		Low level indicator	N	J-108	-	300 #
48						

NOTES:

(1) Ellipsoidal heads, Φ = 2,9m; h = 0,725m (Radius relation 2:1)

(*) All measures in the picture are represented in meters.

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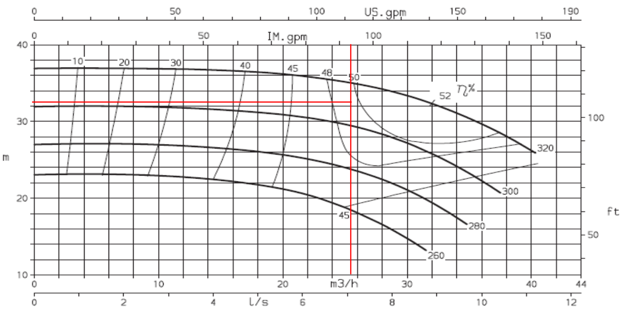
CENTRIFUGAL PUMP DATA SHEET

1	GENERAL	Manufacturer : KSB		
2		Type: CPK/HPK	Model: 50-315	
3		Item No.: P-101 A/B	No. of pumps required: 2	Code: ISO 2858
5	OPERATING CONDITIONS	Liquid pumped: Chlorine liquid		
6		Pumping Temp.(P.T) :	15	ºC
7		Density at P.T. :	1427	kg/m3
8		Vapor Press. at P.T.:	5,88	bar a
9		Viscosity at P.T. :	0,358	cP
10		Capacity		
11		Normal	25,5	m^3/h
12		Max.	28,05	m^3/h
13		Suction Pressure (eff.) :	6,00	bar a
14		Discharge Pressure(eff.)	10,57	bar a
15		Differential Pressure	5,57	bar a
16		Differential Head	32,6	m.l.c.
17		N.P.S.H.Avail.	0,84	m.w.c
18	DESIGN DATA	Design Temperature	55	ºC
19		Max.Allow.working press.(eff)	16	bar a
20		N.P.S.H.Req.(water)	0,50	m.w.c
21		Rot.freq.	1450	min^{-1}
22		Power at Shaft	6,86	kW
23		Efficiency	49,5	%
24		Min.Cont.flow	2,55	m^3/h
25	CONSTRUCCION DETAILS	Arrangement	X Horiz.	Vert
26		Impeller diameter	310	mm
27		Number of Stages	1	
28		Cooling consumption:		m^3/s
29		Bearings		
30		Type	CS-GP-240 GH+N	
31		Lubrication	1)	
32		Coupl.		
33		Type	TSKS-0075-200	
34		Lubr.:		
35		Nozzles / Mark / Nº	Dia.	Rating
36		Suction / DIN / 1	3"	
37		Discharge / DIN / 1	3"	
38		Vents/Drains / DIN	1/2"	
39		Water Cooling		
40	SHAFT SEALING	Mechanical Seal		
41		Manufr.	Burgmann	
42		Type Nº	BDTFO SHFV3-D-/70-E1-A2	
43		Classification code acc. API: Q2U22VMG-Q2AVMG		
44		Stuffing box packing		
45		Stuffing box pressure(eff.)	38	barg
46		Lip Seal	White oil	
47	MATERIALS	Casing and Covers	SS 1,4552	
48		Shaft	SS 1,4571	
49		Impeller	SS 1,4552	
50		Shaft sleeves	SS 1,4571	
51		Casing / Impeller Wear Rings	SS 1,4408	
52	DRIVER	E-motor		
53		Installed Power	10	kW
54		Rot.freq.	50	Hz
55		Turbine		
56		Connection		
57	TESTS	Hidrostatic test	21,5	bar a
58		NPSH test		m.w.c
59				
60	MISC.	Weight of Pump		kg
61		Driver weight		kg
62				
63	REMARKS	1) Oil lubricated antifriction bearings with constant level		
64		oiler.Trico Nº 30003.		
65				
66				

Pump Curve



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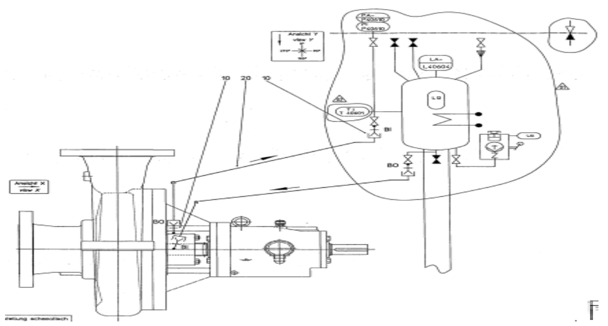

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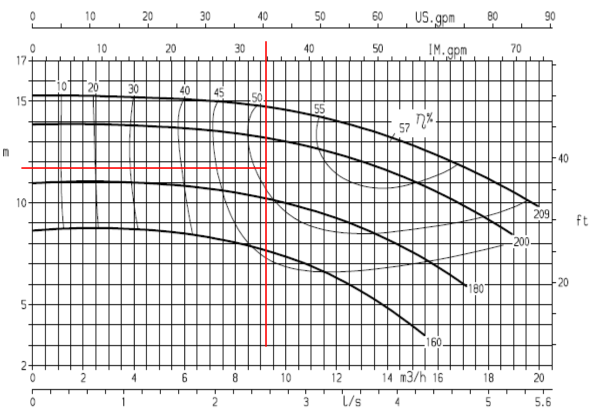
CENTRIFUGAL PUMP DATA SHEET

1	GENERAL	Manufacturer : KSB				
2		Type: CPK/HPK	Model: 40-200			
3		Item No.: P-102	No. of pumps required: 1	Code:		
5	OPERATING CONDITIONS	Liquid pumped: Caustic soda				
6		Pumping Temp.(P.T) :	40	ºC		
7		Density at P.T. :	1545	kg/m3		
8		Vapor Press. at P.T.:	0,12	bar a		
9		Viscosity at P.T. :	0,91	cP		
10		Capacity				
11		Normal	9,45	m^3/h		
12		Max.	10,4	m^3/h		
13		Suction Pressure (eff.) :	4,63	bar a		
14		Discharge Pressure(eff.)	6,26	bar a		
15		Differential Pressure	1,63	bar a		
16		Differential Head	10,7	m.l.c.		
17		N.P.S.H.Avail.	29,7	m.w.c		
18	DESIGN DATA	Design Temperature	80	ºC		
19		Max.Allow.working press.(eff)	2	bar a		
20		N.P.S.H.Req.(water)	0,90	m.w.c		
21		Rot.freq.	1450	min^{-1}		
22		Power at Shaft	0,84	kW		
23		Efficiency	51	%		
24		Min.Cont.flow	0,945	m^3/h		
25	CONSTRUCCION DETAILS	Arrangement	X	Horiz.		Vert
26		Impeller diameter	184	mm		
27		Number of Stages	1			
28		Cooling consumption:		m^3/s		
29		Bearings				
30		Type				
31		Lubrication	Oil			
32		Coupl.	N-EUPEX			
33		Type				
34		Lubr.:				
35		Nozzles	Mark	Nº	Dia.	Rating
36		Suction	DIN	1	2"	
37		Discharge	DIN	1	2"	
38		Vents/Drains				
39		Water Cooling				
40	SHAFT SEALING	Mechanical Seal				
41		Manufr.				
42		Type Nº				
43		Classification code acc. API:				
44		Stuffing box packing				
45		Stuffing box pressure(eff.)		barg		
46		Lip Seal				
47	MATERIALS	Casing and Covers	SS			
48		Shaft	SS			
49		Impeller	SS			
50		Shaft sleeves	SS			
51		Casing / Impeller Wear Rings	SS			
52	DRIVER	E-motor				
53		Installed Power	3	kW		
54		Rot.freq.	50	Hz		
55		Turbine				
56		Connection				
57	TESTS	Hidrostatic test		kg/cm^2g		
58		NPSH test		m.w.c		
59						
60	MISC.	Weight of Pump	38	kg		
61		Driver weight		kg		
62						
63	REMARKS					
64						
65						
66						

Pump Curve



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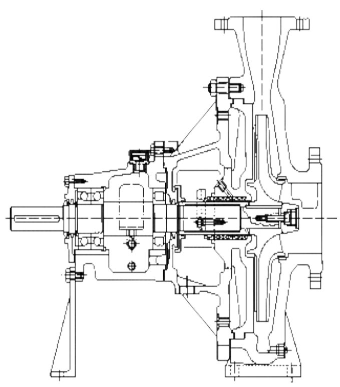

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HEAT EXCHANGER DATA SHEET

1	ITEM No.: E-102					
2	Service:					
3	Type: BEM	Position: Horitzontal	Total surface / unit:	14,6	(m^2)	
4	No. Shell:					

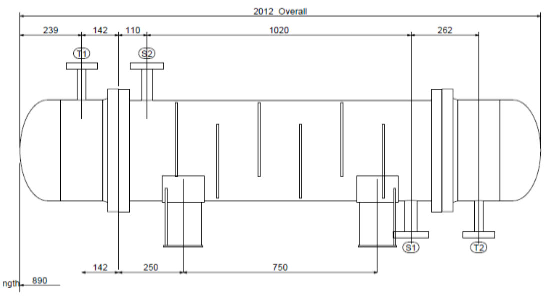
	PERFORMANCE OF UNIT					
6			Shell side		Tube side	
7			Inlet	Outlet	Inlet	Outlet
8	Fluid name		Carbon Tetrachloride		Chlorine	
9	Fluid total flow	kg/s	4,07		1,44	
10	Vapour	kg/s	0	0	0	0
11	Liquid	kg/s	4,07	4,07	1,44	1,44
12	Steam	kg/s	0	0	0	0
13	Water	kg/s				
14	Temperature	°C	38	42	55	45
15	Density (L/V)	kg/m^3	1549,62	1540,75	1307,56	1337,73
16	Viscosity (L/V)	mPa s	0,7816	0,7438	0,2945	0,3062
17	Vapour molecular weight					
18	Specific heat (L/V)	kJ/kg K	0,885	0,904	1,032	1,007
19	Thermal conductivity (L/V)	W/ m K	0,1037	0,1009	0,1651	0,1664
20	Latent heat	kJ/kg				
21	Pressure	kg/cm^2 (g)	4,5		7,7	
21	Pressure	kg/cm^2 (g)	0,18		0,02	
22	Pressure drop (allowable / calculated)	kg/cm^2	0,7	0,025	0,5	0,0213
23	Fouling resistance	m2 K/W	0,00042		0,00035	
24	**Heat exchanged:**	kW	14,7			
25	**Heat transfer rate** (W/m2 K)	Fouled: 111,8		Clean: 123,5		

	CONSTRUCTION PER SHELL					
27	Codes:		**Shell side**	**Tube side**		
28	Design pressure	bar	8	15		
29	Design temperature	°C	80	75		
30	No. of passes		1	1		
31	Stress relief					
32	Radiograph.					
33	Corrosion allowance	mm				

		Service	Mark	Dia.	Rating
34	Nozzles	Service	Mark	Dia.	Rating
35		Chlorine intlet	T1	1 1/2"	#300
36		Refrigeration outlet	S2	2 1/2"	#300
37		Refrigeration intlet	S1	3 1/2"	#300
38		Chlorine outlet	T2	1 1/2"	#300
39					
40					
41					
42					
43					

	MATERIALS			
45		Dia.	Thick. (mm.)	Spec. Mat.
46	Shell:	508	19,05	CS
47	Channel:	ASTM A-516 Grade 70		
48	Tubesheets:			
49	Baffles: nº / mat.		6	CS
50	Baffles spacing:		160	mm.
51				
52	Tubes:			
53	Nº	158		
54	OD	1	inches	
55	BWG:	12		
56	Length	1,25	mm.	
57	Pitch:	31,5	☐	
58				
59				
60				
61				
62				
63	NOTES:			
64				
65	(*) All mesures in the picture are			
66	represented in meters			

SKETCH



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1	ITEM No.: E-103					
2	Service:					
3	Type: BEM	Position: Horitzontal	Total surface / unit:	22,2	(m^2)	
4	No. Shell:					

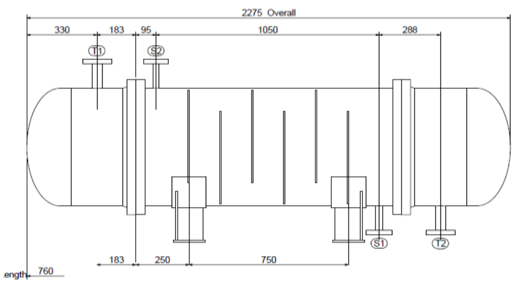
	PERFORMANCE OF UNIT		Shell side		Tube side	
7			Inlet	Outlet	Inlet	Outlet
8	Fluid name		Water		Carbon Tetrachloride	
9	Fluid total flow	kg/s	0,44		4,07	
10	Vapour	kg/s	0	0	0	0
11	Liquid	kg/s	0,44	0,44	4,07	4,07
12	Steam	kg/s	0	0	0	0
13	Water	kg/s				
14	Temperature	°C	27	35	42	38
15	Density (L/V)	kg/m^3	997,94	996,09	1540,75	1549,62
16	Viscosity (L/V)	mPa s	0,856	0,7196	0,7435	0,7801
17	Vapour molecular weight					
18	Specific heat (L/V)	kJ/kg K	4,191	4,189	0,904	0,899
19	Thermal conductivity (L/V)	W/ m K	0,6031	0,6135	0,1009	0,017
20	Latent heat	kJ/kg				
21	Pressure	kg/cm^2 (g)	4,5		4,5	
21	Pressure	kg/cm^2 (g)	0,03		0,03	
22	Pressure drop (allowable / calculated)	kg/cm^2	0,7	0,014	0,5	0,0490
23	Fouling resistance	m2 K/W	0,0004		0,00042	
24	**Heat exchanged:**	kW	14,8			
25	**Heat transfer rate** (W/m2 K)	Fouled: 75,2		Clean: 80,6		

	CONSTRUCTION PER SHELL		Shell side	Tube side
27	Codes:		Shell side	Tube side
28	Design pressure	bar	8	8
29	Design temperature	°C	80	80
30	No. of passes		1	1
31	Stress relief			
32	Radiograph.			
33	Corrosion allowance	mm		

		Service	Mark	Dia.	Rating
34	Nozzles	Service	Mark	Dia.	Rating
35		Carbon Tetrachloride intlet	T1	2 1/2"	#300
36		Refrigeration outlet	S2	1 1/2"	#300
37		Refrigeration intlet	S1	1 1/2"	#300
38		Carbon Tetrachloride outlet	T2	2 1/2"	#300
39					
40					
41					
42					
43					

	MATERIALS	Dia.	Thick. (mm.)	Spec. Mat.
46	Shell:	609,6	19,05	CS
47	Channel:	ASTM A-516 Grade 70		
48	Tubesheets:			
49	Baffles: nº / mat.		6	CS
50	Baffles spacing:		150	mm.
51				
52	Tubes:			
53	Nº	240		
54	OD	1	inches	
55	BWG:	12		
56	Length	1,25	mm.	
57	Pitch:	31,5	☐	
58				
59				
60				
61				
62				

SKETCH



63 NOTES:

64

65 (*) All mesures in the picture are

66 represented in meters

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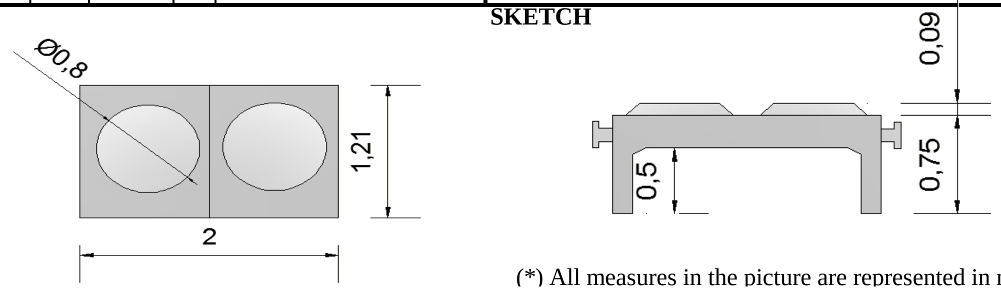
TEM No **E-105**			
Service: Refrigeration of recirculated chlorine			
No. of bundles: 2			
Bundle surface (finned/bare): 0,5	m^2		
Unit surface (finned/bare): 1,9	m^2		
OPERATING CONDITIONS. TUBE SIDE			
Fluid: Chlorine		**Inlet**	**Outlet**
Fluid total flow	kg/h	5184	
Vapour	kg/h	-	-
Liquid	kg/h	5184	5184
Steam	kg/h	-	-
Noncondensables	kg/h	-	-
Temperature	°C	55	45
Density (L)	kg/m^3	1296	1358
Viscosity (L)	cp	0,0272	0,0269
Vapour molecular weight		-	-
Specific Heat (L/V)	kcal/kg.°C	0,509	0,509
Thermal Conductivity (L/V)	kcal/h.m.°C	0,142	0,142
Latent heat	kcal/kg	-	
Pressure	kg/cm^2 (g)	8	
Velocity (Calculated)	m/s	0,52	
Pressure Drop (Calculated)	kg/cm^2	0,13	
Fouling Resistance (min)	$h.m^2.°C/kcal$	4,90E-05	
OPERATING CONDITIONS. AIR SIDE			
Air Quantity (total/per fan)	(kg/h)	7150	
Temperature (in/out)	°C	32	47
Altitude	(m.)	3	
Power (total/per Fan)	kW	-	
Heat Exchanged: 26390	(kcal/h)		
Heat Transfer Rate 2371	(kcal/h.m2.°C)		
DESIGN CONDITIONS			
Design Pressure	kg/cm^2	15	
Design Temperature	°C	60	
Corrosion Allowance	mm	1,0	
Applicable Codes:		Bundle Weight -empty (kg.)	
Tubes	**Fins**	**Header**	
No./Bundle: 56	No./inch: 11	Material: Acero al carbono ASTM-A-515	
Materia ASTM A516 Grade70	Materia Al. ASTM B-209	No. Rows: 7	
OD 1 " BWG 12	OD 2,25 "	No. Passes: 1	No. Tubes/pass 56
Length: 2 m	Thickness: 0,016"	No.Tubes 56	
Pitch: Δ	Type: by expansion	Nozzles 2	
		Size and rating (inlet/outlet) /	
MECHANICAL EQUIPMENT		**STEAM COIL**	
Fans	**Drivers**	Steam Coil Yes X No	
No. 2	No. 1	No. tubes/Bundle:	Steam (kg/h)
Draft	Motor type: IP 54	Material:	Op. Pressure (kg/cm^2)
Diam.: 0,8m No. Blades 4	Power (kW): -	OD BWG	Op. Temperature (°C)
Blade material: Aluminium	Frequency (Hz): 60	Length:	Design Pressure (kg/cm^2)
Power/fan (kW) -	Voltage (V): 400		Design Temp. (°C)
Variable Speed Yes X No			

SKETCH



(*) All measures in the picture are represented in meters.

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GENERAL	
Manufacturer:	
Item: C-101	
Service: Chlorine absorption	
Type: Absorption column	

OPER. CONDIT.

Gas product	Chlorine
Liquid product	Soda solution
Temper.	30 - 60 ºC
Presure	1 kg/cm^2 g
Liquid Density	1220 kg/m^3
Liquid Viscosity	1 cP
Tray Number (Bottom Tray=No.1)	7
Tower Inside Diamenter	953 mm.
Tray Spacing	- mm.
Max. ΔP per Tray	- kg/cm^2
Minimum Area/Downcomer	- m^2
Valves, Bubble Caps / Tray	-
Perforations / Tray	-

DESIGN DATA

Des.Pr.(eff.)		2 kg/cm^2g			
Des.Temp.		100 ºC			
Liquid Density		2160 kg/m^3			
Design Range		- %			
Hydr.Test		2,6 kg/cm^2g			
Code:		ASME Code Section VIII			
Corr.Allow.mm: Shell / Heads		1 / 1 mm.			
Joint Efficiency:		90 %			
Stress.Rel.:		Yes		No	
Radiograph:	X	Yes		No	
Sandblast:	X	Yes		No	
Paint:	X	Yes		No	
Insulation:		Yes	X	No	
Fireproofing:		Yes	X	No	
Wind Load:		36 kg/m^2			
Seismic:		Yes	X	No	
Wt.Empty:		600 kg			
Wt.Full Water:		3460 kg			

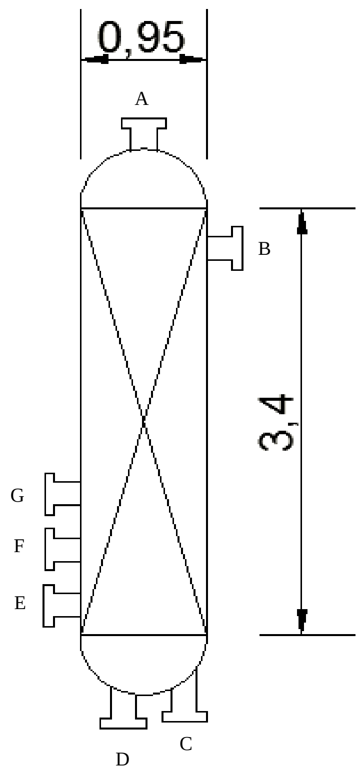
TRAYS & INTERNALS

Tray No.	Diam.	Spacing	Material
Thru - to -	-	-	-
Thru - to -	-	-	-
Thru - to -	-	-	-
Thru - to -	-	-	-
Contact Device: -			
	Bubble Caps -		
	Valves -		
	Perfor. -		
Packing: Ceramic Pall rings			
Demister: -			

MATERIAL SPECIF.

	Thick. (mm.)	Mat'l Class
Shell-Top	25	Reinforced fiberglass polyester
Intermed	25	
Bottom	25	
Head-Top	25	Reinforced fiberglass polyester
Intermed	25	
Bottom	25	
Bottom	25	Reinforced fiberglass polyester
Intermed	25	
Bottom	25	

TOWER SKETCH



NOZZLE

Service	Mark	No.	Size (")	Rating	Service	Mark	No.	Size	Rating
Residual gas outlet	A	J-125	1 1/4	150#					
NaOH solution inlet	B	J-124	4	150#					
Blind flange	C	J-123	-	150#					
Product outlet	D	J-122	5	150#					
Low level indicator	E	J-121	-	150#					
Gas chloritte inlet	F	J-120	2 1/2	150#					
High level indicator	G	J-119	-	150#					

NOTES:

(*) All measures in the picture are represented in meters.

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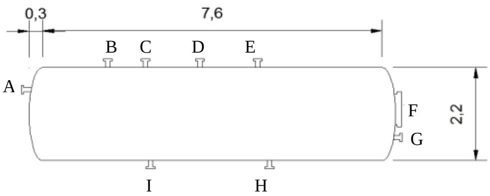
DRUM DATA SHEET

1	GENERAL	Manufacturer:	-			
2		Item:	T-102			
3		Description:	Storage of NaOH solution to feed C-101.	Position:	X Horiz.	Vertical
4	OPERATING	Product:	Caustic soda solution(1)			
5		Operating Pressure (eff.)	1	barg		
6		Operating Temperature	20-55	ºC		
7		Liquid Density	1178	kg/m^3		
8	DESIGN DATA	Design Pressure (eff.)	2	barg		
9		Design Temperature	80	ºC		
10		Hidrostatic Test (eff.)	2,86	kg/cm2g		
11		Corr. Allow. Shell / Heads	1	mm		
12		Joint Eff. Shell / Heads	0,9			
13		Code:	ASME code			
14		Radiograph:	Total			
15		Stress Relieve:	Yes X	No		
16		Seismic:	Yes	No X		
17		Wind Load:	130	km/h		

			Thickness	Mat´l Class
18	MATERIALS		Thickness	Mat´l Class
19		Shell	1,75 mm	Reinforced fiberglass polyester
20		Heads	1,80 mm	Reinforced fiberglass polyester
21		Lining	- mm	
22		Nozzle Necks		Reinforced fiberglass polyester
23		Flanges		Tongue and groove -

25	CONSTRUCTION	Shell	2,2 m	3,2	Reinforced fiberglass pol.	
26		Heads	(3).	-	Reinforced fiberglass pol.	
27		Insulation:	Yes		No	X
28		Fireproofing:	Yes		No	X
29		Sandblast:	Yes	X	No	
30		Paint:	Yes	X	No	
31		Wt. Empty:	730	kg		
32		Wt. Full mixure:	37300	kg		



	NOZZLE SCHEDULE	Service	Mark	Joint name	Size (")	Rating
33		Service	Mark	Joint name	Size (")	Rating
34		Bottom column product entra	A	J-126	5	150 #
35		Pressure Relieve System	B	J-127	3 1/2	150 #
36		Air supply	C	J-128	1 1/2	150 #
37		Soda solution entrance	D	J-129	6	150 #
38		Blind flange	E	J-130	-	150 #
39		Manhole	F	H-102	26	150 #
40		Level indicator	G	J-131	-	150 #
41		Product outlet	H	J-132	4	150 #
42		Product column supply	I	J-133	4	150 #
43						
44						
45						
46						
47						
48						

NOTES:

(1) The tank has a recirculation with C-101, at the begining, it contains a NaOH solution to feed C-101, the bottom products of the column will return to T-102. So, by the end of the process it will contains a mixure of NaOH, H2O, NaCl and NaClO.

(2) Single weided butt joint with backing strip which remains in place after after welding.

(3) Torisferic heads (korbogen), Φ = 2,2m; r2 = 0,34m

(*) All measures in the picture are represented in meters.

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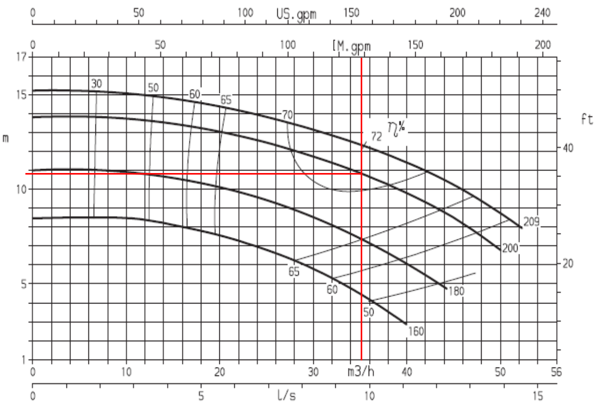
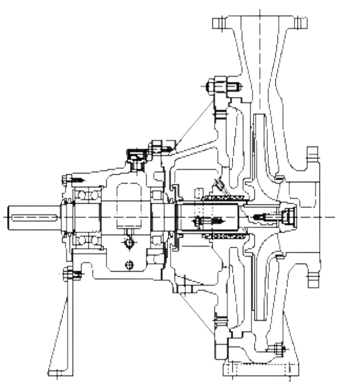
CENTRIFUGAL PUMP DATA SHEET

1	GENERAL	Manufacturer :	KSB			
2	GENERAL	Type:	CPK/HPK	Model:	50-200	
3	GENERAL	Item No.:	P-103A/B	No. of pumps required:	2	Code:
5	OPERATING CONDITIONS	Liquid pumped:	Caustic soda			
6	OPERATING CONDITIONS	Pumping Temp.(P.T) :	40	ºC		
7	OPERATING CONDITIONS	Density at P.T. :	1219	kg/m3		
8	OPERATING CONDITIONS	Vapor Press. at P.T.:	0,07	bar		
9	OPERATING CONDITIONS	Viscosity at P.T. :	0,358	cP		
10	OPERATING CONDITIONS	Capacity				
11	OPERATING CONDITIONS	Normal	35,5	m^3/h		
12	OPERATING CONDITIONS	Max.	39,05	m^3/h		
13	OPERATING CONDITIONS	Suction Pressure (eff.) :	2,15	bar a		
14	OPERATING CONDITIONS	Discharge Pressure(eff.)	3,46	bar a		
15	OPERATING CONDITIONS	Differential Pressure	1,31	bar a		
16	OPERATING CONDITIONS	Differential Head	10,9	m.l.c.		
17	OPERATING CONDITIONS	N.P.S.H.Avail.	9,65	m.w.c		
18	DESIGN DATA	Design Temperature	80	ºC		
19	DESIGN DATA	Max.Allow.working press.(eff)	2	bar a		
20	DESIGN DATA	N.P.S.H.Req.(water)	1,10	m.w.c		
21	DESIGN DATA	Rot.freq.	1450	min^{-1}		
22	DESIGN DATA	Power at Shaft	1,81	kW		
23	DESIGN DATA	Efficiency	71	%		
24	DESIGN DATA	Min.Cont.flow	3,55	m^3/h		
25	CONSTRUCCION DETAILS	Arrangement	X	Horiz.		Vert
26	CONSTRUCCION DETAILS	Impeller diameter	200	mm		
27	CONSTRUCCION DETAILS	Number of Stages	1			
28	CONSTRUCCION DETAILS	Cooling consumption:		m^3/s		
29	CONSTRUCCION DETAILS	Bearings				
30	CONSTRUCCION DETAILS	Type				
31	CONSTRUCCION DETAILS	Lubrication	Oil			
32	CONSTRUCCION DETAILS	Coupl.	N-EUPEX			
33	CONSTRUCCION DETAILS	Type				
34	CONSTRUCCION DETAILS	Lubr.:				
35	CONSTRUCCION DETAILS	Nozzles	Mark	Nº	Dia.	Rating
36	CONSTRUCCION DETAILS	Suction	DIN	1	3 1/2"	
37	CONSTRUCCION DETAILS	Discharge	DIN	1	3 1/2"	
38	CONSTRUCCION DETAILS	Vents/Drains				
39	CONSTRUCCION DETAILS	Water Cooling				
40	SHAFT SEALING	Mechanical Seal				
41	SHAFT SEALING	Manufr.				
42	SHAFT SEALING	Type Nº				
43	SHAFT SEALING	Classification code acc. API:				
44	SHAFT SEALING	Stuffing box packing				
45	SHAFT SEALING	Stuffing box pressure(eff.)		barg		
46	SHAFT SEALING	Lip Seal				
47	MATERIALS	Casing and Covers	SS			
48	MATERIALS	Shaft	SS			
49	MATERIALS	Impeller	SS			
50	MATERIALS	Shaft sleeves	SS			
51	MATERIALS	Casing / Impeller Wear Rings	SS			
52	DRIVER	E-motor				
53	DRIVER	Installed Power	3	kW		
54	DRIVER	Rot.freq.	50	Hz		
55	DRIVER	Turbine				
56	DRIVER	Connection				
57	TESTS	Hidrostatic test		kg/cm^2g		
58	TESTS	NPSH test		m.w.c		
59	TESTS					
60	MISC.	Weight of Pump	38	kg		
61	MISC.	Driver weight		kg		
62	MISC.					
63	REMARKS					
64	REMARKS					
65	REMARKS					
66	REMARKS					

Pump Curve



Gen.Arr.Drawing



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HEAT EXCHANGER DATA SHEET

1	ITEM No.: **E-104**					
2	Service: Refrigeration of soda solution to C-101.					
3	Type: late exchang	Position: /	Total surface / unit:	102	(m^2)	
4	No. Shell:					

	PERFORMANCE OF UNIT					
6			**Hot fluid**		**Cold fluid**	
7			**Inlet**	**Outlet**	**Inlet**	**Outlet**
8	Fluid name		Soda solution		Water	
9	Fluid total flow	kg/h	43308		77954	
10	Vapour	kg/h	-	-	-	-
11	Liquid	kg/h	43308	43308	77954	77954
12	Steam	kg/h	-	-	-	-
13	Temperature	°C	60	42	27	37
14	Density (L/V)	kg/m^3	1219		997,9	996,1
15	Viscosity (L/V)	mPa·s	1,54	2,43	0,856	0,72
16	Vapour molecular weight		-	-	-	-
17	Specific heat	kJ/kg.K	4,18		4,19	4,19
18	Thermal conductivity	W/m.K	0,4657		0,603	0,614
19	Latent heat	kJ/kg	-		-	
20	Inlet pressure	bar	2,0		4,5	
21	Velocity (allowable / calculated)	m/s	0,24		0,53	
22	Pressure drop (allowable / calculated)	bar	0,70 / 0,15		0,70 / 0,28	
23	Fouling resistance	m^2.K/W	0,003		0,0004	
24	**Heat exchanged:**	kW	905,1			
25	**Heat transfer rate**	(W/m2.K)	264			

	PLATE SPECIFICATION					
27	Codes:		ASME SECTION VII Div. 1			
28	Design pressure	bar	10	Equipment heigh	m	1,20
29	Design temperature	°C	180	Total exchange surface	m2	60
30	No. Of plates	-	180	Distance between plates	mm	5
31	Plate exchange surface	m2	0,34	Plates pitch	mm	5
32	Equipment width	m	0,50	Plate thickness	mm	0,4
33	Equipment longitud	m	1,70			
34						
35						
36						

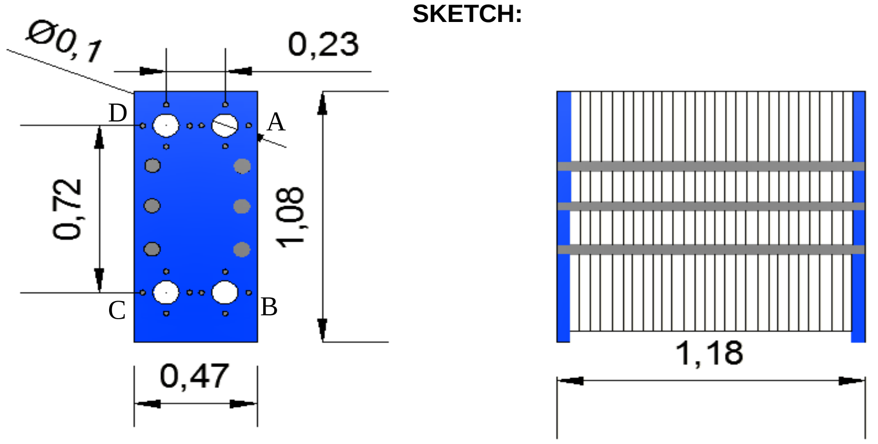
37	Nozzles	Service	Mark	Joint name	Diameter (")	Rating
38		Hot fluid inlet	A	J-134	4	300 #
39		Hot fluid outlet	B	J-137	4	300 #
40		Cold fluid inlet	C	J-135	6	300 #
41		Cold fluid outlet	D	J-136	6	300 #
42						
43						

	MATERIALS	
45	Plate:	Alloy 254 SMO
46	Frameplate	Mild steel
47	Nozzles:	EPDM
48	Gaskets:	Viton
49		
50		

NOTES:

(*) All measures in the picture are represented in meters.

SKETCH:



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4.3. Project and installation description

Chlorite installation produces chlorine. At the moment, it is being studied the implementation of a storage area in order to determine whether variable production of chlorine is economically viable. The company usually supplies 10 t/h to its customers. The plant production, cannot be stopped, so there is a minimum flow production, which is 2 t/h, and the maximum production capacity of the plant is 20 t/h. So, despite the implementation of the variable production, these requirements have to be accomplished.

This project is focused on the design of the chlorine storage area of *Chlorite*. This zone contains one storage tank (T-101) which works at 15 ºC/4,88 barg and receives the product liquefied from the process plant.

To accomplish the product supply to the clients, it is necessary to design a piping system, which contains two main supply pipes; one to the road tanker and another to the neighborhood clients. To impulse the flow to both pipes, it is necessary to install a pump system composed of two pumps (P-101A/B); one of them used in case the other fails.

The tank is also provided with a refrigeration system, which will work in case the tank experiences a big temperature increment (E-102 and E-103). Taking into account that chlorine reacts with water generating hydrochloric acid, which is a high corrosive substance, it is necessary to refrigerate the chlorine using another substance. The selected one has been carbon chloride due to its properties, and, at the same time, this substance is refrigerated with water in E-103. Chlorine enters the tube side of the heat exchanger E-102 at 55 ºC/7,70 bar and is cooled to 45 ºC/7,68 bar. Despite the tank operates at 15 ºC, the refrigeration system has been designed to offer a proper operation at the worst situation. To refrigerate carbon tetrachloride it is necessary to install a second heat exchanger (E-103), as mentioned above. This one uses water in the shell side, which enters at 27 ºC/4,5 bar and is heated to 35 ºC/4,49 bar. Carbon tetrachloride enters to the tubes at 42 ºC/4,50 bar is and cooled to 38 ºC/4,45 bar. Between both exchangers there is one pump (P-102) installed, which ensures the circulation flow.

In case of external fire, the storage area has got installed an absorption system in order to minimize the amount of chlorine sent to the atmosphere, which finally is of 1 % of purity. The absorption column (C-101) works at 30-60 ºC temperature range and 1 bar. This system disposes of a caustic soda storage tank (T-102) and a plate heat exchanger (E-104), which refrigerates the outlet flow from the absorber that has to be recirculated to it in order to allow the desired absorption.

T-102 works at 20-55 ºC range and 1 bar, and E-104 water inlet has the same inlet conditions than those in E-103, meanwhile outlet conditions are 37 ºC/4,20 bar. Operating conditions of the mixture in E-104 are 60 ºC/2,00 bar inlet and 42 ºC/1,90 bar outlet.

In order to impulse the mixture from T-102 to C-101 there is installed a pump system (P-103A/B), which is composed of two pumps, as P-103A/B system.

5. SAFETY IN THE STORAGE UNIT DESIGN

In order to minimize risks and dangerous incidents that could occur in the plant, and which could damage workers, near populations and environment, it is vital to do a safety study of the storage unit. European and Spanish codes have been used to determine safety norms.

The Safety Manual of the chlorine storage unit done by *ME&S Engineering* is detailed below.

5.1. Process safety

5.1.1. Process safety standards

First of all, basic "Decalogue of standards" is specified, including basic rules and industrial hygiene, suitable for any kind of industrial installation. These standards are simple but not less important. Obviously, specific regulations for chlorine storage unit have been written.

- Maintain order and cleanliness in plants and environment. This fact and actuation with caution brings safety to work area.
- Correct or warn potentially dangerous or unsafe conditions.
- Do not operate machines or vehicles without being authorized to do so.
- Use appropriated tools to each activity and care for its conservation. Once the work is finished, leave them in the right place.
- Use the established protective clothes in each task and keep them in good conditions. Thus it is also necessary to wear personal protections where required and special equipment in high dangerous zones.
- Do not remove any warning sign without authorization.
- All wounds require attention. It is required to attend medical service or use first aid kit.
- Not play tricks at work; must respect others.
- Do not improvise; follow instructions, operation manuals and standards. If the procedure is unknown, must ask.
- Pay attention to the work carried out, especially in the final minutes of the workday. Rush is the best ally of accidents.

Moreover, it is forbidden to access to the plant without authorization or accreditation and smoking is only allowed in the habilitated zones.

5.1.2. Safety elements

The storage unit has been designed taking into account the process safety. For this reason, in addition to safety standards, fire prevention systems or emergency action plans, the storage unit has been designed following appropriated instructions and including safety elements.

- Chlorine tank has been provided with instrumentation and redundant control loops to prevent dangerous situations in the equipment. Pumps are duplicated in order to secure the chlorine supply to costumers; in case of the main pump fails, the second one will switch on.
- Chlorine storage unit will be located far enough from process area. That fact reduces flame propagation between equipment in case of fire or explosions.
- All equipment required have been designed following the instructions or codes specified in section 3.2.4.
- The storage unit has been provided with an absorption system where chlorine will be absorbed with soda solution in an absorption column in case of overpressure in the chlorine tank or other equipment with PSV valves installed.
- In order to protect equipment from overpressure, chlorine tank has a safety system compound by two rupture disks and two pressure relief valves. In case of overpressure, these elements will relieve pressure to chlorine column absorber.
- For the same reason, during loading operations, tankers are protected with a safety valve which, in case of overpressure, will discharge to column absorber too.
- Pipes every 120 L of product are provided with a safety bottle to prevent dangerous situations due to overpressure. For a detailed explanation see 5.1.5. *Pressure equipment protection*.
- In order to reduce the toxic cloud in case of chlorine leak, the chlorine tank has a bund with high walls (5 meters tall). In this way, the toxic cloud will be catched between bund walls retarding its expansion. The walls are provided with a deluge water system, which will create a provisional protective barriers to protect near workers. Finally, the storage zone will be wrapped with tall and leafy trees which will also slow down the toxic cloud expansion.
- Chlorine storage zone has several chlorine detectors located around equipment which, in case of toxic atmosphere, will activate the deluge water system.

5.1.3. Preliminary risk analysis

5.1.3.1. Hazard of substances

First of all, danger of the substances involved in the process (chlorine storage and absorption system) has been determined on the basis of various parameters. The classification is shown in the table.

Table 5.1.1. Substances properties (ref.7).

Properties	**Chlorine**	**Carbon tetrachloride**	**Caustic soda**	**Sodium hypochlorite**
CAS number	7782-50-5	56-23-5	1310-73-2	7681-52-9
Molecular weight [g/mol]	70,9	153,8	40,0	74,4
Classification	Toxic	Toxic Toxic for aquatic organisms	-	Toxic for aquatic organisms
Density @ 20ºC (kg/m^3)	1.427	1.520	2.100	1.300
Boiling point [ºC]	-34	76,5	1388	60,4
Ignition point [ºC]	-	-23	-	110
H phrases	315, 319, 331, 335, 400 and 410	301, 311, 331, 351, 372 and 412	290, 314, 315 and 319	290, 314, 335 and 410
R phrases	23-36/37/38-50	23/24/25-40-48/23-52/53-59	35	31-34
S phrases	(1/2-)9-45-61	(1/2-)23-36/37-45-59-61	(1/2-)26-37/39-45	(1/2-)28-45-50
Probit constant *a*[1]	-6,35	-	-	-
Probit constant *b*[1]	0,5	-	-	-
Probit constant *c*[1]	2,75	-	-	-
LD_{50} [mg/kg] rata	>5000	-	-	-
LC_{50} [mg/kg] rata	5,2 mg/l/4h	-	-	-
Vapor pressure @ 20ºC [kPa]	673	12,2	-	2,5

[1] Probit values are obtained from Probit table (ref.8)

5.1.3.2. Notification of Major Accidents (AG1)

Taking into account the danger of the chemical substances and knowing the total amount of each one in the storage unit, the Notification of Major Accidents (AG1) has been done and the results obtained demostrate the storage area is affected by high level toxicity due to large quantity of chlorine. Regarding to toxicity for aquatic organisms, the installation is not affected by high level nor low level. See Annex A.2.1 for more details related to AG1.

5.1.3.3. HAZOP study

HAZOP methodology has been used in order to evaluate the risks of the process. It has been applied including all equipment of the storage area (both tanks, absorption column, exchangers, pumps and pipes). All possible hazard scenarios involving these elements have been considered. Find in next pages the HAZOP study record sheet.

Key word	Deviation	Causes	Consequences	Safeguards
More	Level at tank T-101.	Failure of controller LICA-101. Indicates less level than real.	T-101 overfilled. Pressure increase. Catastrophic rupture with chlorine projection which affects people and environment.	LSHH-102 control valv inlet chlorin PSA-101 se valve VC- chlorine sup Rupture dis and pressu 101/102, rel
	Level at the bottom of C-101.	Failure of controller LICA-102. Indicates less level than real.	Column C-101 flood, with chlorine projection to the atmosphere.	The liquid atmosphere in the bund systems.
	Level at T-102.	Failure of indicator LSA-102, indicates less level than the real.	LSHH-103 will not close the pipe entrance, overfilled at T-102 is produced. Pressure increase. Catastrophic rupture with substance projection to the atmosphere.	PSV-105 liquid to the The liquid will be retai

Key word	Deviation	Causes	Consequences	Safeguards
	Level at road tanker TK-101.	Failure of FICQA-101. Indicates less level than the real.	TK-101 overfilled. Pressure increase. Catastrophic rupture with chlorine projection that affect people and environment.	Vent to th system C-10
Less	Level at T-101.	Failure of controller LICA-101. Indicates more level than real.	Pump P-101A/B cavitation. Possible seal breaks with chlorine projection which affects people and environment.	Alarm LSA which remo P101A/B m
	Level at the bottom of C-101.	Failure of controller LICA-102. Indicates more level than real.	No safety consequences.	
	Level at T-102.	Failure of indicator LSA-102, indicates more level than the real.	Pump P-103 cavitation and possible seal break and liquid projection to the atmosphere that has no safety consequences.	Liquid proj into the bun

Key word	Deviation	Causes	Consequences	Safeguards
	Level at road tanker TK-101.	Failure of FICQA-101. Indicates more than the real.	No safety consequences.	-
More	Flux at T-101.	Failure of controller LICA-101. Indicates less level than real.	T-101 overfilled. Pressure increase. Catastrophic rupture with chlorine projection which affects people and environment.	LSHH-102 control valv inlet chlorin PSA-101 se valve VC-1 inlet chlorin Rupture dis and pressu 101/102, rel
	Flux of caustic soda dilution to column C-101.	Control of failure of FICA-103. Indicates less level than real.	Column C-101 flood with chlorine projection to the atmosphere.	The liquid v atmosphere bund. Chl activate delu

Key word	Deviation	Causes	Consequences	Safeguards
	Entrance flow from the column C-101 to T-102.	Failure of indicator LSA-102. Indicates less level than real.	LSHH-103 does not close the entrance valve so T-101 will be overfilled. Pressure increase. Catastrophic rupture of the storage with product projection to the atmosphere.	PSV-105 re projected tc retained in detectors systems.
	Flux from column C-101 to T-102.	Failure of controller LICA-102. Indicates more level than real.	No safety consequences.	-
	Water refrigeration flux to E-104.	Failure of controller TICA-104.	Flow caustic soda enters C-101 at less temperature. No safety consequences.	-
	Flux to road tanker TK-101.	Failure of FICQA-101. Indicates less than the real.	TK-101 overfilled. Pressure increase. Catastrophic rupture with chlorine projection which affects people and environment.	Vent to th system C-10

Key word	Deviation	Causes	Consequences	Safeguards
Less	Flux at T-101.	Failure of controller LICA-101. Indicates more level than real.	Pump P-101A/B cavitation. Possible seal breaks with chlorine projection that affect to people and environment.	Alarm LS/ which remo P101A/B m
	NaOH flux to column C-101.	Failure of controller FICA-104. Indicates less flow than real.	Bad chlorine absorption, product projection which affects people and environment.	Activation alarm for chlorine QI/
	Flux in the fill of tank T-102.	Failure of indicator LSA-102. Indicates less flow than real.	Pump P-103 cavitation, possible seal break and liquid projection to the atmosphere that has no safety consequences.	Liquid proj bund.
	Flux from column C-101 to T-102.	Failure of controller LICA-102. Indicates less level than real.	Column C-101 flood with chlorine projection to the atmosphere. Pump P-103 cavitation, possible seal break and liquid projection to the atmosphere that has no safety consequences.	Liquid proj bund and it activated.

Key word	Deviation	Causes	Consequences	Safeguards
	Flux to road tanker TK-101.	Failure of FICQA-101. Indicates more flow than the real.	No safety consequences.	-
	Water refrigeration flux to E-104.	Failure of controller TICA-104.	Bad chlorine absorption, product projection which affects people and environment.	Activation alarm for chlorine QI
No	Flux at tank T-101.	Controller failure LICA-101. Indicates more level than real. Close the valve VC-101.	Pump P-103 cavitation, possible seal break and liquid projection to the atmosphere that has no safety consequences.	Liquid proj into the bun
	NaOH flux to column C-101.	Failure of controller FICA-104. Closes valve VC-111.	Bad chlorine absorption, product projection which affects people and environment.	Activation alarm for chlorine QI
	Flux in the fill of tank T-102.	Failure of indicator LSA-102. Indicates less	Pump P-103 cavitation, possible seal break and liquid projection to the atmosphere that has no safety	Liquid proj into the bun

Key word	Deviation	Causes	Consequences	Safeguards
		flow than real.	consequences.	
	Flux from column C-101 to T-102.	Failure of controller LICA-102. Indicates less level than real. Close valve VC-109.	Column C-101 flood with chlorine projection to the atmosphere. Pump P-103 cavitation, possible seal break and liquid projection to the atmosphere that has no safety consequences.	Liquid proj the bund. C activate delu
	Water refrigeration flux to E-104	Failure of controller TICA-104, it closes valve VC-110.	No caustic soda flow, bad chlorine absorption and product projection which affects people and environment.	Activation alarm for chlorine QIA
	Flux to road tanker TK-101.	Failure of FICQA-101, it closes VC-108.	No safety consequences.	-
More	Pressure at tank T-101.	Failure of controller PSA-101. Indicates less pressure than real.	Pressure increase. Catastrophic rupture with chlorine projection which affects people and environment.	PSA-102 in and opens valve VC-10 Rupture dis and pressu 101/102, rel

Key word	**Deviation**	**Causes**	**Consequences**	**Safeguards**
	Pressure at T-102.	Failure of controller LSA-102. Indicates less level than real	LSHH-103 does not close the entrance valve so T-101 will be overfilled. Pressure increase. Catastrophic rupture with storage substance projection to the atmosphere.	PSV-105 re projected to will be re activating th
	Pressure in road tanker TK-101.	Failure of FICQA-101. Indicates less pressure than real.	TK-101 overfilled. Pressure increase. Catastrophic rupture with chlorine projection which affects people and environment.	Vent to th system C-10
	Pressure in pipe.	Chlorine dam into the pipe with solar radiation.	Temperature and pressure increase. Possible pipe rupture with chlorine projection which affects people and environment.	Pressure re bottle SB-10

Key word	Deviation	Causes	Consequences	Safeguards
More	Temperature at tank T-101.	External fire.	Pressure increase. Catastrophic rupture with chlorine projection which affects people and environment.	PSA-101 w flow by FIC Rupture dis and pressu 101/102, rel
	Temperature at column C-101.	Refrigeration water supply to E-104 failure.	Chlorine bad absorption, with chlorine projection which affects people and environment.	Activation alarm for chlorine QI
	Temperature at tank T-102.	Refrigeration water supply to E-104 failure.	Pressure increase. Catastrophic rupture with stored substance projection to the atmosphere.	PSV-105 projected to will be retai
	Temperature in pipe.	Chlorine dam into the pipe and solar radiation.	Temperature and pressure increase. Possible pipe rupture with chlorine projection that affect people and environment.	Pressure rel bottle SB-10

Key word	Deviation	Causes	Consequences	Safeguards
Less	Temperature in tank T-101	Liquid relief and the material reaches -33ºC	Possibility of fragile rupture from the vessel with chlorine projection which affects people and environment.	Suitable r rupture.
Another composition		Water inlet	Hydrochloride acid formation, which will corrode all system in few minutes. Catastrophic rupture with acid hydrochloride projection which affects people and environment.	
Corrosion		Corrosion under insolation.	Possible chlorine leaks.	Annual revi of T-101.

5.1.3.4. Dow Fire and Explosion Index

Dow Index has been done in order to analyse the potential risk due to fire or explosion that may be on the storage area. Although the products on the site are not inflammable, this study includes toxicity and mitigation parameters. The Index has been calculated for the biggest and most dangerous equipment, T-101.

Table 5.1.2. Dow Fire and Explosion Index (ref. 9)

AREA / COUNTRY **Spain**	**Business group** ***Chlorite***	**LOCATION** **Tarragona**	**DATE**
SITE	**MANUFACTURING UNIT**	**PROCESS UNIT** **T-101**	
PREPARED BY:	**APPROVED BY: (Production Manager)**	**BUILDING**	
REVIEWED BY: (Management)	**REVIEWED BY: (Technology)**	**REVIEWED BY: (Safety/Environment)**	
MATERIALS IN PROCESS UNIT **Chlorine**			
STATE OF OPERATION **___ DESIGN___ START UP___ NORMAL OPERATION___ SHUTDOWN**		**BASIC MATERIAL(S) FOR MATERIAL FACTOR**	

MATERIAL FACTOR (See Table 1 or Appendices A or B) Note requirements when unit temperature over 140 ^{o}F (60 ^{o}C)		1
1. General Process Hazards	**Penalty Factor Range**	**Penalty Factor Used**
Base Factor	1,00	1,00
A. Exothermic Chemical Reactions	0,00 to 1,25	0,00
B. Endothermic Processes	0,00 to 0,40	0,00
C. Material Handling and Transfer	0,00 to 1,05	0,00
D. Enclosed or Indoor Process Units	0,00 to 0,90	0,00
E. Access	0,00 to 0,35	0,00
F. Drainage and Spill Control ___________	0,00 to 0,50	0,00
General Process Hazards Factor (F_1) (SUM A to F)		1,00
2. Special Process Hazards		
Base Factor	1,00	1,00
A. Toxic Material(s)	0,0 to 0,80	0,40
B. Sub-Atmospheric Pressure (< 500 mm Hg)	0,50	0,00
C. Operation In or Near Flammable Range ___ Inerted_x_ Not Inerted		
1. Tank Farms Storage Flammable Liquids	0,50	0,00
2. Process Upset or Purge Failure	0,30	0,00
3. Always in Flammable Range	0,80	0,00
D. Dust Explosion (See Table 3)	0,00 to 2,00	0,00
E. Pressure (See Figure 2) Operating Pressure ____ psig or kPa gauge Relief Setting ____ psig or kPa gauge		0,20
F. Low Temperature	0,0 to 0,30	0,00
G. Quantity of Flammable/Unstable Material		0,00
1. Liquids or Gases in Process (See Figure 3)		0,00
2. Liquids or Gases in Storage (See Figure 4)		0,00
3. Combustible Solids in Storage, Dust in Process (See Figure 5)		0,00
H. Corrosion and Erosion	0,00 to 0,75	0,75
I. Leakage – Joints and Packing	0,00 to 1,50	0,30
J. Use of Fired Equipment (See Figure 6)		0,00
K. Hot Oil Heat Exchange System (See Table 5)	0,00 to 1,15	0,00
L. Rotating Equipment	0,00 – 0,50	0,00
Special Process Hazards Factor (F_2) (A to L)		2,65
Process Unit Hazards Factor (F_1 x F_2) = F_3		2,65
Fire and Explosion Index (F_3 x MF = F&EI)		2,65

Table 5.1.3. Loss control credit factors.

LOSS CONTROL CREDIT FACTORS					
1. Process Control Credit Factor (C_1)					
Feature	**Credit Factor Range**	**Credit Factor Used**	**Feature**	**Credit Factor Range**	**Credit Factor Used**
a. Emergency Power	0,98	1,00	f. Inert Gas	0,94 to 0,96	0,94
b. Cooling	0,97 to 0.99	0,99	g. Operating Instructions/ Procedures	0,91 to 0,99	0,96
c. Explosion control	0,84 to 0.98	1,00	h. Reactive Chemical Review	0.91 to 0.98	0,91
d. Emergency Shutdown	0,96 to 0.99	0,98	i. Other Process Hazard Analysis	0,91 to 0,98	0,91
e. Computer Control	0,93 to 0.99	0,99			
		C_1 Value	0,72		
2. Material Insulation Credit Factor (C_2)					
Feature	**Credit Factor Range**	**Credit Factor Used**	**Feature**	**Credit Factor Range**	**Credit Factor Used**
a. Remote Control Value	0,96 to 0,98	0,98	c. Drainage	0,91 to 0,97	0,91
b. Dump/Blowdown	0,96 to 0,98	0,96	d. Interlock	0,98	0,98
		C_2 Value	0,84		
3. Fire Protection Credit Factor (C_3)					
Feature	**Credit Factor Range**	**Credit Factor Used**	**Feature**	**Credit Factor Range**	**Credit Factor Used**
a. Leak Detection	0,94 to 0,98	1,00	f. Water Curtains	0,97 to 0,98	0,98
b. Structural Steel	0,95 to 0,98	0,98	g. Foam	0,92 to 0,97	1,00
c. Fire Water Supply	0,94 to 0,97	0,97	h. Hand Extinguishers/ Monitors	0,93 to 0,98	0,98
d. Special Systems	0,91	1,00	i. Cable Protection	0,94 to 0,98	1,00
e. Sprinkler Systems	0,74 to 0,97	0,81			
		C_3 Value	0,74		
Loss Control Credit Factor = C_1 x C_2 x C_3 =			0,44	(Enter on line 7 below)	

PROCESS UNIT RISK ANALYSIS SUMMARY		
1. Fire & Explosion Index.. ....(See Front)	2,65	
2. Radius of Exposure...(Figure 7)	0,68 m	
3. Area of Exposure...	1,45 m^2	
4. Value of Area of Exposure..		6,02 $MM
5. Damage Factor...(Figure 8)	0,43	
6. Base Maximum Probable Property Damage - (Base MPPD) [4 x 5].........................		2,59 $MM
7. Loss Control Credit Factor...................................(See Above)	0,44	
8. Actual Maximum Probable Property Damage - (Actual MPPD) [6 x 7].................		1,14 $MM

In Annex A.2.2 there are shown more details of DOW Index parameters and calculus methodology.

5.1.4. Determination of intervention and warning areas.

There have been considered few incidents that can be performed in the storage area, to determinate intervention and warning areas, the parameters that should be taken into consideration according to the Instruction 11/2010 SIE (ref.10) are:

- Meteorological conditions (see section 3.2.3.3)
- Type of substance involved in the accident.
- Operating conditions.
- Quantity released during the accident (this value is obtained from the software EFFECTS 8.1)
- Finally, preference order should be considerate according to the “Directriu Bàsica” (RD 1196/2003) (ref.11) AEGL>ERPG>TEEL.

As it has been mentioned, storage area of chlorine is affected by high toxic level due to the large quantity of chlorine stored. For this reason, consequences of possible failures of different equipment have been studied.

Chlorine values of AEGL (Acute Exposure Guideline Levels) are 0,5 mg/m^3 for AEGL-1 and 2,8 mg/m^3 for AEGL-2 and the reference time of the studied leak is 30 minutes. The value of AEGL-1 has been used to calculate the warning zone (ZA) and the value of AEGL-2 for the intervention zone (ZI) according to the criteria 2.3.1.3 from “Directriu Bàsica” (ref.11)

The software ALOHA 5.4.3 has been used to determinate the distances of toxic dispersion due to possible accidents.

Table 5.1.4. Results for intervention and warning areas.

Accident	**ZA [m]**		**ZI [m]**	
	4D	**2F**	**4D**	**2F**
Failure of the chlorine storage tank T-101. Instantaneous release of the complete inventory.	>10.000	>10.000	8.200	>10.000
Failure of the chlorine storage tank T-101. Continuous release of the complete inventory in 10 minutes at a constant rate of release.	>10.000	>10.000	8.200	>10.000
Failure of the chlorine storage tank T-101. Continuous release from a hole with an effective diameter of 10 mm.	100	3.000	411	1.100
Overfilled of the chlorine storage tank T-101.	>10.000	>10.000	8.600	>10.000
Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-1.	2.200	6.200	904	2.300
Leak of the pipe of chlorine 3”-CS-Cl_2-1 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	669	1.900	270	739
Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-5/30.	2.300	6.200	915	2.300
Leak of the pipe of chlorine 3”-CS-Cl_2-3 with an	679	2.000	274	746

effective diameter of 10% of the nominal diameter, a maximum of 50 mm.				
Catastrophic failure with full bore rupture of the largest connecting pipe of the pump P-101A.	5.900	>10.000	2.400	5.100
Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipe, a maximum of 50 mm, of the pump P-101A.	884	2.600	356	981
Full bore rupture of ten pipes simultaneously of chlorine of heat exchanger E-102.	188	565	77	217
Instantaneous release of the complet inventory of the road tanker TK-101.	>10.000	>10.000	6.200	9.900
Continuous release from a hole the size of the largest connection of the road tanker TK-101.	8.100	>10.000	3.300	6.400
Full fore rupture of the loading hose of the road tanker TK-101.	8.100	>10.000	3.300	6.400
Leak of the loading hose of the road tanker TK-101 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	697	2.000	281	766
Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-28.	2.700	7.400	1.100	2.700
Leak of the pipe of chlorine 3”-CS-Cl_2-28 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	823	2.500	332	935

The intervention zone of the worst accident that could occur in the storage unit of *Chlorite* (failure of the storage tank T-101) has been represented. As the image shows, the accident would concern more than 10 km of radius, which means that this substance has an important impact due to its toxicity. In this case, the accident would affect several cities as: Salou, Cap de Salou, Constanti, Vila-seca, la Canonja, Tarragona and also the theme park Port Aventura.

Figure 5.1.1. Intervention Zone in case of a failure of chlorine storage tank.

5.1.5. Pressure equipment protection

The chlorine storage unit includes different pressure equipment in order to maintain the product as liquid. For this reason, it is necessary to protect the equipment with pressure relief systems. In addition, since the stored product is a high toxic substance, it is extremely important to avoid accidental leaks and releases.

The design of the storage unit includes the following elements:

- Chlorine tank has a pressure relief system formed by a 3-way valve which carry the flow to one of the available rupture disks, followed by a pressure relief valve (PSV). In case of overpressure, rupture disk will burst and the PSV will relieve the required flow to return to operating pressure. Once the RD has burst, it is necessary to replace it for a new one. During the repair time, the 3-way valve will conduct the flow to the other relieve system (formed by the same kind of elements). In order to avoid chlorine releases, the relieved chlorine will be treated in an absorption column.
- Pipes every 120 liters of product are provided with a safety bottle which is connected to the main pipe. The bottle contains pressurized air at 5 bar, which is bigger than the normal operating pressure of line (4,8 bar), the air inside the bottle are insulated by an elastic membrane. In case of overpressure in the line, chlorine will expand entering into bottle, compressing the air and reducing the pressure in the pipe. When pipe returns to its normal operating conditions, the air pressure will be bigger than the chlorine pressure, so the elastic membrane will push chlorine to the pipe again.
- Soda solution tank, which belongs to the chlorine absorption system, has a pressure relief valve which, in case of overpressure due to solar radiation or external fire, will relieve the pressure by discharging the solution directly into atmosphere.

5.1.5.1. Rupture disks design

Pressure equipment protection is the most important element in the chlorine tank installation. It is very important to secure that the pressure relief valves (PSV) only discharge when necessary. For this reason, PSV are insulated from chlorine by a rupture disk.

In this way, the rupture disk will provide the chlorine tank with a complete safety system. First of all, allows it to discharge in case of overpressure and, at the same time, protects the pressure relief valves from slight pressure variations.

Taking into account that the rupture disks are followed by a pressure relief valve, the first safety element has been designed to discharge at lower pressure than the second are. Moreover, both elements have been designed to work properly in the worst situation, that is the fire case (taking into account that the tank has fire protection)

The next table shows the most important characteristics of the required disk (designed) and the elected disk, which has been selected from "Leser Catalog. Best availability safety valves and upstream bursting disks in combination" (ref. 12). Referring to the rupture disk holders, these have been selected from the catalogue "Continental disc Corporation. Union holder for standard or composite type rupture discs" (ref. 13)

Table 5.1.5. Disk rupture characteristics

Characteristic	**Designed disk**	**Elected disk**
Burst pressure [barg]	14,3	14,5
Burst temperature [ºC]	50	50
Operating ratio [%]	-	95
Nominal disk size [cm, diameter]	3,06	2,54 (1")
Disk area [cm^2]	7,35	5,06
Burst tolerance [%]	-	5
Disk type	-	Reverse type
Non fragmenting design	Yes	Yes
Rupture disk material	-	316L
Nominal holder size [in]	-	3
Holder rating	-	4000
Piping Schedule	-	80
Holder material	-	ASTM A-516

The complete explanation of the design procedure can be viewed at Annex A.2.3 of the same document and the specification sheet of the rupture disk is also available in section 5.1.5.3 *Specification sheets of pressure relieve systems.*

5.1.5.2. Pressure relieve valves design

Safety and pressure relief valves are automatic valves for keeping the pressure of an installation below a pre-established limit.

As mentioned above, this element has been designed in case of fire. In the storage area there are five pressure relief valves and chlorine tank has two of them; PSV-101 and PSV-102. Due to the high toxicity of the fluid stored, the chlorine released will be sent to the absorption column where it will be treat.

These pressure relief valves have their set point at 15 barg and are designed taking into consideration that T-101 has got fire protection.

Other pressure relief valves are PSV-103 and PSV-104, which are installed in refrigeration bottles in case that the double seal of pumps fails. These overpressure equipment have not been designed because it is not included in the project scope.

The last pressure relief valve is PSV-105, which is installed in the soda tank T-102 and has also been designed for the worst situation; fire case, taking into account that this tank has fire protection. The substance that T-102 contains is not dangerous neither for people nor environment, so in case of relief, the product will be released directly into the atmosphere. It has got the set point at 2 barg.

Orifice areas has been determined taking into account discharge flows and operating parameters. Finally, the required pressure relief valves have been chosen according to General Catalogue of Safety Valves (ref.14)

Table 5.1.6. Pressure relief valve size.

Item	Product	W [lb/h]	$A_{calculated}$ [cm^2]	$A_{selected}$ [cm^2]	Valve PSV
PSV-101/102	Chlorine	16.930	1,13	1,27	1’’ E 2’’
PSV-105	Caustic Soda	12.660	12,63	18,4	3’’ L 4’’

The complete explanation of the design procedure can be viewed in Annex A.2.4 of the same document and the specification sheet of all PSV are also available in 5.1.5.3 *Specification sheets of pressure relieve systems*.

5.1.5.3. Specification sheets of pressure relieve systems

Specification sheets of the rupture disk and both pressure relief valves designed can be viewed in the following pages.

RUPTURE DISK DEVICE SPECIFICATION SHEET	Sheet No.	1	Date	15/04/2014
	Requisition No.	-	Revised	
	Job No.	-	By	

General

1	Item Number		3	Service, Line, or Equip. No.	T-101
2	Tag Number	PRD-101/102	4	Design Code or Standard	ASME

Service Conditions (Include applicable units)

5	Vessel or Piping MWAP	15 barg
6	Fluid	Chlorine
7	Fluid State (initiating rupture)	Liquid
8	Fluid state (relieving conditions)	Gas
9	Requiered Relieving Capacity	27833 kg/h
10	Molecular Weight or Specific Gravity	70,9 g/mol
11	Viscosity at Relieving Temperature	4,482 kg/hm
12	Compressibility Factor (Z)	0,9867
13	Specific Heat Ratio	1,33
14	Normal Maximum Operating Pressure	15 barg
15	Normal Maximum Opertin Temperature	55 ºC
16	Pressure Fluctuations (Static, cyclic, pulsating)	Static
17	Superimposed Back Pressure	0 bar
18	Built-up Back Pressure	0 bar
19	Back Pressure	0 bar (*)
20	Inlet Vacuum Conditions	-
21	Outlet Vacuum Conditions	-
22	Disk Located Upstream of Valve (yes/no)	Yes
23	Disc Located Downstream of Valve (yes/no)	Yes
24	Nonfragmenting Design (yes/no)	Yes

Connections

25	Normal Pipe Size	1"	27	Flange Face (inlet/outlet)	Outlet
26	Flange Standard & Class	Machi-hembrada	28	Piping Schedule or Bore	40

Rupture Disk Holder			**Rupture Disk**		
29	Holder Tag No.	1	43	Nominal Disk Size	1"
30	Nominal Holder Size	2"	44	Calculated Disk Area	7,4 cm2
31	Design Type	ASME code	45	Elected Disk Area	5,1 cm2
32	Model Designator	2U Holders	46	Disk Type	Reverse type
33	Rating	4000	47	Model Designator	BT-KUB
34	Piping Schedule or Bore	80	48	Quantity Required	2
35	Quantity Required	4	49	Specified Burst Temperature	50ºC
36	Holder Material (inlet)	ASTM A-516	50	Specified Burst Pressure	14,5 bar
37	Holder Material (outlet)	Grado 70	51	Max Marked Burst Pressure	15,2 bar
38	Gauge Tap (yes/no) & Size	No	52	Min Marked Burst Pressure	13,8 bar
Accessories			53	Operating ratio	95%
39	Studs & Nuts (y/n) & Matl	No	54	Burst tolerance	5%
40	Jackscrews (yes/no)	No	55	Max Flow Resistance K (L/D	1
41	Telltale Assy (y/n) & Matl	No	56	Rupture Disk Materials	316L
42	Other	-	57	Bursting Element	316L
Observations	(*) To be defined		58	Sealing Membrane	316L
			59	Manufacter's Data	

ME&S Engineering

REV.	*DATE*	*PREP.*	*APPR.*
		Sara C.	Ana G.

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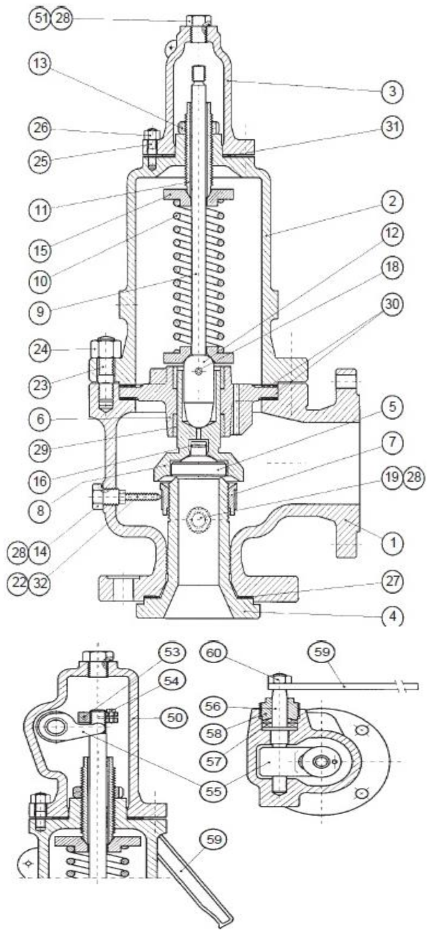
Departament d'Enginyeria Química

RELIEF VALVES

REVISION DATE

	ITEM No.	101
	TAG No.	PSV-101
	VALVE SERVICE	GAS
		TANK
	MANUFACTURER	NACIONAL
	TYPE No.	3-5211
	NUMBER VALVES REQ'D	1
	NORMAL SYSTEM PRESS., [BARG]	5,80
	NORMAL SYSTEM TEMPERATURE, [ºC]	15,0
	GOVERNING UPSET CONDITION	FIRE
	ACCUMULATION, PERCENT	10
VALVE SIZING CONDITIONS	FLOWING FLUID	Chlorine
	FLOW QUANTITY, [Kg/h]	7677,5
	FLOW SPECIFIC GRAVITY	
	FLOW TEMPERATURE, [ºC]	55,0
	FLOW VISCOSITY, [mPa s]	0,2945
	SET PRESSURE, [barg]	15,00
	ACCUM. INLET PRESSURE, [Kg/cm2]	16,5
	BACK PRESS, [Kg/cm2 G]	<10%
	CALCULATED ORIFICE AREA, [cm2]	1,14
CONSTRUCTION – SIZE/RATING	NOMINAL SIZE INS.	E
	ORIFICE AREA, [cm2]/VALVE	1,27
	TOTAL ACTUAL AREA, [cm2]	1,27
	BODY CONN. & RATING - INLET	1"-150
	OUTLET	2"-150
CONSTRUCTION – MAT'L	BODY	A351 CF 8M
	BONNET	AISI 316
	SPRING	AISI 316
CONSTRUCTION – ACCESSORIES	RADIATING BONNET	NO
	STYLE TOP	NO
	LIFTING GEAR - REG./PACKED	NO
	TEST ROD	NO



REMARKS:

Item	Name	Material	Item	Name	Material
1	Body	A351 CF 8M	25	Studs	A193 B8
2	Bonnet	AISI 316	26	Nuts	A 194 Gr8
3	Cap	A351 CF 8M	27	Gasket	Compressed Fibres
50	Lever Cap	A351 CF 8M	28	Gasket	Compressed Fibres
10	Spring	AISI 316	29	Bushing	---
4	Nozzle	ASI 304	30	Gasket	Compressed Fibres
5	Disc	ASI 304	31	Gasket	Compressed Fibres
6	Guide	AISI 316	32	Nut	AISI 304
7	Adjusting Ring	AISI 316	33	Bellows	AISI 316 L
8	Disc Holder	AISI 316	34	Gasket	Compressed Fibres
9	Stem	AISI 316	51	Plug	AISI 304
11	Adjusting Screw	AISI 316	53	Release Nut	AISI 316
12	Push Rod	17-4-PH	54	Screw	AISI 304
13	Nut	AISI 316	55	Cam	AISI 316
14	Lock Screw	AISI 304	56	Cam Shaft	AISI 316
15	Spring Button	AISI 316	57	Packing	Compressed Fibres
16	Disc Retainer	AISI 316	58	Packing Gland	AISI 316
18	Elastic Pin	AISI 302	59	Lever	C.S.
19	Plug	AISI 304	60	Nut	AISI 304
22	Lock Stud	AISI 304			
23	Studs	A 193 B8			
24	Nuts	A 194 Gr8			

Remarks (1) Racing face

ME&S Engineering

REV.	DATE	PREP.	APPR.
		Ana G.	Sara C.

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Departament d'Enginyeria Química

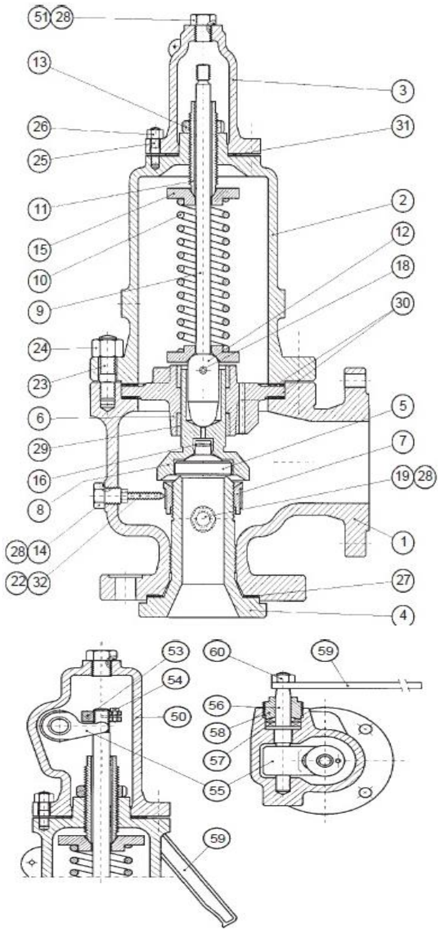
RELIEF VALVES

REVISION DATE

ITEM No.	105
TAG No.	PSV-105
VALVE SERVICE	LIQUID
	TANK
MANUFACTURER	NACIONAL
TYPE No.	3-5211
NUMBER VALVES REQ'D	1
NORMAL SYSTEM PRESS., [BARG]	1,00
NORMAL SYSTEM TEMPERATURE, [ºC]	60,0
GOVERNING UPSET CONDITION	FIRE
ACCUMULATION, PERCENT	10

VALVE SIZING CONDITIONS	FLOWING FLUID	Caustic soda
	FLOW QUANTITY, [Kg/h]	5743
	FLOW SPECIFIC GRAVITY	
	FLOW TEMPERATURE, [ºC]	110,0
	FLOW VISCOSITY, [mPa s]	
	SET PRESSURE, [barg]	2,00
	ACCUM. INLET PRESSURE, [Kg/cm2]	2,20
	BACK PRESS, [Kg/cm2 G]	<10%
	CALCULATED ORIFICE AREA, [cm2]	12,63

CONSTRUCTION	SIZE/RATING	NOMINAL SIZE INS.	L
		ORIFICE AREA, [cm2]/VALVE	18,40
		TOTAL ACTUAL AREA, [cm2]	18,40
		BODY CONN. & RATING - INLET	3"-150
		OUTLET	4"-150
	MAT'L	BODY	A 216 WCB
		BONNET	A.C./C.S.
		SPRING	A.C./C.S.
	ACCESSORIES	RADIATING BONNET	NO
		STYLE TOP	NO
		LIFTING GEAR - REG./PACKED	NO
		TEST ROD	NO



REMARKS:

Item	Name	Material	Item	Name	Material
1	Body	A351 CF 8M	25	Studs	A193 B8
2	Bonnet	AISI 316	26	Nuts	A 194 Gr8
3	Cap	A351 CF 8M	27	Gasket	Compressed Fibres
50	Lever Cap	A351 CF 8M	28	Gasket	Compressed Fibres
10	Spring	AISI 316	29	Bushing	---
4	Nozzle	ASI 304	30	Gasket	Compressed Fibres
5	Disc	ASI 304	31	Gasket	Compressed Fibres
6	Guide	AISI 316	32	Nut	AISI 304
7	Adjusting Ring	AISI 316	33	Bellows	AISI 316 L
8	Disc Holder	AISI 316	34	Gasket	Compressed Fibres
9	Stem	AISI 316	51	Plug	AISI 304
11	Adjusting Screw	AISI 316	53	Release Nut	AISI 316
12	Push Rod	17-4-PH	54	Screw	AISI 304
13	Nut	AISI 316	55	Cam	AISI 316
14	Lock Screw	AISI 304	56	Cam Shaft	AISI 316
15	Spring Button	AISI 316	57	Packing	Compressed Fibres
16	Disc Retainer	AISI 316	58	Packing Gland	AISI 316
18	Elastic Pin	AISI 302	59	Lever	C.S.
19	Plug	AISI 304	60	Nut	AISI 304
22	Lock Stud	AISI 304			
23	Studs	A 193 B8			
24	Nuts	A 194 Gr8			

ME&S Engineering

	Ana G.	Sara C.
DATE	*PREP.*	*APPR.*

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5.1.6. Bunds design

Despite all prevention measures are installed in the storage area in order to prevent accidental product releases, sometimes it is not possible to avoid them. For this reason it is also important to have mitigation measures, as bunds around tanks. Both tanks in the storage unit will be provided with an individual bund.

Soda solution tank will be wrapped into a typical bund to retain possible releases in order to recuperate the product without any impact on the environment.

Chlorine tank will be wrapped into a high walls bund, which offers double protection; on one hand, in case of failure of the tank, the liquid released will be kept into the bund. In this way, the chlorine released could be recuperated without extending to ground, which would damage the environment.

On the other hand, in case of little gaseous leaks or equipment failures, the high walls of the bund will retain the toxic cloud, retarding its expansion to surrounding population and offering more time to solve the problem.

Since both bunds are individual (only wraps one tank) is important to garantee they have enough capacity to contain all the product stored in each tank. Horizontal distance between wall tank and wall bund should be higher than 1 meter, in order to facilitate maintenance and reparation operations. So, the distance in these cases are 2,5 meter.

Taking into account all these information, the dimensions and the volume of each tank has been calculated.

Table 5.1.7. Bund characteristics

Characteristic	Chlorine tank, T-101	Soda solution tank, T-102
Tank volume [m^2]	82	30
Length [m]	19,0	12,0
Width [m]	7,50	7,00
High [m]	5,00	1,00
Area [m^2]	140	87,0
Total volume [m^3]	712	87,0
Net volume [m^3]	620	77,0
Material	Concrete recovered with glass-reinforced polyester	Reinforced concrete

Bund base will be constructed with a 1% slope to facilitate the evacuation of the released product. Moreover, it will have drainage canals for the same reason.

5.2. Work safety

5.2.1. Occupational risk assessment and personal protection equipment

Following *Manual para la identificación y evaluación de riesgos laborales* by *Generalitat de Catalunya* (ref.15), it is possible to identify the main points of safety, hygienic and social risks which could affect workers. Once this analysis has been done, it is necessary to search for possible measures in order to remove or mitigate those risk points.

First of all, Chlorite will provide each worker with a basic equipment for personal protection, which have to be designed following the actual regulations. This equipment must bring comfort, ease of movement and durability. The equipment includes the following items:

- Safety helmet: It protect against blows, prevent collapses with objects, electric shocks and burns.
- Hearing protection: Earplugs must be used when noise exceeds 85 dB.
- Hands and arms protection: Wearing gloves will be required depending on the activities and its associated risk.
- Legs and feet protection: All workers will be provided with typical work boots, with steel metal toecap, which resists contact heat and antislipping rubber sole.
- Work clothes: It includes shirt, jacket and trousers made with protective clothing.
- Respiratory protection: It does not remove pollution but it reduces its concentration to acceptable levels.
- Eyes and face protection: Safety goggles that could be adapted to protect against particles, liquids, fumes, vapor or radiations. Protection could be extend to face using masks or facial protections.
- Work at height: Workers must be provided with harness with a safety line attached to avoid falls and damages when they work at more than 1,8 meters high.
- Showers and eyebaths: Mechanisms that supply water for eyes, face and body. They will be strategically located all around storage area.
- Chlorine detectors: The worker in charge of the chlorine storage unit will have to wear a chlorine detector. He/she must go over storage area every two hours wearing the detector to secure that everything is fine.

5.2.2. Training plan

Operating processes will be detailed in writing and storage unit workers will receive specific instructions about:

- Properties of all substances present in the storage area.
- Operations manual of all equipment.
- Instructions to secure a proper use of safety elements and basic equipment for personal protection.
- Consequences due to erroneous operation or uses of safety elements or installations.
- Hazard which could originate releases or leaks of chlorine.
- Workers will have access to all information related to risk of the products and protocol for action in emergency case.

Formal training not only will be provided to new members but also all workers must assist to a training session once a year. In these annual sessions all workers will share experiences and knowledge; moreover, all changes in the installation or modifications in the operational procedures will be explained to all members.

6. QUANTITATIVE RISK ASSESSMENT

6.1. Introduction

6.1.1. Premise/Antecedent

Chlorite company (hereinafter referred to as: *Chlorite* or Company) is, which is located in Tarragona, is affected by Real Decret 1254/1999 (ref. 1), of 16th of July, by which control measures of inherent high-risks that involves dangerous substances are approved in its higher threshold due to the presence of one dangerous substance classified in Real Decret 948/2005 (ref. 16), of 29th of June, by which RD 1254/1999 (ref. 1) is modified, by which control measures of inherent high-risks that involves dangerous substances are approved in a higher quantities than the specified ones in the 3th Column of Part 1 and 2 of the Annex I of RD 1254/1999 (ref. 1)

The elaboration of a Quantitative Risk Assessment (hereinafter referred to as: QRA) is required in order to accomplish the Instruction 7/2009 SIE: “Requirement of the quantitative risk assessment to the establishments affected by the Catalonian legislation about major accidents (hereinafter referred to as: AG)” (ref. 17)

The present document makes the QRA carried out according to the Instruction 14/2008 SIE (ref. 18)

6.1.2. Affected substances

In table 1 there are the dangerous substances of the establishment, the corresponding lower and higher threshold according to the legislation, RD 948/2005 (ref. 16), and the quantity present in the establishment in accordance with the Notification of major accidents (AG-1), see Annex A.2.1.

Table 6.1.1.Quantities of the classified substances in the establishment according to the AG-1.

Categories	Maximum quantity [t]	Lower threshold [art. 6 & 7]	Higher threshold [art.9]
Noted Substances (part 1 Annex I)			
Chlorine	105,31	10	25
Substances by Categories (part 2 Annex I)			
9i. R50			
Sodium hypoclorite	2,96		
TOTAL	2,96	100	200
9ii. Dangerous for the environment: R51 i R53			
Carbon tetrachloride	0,20		
TOTAL	0,20	200	500

Ratios for toxic substances are shown below:

- with respect to the lower threshold, Σ = 10,54
- with respect to the higher threshold, Σ = 4,21

Ratios for dangerous for the environment substances are shown below:

- with respect to the lower threshold, Σ = 0,03
- with respect to the higher threshold, Σ = 0,014

Therefore, the establishment is affected by high level because the higher threshold for toxic substances is overtaken.

6.1.3. Brief description of the activities

See section 2.3 for the chlorine production description and 4.3 for the storage area.

6.1.4. Brief description of the system

See section 4.3.

6.1.5. Description of the establishment environment

See section 3.2.3.

6.2. Realization of the quantitative risk assessment

6.2.1. Introduction

It has been realized the QRA of the Company situated in Tarragona. For this execution, *Chlorite* has followed the criterion and the methodology set by DEMO in the Instruction 14/2008 (ref. 18) and currently based on BEVI (ref.19)

The procedure followed in this methodology is the next:

1. Identification of the initiators events.
2. Determination of the initiators frequencies (occasions/year)
3. Determination of the probabilities of the events that condition the evolution of the scenario until the final accident.
4. Determination of the lethal consequences of the final accidents.
5. Determination of the individual risk: Iso-Risk Curves.

6. Determination of the social risk. Tables F-N.
7. Analysis of the results.

6.3. Identification of the initiators events

6.3.1. Introduction

The first stage of the QRA realization is especially critical because it conditions the following development of the study, so it has to be the most detailed and objective as possible.

To do this identification, the Company has realized, first, a risk identification, which has been structured by this way:

1. Identification of the classified substances.
2. Definitions of the AG installations.
3. Identification of the initiators events: generics and specifics.
4. Reach criterion of the Lethal Dose (DL1). Determination of the contribution to the external risk of each identified area.
5. Definition of the final initiators.

6.3.2. Identification of the classified substances

Next table shows the dangerous substances aforementioned in the Notification and its classification, according to its utility in the processes carried through.

Table 6.3.1. Substance classification.

Substance	Category	Considered in the QRA?
Chlorine	Product	Yes

Therefore, the unique dangerous substance that is studied is chlorine.

6.3.2.1. Properties of the dangerous substances present in the establishment.

See table 5.1.1.

6.3.3. Definition of AG installations

The Company has distributed the AG installations by this way:

- AG1 – Process area.
- AG2 – Storage area.

Next table shows the above mentions installations..

Table 6.3.2. Considered AG installations.

Area	Characteristics
AG1	**Process area** It involves the brine purification process and the electrolysis for chlorine production. See section 2.3 for more information.
AG2	**Storage area** • 1 chlorine storage tank of 82 m^3. • 1 caustic soda storage tank of 30 m^3. • 3 centrifugal pumps. • 3 heat exchangers. • Pipes: chlorine, water, nitrogen and carbon tetrachloride.

The present QRA does not comprise the study of the process area (AG1) due to the fact that the thesis is focused on the design of the chlorine storage are (AG2), so this is the only one that is going to be studied.

Relating to the storage area, the absorber and all the equipment that form that system (T-102, E-104 and pipes) are not going to be considered in this study because it will only work in case the tank T-101 has an overpressure risk situation.

6.3.4. Definition of AG installations

6.3.4.1. Generic initiators

In order to select the initiators events of the selected AG area, the procedure to follow is that one described in BEVI (ref. 19), which is based on CPR18E del Purple Book (ref. 20).

The main risk factors in the storage area of *Chlorite* are focused on possible errors in the storage tank, pumps, pipes and heat exchangers.

This selection is fixed in accordance with the generic initiators (IG) about loss of containment, which are named “Scenarios” or LOCs, as BEVI (ref. 19) shows.

Regarding the frequency of the final accidents, it will be considered the same as the associated to the process equipment (BEVI (ref. 19)) because they have the same magnitude order.

Next table shows the accidents related to the different equipment considered in this AG installation to make the study. There has only been selected the systems that enclose the worst accidents in case of failure.

AG2. Storage area.

System	Generic initiator events (LOCs)
• Storage tank T-101	• Instantaneous release of the complete inventory (LOC G1 of CPR18E (ref. 20)) • Continuous release of the complete inventory in 10 minutes at a constant rate of release (LOC G2 of CPR18E (ref. 20)) • Continuous release from a hole with an effective diameter of 10 mm (LOC G3 of CPR18E (ref. 20))
• Pipe 3"-CS-Cl_2-1 • Pipe 3"-CS-Cl_2-5/30 • Pipe 3"-CS-Cl_2-32	• Full bore rupture (LOC G1 of CPR18E (ref. 20)) • Leak with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm (LOC G2 of CPR18E (ref. 20))
• Pump P-101A	• Catastrophic failure with full bore rupture of the largest connecting pipe (LOC G1 of CPR18E (ref. 20)) • Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipe, a maximum of 50 mm (LOC G2 of CPR18E (ref. 20))
• Heat exchanger E-102 (dangerous substance inside pipes)	• Full bore rupture of ten pipes simultaneously (LOC G1 of CPR18E (ref. 20)) • Full bore rupture of one pipe (LOC G2 of CPR18E (ref. 20)) • Leak with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm (LOC G3 of CPR18E (ref. 20))
• Road tanker TK-101	• Instantaneous release of the total inventory of the road tanker (LOC G1 of CPR18E (ref. 20)) • Continuous release from a hole the size of the largest connection of the road tanker (LOC G2 of CPR18E (ref. 20)) • Full fore rupture of the loading hose of the road tanker (LOC L1a of CPR18E (ref. 20)) • Leak of the loading hose of the road tanker with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm (LOC L2a of CPR18E (ref. 20))

6.3.4.2. Specific initiators

The specific initiator considered in this study is the overfilled of the tank T-101.

Table 6.3.3. Specific initiator event

Area	Code	Initiator description
AG2	AG2.CL.1.E1	Overfilled of the storage tank T-101.

According to the F-11 criterion of the Instruction 14/2008 (ref.18), there have not been considered the operations events caused by runaway, corrosion or fatigue and failure on the auxiliary services, nor the events caused by external events (seism, inundation, sabotage, etc.), according to F-12 criterion of the Instruction 14/2008 (ref.18)

6.3.4.3. Final initiators; generics and specifics

The initiators have been named based on the area, the kind of installation and the BEVI code (ref.19). For example AG2.CH.1.G1; area AG-2, chlorine storage tank T-101, first hypothesis for the initiator G1.

In following table there are presented all the finally generic initiators considered.

Table 6.3.4. Selected generic and specific initiator events.

Code	**Description of the initiator**
AG2.CL.1.G1	Failure of the chlorine storage tank T-101. Instantaneous release of the complete inventory.
AG2.CL.1.G2	Failure of the chlorine storage tank T-101. Continuous release of the complete inventory in 10 minutes at a constant rate of release.
AG2.CL.1.G3	Failure of the chlorine storage tank T-101. Continuous release from a hole with an effective diameter of 10 mm.
AG2.CL.1.E1	Overfilled of the chlorine storage tank T-101.
AG2.CL.2.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-1.
AG2.CL.2.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-1 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.
AG2.CL.3.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-3.
AG2.CL.3.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-3 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.
AG2.CL.4.G1	Catastrophic failure with full bore rupture of the largest connecting pipe of the pump P-101A.
AG2.CL.4.G2	Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipe, a maximum of 50 mm, of the pump P-101A.
AG2.CL.5.G1	Full bore rupture of ten pipes simultaneously of chlorine of heat exchanger E-102.
AG2.CL.5.G2	Full bore rupture of one pipe of chlorine of heat exchanger E-102.
AG2.CL.5.G3	Leak with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm, of chlorine of heat exchanger E-102.
AG2.CL.6.G1	Instantaneous release of the total inventory of the road tanker TK-101.
AG2.CL.6.G2	Continuous release from a hole the size of the largest connection of the road tanker TK-101.
AG2.CL.6.L1a	Full fore rupture of the loading hose of the road tanker TK-101.
AG2.CL.6.L2a	Leak of the loading hose of the road tanker TK-101 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm..
AG2.CL.7.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-28.

Code	Description of the initiator
AG2.CL.7.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-28 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.

6.3.4.4. Dismissed scenarios

Generic or specific scenarios can be dismissed by their frequency –those that has a frequency lower than 10^{-9} oc/year– and by the quantification of the risk –those that has a final event with a DL1 reach that does not overtake the establishment limits. Therefore, the initiators that will have quantified their occurrence frequency will be that final events set off from the initiators that contribute to the generation of the Iso-Risk Curves.

Next table shows the hypothesis that have been dismissed by the DL1 criterion. There are no hypothesis dismissed by the frequency criterion.

Table 6.3.5. Dismissed hypothesis by DL1 criterion.

Code	Initiator	Final Scenario	Case study	Value [m]	Situation
AG2.CL.5.G1	Full bore rupture of ten pipes simultaneously	Toxic dispersion	Without w.c.	58	Dismissed
			With w.c.	22	Dismissed
AG2.CL.5.G2	Full bore rupture of one pipe of chlorine of heat exchanger E-102.	Toxic dispersion	Without w.c.	n.c.	Dismissed
			With w.c.	n.c.	Dismissed
AG2.CL.5.G3	Leak with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm, of chlorine of heat exchanger E-102.	Toxic dispersion	Without w.c.	n.c	Dismissed
			With w.c.	n.c.	Dismissed

6.3.4.5. List of hypothesis of major accidents considered

According to the risk identification realized and the criterion about the initiators described in BEVI (ref.19) and the dismissed initiators, there have been obtained the hypothesis found in the following table, where there is shown the final list of the initiators considered.

Table 6.3.6. Initiator events selected.

Code	Description of the initiator
AG2.CL.1.G1	Failure of the chlorine storage tank T-101. Instantaneous release of the complete inventory.

Code	Description of the initiator
AG2.CL.1.G2	Failure of the chlorine storage tank T-101. Continuous release of the complete inventory in 10 minutes at a constant rate of release.
AG2.CL.1.G3	Failure of the chlorine storage tank T-101. Continuous release from a hole with an effective diameter of 10 mm.
AG2.CL.1.E1	Overfilled of the chlorine storage tank T-101.
AG2.CL.2.G1	Full bore rupture of the pipe of chlorine 3"-CS-Cl_2-1.
AG2.CL.2.G2	Leak of the pipe of chlorine 3"-CS-Cl_2-1 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.
AG2.CL.3.G1	Full bore rupture of the pipe of chlorine 3"-CS-Cl_2-3.
AG2.CL.3.G2	Leak of the pipe of chlorine 3"-CS-Cl_2-3 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.
AG2.CL.4.G1	Catastrophic failure with full bore rupture of the largest connecting pipe of the pump P-101A.
AG2.CL.4.G2	Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipe, a maximum of 50 mm, of the pump P-101A.
AG2.CL.5.G1	Full bore rupture of ten pipes simultaneously of chlorine of heat exchanger E-102.
AG2.CL.5.G2	Full bore rupture of one pipe of chlorine of heat exchanger E-102.
AG2.CL.5.G3	Leak with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm, of chlorine of heat exchanger E-102.
AG2.CL.6.G1	Instantaneous release of the total inventory of the road tanker TK-101.
AG2.CL.6.G2	Continuous release from a hole the size of the largest connection of the road tanker TK-101.
AG2.CL.6.L1a	Full fore rupture of the loading hose of the road tanker TK-101.
AG2.CL.6.L2a	Leak of the loading hose of the road tanker TK-101 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm..
AG2.CL.7.G1	Full bore rupture of the pipe of chlorine 3"-CS-Cl_2-28.
AG2.CL.7.G2	Leak of the pipe of chlorine 3"-CS-Cl_2-28 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.

The storage area of Chlorine has installed some prevention and mitigation measures:

- Gas detectors to stop the release.

- Bund around the tank T-101 to stop the evaporation.

- Water curtains in all the equipment to stop the evaporation.

Despite the fact that the establishment has installed the measures mentioned above, this QRA includes the risk study considering the equipment have and don't have these measures installed in order to observe the effectiveness of this measures.

The releases and the doses lethal distances have been determined for both cases (with measures installed and without it), but event probabilities and individual and social risk have been studied only for the designed plant (with the measures)

6.4. Determination of the initiator events frequencies

The values of the frequencies of the generic initiators have been based on BEVI (ref. 19) and next criterions have been followed:

1. For generic events, there have been used the occurrence frequencies specified in BEVI (ref. 19).
2. In the case of breaking of pipes , the generic occurrence frequency depends on their diameter and on the length. Units are $m^{-1} \cdot year^{-1}$.
3. According to criterion F2-20 of Instruction 14/2008 (ref. 18), the treatment of the domino effect will be increased with a factor of 2 in the event frequency in that events that can be consequence of a domino effect by another accident in a different system.
4. Those initiators with a frequency lower than 10^{-9} $year^{-1}$ will be dismissed, according to BEVI (ref. 19).
5. According to the point F2-24 of the Instruction 14/2008 SIE (ref. 19), two initiators that have the same consequences and are calculated by the same way can be grouped, so they will be named with both names (for example G1G2 for initiators G1 and G2). The frequency will be the sum of both frequencies.

Following figures show the error tree for the specific initiator that corresponds to the overfilled of the tank.

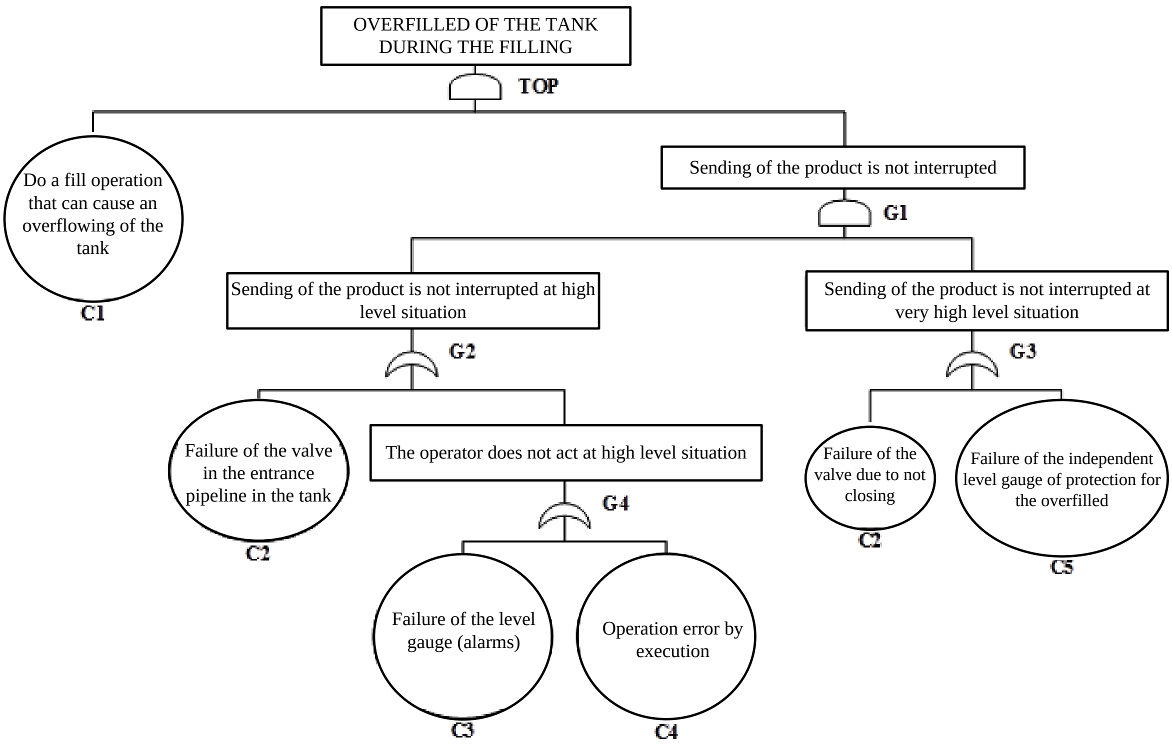


Figure 6.4.1. Error tree: Overfilled of the chlorine storage tank T-101 (initiator AG2.CL.1.E1)
The probabilities that correspond to the error tree are shown in table 6.4.1.

Table 6.4.1. Probabilities of the error tree: Overfilled of the chlorine storage tank T-101 (initiator AG2.CL.1.E1)

Id	Description of the basic event	Frequency	Probability	Error factor	Source
C1	Do a fill operation that can cause an overflowing of the tank.	10 per year	-	-	Estimated.
C2	Failure of the valve in the entrance pipe in the tank.	-	$1{\cdot}10^{-4}$/D	10	WASH-1400. It corresponds to the not stopping of a pump under signal. The error factor has been estimated as 10.
C3	Failure of the level gauge.	-	$2{\cdot}10^{-5}$/D	3	RIJNMOND. Failure of a audible gauge when it sounds. All types of instrumentation has been considered applicable (level, pressure).
C4	Operation error by execution.	-	$3{\cdot}10^{-3}$/D	3	WASH-1400. Operation error by execution.
C5	Failure of the level independent gauge of protection for the overfilled.	-	$2{\cdot}10^{-5}$/D	3	RIJNMOND. Failure of a audible gauge when it sounds. All types of instrumentation has been considered applicable (level, pressure).

Finally, the probability of the event (overfilled of the tank during the overflowing operation) over a period of one year is $3{,}90{\cdot}10^{-7}$.

Table 6.4.2 shows the generic frequencies for each initiator. The colored initiators have not been considered in the individual risk calculation.

Table 6.4.2. Generic initiators frequency, according to BEVI (ref. 19)

Code	Description of the initiator	Considerations	Base frequency / BEVI	Final frequency [oc/year]
AG2.CL.1.G1G2	Failure of the chlorine storage tank T-101. Instantaneous release of the complete inventory. Failure of the chlorine storage tank T-101. Continuous release of the complete inventory in 10 minutes at a constant rate of release.	Quantity of tanks: 1 Domino effect: 1 Table 13 BEVI	$5{,}00{\cdot}10^{-7}$ oc/year	$1{,}00{\cdot}10^{-6}$
AG2.CL.1.G3	Failure of the chlorine storage tank T-101. Continuous release from a hole with an effective diameter of 10 mm.		$1{,}00{\cdot}10^{-5}$ oc/ year	$1{,}00{\cdot}10^{-5}$

Code	**Description of the initiator**	**Considerations**	**Base frequency / BEVI**	**Final frequency [oc/year]**
AG2.CL.2.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-1.	Quantity of pipes : 1 Length: 15 m Diameter: 75,2 mm Domino effect: 1 Table 27 BEVI	$3,00\cdot10^{-7}$ m/ year	$4,50\cdot10^{-6}$
AG2.CL.2.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-1 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.		$2,00\cdot10^{-6}$ m/ year	$3,00\cdot10^{-5}$
AG2.CL.3.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-3.	Quantity of pipes : 1 Length: 30 m Diameter: 75,2 mm Domino effect: 1 Table 27 BEVI	$3,00\cdot10^{-7}$ m/ year	$9,00\cdot10^{-6}$
AG2.CL.3.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-3 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.		$2,00\cdot10^{-6}$ m/ year	$6,00\cdot10^{-5}$
AG2.CL.4.G1	Catastrophic failure with full bore rupture of the largest connecting pipe of the pump P-101A.	Quantity of pipes : 1 Length: 5 m Diameter: 86,9 mm Domino effect: 1 Table 27 BEVI	$1,00\cdot10^{-4}$ m/ year	$5,00\cdot10^{-4}$
AG2.CL.4.G2	Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipe, a maximum of 50 mm, of the pump P-101A.		$4,40\cdot10^{-3}$ m/ year	$2,20\cdot10^{-2}$
AG2.CL.6.G1G2	Instantaneous release of the complet inventory of the road tanker TK-101. Continuous release from a hole the size of the largest connection of the road tanker TK-101.	Quantity: 24 road tankers/year Working hours: 2h/road tanker Domino effect: 1 Table 43 & 50 BEVI	$5,00\cdot10^{-7}$ oc/ year	$5,48\cdot10^{-9}$
AG2.CL.6.L1a	Full fore rupture of the loading hose of the road tanker TK-101.		$4,00\cdot10^{-6}$ oc/ h	$1,92\cdot10^{-4}$
AG2.CL.6.L2a	Leak of the loading hose of the road tanker TK-101 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm..		$4,00\cdot10^{-5}$ oc/ h	$1,92\cdot10^{-3}$
AG2.CL.7.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-28.	Quantity of pipes : 1 Length: 30 m Diameter: 196 mm Domino effect: 1 Table 27 BEVI	$1,00\cdot10^{-7}$ m/ year	$3,00\cdot10^{-6}$
AG2.CL.7.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-28 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.		$5,00\cdot10^{-7}$ m/ year	$1,50\cdot10^{-5}$

Next table shows the frequencies of the specific initiator.

Table 6.4.3. Frequencies of the specific initiator.

Code	Description of the initiator	Considerations	Base frequency / Error trees	Final frequency [oc/year]
AG2.CL.1.E1	Overfilled of the chlorine storage tank T-101.	Domino effect: 1	$3{,}90 \cdot 10^{-7}$	$3{,}90 \cdot 10^{-7}$

6.5. Determination of probabilities of final initiators

The probabilities applied in the QRA has been based on BEVI (ref. 19)

Next figure shows the event tree for the study of the initiators of the storage area of Chlorite.

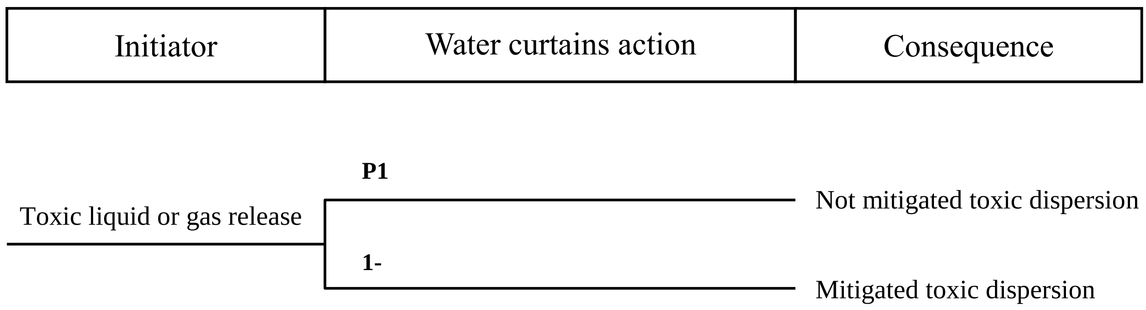


Figure 6.5.1. Event tree: Evolution of a toxic release.

On table 6.5.1 there are exposed the probability value for the water curtains, which have been based in the document “Procediment per incloure les prestacions de les cortines d’abatiment de gasos toxics/inflamables a l’AR/AQR” (ref. 21), and the final probability of the event.

Table 6.5.1. Probability of the accidents.

Code	Description of the initiator	Probability of the water curtain	Accident	Final probability of the accident
AG2.CL.1.G1G2	Failure of the chlorine storage tank T-101. Instantaneous release of the complete inventory. Failure of the chlorine storage tank T-101. Continuous release of the complete inventory in 10 minutes at a constant rate of release.	0,95	Toxic dispersion	$9{,}49 \cdot 10^{-7}$
AG2.CL.1.G3	Failure of the chlorine storage tank T-101. Continuous release from a hole with an effective diameter of 10 mm.	0,95	Toxic dispersion	$9{,}49 \cdot 10^{-6}$
AG2.CL.1.E1	Overfilled of the chlorine storage tank T-101.	0,95	Toxic dispersion	$3{,}70 \cdot 10^{-7}$
AG2.CL.2.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-1.	0,95	Toxic dispersion	$4{,}27 \cdot 10^{-6}$

Code	Description of the initiator	Probability of the water curtain	Accident	Final probability of the accident
AG2.CL.2.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-1 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	0,95	Toxic dispersion	$2,85 \cdot 10^{-5}$
AG2.CL.3.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-3.	0,95	Toxic dispersion	$8,54 \cdot 10^{-6}$
AG2.CL.3.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-3 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	0,95	Toxic dispersion	$5,69 \cdot 10^{-5}$
AG2.CL.4.G1	Catastrophic failure with full bore rupture of the largest connecting pipe of the pump P-101A.	0,95	Toxic dispersion	$4,75 \cdot 10^{-4}$
AG2.CL.4.G2	Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipe, a maximum of 50 mm, of the pump P-101A.	0,95	Toxic dispersion	$2,09 \cdot 10^{-2}$
AG2.CL.6.G1G2	Instantaneous release of the complet inventory of the road tanker TK-101. Continuous release from a hole the size of the largest connection of the road tanker TK-101.	0,95	Toxic dispersion	$5,20 \cdot 10^{-9}$
AG2.CL.6.L1a	Full fore rupture of the loading hose of the road tanker TK-101.	0,95	Toxic dispersion	$1,82 \cdot 10^{-4}$
AG2.CL.6.L2a	Leak of the loading hose of the road tanker TK-101 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm..	0,95	Toxic dispersion	$1,82 \cdot 10^{-3}$
AG2.CL.7.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-28.	0,95	Toxic dispersion	$2,85 \cdot 10^{-6}$
AG2.CL.7.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-28 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	0,95	Toxic dispersion	$1,42 \cdot 10^{-5}$

6.6. <u>Determination of the lethal distances of the final events consequences</u>

6.6.1. Calculation basis for the accidental events

Following there are described the principals criterion and parameters used for the simulation of the initiators and the final accidental events defined in the QRA.

As mentioned above, the study has been done considering the storage area has installed the mitigation measures and it has also been done for the case these measures are not installed.
In section 6.6.2 there are a table with the release and the evaporation results of both studies and in section 6.6.3 there are the distances of these effects.

6.6.1.1. Release duration

According to table 6.5.1, the release duration of all the initiators is 2 minutes, due to the fact that all the equipment of the storage area have installed automatic gas detectors.
Taula 6.6.1. Release duration.

Conditions	**Release duration (minutes)**
Automatic detection and actuation (there is not necessary the intervention of any operator).	2
Automatic detection and remote actuation (from control room).	10
Automatic detection and manual actuation.	30

6.6.1.2. Instantaneous release

To determine the quantity and the flow of the release, it has been considered that all the fluid will be released immediately from the equipment. In case of pumps, according to BEVI (ref. 19), it is considered the failure of the aspiration line.
Despite the fact that water curtains are installed to mitigate the evaporation, the reduction factor to be applied to reduce its effect is applied in the calculation of the release. Acording to the document "Procediment per incloure les prestacions de les cortines d'abatiment de gasos toxics/inflamables a l'AR/AQR" (ref. 21), the reduction factor assigned to the curtains is 90 %, which means the release of the system is only 10 % of the total.

6.6.1.3. Continuous release

In these cases and for pumps, *Liquefied Gas Bottom Discharge (TPDIS model)* of software EFFECTS (version 8.1.8) has been used. Depending on the initiator, the leak can be also calculated taking into account the flow.

As in the instantaneous release, when the system has installed water curtains, the release considered will be the 10 % of the total, as mentioned in the previous section.

6.6.1.4. Total and partial rupture of loading hoses

These accidents has also been calculated using the *Liquefied Gas Bottom Discharge (TPDIS model)* of the *s*oftware EFFECTS (version 8.1.8) or by the flow.

As in the instantaneous and continuous release, when the system has installed water curtains, the release considered will be the 10 % of the total.

6.6.1.5. Flash determination

Due to the fact that the storaged chlorine is a liquiefied gas, it is necessary to determine Flash fraction, which calculation has been done using *Liquefied Gas Instantaneous Release (AMINAL model)* of the software EFFECTS (version 8.1.8). So, it is obtain a liquid phase, which later evaporates, and a vapor phase.

6.6.1.6. Pool area

In case of liquid leak, it has been considered that the substance will be extended with standard thickness of 1cm. Its area is determined by dividing the density of the substance per the total volume released and per the pool thickness. It is considered a maximum limitation of the pool area of 1.500 m^2.

If the pool is formed in a bund, the area to be considered is the smaller between the calculated area as explained above and the bund area.

6.6.1.7. Evaporation determination

To determine the evaporation rate of the liquid phase mentioned on section 6.1.1 , *Pool Evaporation* model of the *s*oftware EFFECTS (version 8.1.8) has been used. To determine later the distances reached by the vapor cloud, the flow considered has been the sum of this evaporation and the vapor phase.

The duration of the evaporation depends on the installation, in the equipment, of measures to stop the evaporation. If the system has water curtains, the evaporation lasts 10 minutes and in the case there is no that measures, the duration is 20 minutes, according to the criterion F4-7 of the Instruction 14/2008 (ref. 18)

6.6.1.8. Meteorological and land conditions

To determine the reach of the lethal effects of the identified accidents, it is necessary to define the meteorological conditions, which can be found in section 3.2.3.3.

6.6.1.9. Informatics models

To determine the consequences of the initiators the following programs has been used:

EFFECTS (version 8.1.5) del TNO:	Release simulation/ Evaporation
ALOHA 5.2.4 de la EPA:	Toxic dispersion
RISKCURVES 7.6:	Individual and social risk

6.6.1.10. Vulnerability criterion adopted

The vulnerability criterion adopted are presented in the Instruction 14/2008 SIE (ref. 18) The only vulnerability effect that can occur on the storage area, according to the substances there are, is toxic dispersion. To determine its reach it is necessary to use Probit equations, which are presented in the study of the Probit equations to use in the Quantity Risk Assessment and Safety Reports (revision 0 of June 2009) realized by TIPS.

The following Probit equation correspond to the chlorine:

$$\mathrm{Pr} = -6.35 + 0.5 \cdot \ln(\mathrm{C}^{2.75} \cdot \mathrm{t}) \qquad (6.5.1)$$

Where *C* is the toxic concentration (mg/m3) and *t* is the exposure time (min)

6.6.2. Calculation basis for the accidental

The following table shows the results of each initiator; release, pool area, evaporation and distances of toxic dispersion (DL1). There are the results for all the study cases mentioned above.

Colored initiators are those that have not been considered in the individual risk study because that initiators does not exceed the establishment limits.

Table 6.6.2. Results of each initiator; release, pool area, evaporation and distances of toxic dispersion (DL1)

Code	Description of the initiator	Case study	Released quantity [kg]	Maximum pool area [m^2]	Evaporation
					4D
AG2.CL.1.G1	Failure of the chlorine storage tank T-101. Instantaneous release of the complete inventory.	Without bund Without w.c.	105.076	1.500	51,1
		Without bund With w.c.	10.508	459	12,8
		With bund Without w.c.	105.076	141	36,0
		With bund With w.c.	10.508	141	9,05
AG2.CL.1.G2	Failure of the chlorine storage tank T-101. Continuous release of the complete inventory in 10 minutes at a constant rate of release.	Without bund Without w.c.	105.076	1.500	51,1
		Without bund With w.c.	10.508	459	12,8
		With bund Without w.c.	105.076	141	36,0
		With bund With w.c.	10.508	141	9,05
AG2.CL.1.G3	Failure of the chlorine storage tank T-101. Continuous release from a hole with an effective diameter of 10 mm.	Without bund Without w.c.	224	9,77	0,16
		Without bund With w.c.	224	9,77	0,16
		With bund Without w.c.	22,4	0,98	0,03
		With bund With w.c.	22,4	0,98	0,03
AG2.CL.1.E1	Overfilled of the chlorine storage	Without bund Without w.c.	116.752	1.500	55,1

Code	Description of the initiator	Case study	Released quantity [kg]	Maximum pool area [m^2]	Evaporation
					4D
	tank T-101.	Without bund With w.c.	11.675	510	14,2
		With bund Without w.c.	116.752	142	39,7
		With bund With w.c.	11.675	142	9,83
AG2.CL.2.G1	Full bore rupture of the pipe of chlorine 3"-CS-Cl_2-1.	Without w.c.	1.020	44,6	0,74
		With w.c.	102	4,46	0,13
AG2.CL.2.G2	Leak of the pipe of chlorine 3"-CS-Cl_2-1 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	Without w.c.	102	4,46	0,08
		With w.c.	10,2	0,45	0,01
AG2.CL.3.G1	Full bore rupture of the pipe of chlorine 3"-CS-Cl_2-3.	Without w.c.	990	34,6	0,74
		With w.c.	99,0	3,46	0,14
AG2.CL.3.G2	Leak of the pipe of chlorine 3"-CS-Cl_2-3 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	Without w.c.	99,0	3,46	0,08
		With w.c.	10,0	0,35	0,01
AG2.CL.4.G1	Catastrophic failure with full bore rupture of the largest connecting pipe of the pump P-101A.	Without w.c.	6.702	293	4,75
		With w.c.	670	29,3	0,84
AG2.CL.4.G2	Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipe, a maximum of 50 mm, of the pump P-101A.	Without w.c.	172	7,50	0,13
		With w.c.	17,2	0,75	0,02
AG2.CL.6.G1	Instantaneous release of the complet inventory of the road tanker TK-101.	Without w.c.	42.358	1.500	28,4
		With w.c.	4.236	185	5,22

Code	**Description of the initiator**	**Case study**	**Released quantity [kg]**	**Maximum pool area [m^2]**	**Evaporation**
					4D
AG2.CL.6.G2	Continuous release from a hole the size of the largest connection of the road tanker TK-101.	Without w.c.	12.275	536	8,66
		With w.c.	1.227	53,6	1,53
AG2.CL.6.L1a	Full fore rupture of the loading hose of the road tanker TK-101.	Without w.c.	12.275	536	8,66
		With w.c.	1.227	53,6	1,53
AG2.CL.6.L2a	Leak of the loading hose of the road tanker TK-101 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm..	Without w.c.	110	4,78	0,08
		With w.c.	11,0	0,48	0,01
AG2.CL.7.G1	Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-28.	Without w.c.	265	NA (1)	2,21
		With w.c.	26,5	NA (1)	0,22
AG2.CL.7.G2	Leak of the pipe of chlorine 3”-CS-Cl_2-28 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.	Without w.c.	26,5	NA (1)	0,22
		With w.c.	2,65	NA (1)	0,02

NA: There is not pool area because the release is a gas.

6.7. Determination of the individual risk

6.7.1. Individual risk

6.7.1.1. Introduction

The individual risk is the probability, referred to one year, of one person, located permanently in a determined place and without specific protection, is dead as a consequence of the accidents considered in the QRA of the studied establishment.

The software RISKCURVES 7.6 of TNO has been used to calculate individual Iso-Risc curves at the storage area to accomplish the Instruction 7/2009 SIE “Requeriment de les anàlisis quantitatives de risc als establiments afectats per la legislació d’accidents greus a Catalunya” (ref. 17)

The acceptance criterion for the individual risk is 10^{-6} oc/year, which means that an individual risk equal or higher than 10^{-6} oc/year cannot be produced in the vulnerable or very vulnerable elements existing or projected around.

The considered atmospheric conditions are those presented in the section 3.2.3.3.

6.7.1.2. Affectation of the individual risk

As can be seen in the following figure, the 10^{-6} oc/year Iso-Risk curve obtained exceeds the establishment limits on the south-east, south and south-west. Despite that fact, it does not affect any vulnerable or very vulnerable element of the surrounding.

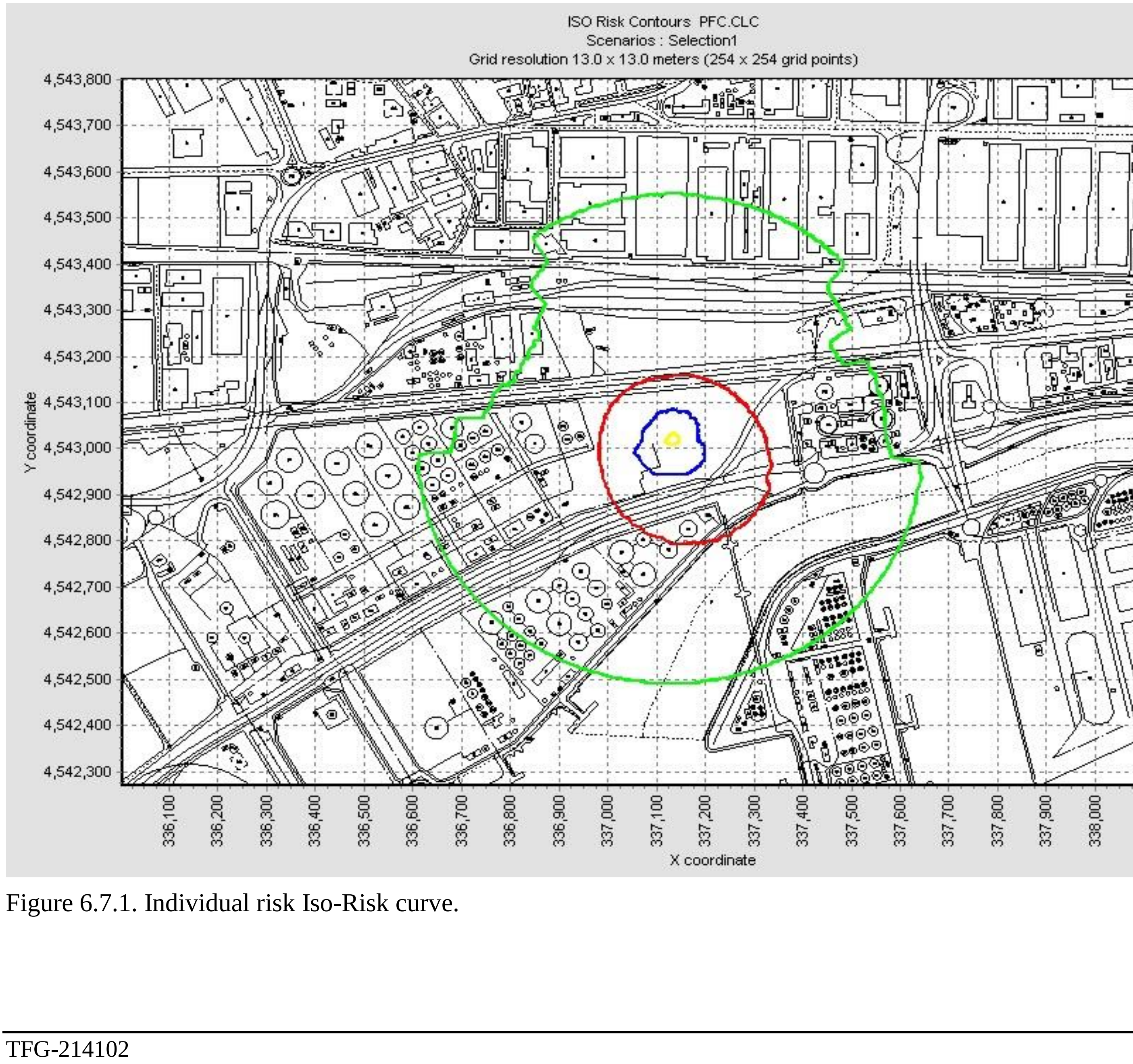


Figure 6.7.1. Individual risk Iso-Risk curve.

6.7.2. Safety area of the establishment

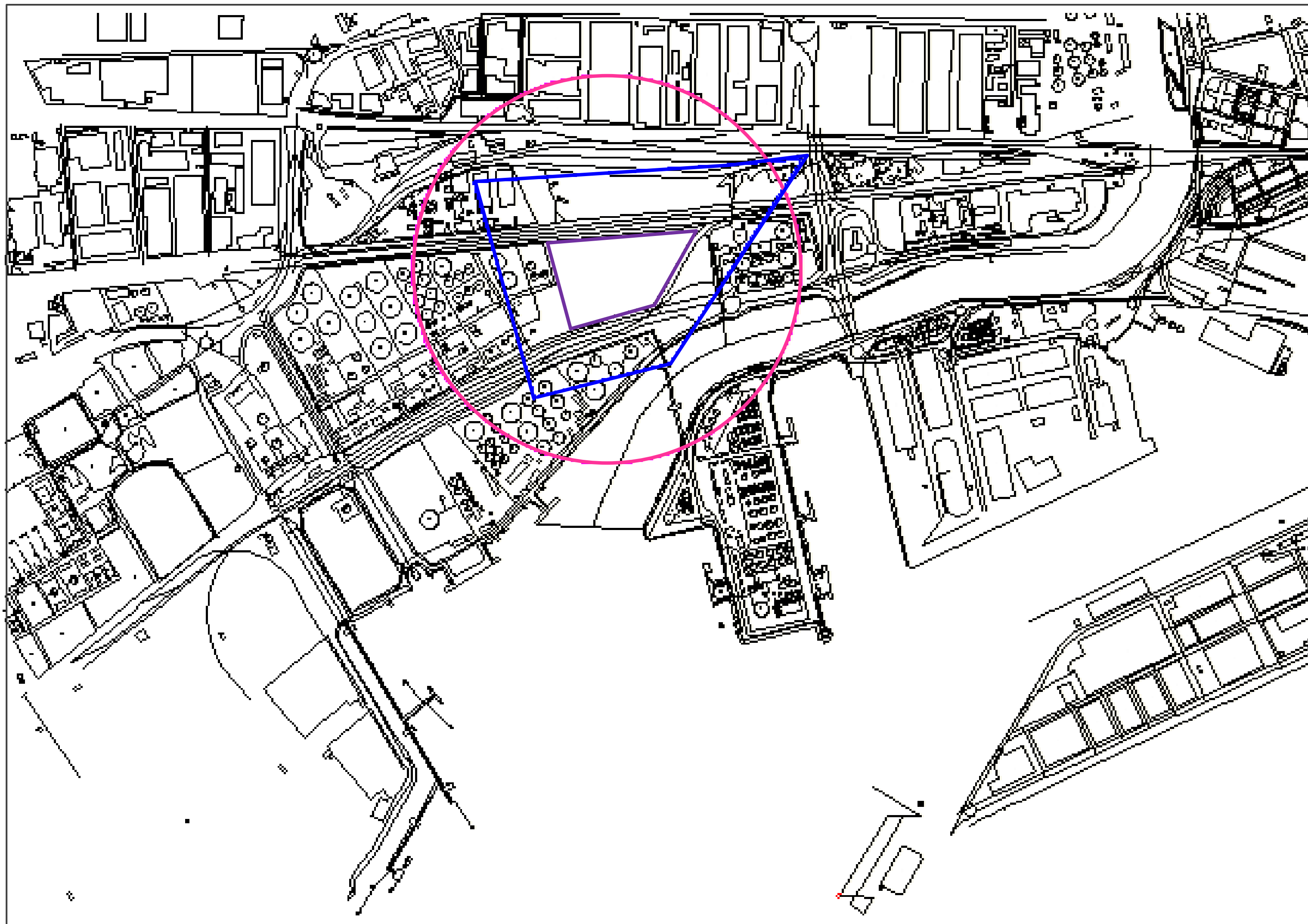
6.7.2.1 Introduction

The safety area is the external area of the industrial establishment and it is framed in the internal area by the establishment perimeter and in the external area by external outline of the figure that involves next geometrical areas:

- Safety circles, which corresponds to the radius indicated on table 1 of Annex 1 of Instruction 9/2007 SIE (ref. 22), measured from the origin of the accident. In this case, it is applied to the chlorine tank T-101, to which corresponds a safety radius of 500 m.
- Perimetral frame measured from the establishment perimeter. For a high level establishment, this value is 150 m.

6.7.2.2. Affectation of the safety area

The safety area includes some industries of the industrial park, so it does not affect any vulnerable or very vulnerable element.



Perimetral frame
Security circle
Chlorite establishment

	DATE	NAME	
DRAWN	2014	Ana G.	ME&S E
CHECKED	2014	Sara C.	
APPROVED	2014	Cristina N.	
SCALE			
1:5.500	*Chlorine storage* *and application of risk* **SAFETY**		

6.8. <u>Determination of the social risk</u>

6.8.1. Introduction

The social risk is the probability, referred to one year, that an accident originated in the establishment produce a quantity of N or more deaths at the same time. It is represented by F-N curves in a logarithmic graphic.

The acceptance criterion of the social risk is indicated in the Purple Book CPR18E (ref. 20). If the obtained curve is located below the represented curve according to CPR18E (ref. 20), the social risk would be acceptable.

The acceptance criterion, despite the fact it has to be calculated, is approximately and does not affect positively or negatively in the report.

The area delimited for the surrounding formed by the DL1 of major reach of the considered accidents has a value of 1,60 km, corresponds to the initiator AG2.Cl_2.1.E1 and affects one part of a town, Torreforta. Finally, the study of the social risk has been done with the software RISKCURVES 7.6.

6.8.2. Affectation of the social risk

The curve obtained for the social risk study is exposed on figure 6.8.1.

It can be seen that the social risk curve is located under the limit acceptation curve, which means that the social risk associated to the storage area of *Chlorite* is acceptable.

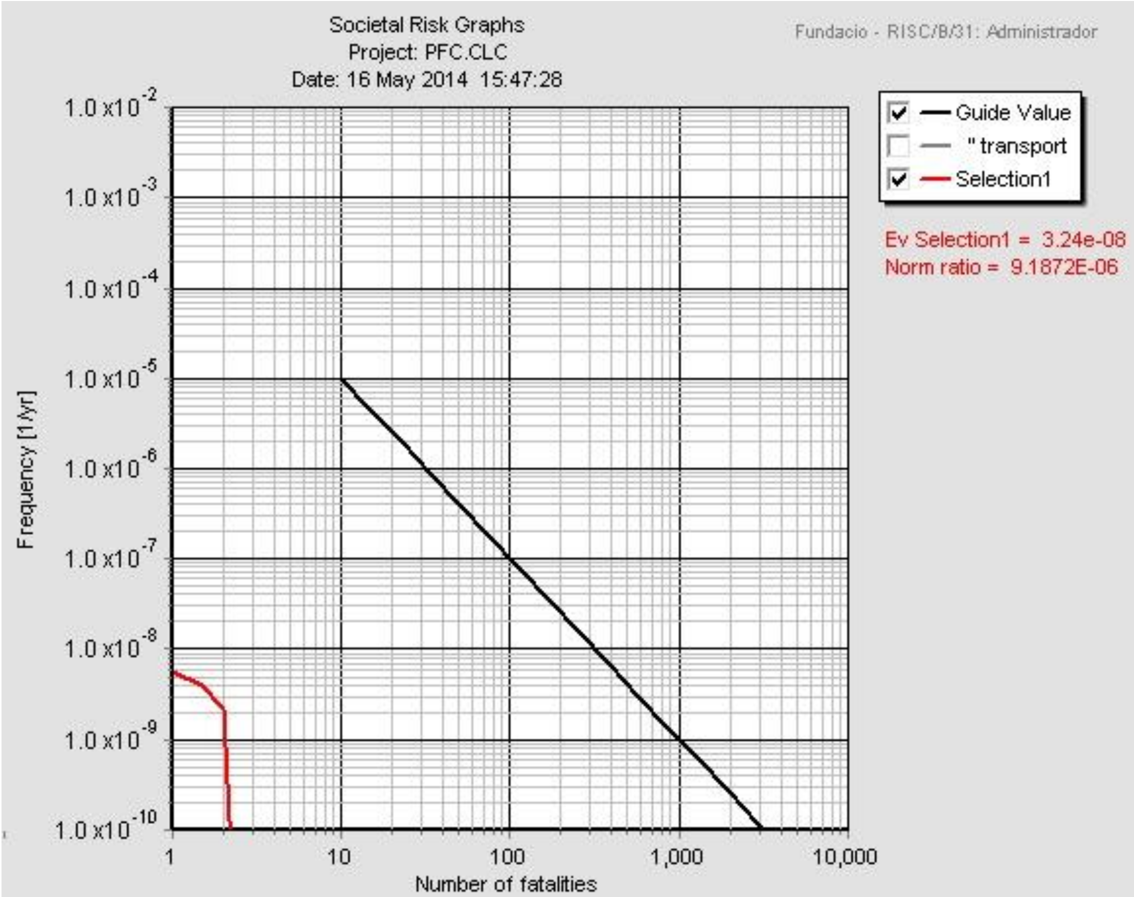


Figure 6.8.1. Social risk curve.

6.9. <u>Results analysis. Acceptability criterion</u>

This report constitute the QRA evaluation of the storage area of *Chorite* establishment, due to the request according to the Instruction 7/2009 SIE (ref.17)

In this study report, there has only been considered the installation AG2, which it does not mean area AG1 is dismissed, but the thesis is focused on the storage area (AG2)

Referring to the considered initiators of the AG2 area, the one referred to the heat exchanger E-103 has been dismissed due to its toxic dispersion affection, which does not exceed the establishment limits.

There is not any initiator with an occurrence frequency smaller than 10^{-9} oc/year, so there are not any initiator that has been dismissed based on this criterion.

The accident that has a higher probability of occurrence is the AG2.CL.4.G2 (Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipe, a maximum of 50 mm, of the pump P-101A) and the one which have a smaller probability are AG.CL.6.G1 (Instantaneous release of the total inventory of the road tanker TK-101) and

AG.CL.6.G2 (Continuous release from a hole the size of the largest connection of the road tanker TK-101)

The studied equipment of the storage area that can produce the worst accident is the storage tank T-101 (with bund and water curtains), which effect reach 1,6 km around.

The following tables show the results of the comparison study done related to the mitigation measures.

Table 6.9.1. % Reduction of lethal dispersion distances applying water curtains in pipes , road tanker and pump.

Equipment	Initiator	% Reduction lethal dispersion distances
Pipes	2.G1	64%
	2.G2	65%
	3.G1	64%
	3.G2	63%
	7.G1	64%
	7.G2	67%
Road tanker	6.G1	63%
	6.G2	67%
	6.L1a	67%
	6.L2a	64%
Pump	4.G1	64%
	4.G2	64%

As can be shown in table 6.9.2., the water curtains make, approximately, the distances a 65% lower in pipes , the road tanker and the pump. It means this mitigation measure is very effective to reduce the dispersion of the toxic cloud formed when an accident occurs in a chlorine equipment in the storage area of *Chlorite*.

Table 6.9.2. % Reduction of lethal dispersion distances applying bund and water curtains in the tank T-101.

Equipment	Initiator	% reduction			
		Bund study		Water curtains study	
		Water curtains	No water curtains	Bund	No bund
Tank	G1	16%	8%	49%	53%
	G2	16%	8%	49%	53%
	G3	64%	64%	0%	0%
	E1	20%	8%	47%	54%

Regarding the effect of the water curtain in the storage tank, this mitigation measure has a little bit lower efficiency than in the other equipment. In this case, the distances are reduced approximately 50% if the tank disposes of water curtains. The difference in the effectiveness of the water curtains between the tank and the other equipment lies in the amount of the substance released; the tank involves much more quantity of fluid than the other systems.

In G3 initiator, water curtains and the bund have not any effect on the dispersion because the pool area is very small (smaller than the bund) and it is the same for both cases.

Regarding the effect of the bund installed in a storage tank, it has a small effect (about 13%) on the evaporation, so, in the toxic dispersion.

The option applied in this design (installation of water curtains and bund in the storage tank) is better than the installation of only one mitigation measure, as can be shown in table 6.9.2. Nevertheless, the reduction effect of both measures is still lower than applying only water curtains in smaller equipment. This is because the quantity of substance in the tank is much bigger than in the pipes, the pump and the road tanker.

Finally, once the comparison of the mitigation measures has been done, it is possible to say that water curtains has much bigger effect than bunds in the toxic dispersion mitigation in tank accidents. Moreover, it is also clear that the effect of water curtains is bigger as smaller is the amount of fluid released, which means that systems that involve high quantities of fluid should have installed mitigation measures, a part from water curtains. Even though, the study can conclude that the measures installed in the storage area of *Chlorite* (considering the bund and water curtains) are appropriate, as can also be seen in the later study done about the effects of the accidents on the population (individual and social risk), which is next commented.

The individual risk and the safety area studies demonstrate that the effects of the worst accident does not affect any vulnerable or very vulnerable element in the surrounding.

After the determination of the social risk curve, it is possible to say that the social risk associated to the storage area is acceptable.

Finally, according to the probabilities of occurrence of the accidents, the lethal dispersion distances obtained, the individual risk, the safety area and the social risk studies, it is clear that the storage area of *Chlorite* is properly designed and secure.

7. ENVIROMENTAL ASPECTS IN THE DESIGN

7.1. Preliminary study of the environmental impacts

The environmental impact is defined as the effect produced on the environment by a determined human action. Those actions, motivated by different reasons, cause collateral effects on the natural or social environment.

While the main objectives of the project always achieve positive effects (e.g. economic profits), the secondary effects are usually negative (e.g. pollutants emission). Once the potential impact sources for each phase of the project are determined, it is necessary to identify and characterize the concrete impacts to evaluate it.

It is important to take into account that the following environmental study only includes the new chlorine storage area.

7.1.1. Sources for possible impacts

- Construction phase: study, design and construction:
  - Transport of the building materials including land and/or cruise arrivals.
  - Area and ground adaptation, laying foundations, construction, etc.
  - Equipment installation, instrumentation, outbuildings, etc.
  - Workers training: engineers, builders, workers, etc.

- Operation phase: the industrial activity generates the following impacts:
  - Storage and transport of the product (chlorine).
  - Equipment operation (including small leaks due to valves, pumps, connections, etc.)
  - Residues emissions (water, purge, etc.)

- Dismantling phase: final of productive activity and end of useful life of the equipment:
  - Equipment and installation dismantling, materials recycling, residues treatment.
  - Residues and scrap transport.

7.1.2. Potential impacts description

The potential impacts caused by the project and the industrial activity are described below. They are classified according to the previous information.

- Construction phase:

  Noise impact due to installation construction probably will not exceed law limits. First of all, the storage unit will be built in a total industrialized site and the law limits are higher in that kind of areas. Moreover, *Chlorite* industry has a piece of land prepared for future enlargements so the preparation of the ground will be easy.

  Visual impact will be minimum since the storage area is located in a fully industrialized zone ("Polígon Industrial Gran Indústria de Tarragona"). In addition, the installation only includes two horizontal tanks and one absorption tower as the biggest equipment.

  Cabling and structures to supply electricity will not be installed since they are already integrated in the area.

  Finally, flora and fauna impact in the area will play a minor role for the same reason. The lack or shortage of flora or fauna in industrial zones reduces that kind of impact.

- Operation phase:

  In addition to noise, visual, flora and fauna impacts, which remain present in the operation phase, are necessary to include some other ones which appears during the normal operation of the storage unit.

  These impacts are produced by all kind of emissions (solid, liquid or gaseous) due to the industrial activities. In order to minimize it, the equipment required have been designed trying to prevent leaks and provided with safety systems which avert accidental emissions. Moreover, both tanks have an independent bund to collect liquid leaks in case of an accident.

  Regarding the economic impact, the installation of a new area of storage in *Chlorite* installation will generate new jobs near Tarragona, which is a positive social impact.

- Dismantling phase:

  The final of productive activity and the end of the useful life of the equipment will generate impacts due to dismantling. On one hand, recycle and/or reuse of the equipment and their materials will reduce the exploitation of metals, so it will be a little positive impact. Moreover, all negative impacts due to normal operation of the equipment will disappear.

  Regarding the social impact, which affects the three phases, is a positive impact due to job creation during each one of the phases. Taking into account that the storage area is located inside *Chlorite* Industry at "Polígon Industrial Gran Indústria de Tarragona", the negative social impacts will be minimum or nonexistent.

7.1.3. Potential impacts description

Once the specific impacts have been determined, they have to be characterized and evaluated using, first of all, a partial quantitative method (incidence rate) and, then, a qualitative method which shows the incidence level on inert, biotic, perceptive and socioeconomic medium (cause and effect matrix). Find in next page the obtained results.

As one may expect, the environment impact is the biggest one due to the normal activity of the storage area and its emissions. Consequently, find proper treatments for the generated residues and alternatives to reduce the emissions might be good solutions to reduce the environment impact. As it has been mentioned, fauna and flora impact are moderated since the storage area is located in an industrial zone where vegetal and animals are limited.

According to the results, the implementation of the storage unit will create a large positive social and economic impact due to new jobs created.

Finally, the location impact has been evaluated to show the profit of locating the storage unit in an industrialized zone instead of a natural zone. That decision do not offer a good impact but reduce significantly the negative environment impact due to construction.

Item	Type	Code	Weight	Imp				
				Noise	Visual	Flora	Fauna	Envi
Sign	**Beneficial** **Damaging** **Hard quantifying**	+ - x	/	-	-	-	-	
Immediacy	**Indirect** **Direct**	1 3	2	3	3	3	3	
Accumulation	**Simple** **Cumulative** **Synergistic**	1 2 3	3	1	1	1	1	
Synergy	**Minor** **Medium** **High**	1 2 3	3	1	1	1	1	
Moment	**Long term** **Medium term** **Short term**	1 2 3	2	3	1	1	1	
Percistence	**Temporary** **Permanent**	1 3	2	1	3	3	3	
Reversibility	**Short term** **Medium term** **Long-term**	1 2 3	3	1	1	2	2	
Recoverability	**Easy** **Medium** **Hard**	1 2 3	2	1	1	1	1	
Continuation	**Discontinuous** **Continuous**	1 3	1	1	3	3	3	
Regularity	**Irregular** **Periodic**	1 3	1	1	3	3	3	
Incidence rate				27	31	34	34	
Standard incidence rate				0,21	0,32	0,39	0,39	

Maximum rate	57
Minimum rate	19

			ENVIROMENTA											
			Inert medium										env	
			Topography	Mineral resource	Agrological capacity	Erosion	Superficial drainage	Subterranean drainage	Air quality - City center	Air quality - Suburbs	Noise quality - City center	Noise quality - Suburbs	Vegetation	
PROJECT ACTIONS	PLANNING	Social acceptance												
	CONSTRUCTION PHASE	Clearance	Moderate			Moderate	Moderate						Critical	
		Flatwork	Moderate			Moderate	Moderate						Severe	
		Dismantling and embankment	Moderate			Moderate	Moderate							
		Landfills	Compatible											
		Structures and factory constructions					Severe							
		Permanent land occupation		Compatible									Critical	
		Temporal occupation											Moderate	
		Plant building								Compatible	Compatible	Severe		
	EXPLOTA-TION PHASE	Noise emission												
		Pollutants emission								Compatible				Severe
		Exploitation plant										Compatible		
		Plant presence												

Critical	Severe	Moderate	Compatible	Positive

7.1.4. Corrective measures

- In order to reduce negative impacts due to storage area implementation, there are some possible measures that could be installed to protect the equipment and to reduce or balance out that impacts.
- Previous steps as determination, characterization and evaluation of all impacts allows to find the best measures to treat critical, sever and moderate impacts, the compatible ones are not too important.
- The possible measures to implant at new chlorine storage area are listed below:
- <u>Atmospheric emissions:</u>
- Atmospheric emissions at chlorine storage area could come from small leaks due to valves, pumps or connections. Trying to minimize it, all installation have been designed with efficient joints and proper valves, moreover, chlorine pumps have been provided with double mechanic barriers.
- In order to detect immediately any chlorine leak, there will be chlorine detectors installed around the tank and secondary equipment; in case of leak, the deluge system will be activated.
- Finally, in case of overpressure in the equipment, the chlorine discharged by pressure relieve valves will be treated in an absorption column.
- <u>Liquid emissions:</u>
- Liquid emissions in storage will be very rare, despite this fact, both chlorine and soda tank will be provide with an independent bund to collect liquid leaks in case of accident. Bunds will be useful to collect water from equipment cleaning.
- In this way, all liquid emissions at storage unit will could be correctly collected and treated.
- <u>Impacts on ground and roads:</u>
- Use of innovative and respectful techniques with environment to produce the minimum impact on ground characteristics and its morphology.
- <u>Flora and fauna impact:</u>
- As it has been mentioned, that kind of impact is not too relevant since the storage area is located in an industrialized site and the required area are not too large. However, the clearance and flatwork should be done in a sequential way, allowing the migration of animals.
- <u>Other general measures:</u>

- Other possible measures could be the use of respectful materials or reused equipment if it was possible. The use of structures and color paint which reduce visual impact could be another possibility.
- Finally, it could be interesting to provide the installation with efficient streetlights.
- Social acceptance:
- In order to benefit the nearest population, the jobs required in each phase will be offered to them, decreasing the grave unemployment situation in Tarragona’s zone.

7.2. Identification and evaluation of air, water and land emissions

- Once the environmental impacts produced are determined, there will be characterised and quantified the emissions produced during the operation phase in the storage area, according to legislation.

7.2.1. Atmospheric emissions

The only gas emission which contains a dangerous product is the chlorine steam from the top of the absorber column. Moreover, there can be slight emissions from the process accessories due to their wearing away, because despite the fact that chlorine is kept as a liquid, when it is leaked it becomes gas, due to the atmospheric conditions. Table 7.2.1 shows the different taxes of gas releases depending on the accessory.

Table 7.2.1. Taxes of gas release from accessories.

Accessory	Quantity [Nº]	Release base factor[kg/h/source][1]	Release rate [kg/h]
Joint, union and connexions	50	$6{,}00\cdot10^{-5}$	$3{,}00\cdot10^{-3}$
Gas valve	29	$6{,}00\cdot10^{-4}$	$1{,}74\cdot10^{-2}$
Liquid valve	95	$1{,}70\cdot10^{-3}$	$1{,}62\cdot10^{-1}$
Pressure safe valve	5	$4{,}47\cdot10^{-2}$	$2{,}24\cdot10^{-1}$
Pump	3	$1{,}20\cdot10^{-2}$	$3{,}60\cdot10^{-2}$

[1] Value obtained from Guidelines for fugitive emissions calculations (ref. 23)

These releases are very small and they keep below the legal limit (ref. 24)

7.2.2. Liquid emissions

The possible liquid emissions that can occur in the storage area of *Chlorite* are chlorine from tank T-101 and pipes, carbon tetrachloride from the refrigerating system of chlorine pipes, soda from PSV-105 installed in the tank T-102 and oil from the motor of the pumps.

The only dangerous substances to take into account are chlorine and carbon tetrachloride. In the first case, chlorine would be contained in the bund of the tank T-101, where there are also installed sprinklers to mitigate the release. Referring to the other leak, it would be absorbed in sand.

7.2.3. Solid emissions

The storage area does not have any solid substance. So, it is not possible a solid emission.

Nevertheless, there can be tools from mechanics and waste from tank insulation and pipes corrosion.

7.2.4. Noise

According to the legislation, the maximum allowable noise permitted in the equipment is 80 dB. The most critical systems are the pumps, thus the manufacturer must ensure not to overtake the limit.

7.3. <u>Energy management systems</u>

According to the specification ISO 50001 (ref. 25), it is necessary to specify the requirements for establishing, implementing, maintaining and improving the energy management system of the storage area of *Chlorite*. This is carried out following the Deming Cicle (Plan-Do-Check-Act)

One of the proposed measures by the Company are the implementation of variable-frequency drive to control the motor speed and torque of the pump by varying motor input frequency and voltage. Another alternative is the improvement of $\cos\Psi$ of the power factor (ratio of the real power flowing to the load, to the apparent power of the circuit)

7.4. Generation of greenhouse effect gases

There are two different types of greenhouse effect gases emissions: direct, which comes from process, and indirect, derived from the emissions due to electricity production consumed by the establishment. The storage area only generates indirect emissions, due to the fact that this area does not produce any product.

To convert the total consumption of the area to kg CO_2 equivalent/year, it is required a conversion factor, which has a value of 0,248 kg CO_2 equivalent/kWh (ref. 26)

Previously, there have been analysed all the elements of the storage area that consumes electric energy. There have only been considered the pumps because the plant illumination consumption is too difficult to estimate and it has less weight in the global consumption.

Table 7.4.1. Kg CO_2 equivalent emissions for year.

Power [kW]	kg CO_2 equivalent/h	kg CO_2 equivalent/year
6,86	1,70	14903
0,84	0,21	1820
1,81	0,45	3932

7.5. Environmental analysis - CIRMA

In order to quantify the environmental damage of the project it has been followed the Guide: ‘‘*Guía para la realización del análisis del riesgo medioambiental en el ámbito del real decreto 1254/199 (SEVESO II)*’’ (ref. 27) and it has also been calculated the index of environmental risk of chlorine storage.

The scenarios proposed are those which involve chlorine and carbon tetrachloride, substances that have a harmful risk phase for the environment, R-50 and R-52/53, respectively.

The set scenarios are: the failure of the chlorine storage tank T-101 (an instantaneous release of the complete inventory) and the full bore rupture of the pipe of chlorine 3’’-CS-CL_2-14, CIRMA program has been used to calculate them.

In the methodology described in the previous guide mentioned (ref. 27) is assigned a score for each of the four components that make up the system of risk:

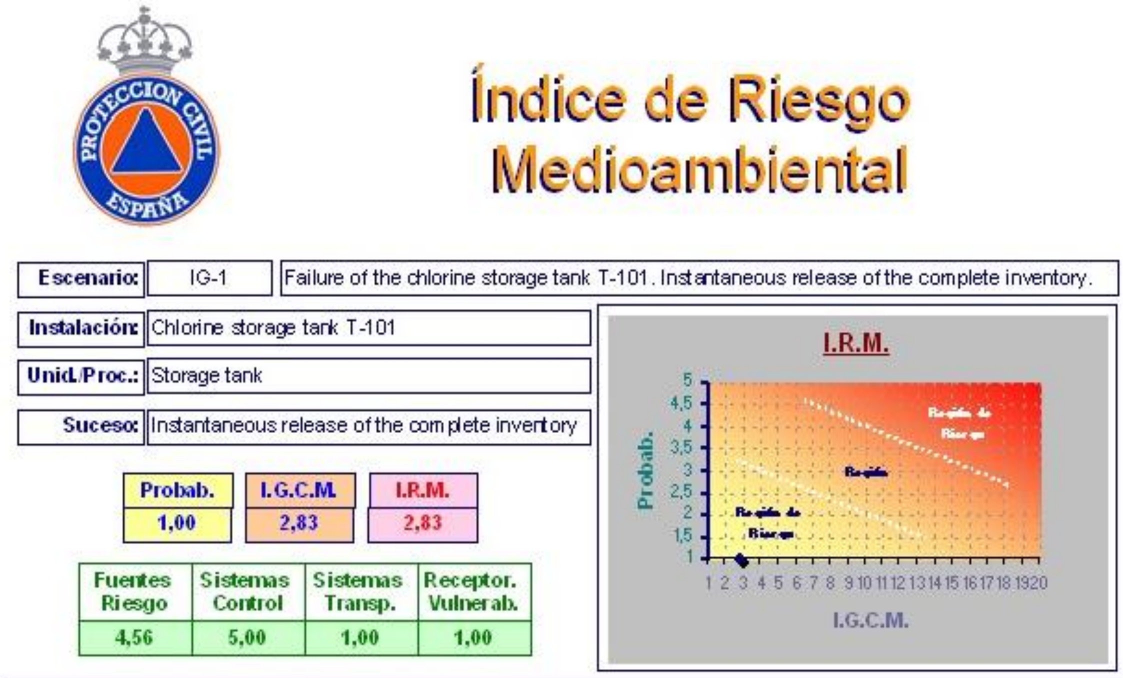
- Risk Sources: taking into account the amount substance present in the scenario and their dangerousness.
- Primary control system: where systems of control and its effectiveness are considered.
- Transport systems: where it is assessed the risk associated to the transport and the magnitude of damage to the population.

- Vulnerable factors: it involves the natural environment, socioeconomic environment and their affectation.
- Index of environmental risk for an accidental setting, is obtained through the product between the probability factor/frequency and the IGCM factor (overall rating of environmental consequences)
- The value of these factors determines some regions of tolerability of risk:
    - Moderated region risk: In this case the risk level is acceptable.
    - ALARP region (As Low As Reasonably Practicable): In this case it is tolerable, but should be reduced to lower levels, without resorting disproportionate costs.
    - High risk level: In this case should be implemented: risk reduction measures, regardless of the cost associated.

The obtained results are shown in table 7.5.1:

Table 7.5.1. Analysis of environmental vulnerability results.

Accident description	IGCM	IRM	Probability/ Frequency	Risk valuation
Failure of the chlorine storage tank T-101, an instantaneous release of the complete inventory.	2,83	2.83	1	Tolerable
Full bore rupture of the pipe of chlorine 3''-CS-CL_2-14	1,15	1,15	1	Tolerable

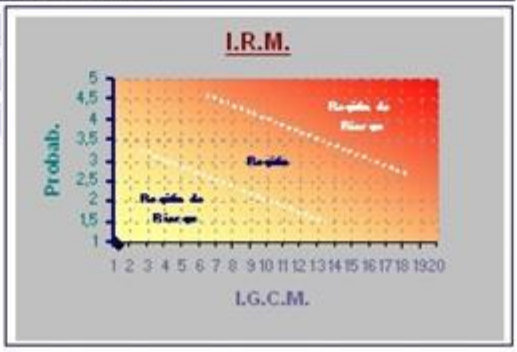


Índice de Riesgo Medioambiental

Escenario:	IG-2	Full bore rupture of the pipe of chlorine 3"-CS-Cl2-19.
Instalación:	Carbon tetrachloride piipeline 2"-CS-Cl2-19	
Unid.Proc.:	Pipeline	
Suceso:	Full bore rupture of the pipe	

Probab.	I.G.C.M.	I.R.M.
1,00	1,15	1,15

Fuentes Riesgo	Sistemas Control	Sistemas Transp.	Receptor. Vulnerab.
2,29	0,00	1,00	1,00



The first scenario is toxic for aquatic organisms, (R-50), and the second scenario is harmful to aquatic organisms and may cause long-term adverse effects in the aquatic environment (R52/53), despite being dangerous substances it has been determinate that for both cases the risk is tolerable, which means that the risk level is acceptable.

8. MAINTENANCE

8.1. Introduction

The plant maintenance includes all the essentials procedures and technics implemented in the plant to prevent breakdowns, to realize revisions and reparations of equipment and systems. The main objective of a good maintenance is to be able to stretch on the shelf life of the equipment in a rentable and efficiently way.

Next maintenance explanation is due to the storage area of *Chlorite*.

The objective is to achieve the accomplishment of the follow terms:

- To prevent accidents and guarantee the personal safety of the plant.
- To enlarge the shelf life of the equipment and installations of the area.
- To make sure the equipment works at optimal conditions.
- To define procedures which allow quick emergency repairs.
- To realize systematic repairs of the involved equipment.

This section includes the explanation of the three types of maintenance applied in the storage area of the establishment

8.2. Corrective maintenance

The corrective maintenance is applied once the system has failed. It consists of a passive maintenance and it requires a big precision and knowledge of the activity. This measure is performed when the equipment cost is smaller than the repair cost.

There will be implanted two types of this corrective method:

- Palliative: Immediately reparation of the equipment without a correction of the source of the breakdown. It has low costs relating the workforce but huge costs of the spare part.
- Curative: Equipment repair by correcting the breakdown source. It involves a big workforce cost, nevertheless it requires low costs related to the materials and spare parts.

8.3. Preventive maintenance

This methodology consists of the plan of periodic revisions in order to reduce the breakdown and malfunction probability of the installations.

During the revision process it is necessary to check the critical aspects of the installations depending on the type of the equipment, the danger related to its operation and its critical nature.

Next sections show the inspections and tests to be made in the plant equipment according to legislation.

8.3.1. Valves maintenance

Valves maintenance is necessary to make sure the valves do not have any kind of leak and pistons will be lubricated to ensure they work correctly.

8.3.2. Pressure safety valves maintenance

Pressure safety valves will be disassembled and adjusted when an equipment inspection has to be carried out. Moreover, it should be carefully cleaned to ensure there is no dirty that could block the fluid through the valve.

8.3.3. Tank maintenance

According to the legislation ITC EP-3 “Instrucción Técnica Complementaria para Refinerías de Petróleos y Plantas Petroquímicas” (ref. 28) the pressurized tank T-101 has been classified.

Table 8.3.1. Tank classification.

Item	**Subst.**	**Pot.(1) Risk**	**Fluid Charact. (2)**	**Classific. (3)**	**Exterior Inspection**	**Interior Inspection**	**Pressure Inspection**
T-101	Chlorine	1	Group 1.2	Class 1	Internal inspector every 4 years	Every 6 years	Every 12 years

(1) Pot: Potencial
(2) Charact.: Characteristic
(3) Classific. Classification

For tank T-102, as it is not pressurized, if pitting is detected, an analysis with penetration liquids will be necessary. If the damage is light, the pores must be covered in order to avoid loss of containment. If the damage is severe, the affected area must be replaced.
It is also necessary to measure the thickness of the tank by ultrasound periodically, to ensure there is no material corrosion.

8.3.4. Heat exchanger maintenance

To catalogue the heat exchangers, the Instruction ITC EP-3 (ref. 28) has been also used.

Table 8.3.2. Heat exchangers classification.

Item	Subst.	Risk pot.	Fluid charact.	Classific.	Exterior Inspection	Interior Inspection	Pressure Inspection
Tube E-102	Chlorine	5	Group 1.2	Class 5	Internal inspector every 8 years	Not required	Not required
Shell E-102	Carbon tetrachloride	5	Group 2.2	Class 5	Internal inspector every 8 years	Not required	Not required
Tube E-103	Water	5	Group 2.2	Class 5	Internal inspector every 8 years	Not required	Not required
Shell E-103	Carbon tetrachloride	5	Group 2.2	Class 5	Internal inspector every 8 years	Not required	Not required

8.3.5. Pump maintenance

To make sure a correct maintenance of the pump is done, legislation ITC EP-3 (ref. 28) is used.

Table 8.3.3. Pumps classification.

Item	Subst.	Risk pot.	Fluid charact.	Classific.	Exterior Inspection	Interior Inspection	Pressure Inspection
P-101A/B	Chlorine	5	Group 1.2	Class 5	Internal inspector every 8 years	Not required	Not required
P-102	Carbon tetrachloride	5	Group 2.2	Class 5	Internal inspector every 8 years	Not required	Not required
P-103A/B	Caustic soda	5	Group 2.2	Class 5	Internal inspector every 8 years	Not required	Not required

8.4. Predictive maintenance

Predictive maintenance is based on the determination of the machine state, installation and equipment operation. There will be a warning before the breakdown of the equipment to be aware of the sign in order to take, then, measures.

It consists of making non-destructive tests, like oil analysis, wearing out particle analysis, vibrations measures, temperature measures, pressure measures, etc.

In case that the aero refrigerant alternative is used, it will be applied the vibrations on-line measure by a Bently sensor, concretely a 990 vibration transmitter which provides a 4-20 mA signal.

8.5. Rehability Centered Maintenance (RCM)

RCM method (ref. 29), basically, consists on focusing maintenance resources into the most critical or dangerous failures related to safety, environment and productivity of the unit. RCM analysis should be useful and simple, and it should be elaborated taking into account all historic knowledge about operation and maintenance. The main objectives of RCM are:

- Reduce failure probability of those elements that could affect environment and process safety.

- Increase availability and reliability of all storage unit equipment.
- Reduce maintenance costs.

First of all, the areas or main systems of the installation analyzed have to be separated and defined. In the chlorine storage unit five independent systems have been studied: chlorine tank T-101, tube and shell exchanger E-102, pump P-101A/B, absorption column C-101 and road tanker TK-101.

Once the systems have been defined, the failures function of each equipment has to be detected to determine its critical nature using following criteria: availability, frequency, detectability and safety and environment affectation. These items will be quantified following next instructions.

Table 8.5.1. Functional failures critical nature.

D: Availability			**Value**
Shut-down during more than 12 hours			4
Shut-down during 6 to 12 hours			3
Shut-down during 6 hours maximum			2
No effects (redundant equipment)			1
F: Frequency			**Value**
Less than every 8.760 hours			4
Between 8.760 and 17.520 hours			3
Between 17.520 and 35.040 hours			2
More than every 35.040 hours			1
D: Frequency			**Value**
Undetectable functional failure or its detection does not prevent unavailability			2
Functional failure detection is possible and could be solved without unit shut-down.			1
S: Safety and environment			
People's effects	**Damage extension**	**Environment impact**	**Value**
Deaths	Extents to neighboring industries	Large durability of contamination	9
Serious personal injuries. Hospitalization.	Affects all *Chlorite* industry	Important, difficult decontamination	6
Accidental injuries requiring medical treatment	Localized extension	Low importance	3

Minor injures	No extension	Minor	1

Table 8.5.2. Functional failures sheet analysis for chlorine storage unit.

Function	Functional Failure	Detecting measures	D	F	D	S	Total	Preventive tasks
Chlorine storage	Chlorine leak	Chlorine detectors	4	1	2	6	13	Periodic revisions of state of corrosion at the tank (under insulation)
Chlorine impulsion	Chlorine leak	Chlorine detectors	1	2	1	6	10	Periodic revisions of double steal pumps
Refrigeration of chlorine	Product out of specification	-	4	1	2	1	8	Periodic revisions to secure the tubs are not perforated
Chlorine absorption	Chlorine leak and bad absorption	Chlorine detectors and high alarm of QIA-102	4	1	2	3	10	Periodic revisions to detect corrosion
Loading operations	Chlorine leak	Chlorine detectors	1	3	1	3	6	Periodic revisions of loading arm
Loading operations	Chlorine leak	Chlorine detectors	1	2	1	3	6	Use nitrogen to pressurise tanker to prove there is no leaks before loading

Table 8.5.3. Cause and mode analysis sheet of technical failures for chlorine storage unit.

						Critical nature				
		Element	**Technical Failure**	**Failure cause**	**Effects**	**D**	**F**	**C**	**S**	**Total**
Chlorine tank T-101	**Product storage**	Shell	Thickness loss	Corrosion under insulation	Chlorine leak	4	1	2	6	13
		Joint	Joint failure	Very localized corrosion	Chlorine leak	4	1	2	6	13
Tube and shell E-102	**Refrigeration of chlorine recirculation**	Shell	Thickness loss	General corrosion	Carbon tetrachloride leak	2	1	2	1	6
		Joint	Joint failure	Very localized corrosion	Carbon tetrachloride leak	2	1	2	1	6
				Human error during assembly	Carbon tetrachloride leak	2	1	2	1	6
				Material deterioration	Carbon tetrachloride leak	2	1	2	1	6
		Tubes	Thickness loss	Material deterioration	Product out of spec	4	1	2	1	8
Absorption column C-101	**Chlorine absorption**	Shell	Thickness loss	General corrosion	Chlorine leak and bad absorption	4	1	2	3	10
		Joint	Joint failure	Very localized corrosion	Chlorine leak and bad absorption	4	1	2	3	10

9. OPERATIONS MANUAL

This section shows the start-up of the chlorine tank T-101.

9.1. Cleaning

The inside of the chlorine tank, pumps and pipes should be cleaned without any kind of residues from the assembly and odd materials.

9.2. Inertisation with nitrogen

Inertisation with nitrogen consists of the supply of nitrogen to the tank. The steps that should be followed are:

Open nitrogen collector of the area. Nitrogen inlet is regulated with the manual valve VGA-118.

Open all manual valves of the tank. These ones that connect with pressure and level instrumentation should also be opened, as well as suction and discharge valves of the pumps and manual valve VGA-114. Automatic valve VC-108 should be closed, due to it is located at the battery limit.

Open all automatic valves of the tank (VC-103)

At this moment, line rejects starts at pipeline 7 and continues through tank T-101, pump P-101A/B, heat exchanger E-102 and, finally, returns to the tank.

The tank will be pressurized to 6 bar using the nitrogen and leaks at joint connections will be checked.

To empty the storage tank, open all venting valves, which allow the rejection of these pipelines. Let the tank to reach atmospheric pressure and close venting valves.

Repeat this procedure in order to achieve a higher clearance.

9.3. Tank filling

Previously, the tank should be cleaned and inerted with nitrogen, like it is explained in section First time the tank is filled, next steps should be followed:

- All manual venting must be closed.
- Instrument valves (PSA, LSA, FICA and LICA) must be opened and indicators (TIA, PSA, LSA, LSHH, LSLL and PSHH), switched on.
- Close manual valves VGA-109, VGA-118 and VGA-117.
- Open manual valves VGA-101, VGA-102, VGA-119, VGA-120 and VGA-121.
- Proceed to supply the tank with chlorine using pipeline 1.
- When the tank has reached the 50 % of level, the storage area starts working.

9.4. Relieving load treatment

As it has been mentioned in the absorption system design, this system will always work despite the fact that, usually, there is not any chlorine release. First time the absorption column is filled, steps to be followed are:

- All manual venting must be closed.
- Instrument valves (FICA, and LICA) must be opened and indicators (LSA, LSHH and LSLL), switched on.
- Close manual valve VGA-152, VGA-153 and VGA-154.
- Open valves VGA-149, VGA-150, VGA-151, introducing caustic soda solution to T-102. When the soda tank reaches 20% of level, switch on the motor of the pump P-103A. Then, open valves VGA-154, VGA 155 and VGA-157 close all the valves of pipe 24.
- Switch on the refrigeration system for E-104, open VGA-159, VGA-160 and VGA-161.
- Open manual valves VGA-162 and VGA-163.
- The caustic soda dilution enters into the absorption column and it will be recirculated continuously to ensure that the safety system is activated.

In case of a chlorine relief, the absorption column will start operating with all the valves of pipes 24 and 25 closed.

When the caustic soda tank reaches 95% of level, close all the valves of pipes 17, 18, 19, 20 21, 22 and 23, and the motor of the pump P-103A will be switched off. Next open VGA-152 in order to let the air supply and, finally, open VGA-153 in order to empty the caustic soda tank.

To repeat the absorption column start-up, repeat the stages explained above.

9.5. Road tanker

First stage is to level the road tanker to fit, using an arm, then:

- Chock the road tanker.
- Connect the displacement sensor to the tanker.
- Connect the ground lead.
- Connect the nitrogen arm to the gas phase of the road tanker and chlorine supply arm, to the loading point.
- Open the automatic valves of pipes 6 and 26, FSV-101 and FSV-102.
- Open the nitrogen manual valves VGA-139 and VGA-138. Manometer should indicate 6 barg; if pressure is higher, do not proceed with the chlorine loading.
- Open manual values of pipes 26 and 6, so filling operation starts. The required time to fill the road tanker is about 1 hour and a half.

Once the operation has finished, close all valves of pipes 6 and 26. Then, unfasten both arms. Finally, disconnect the ground lead as well as the displacement sensor and take of the road tanker.

9.6. Shut down in case of power failure

In case of power failure in the chlorine storage unit, the motor of pumps 101A/B, 102 and 103A/B will be switched off.

9.7. Shut down in case of refrigeration water failure

In the chlorine storage area there are two systems that use refrigeration water; E-103 and E-104.

If refrigeration system of E-103 fails, neither carbon tetrachloride nor chlorine would be cooled. That means that the tank temperature would not be decreased. Regarding to E-104, this exchanger would suffer the same consequences in that situation.

This water refrigeration problem affects both heat exchangers because the water supply is the same.

10. ECONOMIC STUDY

Once the chlorine storage unit has been designed, the viability of the project must be checked using an economic study to determine if the implementation of the storage unit would generate substantial economic benefits.

First of all, fixed investment of the project has to be evaluated; in other words, foundations laying cost, infrastructure works cost and, finally, cost of purchase and installation of all equipment and instrumentation required have to be quantified.

Subsequently, the operating cost have to be determined taking into account the annual expenses balance produced by the own storage installation.

Finally, with all these information, the NPV (Net Pressure Value) method will be used to establish the economic performance of the project in a useful life of 20 years. Moreover, the inversion pay-back will be calculated and the Internal Rate of Return too (IRR)

The economic study has been done taking into account that the storage area will be installed in an existent industry, which is provided with trained engineers, available utilities and other available services that will reduce the main cost of the project.

10.1. Economic studies realized

In order to minimize the possible accidents and its consequences in the chlorine storage area, different options for the installation design has been studied. Find attached the specific information at 4.2.1 Design alternatives.

On one hand, to maintain de desired temperature inside the chlorine tank is necessary to have a refrigerated recirculation. Since the hot product in the exchanger is chlorine, it is not possible to have water as a cool product because in case of little leak in the equipment, there will be hydrochloric acid formation and all installation will be destroyed by corrosion, releasing toxic substances and damaging population.

For this reason, two alternatives have been studied:

- [Option 1] Use of an intermediate cool product (carbon tetrachloride). The installation will have two tube and shell exchanger, the first one will refrigerate carbon tetrachloride with cool water, and the second one will use that cool carbon tetrachloride to refrigerate the chlorine recirculation. With this system chlorine will be not in contact with water. To more details, P&ID diagram and exchangers design can be viewed at 4.1.5 Piping and instrumentation diagram.

- [Option 2] Use of an industrial air cooler to refrigerate the chlorine recirculation. As with the previously mentioned system, with this equipment will be not any corrosion risk due to hydrochloric acid formation.
- On the other hand, in order to reduce the main risk due to chlorine storage, two alternatives have been studied.
- [Option 3] Replace the 82 m^3 chlorine tank by two tanks with less capacity (41 m^3) This change offers an important reduction of lethal distances in case of catastrophic rupture of the tank since the quantity of realised chlorine will be the half.
- [Option 4] Replace the ordinary tank by a double-wall tank of the same capacity. This kind of tanks reduce the probability of accident since, if the first wall have a leak, the chlorine released will be retained into the second wall.

Once the safety effectiveness of these alternatives have been proven is crucial to determine which ones are economically viable.

10.2. Fixed and working capital investment

First of all, the procedure stipulated in Turton (ref. 30) has been used to determine the purchased equipment costs. This method takes into account the size, the design pressure and the material of the equipment to find its prize on 2001. Find attached at following table the obtained results.

Table 10.2.1. Major equipment prices.

Item	C_{BM} 2001 (€)
T-101	263.900
T-102	62.680
E-102	9.770
E-103	17.760
E-104	52.610
C-101	19.080
P-101A/B	9.550
P-102	3.330
P-103A/B	7.110
Aircooler	46.180
Two chlorine tanks (41m^3)	325.700
Double-wall tank (82m^3)	527.830

Once the specific price of each equipment is known, the total purchase cost for each design alternative can be calculated.

The values have been calculated taking into account that each alternative includes the following equipment:

- Option 1: T-101, T-102, E-102, E-103, E-104, C-101, P-101A/B, P-102, P-103A/B.
- Option 2: T-101, T-102, E-104, C-101, P-101A/B, P-103A/B, aircooler.
- Option 3 : Two chlorine tanks ($41 m^3$), T-102, E-102, E-103, E-104, C-101, P-101A/B, P-102, P-103A/B.
- Option 4: Double-wall tank, T-102, E-102, E-103, E-104, C-101, P-101A/B, P-102, P-103A/B.

Table 10.2.2. Total purchase costs (PCE 2011)

Alternatives	PCE 2001 (€)
Option 1	450.790
Option 2	466.120
Option 3	512.520
Option 4	714.710

The installation, piping and instrumentation costs for each piece of equipment are costed separately. Other factors as costs of design and engineering, contractor's fee and contingency must be taking into account too. The following data have been used to quantify all these costs.

Table 10.2.3. Typical factors for estimation of project fixed capital cost. (ref. 31)

Item	Factor (for liquid phase)
Major equipment, total purchase cost	PCE
Equipment erection, f_1	0,40
Piping, f_2	0,70
Instrumentation , f_3	0,20
Electrical, f_4	0,10
Buildings, process, f_5	0,15
Utilities (1)	-
Storages (1)	-
Site development (1)	-
Ancillary buildings (1)	-
Total physical plant cost (PPC) = PCE·(1 + f_1 +…f_5)	PCE x 2,55
Design and engineering	0,30
Contractor's fee	0,05
Contingency	0,10
Fixed capital = PPC·(1 + f_{10} + f_{11} + f_{12})	PPC x 1,45

(1) Omitted for additions to existing sites.

Finally, the plant costs indexes (CEPSI) for 2001 and 2014 have been used to convert the 2001 fixed capital to current year (ref.31) (ref.32)

Table 10.2.4. Final fixed capital for each alternative.

Alternatives	PPC 2001 [€]	Fixed capital 2001 [€]	Fixed capital 2014 [€]
Option 1	1.104.400	1.601.400	2.307.000
Option 2	1.142.000	1.655.900	2.385.500
Option 3	1.255.700	1.820.700	2.623.000
Option 4	1.751.000	2.539.000	3.657.700

10.3. Operating cost

Once the fixed capital inversions are determined, is important to quantify the operating cost of the chlorine storage unit.

Since the storage zone will be implemented in an existing product plant, the operating cost only includes the maintenance of the equipment and the journals of the extra plant operators required:

- The maintenance annual cost of the installation has been estimated as a 2% of the total fixed capital.
- Taking into account that the normal operation of the storage zone will be relatively calm, the unit will be controlled and supervised 24h per day by a plant operator. For these reason, four people will be needed to cover the four work shifts (morning shift, evening shift, night shift and week of rest).

The operating minority costs as electricity, instrumentation air or cleaning of unit have been neglected since *Chlorite* industries will supply it and the extra cost will be minimum.

The final values for operating costs for each alternatives are shown in the next table.

Table 10.3.1. Operating costs for each alternative.

Alternatives	Maintenance costs [€/year]	Operators journal costs [€/year]	Total operating cost [€/year]
Option 1	46.140	72.800	118.900
Option 2	47.710	72.800	120.500
Option 3	52.460	72.800	125.300
Option 4	71.150	72.800	146.000

10.4. Annual economic savings

Finally, quantify the annual economic savings is essential to secure the viability of the project.

Nowadays, the prices of energy increases or decreases depending on the month, the day of the week and the hours of the day. The chlorine process production of *Clhorite* industry requires approximately 2,26MW per ton of produced chlorine.

Moreover, *Chlorite* must supply its customers with 10 ton/hour by pipe 24 hours a day, 365 days per year. For this reason, with the actual conditions (without storage tank), *Chlorite* must produce a minimum of 10t/h regardless of the electricity price.

The new chlorine storage vessel will allow *Chlorite* to increase its production during the cheapest hourly segment and to decrease it in the most expensive ones. In that way, the chlorine excess production may be stored to be supplied whenever required. That fact will allow *Chlorite* to decrease its production during the expensive hourly segments without stopping supply costumers.

The prices for different hourly segment are:

Table 10.4.1. Energy prices for different hourly segments (ref. 33)

Hourly segment	Energy prices (€/kW)
1	95,01
2	80,16
3	63,21
4	54,02
5	51,76
6	42,27

Therefore, the profit of this project will be the difference between produce during expensive hours or in the cheaper ones. To calculate the electricity cost difference between both situations, without and with tank, the following design parameters has been taken into account.

- The tank capacity is 82m^3, 105 chlorine ton.
- The maximum productive capacity is 20t/h.
- The minimum chlorine production is 2t/h, is a continuous process.
- The chlorine production requires 2,26MW per ton of produced chlorine.
- Chlorite must supply its customers with 10t/h by pipe (gas phase).
- To storage the excess of chlorine is necessary to liquefy it (12€/t) and later, gasify it to supply customers (2€/t)

- Finally, the hourly segments for each month or period and for Saturdays, Sundays and holyday days, are specify in the next table:

Table 10.4.2. Hourly segments (ref. 33)

Time planning [h]	December January February	March 1-15 of June September November	April March October	15-30 of June July	August	Saturdays Sundays Holiday
00:00	6	6	6	6	6	6
01:00	6	6	6	6	6	6
02:00	6	6	6	6	6	6
03:00	6	6	6	6	6	6
04:00	6	6	6	6	6	6
05:00	6	6	6	6	6	6
06:00	6	6	6	6	6	6
07:00	6	6	6	6	6	6
08:00	2	4	5	2	6	6
09:00	2	4	5	2	6	6
10:00	1	4	5	2	6	6
11:00	1	4	5	1	6	6
12:00	1	4	5	1	6	6
13:00	2	4	5	1	6	6
14:00	2	4	5	1	6	6
15:00	2	4	5	1	6	6
16:00	2	3	5	1	6	6
17:00	2	3	5	1	6	6
18:00	1	3	5	1	6	6
19:00	1	3	5	2	6	6
20:00	1	3	5	2	6	6
21:00	2	3	5	2	6	6
22:00	2	4	5	2	6	6
23:00	2	4	5	2	6	6

With all these information, the following parameters have been calculated:

- Production price per month without taking into consideration the storage tank, actual situation. It means that the production is 10 t/h in continuous.

- Production price per month taking into account the storage unit. It means that the production between 00:00 and 08:00h will be 20t/h (10 tones will be directly supplied and 10 tones liquefied and stored each hour). During the most expensive hours, the production will be the minimum stipulated (2 t/h) and 8 t/h will be gasified and supplied to accomplish the 10 t/h required by customers. Regardless the rest of hours, the production distribution will be different depending on the month, but it will be the minimum required to supply costumers.

Finally, during the weekends, there will be an excess of production due to fill the storage tank, so, the production on Mondays will be cheaper.

Finally, to obtain a representative results is important to take into account all specified data, as different prices between hours, days and months; liquefy and gasify prices, etc. Find attached the month price production for both cases, with or without tank:

Table 10.4.3. Production cost per month and economic savings.

Month	Price production without tank [€/month]	Price production with tank [€/month]	Economic savings [€/month]
January	906.100	720.190	185.910
February	806.610	644.100	162.510
March	844.250	668.650	175.610
April	609.120	581.570	27.550
May	627.040	599.480	27.550
June	856.830	637.110	219.720
July	939201	624.200	212.390
August	555.380	555.380	0
September	840.090	653.710	186.390
October	630.290	601.110	29.180
November	812.580	648.760	163.820
December	806.610	715.900	90.710
	TOTAL ANNUAL SAVINGS (€/year)		**1.390.630**

10.5. Cash flows and economic viability of project

Once fixed capital inversion, annual operating costs and annual savings are determined, the viability of the project can be evaluated.

First of all, the pay-back of each alternative have been calculated with the following equation:

$$Pay\ back = \frac{FCI}{B+ED} \qquad 10.5.1.$$

Where pay-back is the year which the capital investment will be recuperated (years), FCI is the fixed capital investment (€), B represents the benefits (total annual savings, €/year) and ED is the equipment depreciation per year (€/year)

The results for different alternatives pay-backs are:

Table 10.5.1. Pay-back of each alternative project.

Alternative	Pay-back (year)
Option 1	2,5
Option 2	2,6
Option 3	2,7
Option 4	3,3

To calculate cash-flows has been established that construction starts on September 2014 and will be finished by begging on January 2015. The following figure shows the accumulative cash-flow for each alternative.

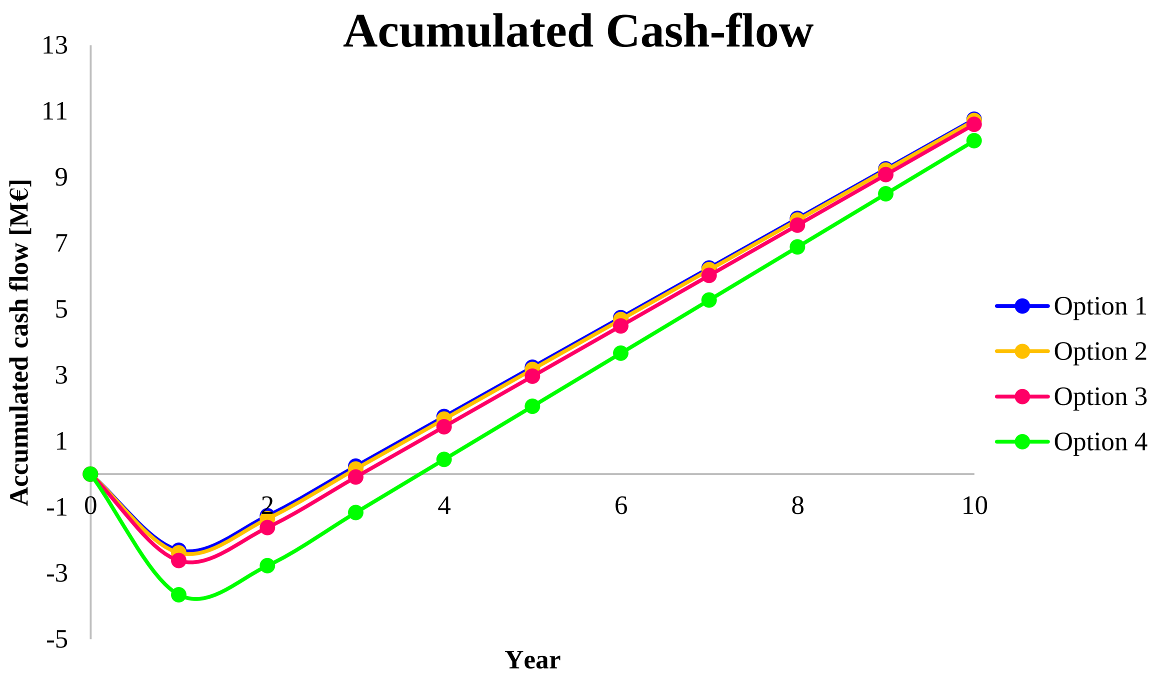


Figure 10.5.1. Accumulated Cash-flow versus time for each alternative.

Moreover, to determine the viability and the investment reliability, is important to know the value of the NPV (Net Present Value) and IRR (Internal Rate of Return), both parameters have been calculated for the first ten years cash-flow.

Table 10.5.6. NPV and IRR of each alternative project.

Alternative	NPV, 10% [M€]	IRR [%]
Option 1	6,09	58
Option 2	6,04	57
Option 3	5,91	52
Option 4	4,77	38

According to the results, the first three alternatives are viable and will generate important profits to Chlorite enterprise. The forth option (double wall tank) have a positive NPV and IRR too, but its values are quiet low comparing with other options.

Taking into account that the difference between two first options is the type of heat exchanger used, the best option is the first one since it has a bigger NPV and IRR.

From the safety point of view, the best option is the third one since it has a positive NPV and IRR. Moreover, in case of catastrophic rupture of one tank (41 m^3), the lethal distances due to toxicity of chlorine will be smaller than in the first option (82 m^3 tank).

10.6. Sensitivity analysis

Finally, the sensitivity analysis has been made to know if the projects will be viable despite any negative unexpected event.

Two possible negative situations have been analyzed:

- The value of fixed capital investment is 15% higher than the expected.
- The annual economic savings are 10% lower than the expected

10.6.1. The value of fixed capital investment is 15% higher than the expected

The results for different alternatives pay-backs in case of the capital investment were higher are:

Table 10.6.1. Pay-back of each alternative project.

Alternative	Pay-back [year]
Option 1	2,7
Option 2	2,8
Option 3	2,9
Option 4	3,5

The following figure shows the accumulative cash-flow for each alternative.

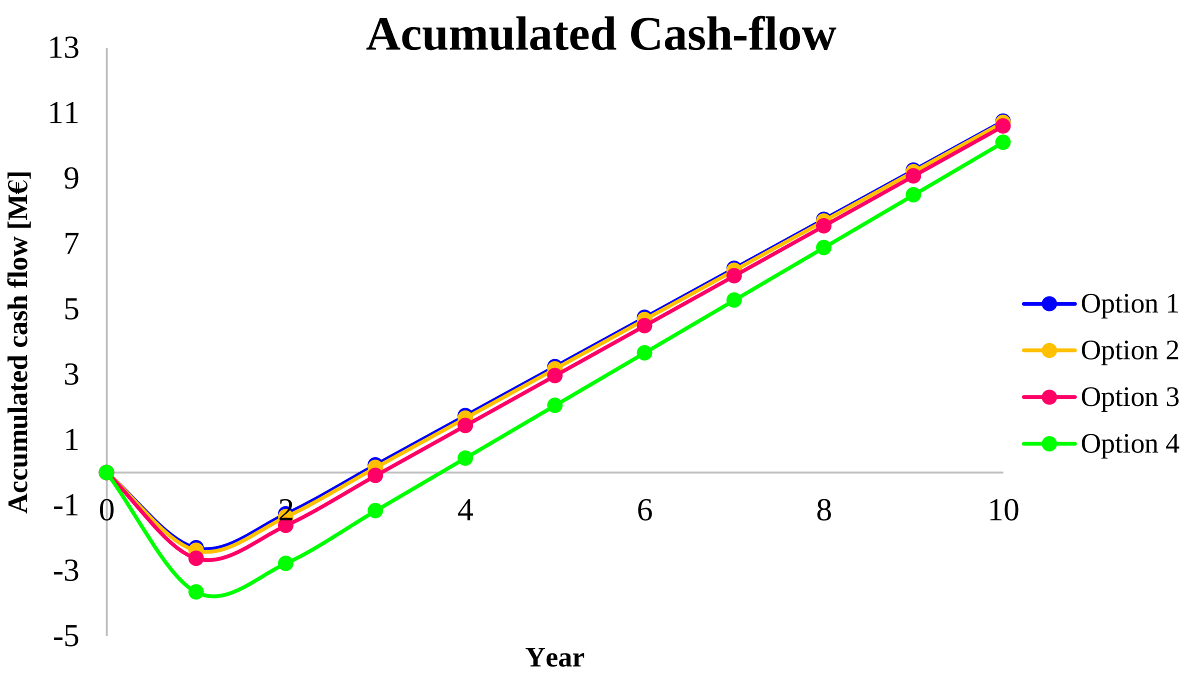


Figure 10.6.1. Accumulated Cash-flow versus time for each alternative.

Values of NPV and IRR have been calculated too, both parameters have been calculated for the first ten years cash-flow, the results are listed below.

Table 10.6.2. NPV and IRR of each alternative project (FCI 15% higher)

Alternative	NPV, 10% [M€]	IRR [%]
Option 1	5,89	51
Option 2	5,84	50
Option 3	5,69	46
Option 4	4,45	34

10.6.2. The annual economic savings are 10% lower than the expected

The results for different alternatives pay-backs in case of the economic savings are 10% lower than the expected are:

Table 10.6.3. Pay-back of each alternative project.

Alternative	Pay-back [year]
Option 1	2,7
Option 2	2,8
Option 3	2,9
Option 4	3,5

The following figure shows the accumulative cash-flow for each option.

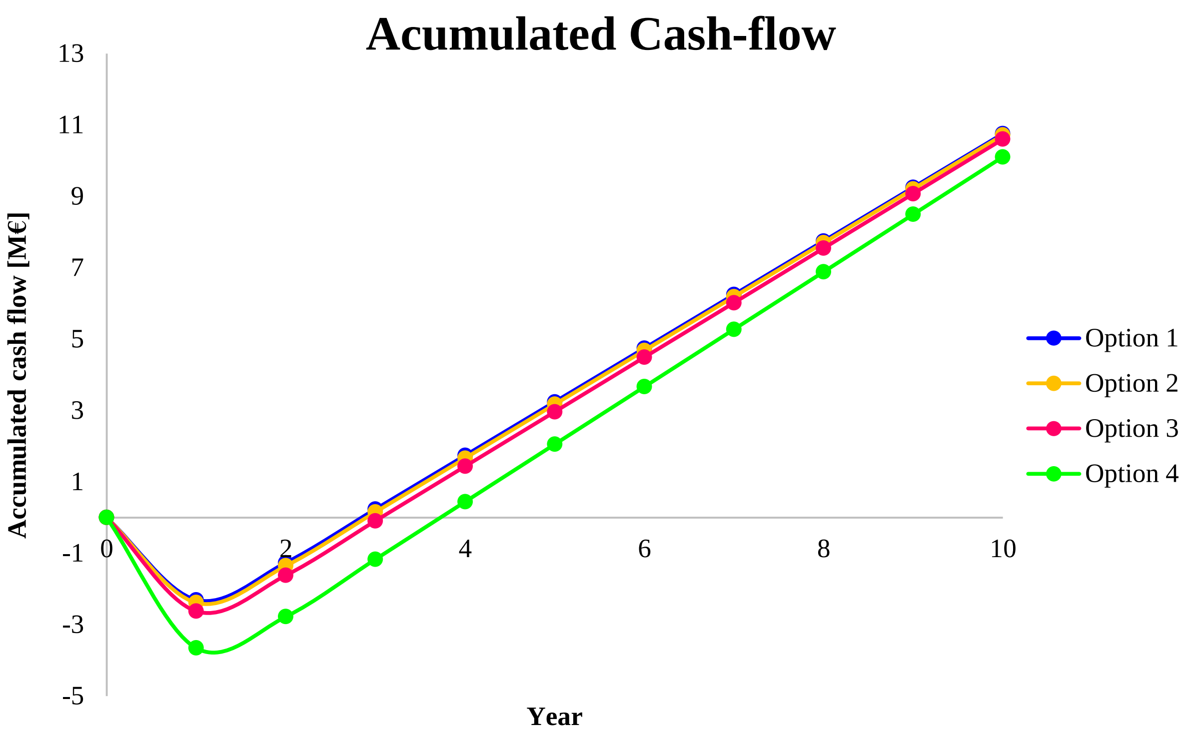


Figure 10.6.2. Accumulated Cash-flow versus time for each alternative

Finally, NPV and IRR have been calculated for the first ten years cash-flow too:

Table 10.6.4. NPV and IRR of each alternative project (Savings 10% lower)

Alternative	NPV, 10% [M€]	IRR [%]
Option 1	5,31	53
Option 2	5,27	51
Option 3	5,13	47
Option 4	4,04	35

10.6.3. Conclusions

As the results of sensitivity analysis prove, all alternatives have positives values of NPV and IRR despite these possible unexpected events. Therefore, all alternatives are viable and would generate benefits to *Chlorite*; obviously, the best option, from the economic point of view, is the first one, the forth option is the worst.

11. SAFETY AND ECONOMIC COMPARATIVE

This section contains the analysis of the combination of the alternatives mentioned above, in order to determine which one is the most optimal and, so, the one that will be installed in *Chlorite*.

The following table shows the combined alternatives proposed.

Table 11.1. Alternatives comparison.

Option	Alternative	Investment [M€]	Probability [oc/year](ref. 19)	Distance [m]
1	One tank 82m^3 and two heat exchangers	2,31	$4,75 \cdot 10^{-7}$	1.600
2	One tank 82m^3 and air cooler	2,39	$4,75 \cdot 10^{-7}$	1.600
3	Two tanks 41 m^3 and two heat exchangers	2,62	$9,49 \cdot 10^{-7}$	1.100
4	Two tanks 41 m^3 and air cooler	2,70	$9,49 \cdot 10^{-7}$	1.100
5	Double wall tank 82 m^3 and two heat exchangers	3,66	$1,19 \cdot 10^{-9}$	1.600
6	Double wall tank 82 m^3 and air cooler	3,74	$1,19 \cdot 10^{-9}$	1.600

In order to make a good comparison, three parameters have been considered: investment, probability of occurrence of an accident and the distance that the toxic dispersion would reach due to the accident. The optimal option will be the one that has an acceptable relation between these parameters, which means slight economical investment, low probability of occurrence and the minimum distance reached. Despite that this is required, there is no option that accomplish the three requirements, so all of them are following compared.

It must be said that the economic study of all the alternatives includes the cost of the absorption system required.

First alternative to be dismissed is number 6, followed by number 5, due to the huge investment cost. Despite it is the option with a lower occurrence probability, the reach of the toxic chlorine dispersion is one of the highest. Thus, the criterion to dismiss these options is the economic factor.

Next alternative to be dismissed are number 4 and 3, respectively. Even though these alternative are those which generate the shorter dispersion distance, these have a major economic investment and the highest probability referred to the other alternatives proposed.

The last two options (1 and 2) are the most economic viable in comparison with all the others, despite these alternatives produce long distances. Referring to probability, it is not a discriminative criterion due to its intermediate value. So, the optimal option is number 1 because it involves a little bit smaller economic inversion than number 2.

Finally, the alternative implemented in *Chlorite* involves one storage tank of 82 m^3 and, as a refrigeration system, two tube and shell heat exchangers.

12. BIBLIOGRAPHY

(1) Real Decreto 1254/1999, de 16 de julio, por el que se aprueban las medidas de control de los riesgos inherentes a los accidentes graves en los que intervengan sustancias peligrosas.

(2) Funke safety heat exchangers:
http://www.funke.de/index.php?article_id=18&clang=1

(3) ITC MIE-APQ-6: almacenamiento de líquidos corrosivos. Real Decreto 379/2010, de 6 de abril por el que se aprueba el Reglamento de almacenamiento de productos químicos y sus instrucciones técnicas complementarias MIE-APQ-1, MIE-APQ-2, MIE-APQ-3, MIE-APQ-4, MIE-APQ-5, MIE-APQ-6 y MIE-APQ-7. BOE núm. 112 de 10 de mayo de 2001.

(4) Distributed control systems (DCS) Maintenance support upgrade services from Honeywell:
https://www.honeywellprocess.com

(5) Alpha Naval Catalogue, specifically Alpha Blue BDM model.

(6) Alfa Laval catalogue M10 Plate Heat Exchanger:
http://www.alfalaval.com/solution-finder/products/sealed-industrial-range-phe/Documents/M10.pdf

(7) ECHA, European chemicals agency: http://echa.europa.eu/es/regulations/reach

(8) NTP 291: Modelos de vulnerabilidad de las personas por accidentes mayores: método Probit:

http://www.insht.es/InshtWeb/Contenidos/Documentacion/FichasTecnicas/NTP/Ficheros/201a300/ntp_291.pdf

(9) "DOW'S FIRE & EXPLOSION INDEX HAZARD CLASSIFICATION GUIDE"- SEVENTH EDITION- a AIChE technical manual published by the American Institute of Chemical Engineers.

(10) Instrucció 11/2010 SIE "Criteris per l'elaboració I l'avaluació de l'informe de seguretat a presentar pels establiments afectats en nivell alt per la legislació vigent en matèria d'accidents greus".

(11) Real Decreto 1196/2003, de 19 de septiembre, por el que se aprueba la Directriz básica de protección civil para el control y planificación ante el riesgo de accidentes graves en los que intervienen sustancias peligrosas.

(12) Leser Catalog. Best availability safety valves and upstream bursting disks in combination.

(13) Continental disc Corporation. Union holder for standard or composite type rupture discs.

(14) Válvulas nacional S.A -General Catalogue-Safety Valve 3-5211 and 3-526.

(15) Manual para la identificación y evaluación de riesgos laborales por la Generalitat de Catalunya.

(16) Real Decreto 948/2005, de 29 de julio, por el que se modifica el Real Decreto 1254/1999, de 16 de Julio, por el que se aprueban medidas de control de los riesgos inherentes a los accidentes graves en los que intervengan sustancias peligrosas.

(17) Instrucció 7/2009 SIE. Requeriment de les anàlisis quantitatives de risc als establiments afectats per la legislació d'accidents greus a Catalunya.

(18) Instrucció 14/2008 SIE. Criteris per la realització de les anàlisis quantitatives de risc a Catalunya. (Purple Book i criteris complementaris).

(19) Document Reference Manual BEVI Risk Assessments version 3.1.

(20) Guidelines for quantitative risk assessment. CPR18E. Purple Book. Committee for the Prevention of Disasters First Edition 1999.

(21) Procediment per incloure les prestacions de les cortines d'abatiment de gasos tòxics/inflamables a l'AR/AQR.

(22) Instrucción 9/2007 SIE de Criteris per a l'elaboració de l'informe o decisió vinculant previstos als articles 7 i 10 del Decret 174/2001 per la sol·licitud de l'autorització ambiental per establiments afectats per la legislació vigent en matèria d'accidents greus nous o canvis substancials en els existents.

(23) Guidelines for fugitive emissions calculations: http://www.aqmd.gov/aer/Updates/GuideFugitiveEmisCalcu.pdf

(25) ISO 50001: Energy management : http://www.iso.org/iso/home/standards/management-standards/iso50001.htm

(26) ISO 50001: Energy management : http://www20.gencat.cat/docs/canviclimatic/Home/Redueix%20emissions/Guia%20de%20calcul%20demissions%20de%20CO2/140303_Guia%20practica%20calcul%20emissions_sense%20canvis_CA.pdf

(27) Guía para la realización del análisis del riesgo medioambiental (en el ámbito del Real Decreto 1254/99 [Seveso II]).

(28) Real Decreto 2060/2008 "Reglamento de equipos a presión y sus instrucciones técnicas complementarias" y en concreto la ITC EP-3.

(29) Romera Solanas, M.A. Aplicación del RCM en un proceso químico, Mantenimiento, Marzo 2004, p36-41.

(30) RICHARD TURTON: Analysis, Synthesis and Design of Chemical Processes. Third Edition.

(31) Capítol 6 del llibre Coulson & Richardson Engineering, Volume 6, Pergamon Press, 1983.

(32) Business news. Chemical Engineering: www.che.com

(33) Orden IET/107/2014: www.cmie.es

(34) ANTONIO CREUS, “Instrumentación Industrial” 6ª edición. Ed. Marcombo.

(35) KAYODE COKER, “Ludwig’s Applied Process Design for Chemical and Petrochemical Plants” Vol 1 4º Edición. Ed. Elsevier.

(36) EUGENE F. MEGYESY, “Pressure vessel handbook”. Thirteenth Edition.

(37) NIST Chemestry WebBook: http://webbook.nist.gov/chemestry

(38) Institut cartogràfic i Geològic de Catalunya: http://www.icc.es/

(39) ULLMAN‘S : Encyclopedia of industrial chemistry

ANNEX

Chlorine storage unit design and application of risk mitigation measures
TFG-211402

INDEX

A.1. BASIC DESIGN PROCEDURES

A.1.1. Pipe sizing

A.1.1.1. Nominal pipe size

In order to determine the nominal pipe size, it is necessary to establish, for each pipe, a fluid rate (which has been supposed to be 1,60 m/s) and the fluid flow. With these two parameters it is possible to obtain the inside diameter of the pipe by applying next equation:

$$D_i = \sqrt{\frac{F \cdot 4}{r_0 \cdot \pi}} \qquad \text{A.1.1.1.}$$

Where r_0 is the supposed flow rate; F, fluid flow and D_i is the internal diameter determined by r_0 and F.

With this value and using the table of standardized diameters (table A-14 from the book "Applied process design for chemical and petrochemical plants", Ernest E. Ludwig), the nominal size of each pipe is obtained, as well as the fluid rate is recalculated with this new diameter.

A.1.1.2. Losses

A.1.1.2.1. Major losses

To obtain the friction losses generated, first of all it is required the calculation of Reynolds number, Re, in order to determine the friction factor, f:

$$Re = \frac{\rho \cdot r_{real} \cdot D_{i-real}}{\mu} \qquad \text{A.1.1.2.}$$

$$f = \frac{0,25}{\left[\log\left(\frac{\varepsilon/D_{i-real}}{3,7} + \frac{5,74}{Re^{0,9}}\right)\right]^2} \qquad \text{A.1.1.3.}$$

Where ρ is the density of chlorine at 15 ºC, 1.427 kg/m^3; μ, dynamic viscosity 3,58·10^{-4} kg/m·s and ε is the absolute roughness factor, 4,57·10^{-5} m.

To determine the major losses a pipe, h_f, the length of the pipes has to be established and equation A.1.1.4. has to be used:

$$h_f = f \cdot \frac{L}{D_{i-real}} \cdot \frac{{r_{real}}^2}{2 \cdot g} \qquad \text{A.1.1.4.}$$

Where L is the pipe length and g corresponds to gravity, 9,81 m/s^2.

A.1.1.2.1. Minor losses

Minor losses are calculated using equation A.1.1.5. where k_L factor corresponds to the addition of all *k* values of the fittings installed in each pipe.

$$h_L = k_L \cdot \frac{r_{real}^2}{2 \cdot g} \qquad \text{A.1.1.5.}$$

Table A.1.1.1. Pipe fittings.

Fitting	*K* value
Gate Valve	0,33·f
Three-Way Valve	30·f
Globe Valve	340·f
Check Valve	100·f
90 Deg. Elbow	30·f
Pipe Entrance	0,5
Pipe Exit	1
Standard Tee - flow thru run	20·f
Standard Tee - flow thru branch	60·f
Purge	20·f
Flow Orifice	0,36
Rupture Disc	1

A.1.1.2.1. Total losses

The total losses are obtained by the addition of the major and the minor losses (equation A.1.1.6.). It is also possible to obtain, from the total loss, the pressure drop of the pipe using equation A.1.1.7.

$$h_{LT} = h_f + h_f \qquad \text{A.1.1.6.}$$

$$\Delta P = h_{LT} \cdot \rho \cdot g \qquad \text{A.1.1.7.}$$

Next table shows the results of all the calculations explained above.

Table A.1.1.2. Parameters and total loss.

Pipe	Re [-]	f [-]	L [m]	ΔP [bar]
3”-CS-Cl_2-1	$4{,}03\cdot10^{-5}$	0,0186	15	0,770
3”-CS-Cl_2-2	$4{,}78\cdot10^{5}$	0,0185	5	0,092
3”-CS-Cl_2-2a	$4{,}78\cdot10^{5}$	0,0185	1,5	0,051
3”-CS-Cl_2-3	$4{,}78\cdot10^{5}$	0,0185	42	1,766
3”-CS-Cl_2-3a	$4{,}78\cdot10^{5}$	0,0185	7	0,084
1 ¼”-CS-Cl_2-4	$4{,}57\cdot10^{5}$	0,0227	3	0,050
1 ¼”-CS-Cl_2-5	$1{,}67\cdot10^{5}$	0,0227	10	0,124

Pipe	Re [-]	f [-]	L [m]	ΔP [bar]
3”-CS-Cl_2-6	$4{,}03\cdot10^5$	0,0186	15	0,892
1"-CS-N_2-7	$6{,}95\cdot10^2$	0,0921	30	0,054
1”-CS-Cl_2-8	$4{,}50\cdot10^2$	0,1421	30	0,021
2”-CS-CCl_4-12	$2{,}86\cdot10^5$	0,0204	2,5	0,049
2”-CS-CCl_4-13	$2{,}86\cdot10^5$	0,0204	2,5	0,762
2”-CS-CCl_4-14	$2{,}87\cdot10^5$	0,0204	5,5	0,068
1”-CS-H_2O-15	$1{,}69\cdot10^4$	0,0306	10	0,705
1”-CS-H_2O-16	$1{,}69\cdot10^4$	0,0306	10	0,004
4”-FG-NaOH-17	$5{,}11\cdot10^5$	0,0175	4	0,754
3 ½ ”-FG-NaOH-18	$4{,}92\cdot10^5$	0,0180	3,5	0,084
3 ½ ”-FG-NaOH-18a	$4{,}92\cdot10^5$	0,0180	1,5	0,047
3 ½ ”-FG-NaOH-19	$4{,}92\cdot10^5$	0,0180	3	0,100
3 ½ ”-FG-NaOH-19a	$4{,}92\cdot10^5$	0,0180	1	0,060
5”-CS-H_2O-20	$6{,}23\cdot10^5$	0,0167	10	0,764
5”-CS-H_2O-21	$6{,}23\cdot10^5$	0,0167	10	0,032
3 ½”-FG-NaOH-22	$4{,}92\cdot10^5$	0,0180	8	0,803
1”-CS-Air-23	$2{,}87\cdot10^2$	0,1193	18	0,009
5”-FG-NaOH-24	$6{,}95\cdot10^2$	0,0784	30	0,751
3 ½”-FG-NaOH-25	$4{,}01\cdot10^5$	0,0181	10	0,038
1”-CS-N_2-26	$6{,}95\cdot10^2$	0,0784	30	0,987
1 ½”-CS-Cl_2-27	$6{,}55\cdot10^3$	0,0365	60	1,143
1”-CS-Air-29	$5{,}91\cdot10^2$	0,0841	10	0,016

A.1.2. <u>Control valves design</u>

In order to design the control valves, it has been calculated the necessary flow coefficient required to select a standard valve size.

To ensure that there is an oversized device which allows the regulation of the aperture percentage of valve opening, it has been taken into account that all control valves are designed with an extra 25% of operating flow rate.

The equation used for liquids and gases is A.1.2.1.and A.1.2.2., respectively.

$$C_V=1{,}16\cdot L\cdot\sqrt{\frac{\rho s}{\Delta P}} \qquad \text{A.1.2.1.}$$

$$C_V=\frac{Q}{295}\cdot\sqrt{\frac{\rho\cdot T}{\Delta P\cdot(P_1+P_2)}} \qquad \text{A.1.2.2.}$$

Where:

Cv	Valve flow coefficient
L	Liquid flow [m^3/h]
V	Gas flow [m^3/h]
Ps	Density at the service temperature [g/cm^3]
P	Gas density [air=1]
ΔP	Pressure drop [bar]
T	Service temperature [ºK]
P_1	Inlet pressure [bar]
P_2	Outlet pressure [bar]

Once are calculated the discharge coefficient for the control valves of storage chlorine area, using the catalogue XOMOX, it have been obtained the standard Cv values, the nominal valve diameter, and the seat of the valves, all these information is shown on section 4.2.2.2.1.

A.1.3. Orifice plate design

For the design of the orifice plates it is necessary to take into account the initial conditions:

ρ(55ºC)	Density, [kg/m^3]
D	Diameter of the pipe, [mm]
Qm	Mass flow rate, [kg/s]
PD	Pressure drop, [bar]

Table A.1.3.1. Design parameters for each orifice plate

	FICAQ-1	FICA-1	FIC-1
ρ(55ºC)	1.427	1.550	1.219
D	75,2	50,6	86,9
Qm	8,52	4,09	12,0
PD	0,6	0,6	0,6

Then, the diameter of the orifice plate is calculated by the follow equation:

$$d = \sqrt{\frac{Qm \cdot 10^4}{2.1 \cdot \sqrt{(PD \cdot \rho)}}} \qquad \text{A.1.3.1.}$$

Where "d" is the diameter of the orifice plate in mm.

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A.1.4. Restriction orifice design

For the design of the restriction orifice we should take into account the initial conditions:

ρ(55ºC)	89,08	Density, [lb/ft3]
D	3,07	Diameter of the pipe, [in]
W	3,20	Mass flow rate, [lb/s]
M	0,295	Viscosity, [cP]
ΔP	2,54	Pressure drop, [psi]

Then, we proceed to calculate the relationship between the internal diameter of the pipe and the orifice using the equations A.1.4.1. and A.1.4.2.

$$K \cdot \beta^2 = \frac{1{,}913 \cdot W}{d^2 \cdot Y \cdot \sqrt{\frac{\Delta P}{\nu}}} \quad \text{A.1.4.1.}$$

Where:

Β	Relationship between the diameter of the pipe and the orifice, [-]	0,27
W	Mass flow rate, [lb/s]	3,20
Y	Expansion factor, [-]	1,00
ΔP	Pressure drop, [in]	70,5
Ν	Specific volume, [ft^3/lb]	0,01
d	Internal diameter, [in]	0,83

$$Re = \frac{48 \cdot W}{\Pi \cdot d \cdot \mu} \quad \text{A.1.4.2.}$$

Re	Reynolds number, [-]	80.600
Μ	Viscosity, [lb/ft]	0,0002

Once we have got the values, we obtain the relationship between the diameters.

$$\beta = \frac{D}{d} \quad \text{A.1.4.3.}$$

D	Diameter of the pipe, [in]	3,07
d	Internal diameter, [in]	0,83

A.1.5. Chlorine tank design

To secure a proper design of the required chlorine tank the design basis established at “ITC MIE APQ-3: «Almacenamiento de cloro» REAL DECRETO 379/2001” have been followed.

As it has been explained in the section 4.2.3.1 Chlorine tank, the optimum geometry is that formed by cylindrical shell with ellipsoidal heads and it will be horizontally placed. The design pressure will be the chlorine vapour pressure at maximum possible temperature (55ºC on summer, due to sunlight), and the design temperature those 55ºC plus 20ºC, so 75ºC.

With all these information, the dimensions of the tank can be determined by geometrical relations knowing the required volume ($82m^3$) and taking into account that the recommended relation L/D for pressures up to 7 bar is L/D= 4.

To determine the required thickness for both parts (ellipsoidal heads and cylindrical shell) has been used the following expressions:

$$t\ (heads) = \frac{P \cdot D}{2 \cdot S \cdot E - 0.2 \cdot P} \qquad A.1.5.1.$$

$$t\ (shell) = \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} \qquad A.1.5.2.$$

Where:

Table A.1.5.1. Values of parameters used in minimum thickness required calculation.

Item	Value	Description [Units]
P	1,54	Maximum pressure at bottom (Design plus hydrostatic pressure) [MPa]
D	2,9	Tank diameter [m]
R	1,45	Tank radius [m]
S	138 – 1,5	Allowable stress of material [Mpa] – Security factor (1)
E	1	Joint efficiency (2)

(1) 2007 ASME Boiler & Pressure Vessel Code- II Part D-Properties (customary) MATERIALS- PG 20-Table1A.
(2) Joint efficiency must be 1 (Fully radiographed) since is stipulated in Chlorine Instruction.

The horizontal vessel will be supported by two saddles, it is now possible to calculate the different stresses. Find attached the design data and all equations used:

Table A.1.5.2. Values of parameters used in minimum thickness required calculation.

Item	Value	Description [Units]
A	24	Distance from tangent line of head to centre of saddle [in]
b	12	Width of saddle [in]
H	28,5	Depth of dish of head [in]
L	450,7	Length of vessel [in]
P	218	Internal design pressure [Psi]
Q	156.320	Load on one saddle [lb.]
R	58	Outside radius of shell [in]
ts	1	Thickness of shell [in]
th	0,99	Thickness of head [in]
Ɵ	120	Contact angle (saddles – vessel) [º]
h	1,5	Height of saddles [m]

Longitudinal bending stress includes stress at the saddles (S_1) and at midspan (S_2):

$$S_1=\frac{Q\cdot A\left(1-\frac{1-\frac{A}{L}+\frac{R^2-H^2}{2\cdot A\cdot L}}{1+\frac{4H}{3L}}\right)}{K_1\cdot R^2\cdot t_s} \qquad \text{A.1.5.3.}$$

$$S_2=\frac{\frac{Q\cdot L}{4}\left(\frac{1+2\cdot\frac{R^2-H^2}{L^2}}{1+\frac{4H}{3L}}-\frac{4A}{L}\right)}{\pi\cdot R^2\cdot t_s} \qquad \text{A.1.5.4.}$$

Tangential shear stress, since A (24) < R/2 (28) (saddles close to heads), includes tangential shear stress in shell (S_3), in head (S_4) and additional stress in head (S_5):

$$S_3=\frac{K_4\cdot Q}{R\cdot t_s} \qquad \text{A.1.5.5.}$$

$$S_4=\frac{K_4\cdot Q}{R\cdot t_h} \qquad \text{A.1.5.6.}$$

$$S_5=\frac{K_5\cdot Q}{R\cdot t_h} \qquad \text{A.1.5.7.}$$

Circumferential stress, taking into account that L (516) < 8R (465), includes stress at the horn of saddle (S_6) and stresses at bottom of shell (S_7):

$$S_6= -\frac{Q}{4\cdot t_s(b+1.56\sqrt{R\cdot t_s}}-\frac{12K_6\cdot Q}{L\cdot t_s^2} \qquad \text{A.1.5.8.}$$

$$S_7= -\frac{K_7\cdot Q}{t_s(b+1.56\sqrt{R\cdot t_s}} \qquad \text{A.1.5.9.}$$

The values of constants K have been determined for a contact angle of 120º in the Pressure Vessel Handbook, Eugene F. Megyesy, table page 90, and figure page 91.

Finally, to design the required foundations to support the installation of chlorine tank is important to bear in mind that the maximum total load on the floor is 20.000 kg/m^2. In this way, is necessary to choose a proper geometry and measures for the foundations, since chlorine tank is supported by two saddles, it will have two rectangle foundations too. The equations to determine the proper measures are:

$$S_1= -\frac{W}{a} \qquad \text{A.1.5.10.}$$

$$S_2= -\frac{M_f}{Z} \qquad \text{A.1.5.11.}$$

$S = S_1 + S_2$ A.1.5.12.

Where:

Table A.1.5.3. Values of parameters used in minimum thickness required calculation.

Item	Value	Description [Units]
S_1	16.740	Pressure in displacer [kg/m^2]
S_2	165	Unit load in ground due to rollover [kg/m^2]
S	16.900	Total load on the floor [kg/m^2]
W	75.300	Load on one foundation [kg]
a	4,5	Foundation base area [m^2]
Mf	$Mf = P_l \cdot L$	Tilting moment relative to the base of the foundation [kg/cm]
Z	$Z = 0.118d^3$	Section modulus for the foundation rectangle base
P_l	$P_l = P_c \cdot D_o \cdot H$	
P_c	$Pc = 0{,}025V^2$	Wind pressure [kg/m^2]
V	50	Maximum wind velocity in Tarragona [m/s]
d	3	Shortest distance between sides [m]
H	6,2	Total high tank (since foundations to top shell tank) [m]
D_o	2,9	External tank diameter [m]

The pedestals dimensions have been defined with similar values of saddles (3 meters length, 0,4 meters width and 1,2 meters height), and the foundations measures are 0,4 meters width (as pedestals), and a relation between longitude/thickness of 6.

Through all these relations, a solver function of *Excel Programme*, has found the optimum length (and consequently, thickness (L/6)) of both foundations to find the cheapest (but secure) design to support the tank installation. In these way, the total load on the floor will be 16.900 kg/m^2, having a safety margin to the maximum value, 20.000 kg/m^2.

A.1.6. <u>Pumps design</u>

The design of the pump consists of the determination of the total head, NPSH required and available and, finally, the pump input.

A.1.6.1. Total head

To calculate the total head it is necessary to apply the next equations:

$$H = P_d - P_s \quad \text{A.1.6.1.}$$

$$P_d = P_{battery\ limit} + H_d - h_{L_d} \quad \text{A.1.6.2.}$$

$$P_s = P_{T-101} + H_s - h_{L_s}$$ A.1.6.3.

Where:

Table A.1.6.1. Description and value of equation items.

Item	Description [units]	P-101 A/B	P-102
F	Flow [m^3/h]	25,5	9,45
P_{final}	Final pressure [barg]	7,70	3,50
$P_{initial}$	Initial pressure [barg]	4,88	3,63
H_d	Discharge head [m]	7,00	2,31
$H_{s.\ line}$	Suction head [m]	1,50	1,50
h_{Ld}	Discharge total head loss [m]	6,34	9,27
h_{Ls}	Suction total head loss [m]	0,66	0,32
P_d	Discharge pressure [barg]	9,57	5,26
P_s	Suction pressure [barg]	5,00	3,63
H	Total head [m]	32,6	10,7

Using the pump curve, the flow and the total head, it is possible to obtain the impeller diameter and the efficiency of the pump, as can be seen in table A.1.6.2. and in figure A.1.6.1 and A.1.6.2.

Table A.1.6.2. Characteristics of the pump.

Item	Description [units]	P-101 A/B	P-102
$D_{impeller}$	Impeller diameter [mm]	310	184
η_{pump}	Efficiency of the pump [%]	49,5	51,0

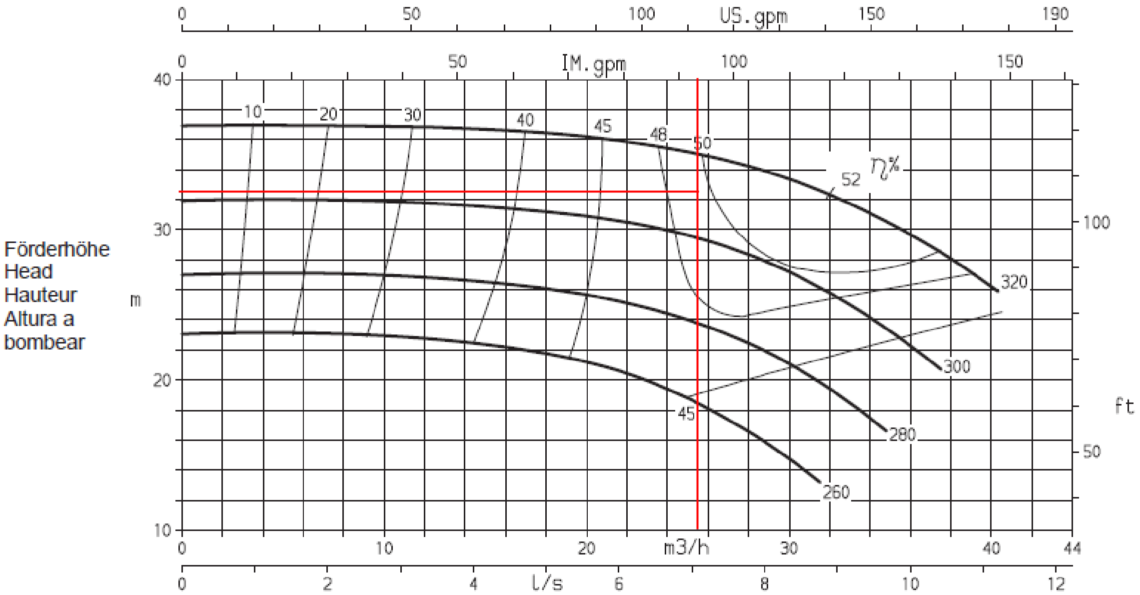


Figure A.1.6.1. Head of the pump P-101A/B, CPK/HPK 50-315 (1.450 rpm).

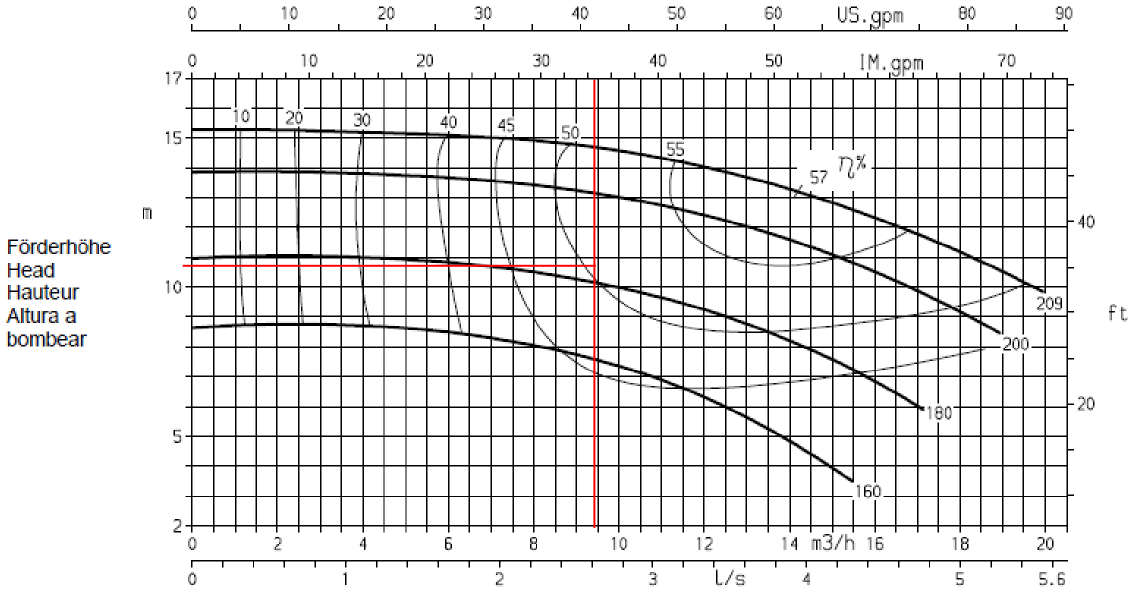


Figure A.1.6.2. Head of the pump P-102, CPK/HPK 40-200 (1.450 rpm).

A.1.6.2. NPSH

Once the total head has been calculated, next step consists in determining the net positive suction head (NPSH). To avoid cavitating problems, it is necessary that the available $NPSH_A$ is bigger than the required minimum $NPSH_R$.

A.1.6.2.1. $NPSH_R$

This value is determined by the pump curve, the flow and the impeller diameter, as shown in figure A.1.6.3. and A.1.6.4.

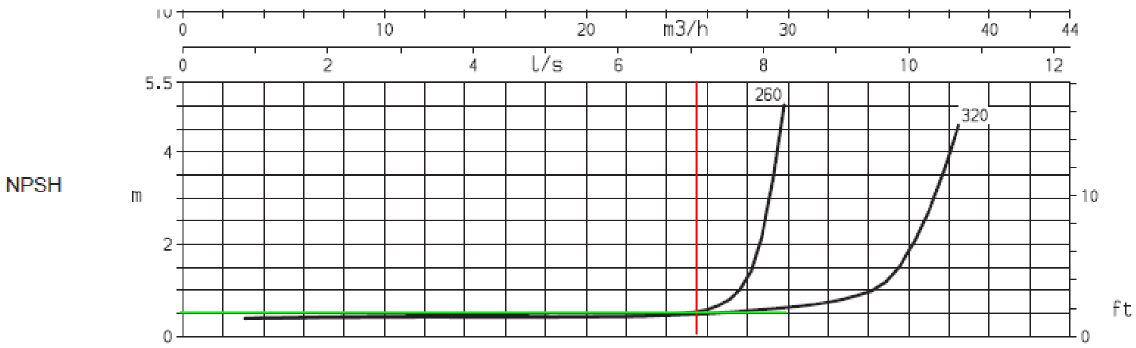
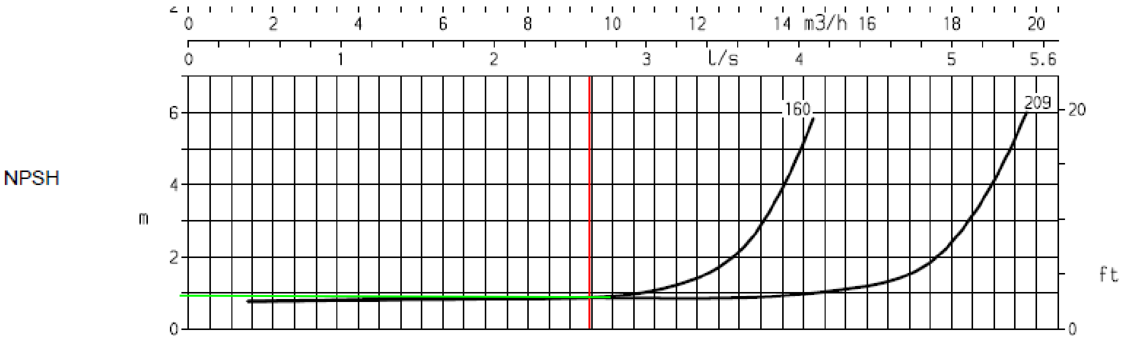


Figure A.1.6.3. $NPSH_R$ of the pump P-101A/B, CPK/HPK 50-315 (1.450 rpm).



The $NPSH_R$ obtained are exposed following:

- P-101A/B, CPK/HPK 50-315 (1.450 rpm): 1,10 m.
- P-102, CPK/HPK 40-200 (1.450 rpm): 0,90m.

A.1.6.2.2. $NPSH_A$

The $NPSH_A$ is calculated using the following equation:

$$P_d = P_{T-101} + H_s - h_{L_s} - P^{vap} \qquad \text{A.1.6.4.}$$

Where P^{vap} is the vapor pressure at the suction temperature 5,88 bar for chlorine, 0,12 bar for carbon tetrachloride and 1,00 bar a for hydroxide sodium.

The $NPSH_A$ calculated is:

- P-101A/B, CPK/HPK 50-315 (1.450 rpm): 0,84 m.
- P-102, CPK/HPK 40-200 (1.450 rpm): 29,7 m.

A.1.6.3. Pump input

The required power to make the pump work is also determined by de pump curve using the flow and the impeller diameter, as is shown in the following figures.

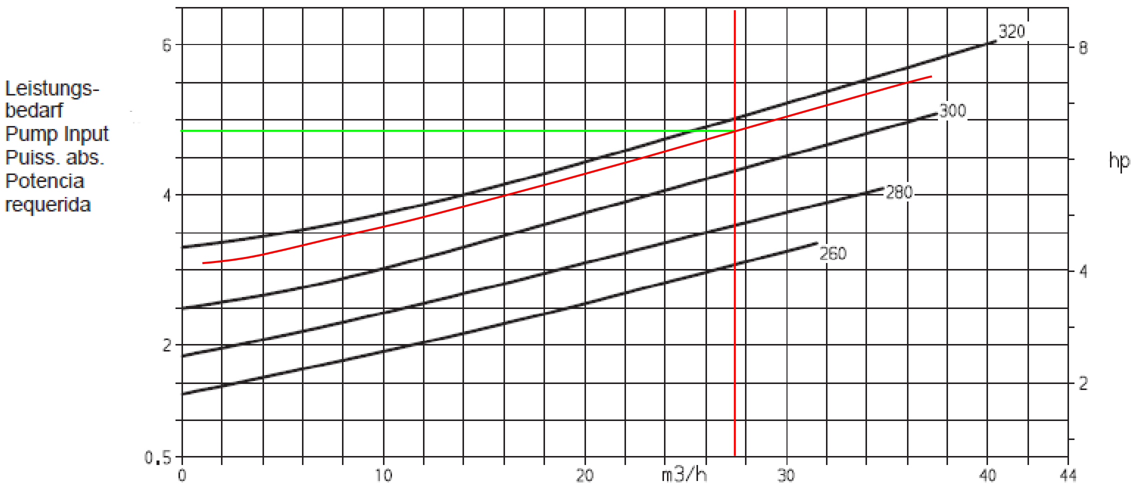


Figure A.1.6.5. Power input of the pump P-101A/B, CPK/HPK 50-315 (1.450 rpm).

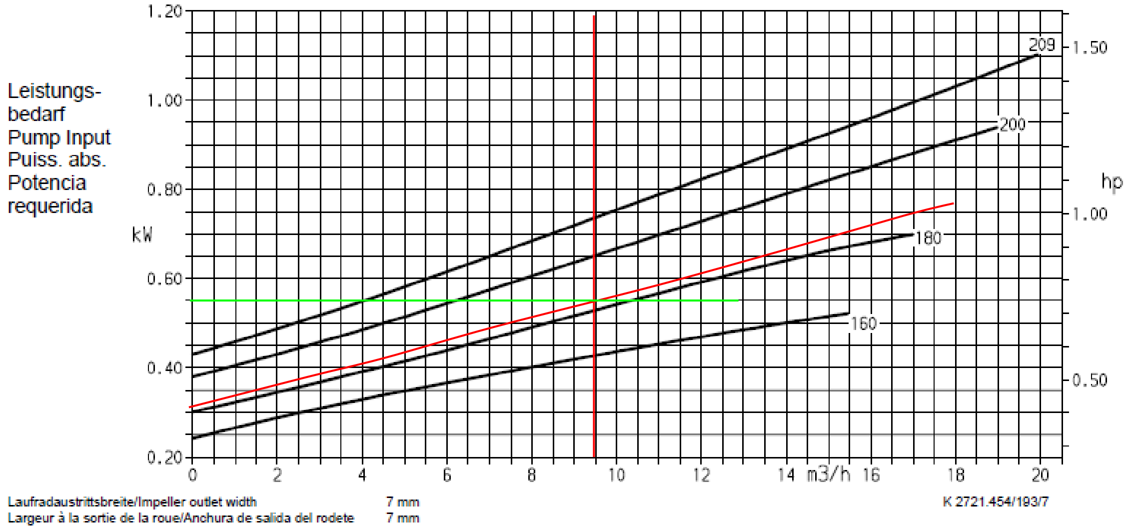


Figure A.1.6.6. Power input of the pump P-102, CPK/HPK 40-200 (1.450 rpm).

The pump input obtained for each pump is:

- P-101A/B, CPK/HPK 50-315 (1.450 rpm): 6,86 kW.
- P-102, CPK/HPK 40-200 (1.450 rpm): 0,84 kW.

A.1.7. Exchangers design

Before calculating the method *Kern*, it should be calculated the energy balance of the exchanger. In order to define the heat, equation A.1.7.1. has to be used:

$$Q=mCp\Delta T \qquad \text{A.1.7.1.}$$

Then, it is necessary to calculate the logarithmic difference of temperature and the correction factor, in order to make these calculations, the following equations have been used:

$$\Delta T_{LM}=\frac{(T_{e,c}-T_{s,f})-(T_{s,c}-T_{e,f})}{\ln(\frac{T_{e,c}-T_{s,f}}{T_{s,c}-T_{e,f}})} \quad \text{A.1.7.2.}$$

$$\Delta T=\Delta T_{LM}F_T \quad \text{A.1.7.3.}$$

To calculate the correction factor it is necessary to use the figure A.1.7.1, and calculate the parameters R and P by following expressions:

$$\mathbf{R}=\frac{\mathbf{T_e-T_s}}{\mathbf{t_s-t_e}} \quad \text{A.1.7.4.}$$

$$\mathbf{P}=\frac{\mathbf{t_s-t_e}}{\mathbf{T_e-t_e}} \quad \text{A.1.7.5.}$$

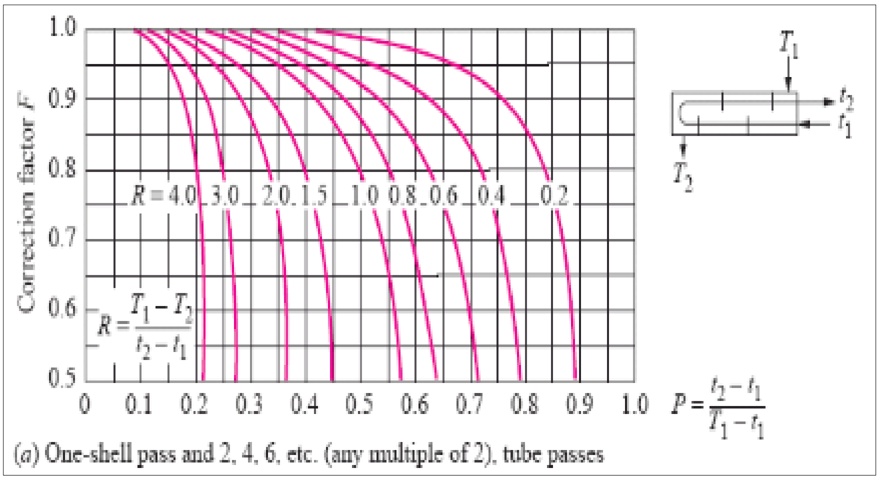


Figure A.1.7.1. Diagram to calculate the correction factor.

Table A.1.7.1. Obtained results.

Item	ΔT_{LM} [K]	R	P
E-102	9,69	0,4	0.,59
E-103	8,85	2,0	0,27

Then, an initial value of the overall heat transfer coefficient is fixed, which depends on the fluid that circulates through the inside of the tube. Then, the area of the heat exchanger is calculated:

$$A=\frac{\dot{Q}}{U_i\Delta T} \quad \text{A.1.7.6.}$$

Using equation A.1.7.7. it is possible to determine the number of tubes.

$$N_T=\frac{A}{L_T a'} \quad \text{A.1.7.7.}$$

where:

$$a'=\pi D \quad \text{A.1.7.8.}$$

When the number of tubes is obtained, next procedure is to find a standardised number of tubes and recalculate the exchange area, with the equation A.7.

$$A=N_T L_T a'$$ A.1.7.9.

Table A.1.7.2. Dimensions of heat exchangers.

Item	A estimated [m^2]	OD tabulate [m]	L [m]	N_T estimated	N_T real	A real [m^2]
E-102	17,0	0,025	1,25	170,4	179	17,9
E-103	21,3	0,025	1,25	213,6	215	21,4

In order to define the convection coefficients for tubes side, it is necessary to calculate the section area of tubes, to be able to determine the rate.

$$a_{PT}=\frac{N_T a''}{n}$$ A.1.7.10.

$$V=\frac{\dot{m}}{\rho a_{PT}}$$ A.1.7.11.

$$a''=\frac{\pi Di^2}{4}$$ A.1.7.12.

Then it is calculated the Reynolds, Prandalt and Nusselt numbers.

$$Re=\frac{VDi\rho}{\mu}$$ A.1.7.13.

$$Pr=\frac{Cp\mu}{k}$$ A.1.7.14.

Nusselt number will be calculated according to Reynols, and Prandlt;

$$Nu=0.027Re^{0.8}Pr^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14}$$ A.1.7.15.

Then, it can be calculated the convection coefficient.

$$h_i=\frac{Nu\,k}{Di}$$ A.1.7.16.

$$h_{i0}=h_i\frac{\mathbf{D_i}}{\mathbf{D_0}}$$ A.1.7.17.

Table A.1.7.2. Values for tube side.

Item	a_{PT} [m^2]	V [m/s]	Re	Pr	Nu	h_i [W/m^2K]	h_{i0} [W/m^2K]
E-102	0,063	0,018	32.095	0,16	33,07	156,1	130,2
E-103	0,076	0,035	1.455	6,90	10,72	51,5	42,9

To know the total pressure drop in the tubes, it must be taken into account next pressure losses:

$$\Delta P_T=f\frac{L_T n}{Di(^{\mu}/_{\mu_w})^{0.14}}\frac{\rho V^2}{2}$$ A.1.7.18.

$$f=(0.79\ln Re-1.64)^{-2}$$ A.1.7.19.

$$\Delta P_r = 4n\frac{\rho V^2}{2} \quad \text{A.1.7.20.}$$

$$\Delta P = \Delta P_T + \Delta P_R \quad \text{A.1.7.21.}$$

Then, it is calculated the convection coefficient on the shell side.

$$B = \frac{DI}{z} \quad \text{A.1.7.22.}$$

$$a_{PC} = \frac{DI\ c'B}{P_T} \quad \text{A.1.7.23.}$$

It is also calculated the hydraulic diameter, which depends on the dispersion of the tubes in the space.

$$D_H = \frac{4(\frac{P_T}{2}0.86P_T - \frac{1}{2}\frac{\pi D^2}{4})}{\frac{\pi D}{2}} \quad \text{A.1.7.24.}$$

Next step is to determine the rate in the shell side by the equation.

$$V = \frac{\dot{m}}{\rho a_{PC}} \quad \text{A.1.7.25.}$$

And it is also calculated the Reynolds, Prandalt and Nusselt numbers.

$$Re = \frac{V\mathbf{D_H}\rho}{\mu} \quad \text{A.1.7.26.}$$

$$Pr = \frac{Cp\mu}{k} \quad \text{A.1.7.27.}$$

$$Nu = 0.36Re^{0.55}Pr^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14} \quad \text{A.1.7.28.}$$

Then the convection on the shell side:

$$h_0 = \frac{Nu\ k}{\mathbf{D_H}} \quad \text{A.1.7.29.}$$

Table A.1.7.3. Pressure drop results.

Item	**ΔP_{tube} [bar]**	**ΔP_{shell} [bar]**
E-102	0,001	0,002
E-103	0,010	0,005

Table A.1.7.4. Shell side convection parameters.

Item	**a_{PC} [m^2]**	**V [m/s]**	**Re**	**Pr**	**Nu**	**h_0 [W/m^2K]**
E-102	0,06	0,046	23.009	0,001	4,49	18,2
E-103	0,07	0,006	172,8	0,007	1,12	25,9

The global coefficient is:

$$\frac{1}{U_S}=\frac{1}{U_L}+R''_{fc}+R''_{ff}$$ A.1.7.30.

Table A.1.7.4. Global coefficient, required surface and deviation.

Item	U [W/m^2°C]
E-102	95,2
E-103	79,5

A.1.8. Air cooler design

First of all it has been supposed a heat transfer global coefficient. The second step is to determinate Δta, and then calculates Δt by next equation.

$$MLDT=\frac{\Delta t_1-\Delta t_2}{2{,}3\log\frac{\Delta t_1}{\Delta t_2}}$$ A.1.8.1.

Then, it has been calculated R and S values using equations A.1.8.2.and A.1.8.3.respectively, and obtaining Ft parameter from figure A.1.8.1., and Δt will be obtained from equation A.1.8.4.

$$R=\frac{T_1-T_2}{t_2-t_1}$$ A.1.8.2.

$$S=\frac{t_2-t_1}{T_1-t_1}$$ A.1.8.3.

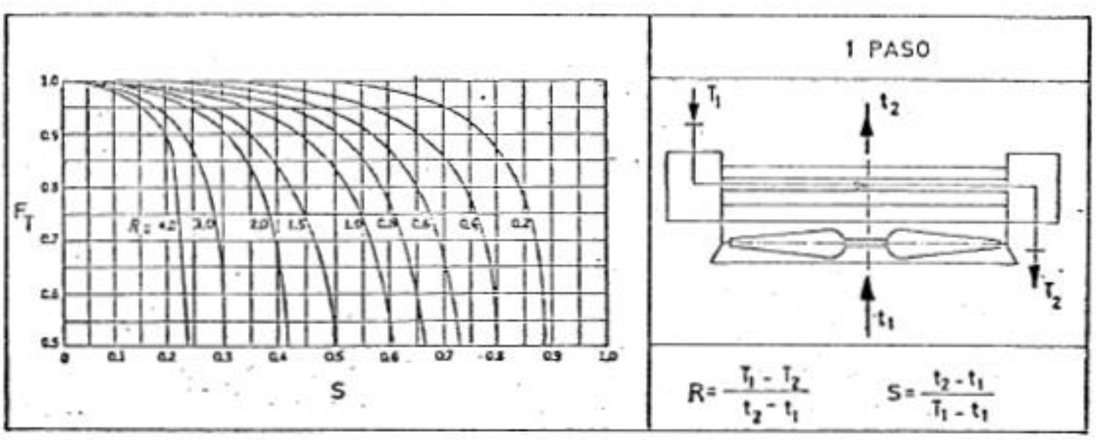


Figure A.1.8.1. Factor Ft, to MLDT correction.

$$\Delta t=F_T\cdot(MLDT)$$ A.1.8.4.

Then, it is calculated Ab and it procedures to realize air cooler dimension, to determinate the area it is used the equation A.1.8.5., and to find the number of tubes (equation A.1.8.6).

$$A_b=\frac{Q}{U_S\cdot\Delta t}$$ A.1.8.5.

$$n_t=\frac{A_b}{S_b\cdot(L-0.15)}$$ A.1.8.6.

Where Sb is calculated using the parameters and next equation:

$$S_b = \Pi \cdot de \cdot (1 - 39{,}4 \cdot N \cdot ef) \qquad \text{A.1.8.7.}$$

Once the number of tubes is calculated, it should be found a standard number of tubes and recalculate the global heat coefficient transference.

Next step is to determine the properties of chlorine and air to calculate the pressure drop. Chlorine circulates inside the tubes and next parameters should be calculated: velocity, Reynolds number and condensation coefficient:

$$G_t = \frac{m_t}{\frac{n_t \cdot a_P}{n_p}} \qquad \text{A.1.8.8.}$$

$$V_t = \frac{G}{\rho} \qquad \text{A.1.8.9.}$$

$$Re = \frac{d_i \cdot G}{\mu} \qquad \text{A.1.8.10.}$$

Using figures A.1.8.2 and A.1.8.3, f_t and J_t have been determined and, finally, h_i has been calculated using equation A.1.8.11.

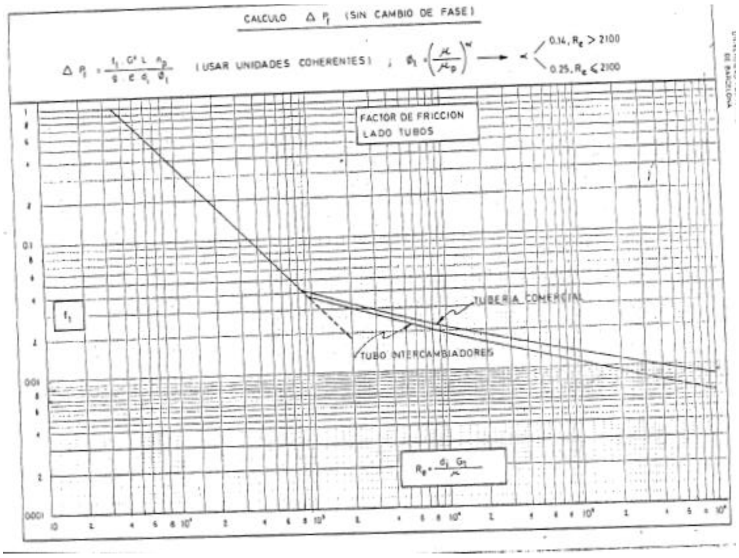


Figure A.1.8.2. Determination of F_t number using Reynolds number.

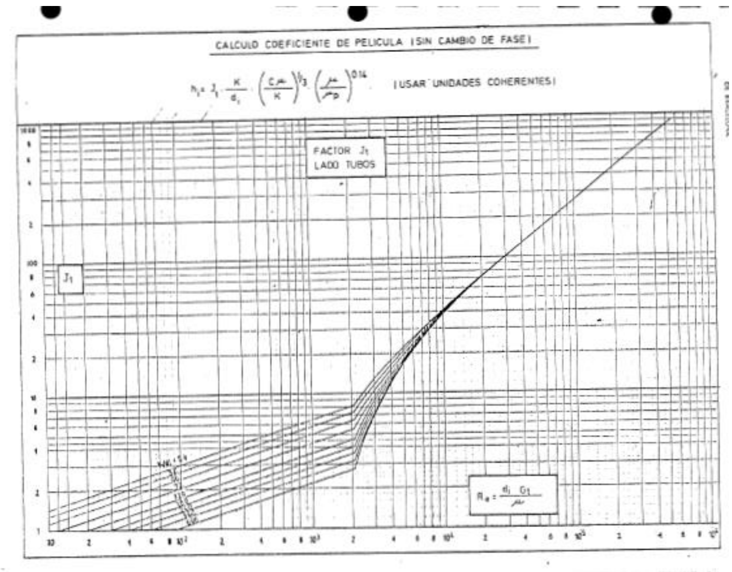


Figure A.1.8.3. J_t number determination using Reynolds number

$$h_i = J_t \cdot \frac{k}{d_i} \cdot \left[\frac{c\mu}{k}\right]^{1/3} \cdot \left[\frac{\mu}{\mu p}\right]^{0,14} \qquad \text{A.1.8.11.}$$

To calculate the total pressure drop, firstly next parameters should be calculated; ΔP_f, ΔP_v, ΔP_e and ΔP_s.

$$\Delta P_f = \frac{f_t \cdot G^2 \cdot L \cdot n_p}{g \cdot \rho \cdot d_i \cdot \phi_t} \qquad \text{A.1.8.12.}$$

$$\Delta P_v = \frac{2 \cdot n_p \cdot G^2}{\rho \cdot g} \qquad \text{A.1.8.13.}$$

$$\Delta P_e + \Delta P_s = \frac{1,5 \cdot G^2}{2 \cdot \rho \cdot g} \qquad \text{A.1.8.14.}$$

$$\Delta P_t = \Delta P_f + \Delta P_v + \Delta P_e + \Delta P_s \qquad \text{A.1.8.15.}$$

There is a design restriction that indicates that ΔPt should be less than 0,7 bar. Taking into account external tubes, equations A.1.8.8 to A.1.8.15 for air should also be calculated.

Next step is the calculation of the frontal area (A_f) using equation A.1.8.16; the equivalent diameter D_e, with equation A.1.8.17 and volumetric diameter using equation A.1.8.18.

$$A_F = n_h \cdot L_{ef} \cdot (a_c - n_{tfh} \cdot [d_e + (d_f - d_e) \cdot e_f \cdot N_f \cdot 39,4]) \qquad \text{A.1.8.16.}$$

$$D_e = \frac{S_b + S_f}{n \cdot (39,4 \cdot (2 \cdot H_f - e_f) \cdot N_f + 1)} \qquad \text{A.1.8.17.}$$

$$D_v = \frac{4 \cdot 0,866 \cdot P^2 - \Pi \cdot [d_e{}^2 + (d_f{}^2 - d_e{}^2) \cdot 39,4 \cdot N_f \cdot e_f]}{2 \cdot (S_b + S_f) \cdot {}^3/_6} \qquad \text{A.1.8.18.}$$

Then, the factor h_f and ΔP_a should be calculated using next equations:

$$m_a = \frac{Q}{C_{pa} \cdot \Delta ta} \qquad \text{A.1.8.19.}$$

$$G_a = \frac{m_a}{A_F} \quad \text{A.1.8.20.}$$

$$v_a = \frac{G_a}{3600 \cdot \rho a} \quad \text{A.1.8.21.}$$

$$Re_h = \frac{G_a \cdot D_e}{\mu_a} \quad \text{A.1.8.22.}$$

$$Re_{\Delta P} = \frac{G_a \cdot D_v}{\mu_a} \quad \text{A.1.8.23.}$$

With the result of equation A.1.8.22, see figure A.1.8.4. For equation A.1.8.23 see figure A.1.8.5.

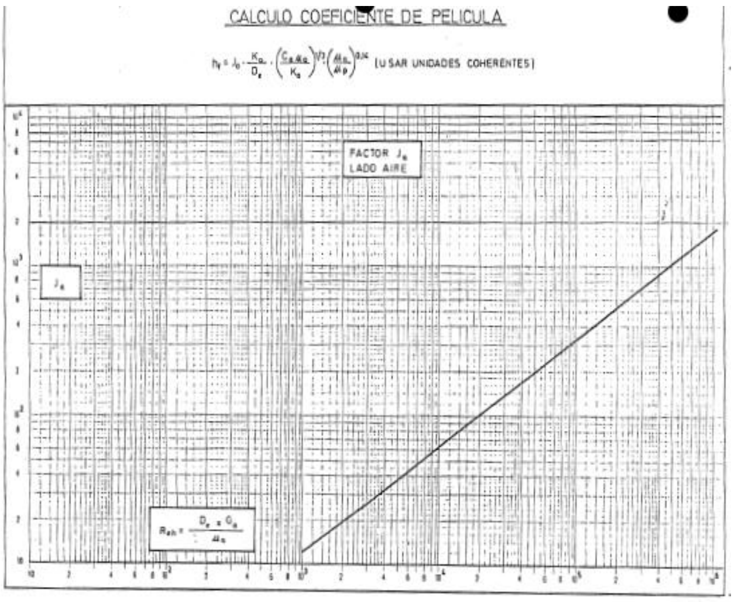


Figure A.1.8.4. Determination of the value J_a using Re_h.

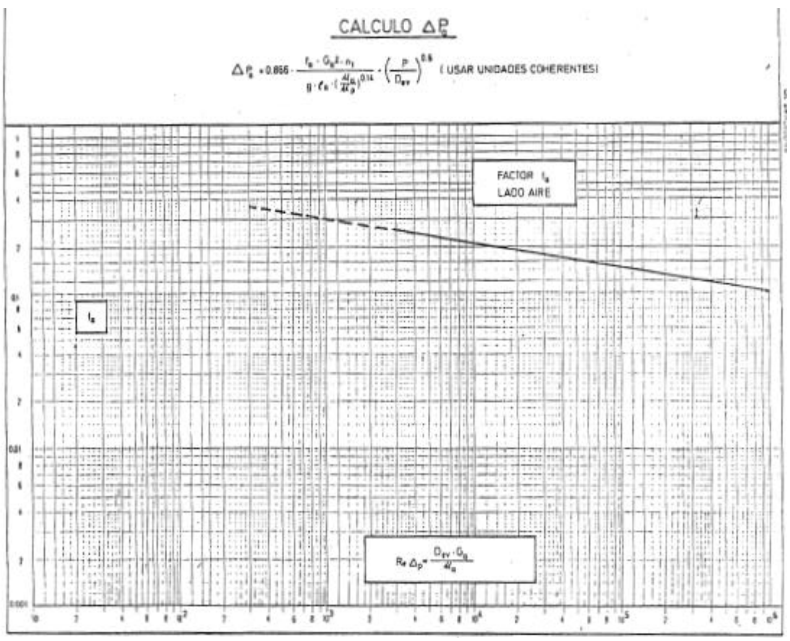


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Figure A.1.8.5. Determination of the value f_a using $Re_{\Delta P}$.

$$h_f = J_a \cdot \frac{k_a}{D_e} \cdot \left[\frac{C_{pa} \cdot \mu_a}{k_a}\right]^{1/3} \cdot \left[\frac{\mu_a}{\mu p}\right]^{0,14} \quad \text{A.1.8.24.}$$

$$\Delta P_a = \frac{f_a \cdot G_a^2 \cdot n_f \cdot (0,866 \cdot P)}{g \cdot \rho_a \cdot D_{ev} \cdot \phi_a} \cdot \left(\frac{D_{ev}}{P}\right)^{0,4} \quad \text{A.1.8.25.}$$

Another step consists on calculating r_p and r_c using equations A.1.8.26 and A.1.8.27, respectively.

$$r_p = \frac{d_e - d_i}{2 \cdot k} \quad \text{A.1.8.26.}$$

Where r_c is a fixed parameter that has a value of $0,5 \cdot 10^{-5}$ h m^2 ºC/kcal.

Then, the global coefficient is recalculated using the parameters found in the previous calculus.

Referring to h_i, f_i, r_p and r_c to common area:

$$h_{ib} = h_{ib} \cdot \frac{S_i}{S_b} \quad \text{A.1.8.27.}$$

$$f_{ib} = f_{ib} \cdot \frac{S_b}{S_i} \quad \text{A.1.8.28.}$$

$$r_{pb} = \frac{d_e - d_i}{2 \cdot k} \cdot \frac{d_e}{\frac{d_e - d_i}{2}} \quad \text{A.1.8.29.}$$

$$r_{cb} = r_c \quad \text{A.1.8.30.}$$

Then it is calculated Ω and h_{ob}:

$$h'_f = \frac{1}{f_o + \frac{1}{h_f}} \quad \text{A.1.8.31.}$$

$$r_f \cdot \sqrt{\frac{2 \cdot h'_f}{kal \cdot e_f}} \quad \text{A.1.8.32.}$$

And from figure A.1.8.6, it is obtained the value of Ω.

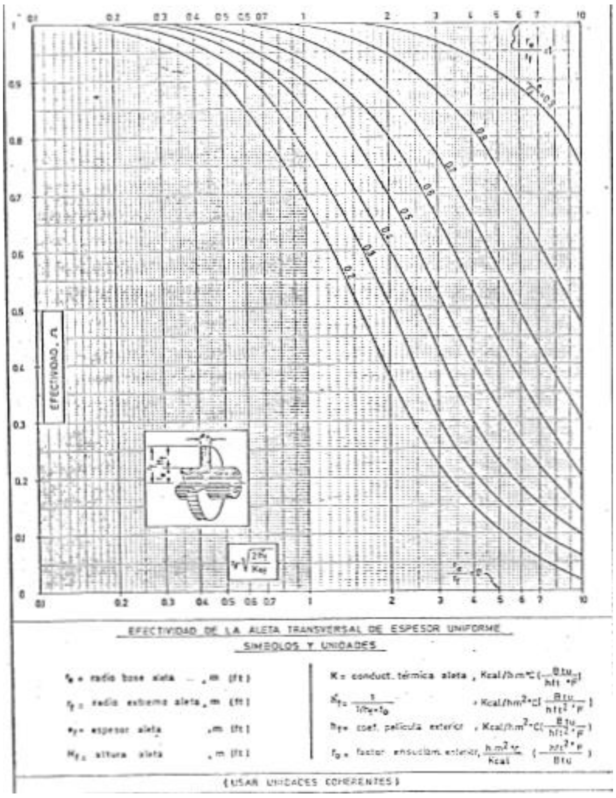

Figure A.1.8.6. Transversal fin effectiveness.

$$h'_{ob} = h'_f \cdot \frac{S_b + \Omega \cdot S_f}{S_b} \qquad \text{A.1.8.33.}$$

Then, Us is calculate using the following equation:

$$\frac{1}{U_s calculated} = \frac{1}{h'_{ob}} + r_{cb} + \frac{1}{h_{ib}} + r_{pb} + f_{ib} \qquad \text{A.1.8.34.}$$

Finally calculate the difference between U_c calculated and U_s supposed in %. If this difference is not a high value, the supposition will be considered correct. On the other hand, the air cooler would be recalculated using a different initial U_s.

Table A.1.8.1.Operating conditions.

Parameter	**Tube**	**Air**
Flow, [kg/h]	5.180	7.150
Temperature entrance, [ºC]	55	32
Temperature outlet, [ºC]	45	47
ΔP max, [kg/cm^2]	0,7	0,7
Fouling, [ºCm^{2}h/kcal]	0,0004	0,0004
Heat transfer, [kcal/h]	26.390	26.390
Relative humidity, [%]	60	60

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A.1.9. Absorption column

The methodology followed to dimension the chlorine packing absorption in the storage unit of *Chlorite* is following exposed.

First of all, determine the material global balances using equation A.1.9.1 assuming that the molar flows are constant:

$$L_B + V_T = L_T + V_B \qquad \text{A.1.9.1.}$$

Then, determine chlorine global balance using equation A.1.9.2, and obtain the theory stage form package absorption column.

$$L_B \cdot x_{Cl,B} + V_T \cdot y_{Cl,T} = L_T \cdot x_{Cl,T} + V_B \cdot y_{Cl,B} \qquad \text{A.1.9.2.}$$

To determine the equilibrium line, it have been calculated with molar relations according to equations A.1.9.3 and A.1.9.4, and using the flow of inert components in each phase assuming that they are constants (see equations A.1.9.5 and A.1.9.6).

$$X = \frac{x}{1-x} \qquad \text{A.1.9.3.}$$

$$Y = \frac{y}{1-y} \qquad \text{A.1.9.4.}$$

$$L' = L \cdot (1 - x) \qquad \text{A.1.9.5.}$$

$$V' = V \cdot (1 - y) \qquad \text{A.1.9.6.}$$

Finally, the operating line will be obtained from the general equation A.1.9.7.

$$Y_{i+1} = \frac{L\prime}{V\prime} \cdot X_i + \frac{V' \cdot Y_1 - L' \cdot X_0}{V\prime} \qquad \text{A.1.9.7.}$$

The equilibrium line is obtained using bibliographic parameters and it follows the equation A.1.9.8.

$$y = K_{equilibrium} \cdot x \qquad \text{A.1.9.8.}$$

Next figure shows the equilibrium line and operation line of chlorine absorption.

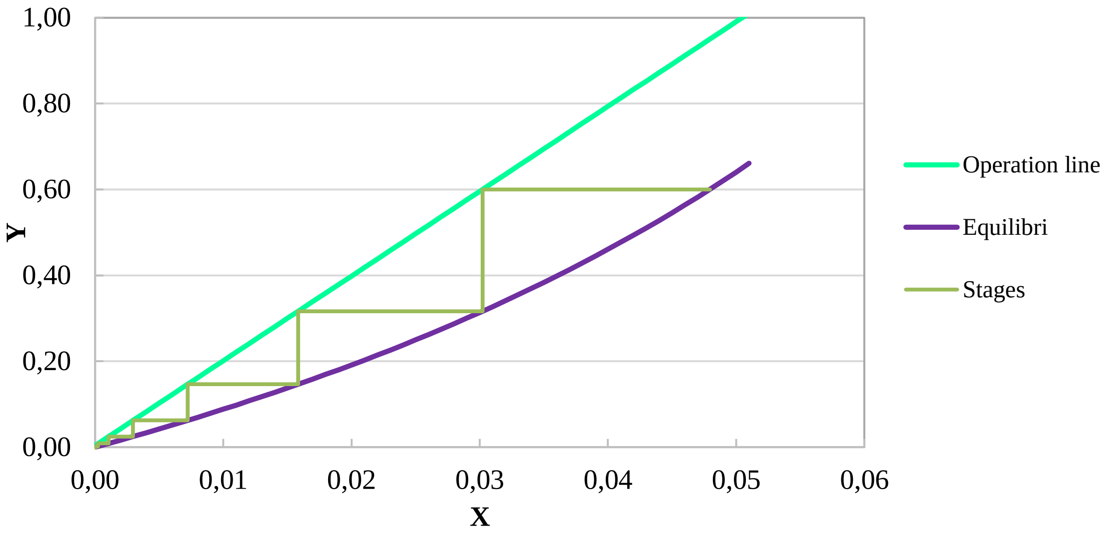

Figure A.1.9.1. Operation and equilibrium lines.

Table A.1.9.1. Results of the operation and equilibrium lines.

Parameter	Value
L' [kmol/h]	2.141,6
V' [kmol/h]	108,6
K equilibrium	8,2
L'/V'	19,73
(L'/V')min	6,83
N_{real}, Real stage number	6

Next step is the determination of the equivalent height of a theoretical stages (HEPT), however a previous stage consists of defining a theoretical stage (see equations A.1.9.10 and A.1.9.11).

$$HEPT = \frac{z\ (paking\ height)}{N\ (theoretical\ number\ of\ stages)} \qquad \text{A.1.9.9.}$$

That means that for a theoretical stage the equation is:

$$Z_{x=1} = HEPT = N_{oy} \cdot H_{oy} \qquad \text{A.1.9.10.}$$

$$N_{oy} = \int_{y1}^{y2} \frac{dy}{y-y*} \qquad \text{A.1.9.11.}$$

Next table contains the values obtained in the pseudo equilibrium, using figure A.1.9.2.

Table A.1.9.2. Numeric integration for theoretical number of stages.

Y	X	Y*	Y-Y*	1/(y-y*)
1,00	0,05	0,41	0,58	1,71
0,90	0,05	0,37	0,53	1,90
0,80	0,04	0,33	0,47	2,14
0,70	0,04	0,29	0,41	2,44
0,60	0,03	0,25	0,35	2,85

Y	X	Y*	Y-Y*	1/(y-y*)
0,50	0,03	0,21	0,29	3,42
0,40	0,02	0,16	0,23	4,27
0,30	0,01	0,12	0,18	5,70
0,20	0,01	0,08	0,12	8,54
0,10	0,00	0,04	0,06	17,0
0,08	0,00	0,03	0,05	21,3
0,06	0,00	0,02	0,04	28,3
0,04	0,00	0,01	0,02	42,3
0,02	0,00	0,01	0,01	83,6

Appling numeric integration to figure A.1.9.2, it has been obtained a N_{oy} value of 7,1.

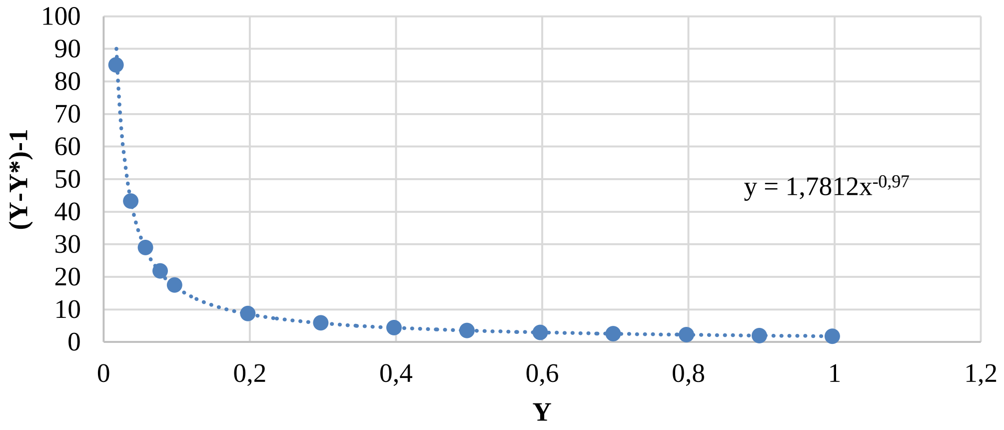

Figure A.1.9.2. Numeric integration to obtain a theoretical stage (N_{oy}).

Another step required to determine absorption dimensions is to calculate the diameter and height of the packing chlorine absorption. There are different types of packing; for a chlorine absorption it has been selected ceramic Pall rings. It has been used the equation A.1.9.12 to determine the pressure drop.

$$\Delta P_{flood} = 0{,}115 \cdot F_P^{0{,}7} \qquad \text{A.1.9.12.}$$

Once there is determined the pressure drop using the figure A.1.9.3, it is obtained the flood of the packing absorption C-101, $G_{y,flo}$.

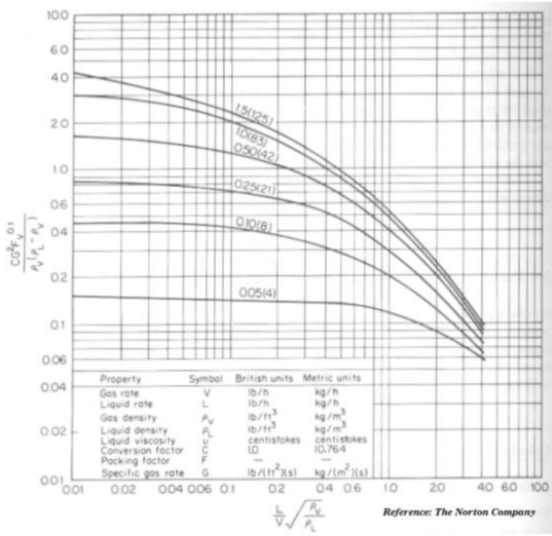

Figure A.1.9.3. Flood and pressure drop general correlation in packing columns from The Norton Company.

It has been A.1.9.3considered a 75% of the flood to obtain the packing flood, G_y.

The area of the absorption has been calculated with the expression A.1.9.13, and the diameter of chlorine packing absorption, with the equation A.1.9.14.

$$A = \frac{G}{G_y} \quad \text{x.13} \qquad \text{A.1.9.13.}$$

$$D = \sqrt{\frac{4 \cdot A}{\Pi}} \quad \text{x.14} \qquad \text{A.1.9.14.}$$

It has also been calculated the flood velocity inundation using next figure.

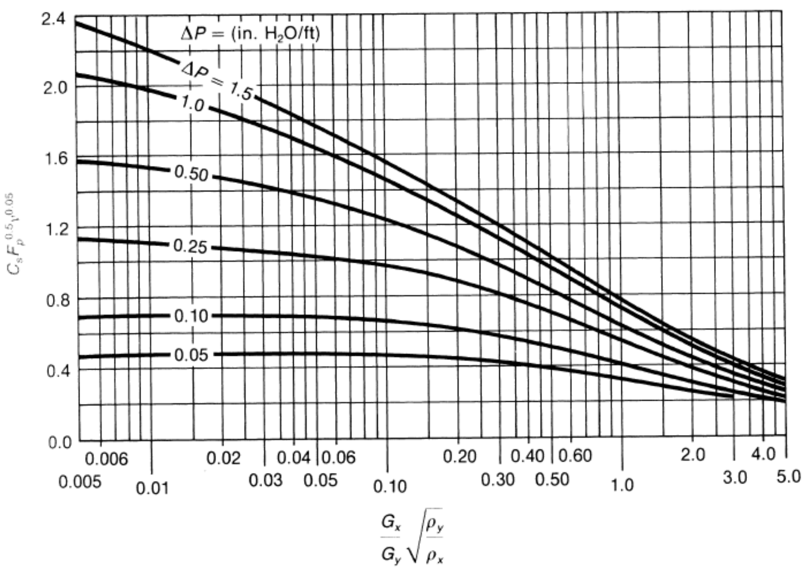

Figure A.1.9.4.. Figure to determinate flood inundation.

From this figure it is obtained a value for $C_S F_P^{0,5} \nu^{0,05}$ and next step is to obtain the value for the unknown parameter Cs. Then determine the flood velocity inundation by following equation:

$$u_{V,flood} = \frac{C_S}{\left[\frac{\rho v}{\rho l - \rho v}\right]^{1/2}}$$ A.1.9.15.

Going back to determine the height of the packing chlorine absorption. Once the packing flood is determined, it can procedure to calculate H_{oy} with next expression.

$$H_{oy} = \frac{G_y}{K_{oy\,a}}$$ A.1.9.16.

Once H_{oy} and N_{oy} are calculated, the total height of the absorption is calculated using the equation A.1.9.10 and, finally the equivalent height related to theoretical stage with the equation A.1.9.3.Mechanical parameters for C-101 is calculated.

Table A.1.9.3. Values of used parameters and results.

Mechanical parameter	**Value**
$\rho_{v,}$ vapor density [kg/m^3]	3,04
ρ_l, liquid density [kg/m^3]	1.219
Liquid flow [kmol/h]	2.249
Vapor flow [kmol/h]	7.685
ν , liquid viscosity [cP]	1,002
G, total vaopr flow [kg/h]	7.685,2
F_P, Packing factor [ft^{-1}]	28,0
Pressure drop, [in]	1,18
$G_{y,flo}$, packing flood [kg/m^{2}s]	3,99
G_y , packing flood [kg/m^{2}s]	2,99
Column area, [m^2]	0,71
Absorption diameter, [m]	0,95
$U_{v,flood}$, flood velocity inundation, [m/s]	1,38
Cs	0,23
H_{oy}, height of the packing absorption, [m]	0,47
N_{oy}, [m]	7,10
H_{oy}, height of the packing absorption, [m]	0,47
Z, total absorption height, [m]	3,37
HETP, equivalent height of theoretical stage, [m]	0,56

A.1.10. Absorption column design

As it has been explained at 4.2.3.4.2. *Absorption system tank*, the optimum geometry is that formed by cylindrical shell with torispherical heads (Korbogen) and it will be horizontally placed. The design pressure will be working pressure plus one extra bar (2 barg), and the design temperature the maximum working temperature plus 20ºC (80ºC altogether).

With all these information, the measures of the tank can be determined by geometrical relations knowing the required volume (30m^3) and taking into account that the recommended relation L/D for pressures near 2 bar is L/D= 3.

To determine the required thickness of both parts (thorispherical heads and cylindrical shell), it has been used the following expressions:

$$t\ (heads) = \frac{P \cdot M \cdot L}{2 \cdot S \cdot E - 0.2 \cdot P} \qquad \text{A.1.10.1.}$$

$$t\ (shell) = \frac{P \cdot R}{2S \cdot E - 0.2 \cdot P} \qquad \text{A.1.10.2.}$$

Where:

Table A.1.10.1. Values of parameters used in minimum thickness required calculation.

Item	Value	Description [Units]
P	0,22	Maximum pressure at bottom (Design plus hydrostatic
M	1,32	Relation between two radius dish.
L	1,76	Inside radius of dish [m]
D	2,20	Tank diameter [m]
R	1,10	Tank radius [m]
S	368 – 1,50	Allowable stress of material [Mpa] – Security factor (1)
E	0,9	Joint efficiency (2)

(1) http://catalog.wshampshire.com/Asset/psg_teflon_ptfe.pdf

(2) Single welded butt joint with backing strip which remains in place after welding.

The horizontal vessel will be supported by two saddles, it is now possible to calculate the different stresses. Find attached the design data and all equations used:

Table A.1.10.2. Values of parameters used in minimum thickness required calculation.

Item	Value	Description [Units]
A	18,0	Distance from tangent line of head to centre of saddle [in]
b	9,00	Width of saddle [in]
H	13,5	Depth of dish of head [in]
L	282	Length of vessel [in]
P	29,0	Internal design pressure [Psi]
Q	41.100	Load on one saddle [lb.]
R	43,0	Outside radius of shell [in]
ts	0,069	Thickness of shell [in]
th	0,071	Thickness of head [in]
ϴ	120	Contact angle (saddles – vessel) [º]
h	1,50	Height of saddles [m]

The procedure to determinate the stress at saddles and to design the optimum measures of foundations is the same as for the chlorine tank. To obtain more details, see Annex A.1.5. *Chlorine tank*.

A.1.11. Pump P-103A/B

Referring to the pump P-103A/B, it has been designed following the same mechanism that the shown in section A.1.6.

The pump installed is CPK/HPK 50-200 (1.450 rpm).

Next table and figures show the intermediate and final results obtained.

Table A.1.11.1 Description and value of equation items.

Item	Description [units]	P-103 A/B
F	Flow [m^3/h]	35,5
P_{final}	Final pressure [bara]	1,00
$P_{initial}$	Initial pressure [bara]	1,00
H_d	Discharge head [m]	3,40
$H_{s.\ line}$	Suction head [m]	1,50
h_{Ld}	Discharge total head loss [m]	8,82
h_{Ls}	Suction total head loss [m]	0,22
P_d	Discharge pressure [barg]	2,46
P_s	Suction pressure [barg]	1,15
H	Total head [m]	10,9
$D_{impeller}$	Impeller diameter [mm]	200
η_{pump}	Efficiency of the pump [%]	71,0
$NPSH_R$	Net positive suction head required	1,10
$NPSH_A$	Net positive suction head available	9,65
Pot.	Pump input [kW]	1,81

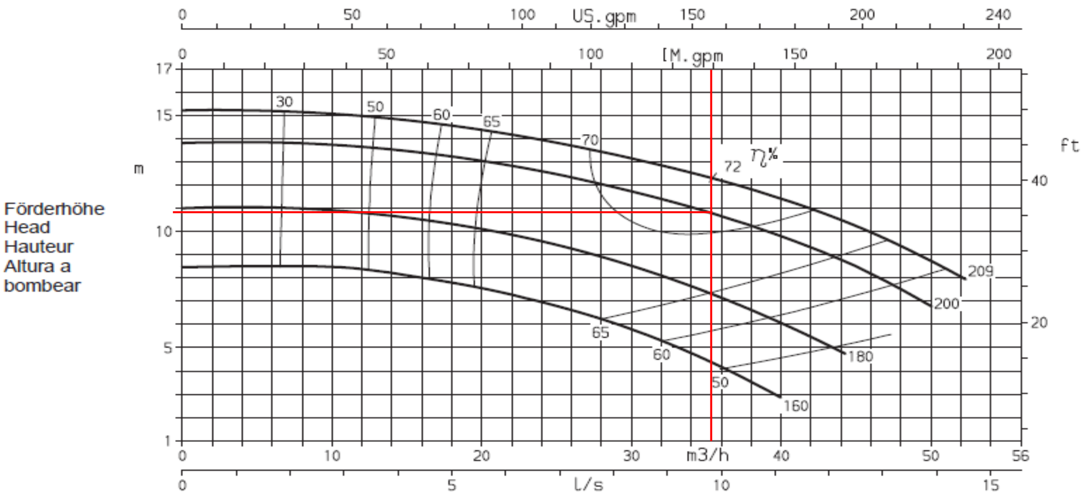

Figure A.1.11.1. Head of the pump P-103A/B, CPK/HPK 50-200 (1.450 rpm).

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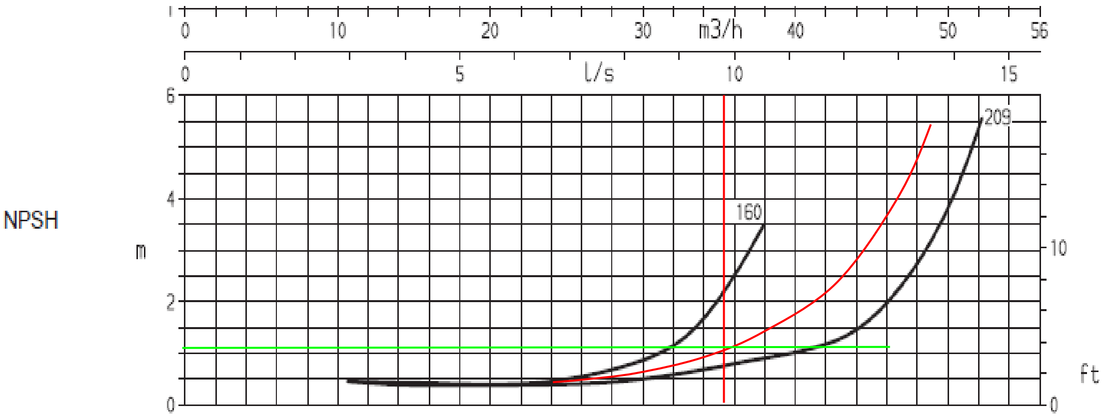

Figure A.1.11.2. $NPSH_R$ of the pump P-103A/B, CPK/HPK 50-200 (1.450 rpm)

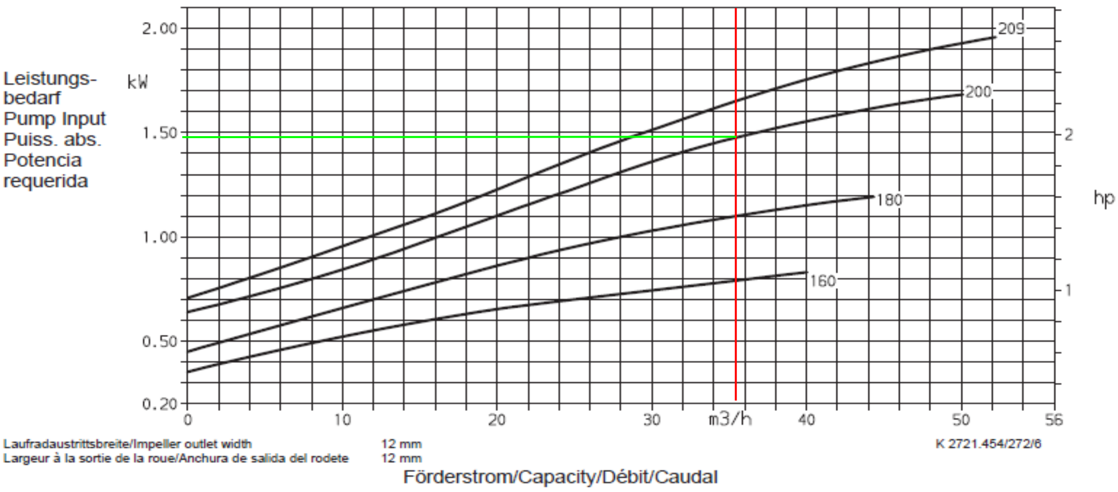

Figure A.1.11.3. Power input of the pump P-103A/B, CPK/HPK 50-200 (1.450 rpm)

A.1.12. Plate heat exchanger design

In order to determine the plate heat exchanger, next parameters have been calculated: geometrical parameters, global heat transfer and pressure drop.

The exchanger surface has been fixed from the Alfa Laval catalogue (Ref. 5) like horizontal distance between ports, plate width, plate thickness and also the effective length. To determine the geometrical parameters there have been used equations A.1.12.1. to A.1.12.7.

$$A=(n-2)\cdot A_P \qquad \text{A.1.12.1.}$$

$$A_P=L_E\cdot W \qquad \text{A.1.12.2.}$$

$$W=(HPCD)+D+0.0015 \qquad \text{A.1.12.3.}$$

$$S_C=W\cdot b \qquad \text{A.1.12.4.}$$

$$b=P_T-\varepsilon \qquad \text{A.1.12.5.}$$

$$D_e=\frac{2\cdot b}{\phi}$$ A.1.12.6.

$$N_C=\frac{n-1}{2}$$ A.1.12.7.

Table A.1.12.1. Results for the geometrical parameters.

Parameter	Value
Surface exchange, A, $[m^2]$ ([1]	60
Effective surface of the plate, Ap, $[m^2]$	0,338
Total number of plates, n, [-]	180
Height, h, [m] [1]	1,18
Length, L, [m] [1]	1,689
Plate width, W, [m] [1]	0,469
Effective length, Le, [m] [1]	0,718
Horizontal length between the gates, HPCD, [m] [1]	0,226
Gate diameter, D, [m]	0,228
Passage canal area, Sc, $[m^2]$	0,002
Distance between plates, b, [m]	0,005
Pitch between plates, P_T, [m]	0,005
Plate thickness, ε, [m] [1]	$4{,}0\cdot10^{-4}$
Equivalent diameter, De, [m]	$8{,}64\cdot10^{-3}$
ϕ, [-]	1,17
Number of canals for fluid, NC,[-]	89
Chevron angle, β, [º]	60

(1) Datum from ‘‘http://www.alfalaval.com/solution-finder/products/gasketed-industrial-range-phe/Documents/TL6.pdf’’.

Next step is to determinate the global heat transfer, see equation A.1.12.8., to calculate this parameter, firstly it has to be calculated the canal flow, Reynolds and Nusselt numbers, using the equations A.1.12.10., A.1.12.11 and figure A.1.12.1.

$$M_C=\frac{M}{N_C}$$ A.1.12.8.

$$m=\frac{M_C}{S_C}$$ A.1.12.9.

$$Re=\frac{m\cdot D_e}{\eta}$$ A.1.12.10.

$$\frac{Nu}{Pr^{1/3}\cdot\left(\eta/\eta_W\right)^{0.17}}$$ A.1.12.11.

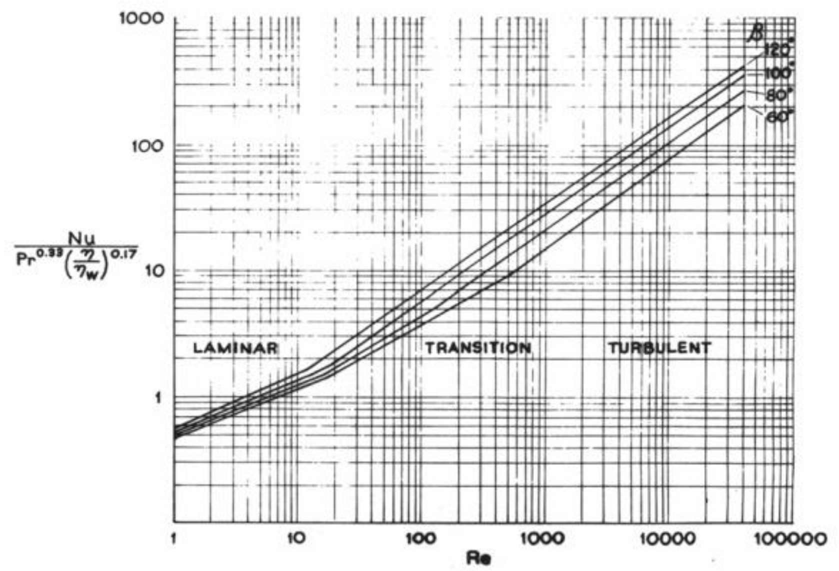

Figure A.1.12.1. Nusselt number for plates with Chevron corrugation

Heat transfer coefficient is calculated using the equation A.1.12.12.

$$h=\frac{Nu \cdot k}{D_e} \qquad \text{A.1.12.12.}$$

$$\frac{1}{U}=\frac{1}{h_c}+\frac{1}{h_f}+R''_{f,c}+R''_{f,f} \qquad \text{A.1.12.13.}$$

Table A.1.12.2. Results for the global heat transfer.

Parameters	Hot fluid	Cold fluid
Flow, M, [kg/s]	12,03	21,65
Input temperature, Ti, [ºC]	60	27
Output temperature, To, [ºC]	42	37
Heat, Q, [kJ/s]	905,1	905,1
Canal flow, M_C, [kg/s]	0,078	0,242
Mass velocity in the canal, m, [kg/s m^2]	56,69	102,0
Dynamic viscosity, η, [Pa s]	$4{,}43 \cdot 10^{-3}$	$1{,}00 \cdot 10^{-3}$
Reynolds, Re, [-]	110,6	880,2
Prandlt, Pr, [-]	3,75	4,60
Nusselt, Nu, [-]	7,96	24,82
Thermal conductivity, k, [W/m ºC]	0,466	0,580
Heat transfer coefficient, h, [W/m^2 ºC]	429	1665
Fouling resistivity, R”f, [m^2 ºC/W]	0,0004	0,0005
Global heat transfer, U, [W/m^2 ºC]	264	264

To determine the pressure drop, first of all, the friction factor should be calculated using the figure A.1.12.2., then the velocity in hot and cold side and, finally using the equation A.1.12.18 the pressure drop can be obtained.

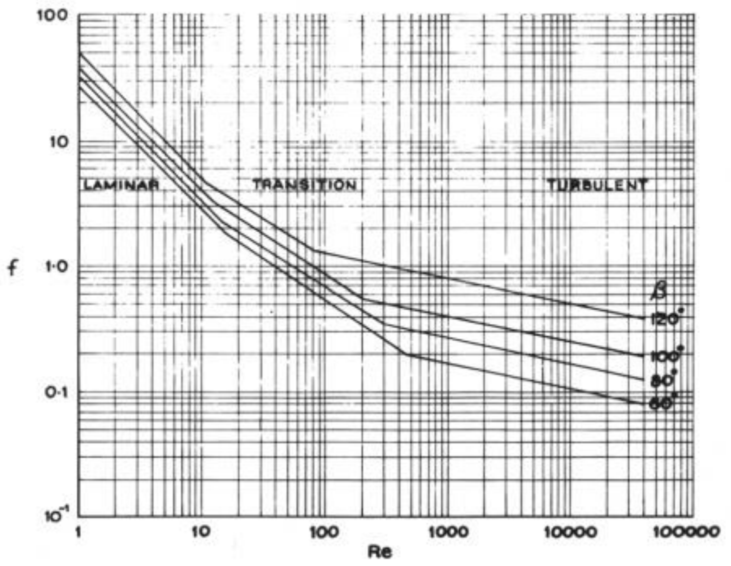

Figure A.1.12.2., Fanning friction factor for plates with Chevron corrugation.

$$\Delta P_c = \frac{2 \cdot f \cdot m^2 \cdot L_e \cdot N_p}{\rho \cdot D_e} \cdot \left({}^{\eta}/_{\eta_W} \right)^{-0.17} \quad \text{A.1.12.14.}$$

$$S_p = \frac{\Pi \cdot D^2}{4} \quad \text{A.1.12.15.}$$

$$V_p = \frac{M}{\rho \cdot S_p} \quad \text{A.1.12.16.}$$

$$\Delta P_p = 1.5 \cdot \frac{\rho \cdot V_p^2}{2} \quad \text{A.1.12.17.}$$

$$\Delta P = \Delta P_c + \Delta P_p \quad \text{A.1.12.18.}$$

Table A.1.12.3. Results for the pressure drop.

Characteristic	**Hot fluid**	**Cold fluid**
Friction factor, f, [-]	0,50	0,18
Canal pressure drop, ΔP_C, [Pa]	$1{,}52 \cdot 10^4$	$2{,}78 \cdot 10^4$
Port pas area, S_P, [m^2]	$4.11 \cdot 10^{-2}$	$4.11 \cdot 10^{-2}$
Gate fluid velocity, V_P, [m/s]	0,239	0,526
Gate pressure drop, ΔP_P, [Pa]	52,6	207,9
Total pressure drop, ΔP, [Pa]	$1{,}53 \cdot 10^4$	$2{,}08 \cdot 10^2$
Total pressure drop, ΔP, [bar]	0,15	0,28

A.2. PROCESS SAFETY

A.2.1. AG-1

1

2

3

A.2.2. Dow Fire and Explosion Study

There has been realized a study to analyse the potential risk of fire or explosion that may be on site. Although the products on the site are not inflammable, this study includes toxicity and mitigation parameters. It has been calculated the DOW index for the chlorine storage, T-101.

A.2.2.1. Process unit hazards factors

Material Factor it's been found in appendix A of the bibliography (Ref. 9), it depends on the chemical compound, for chlorine is 1.

1. General process hazards:
   - A. Exothermic Chemical Reactions: there has not been taken this penalty because the storage unit it is not a reactor in which a chemical reaction takes place.
   - B. Endothermic Processes: For the same reason as A, there is no penalty.
   - C. Material Handling and Transfer: This area of consideration is not for normal storage tanks.
   - D. Enclosed or Indoor Process Units: It is an open area where is the tank 101, so there is no penalty.
   - E. Access: The tank volume is 82 m^2, according to this point, there is a penalty of 0,00.
   - F. Drainage and spill control: This point is calculated with the volume of flammable material, as it has been said before, chlorine it is only a toxic substance, so there is no penalty.
2. Special process hazards:
   - A. Toxic materials: At page 20 of the bibliography (Ref. 9) you find parameter N_H, which is the value definition from NFPA 704, and this one, is 2 and is multiplied by 0,2. La penalty is 0,4.
   - B. Sub-Atmospheric Pressure: This penalty is applied only if the absolute pressure is less than 500 mmHg, the tank works at a pressure over the atmospheric so the penalty is 0,00.
   - C. Operation in or near flammable range: the storage tank does not work near or in flammable range.
   - D. Dust explosion: In this point, there is no penalty because this section applies to systems involving dust handling operations.
   - E. Relief pressure: Using the figure 2 on the bibliography (9), Pressure penalty for flammable & combustible liquids, there is a penalty of 0,2.

F. Low temperature: there is no penalty because the tank does not work between 10 ºC and -29 ºC.

G. Quantity of flammable/unstable material: chlorine is not an inflammable material, there is a penalty of 0,00.

H. Corrosion and erosion: There is a penalty of 0,75, this is common in process areas exposed to contamination by chlorine vapor aver prolonged periods.

I. Leakage - joints and packing: for processes known to give regular leakage problems at the equipment the penalty is 0,30.

J. Use of fire equipment: No penalty, there are not used in this operation.

K. Hot oil heat Exchange system: This system is not used.

L. Rotating equipment: The pump is not in excess of 75 hp, so there is no penalty.

Fire and explosion index is 2,65 so the tank has got a light degree of hazard.

A.2.2.2. Loss control credit factors

The next step is to calculate the loss control factors:

1. Process control (C_1)

a) Emergency power: the installation does not have emergency power so the credit factor is 1,00.

b) Cooling: Cooling systems are designed to maintain normal cooling for at least 10 minutes, the credit factor is 0,99.

c) Explosion control: It is used a factor of 0,98 because there are overpressure relief systems to protect the equipment.

d) Emergency shutdown: the tank has got a redundancy system that activates when conditions became abnormal, initiating a shutdown sequence, so it is used a factor of 0,96.

e) Computer control: It is been used a factor of 0,99 because an on-line computer functions are used as an aid to operators and is not directly in control of key operations.

f) Inert gas: the inert system has sufficient capacity to purge the total volume of the unit automatically, the factor is 0,94.

g) Operating instructions/procedures: 0,96

1. Start-up: 0,5
2. Routine shutdown: 0,5
3. Normal operating conditions: 0,5
4. Turndown operating conditions: 0,0
5. Standby running conditions: 0,0

6. Uprated operating conditions: 0,0
7. Restarting shortly after a shutdown: 1,0
8. Restarting plant from a post-maintenance condition: 1,0
9. Maintenance procedures: 0,0
10. Emergency shutdown: 0,0
11. Manufacturing unit equipment/piping modifications and additions: 0,0
12. Foreseeable abnormal fault situations: 3

$$f = 1{,}0 - \frac{0{,}5+0{,}5+0{,}5+1{,}0+1{,}0+3{,}0}{100} = 0{,}96 \quad \text{A.2.2.1.}$$

h) Reactive chemical review: the program is a continuing part of the operations that involves a 0,91 factor.

i) Other process hazard analysis: It has been done a Quantitative Risk Assessment (QRA), and is a 0,91 factor.

2. Material isolation credit factor (C_2)

a) Remote control valves: The tank can be quickly isolated in an emergency, it is been used a factor of 0,98.

b) Dump/blowdown: The dump tank is located outside the unit area, the factor is 0,96.

c) Drainage: drainage conditions are good to drain the contents away from under or near equipment, a 0,91 factor is used.

d) Interlock: the process is provided with an interlock system which prevents incorrect material flow that could produce undesirable reaction, a 0,98 factor is used.

3. Fire protection credit factor (C_3)

a) Leak detection: this point does not affect on the site, so the factor is 1,00.

b) Structural steel: it is been used fireproofing for a minimum height of 5 m, a 0,98 factor is used.

c) Fire water supply: firefighting supply is sable of deliver the maximum calculates demand for a period of four hours, so the factor is 0,97.

d) Special systems: these systems are not taken into account and the factor is 1,00.

e) Sprinkler systems: it is been used an extra hard occupancy for dry pipes and the credit factor applied is 0,81.

f) Water curtains: storage unit has got water curtains a 0,97 factor is applied.

g) Foam: this point is not applied, so the factor is 1,00.

h) Hand extinguishers/monitors: it is used a 0,98 factor because there is an adequate supply available of hand and portable fire extinguishers suitable for the fire risk involved.

i) Cable protection de cables: there is no cable protection, the factor is 1,00.

A.2.3. Rupture disk design

To properly design the required area of the rupture disk, it is necessary to take into account the main characteristics of the tank and the liquid stored. The rupture disk for the chlorine tank has been elements have been designed to supply the worst situation, it means the fire case.

First of all, the relief load and the discharge flow have to be calculated with the following expressions:

$$Q=21000\cdot F\cdot Aw^{0.82} \quad \text{A.2.3.1}$$

$$W=\frac{Q}{\lambda} \quad \text{A.2.3.2}$$

Where:

Q	Heat of absorption of the wet area, [Btu/h]
F	Coefficient of isolation
Aw	Wet area, [ft^2]
W	Diskharge flow, [lb/h]
λ	Latent heat, [Btu/lb]

The parameters and the relief load obtained for T-101 are:

Table A.2.3.1. Results of relief load for the Chlorine.

Product	Q [Btu/h]	W [lb/h]	F	Aw [ft^2]	λ [Btu/lb]
Chlorine	$7{,}60\cdot10^6$	61375	1,0	1.319	123,8

It is now possible to calculate the area of the rupture disk taking into account the situation of the disk, it will be installed between the tank and the pressure relieve valve, because of that, the pressure of discharge will have to be lower than the design pressure of the tank. For that reason, the pressure of discharge of the disk will be lower than the pressure of discharge of the pressure relieve valve, situated behind it.

First of all, the parameters of design have to be determined according to the information given above.

Table A.2.3.2. Parameters for the disk rupture design.

Item	Value	Description [Units]
Pb	15,3	Relieve Pressure [bar]
Kd	0,6	Discharge coefficient [-](1)
M	70,9	Chlorine molecular weight [g/mol]
T	50	Relieving temperature, [ºC]

Item	Value	Description [Units]
Z	1	Compressibility factor [-]
C	355	Sonic flow constant for gas or vapour [-]
K_b	1	[lb/h]

(1) Discharge coefficient for rupture disks.

With all these information and, knowing that the flow will be sonic, the disk area can be calculated by the following equation.

$$A=\frac{W}{C\cdot K_d\cdot P_b\cdot K_b}\cdot\sqrt{\frac{Z\cdot T}{M}} \quad \text{A.2.3.3.}$$

Where A is the disk area, resolving the equation is obtained a value of 2.20" or 5,6 cm. All other items in the equation are defined at table above A.2.3.2.

A.2.3. <u>Pressure relief valves design</u>

First of all, it is necessary to determine the quantity to relieve with next expression:

$$Q=21000\cdot F\cdot Aw^{0.82} \quad \text{A.2.3.1.}$$

Where:

Q	Heat of absorption of the wet area, [Btu/h]
F	Coefficient of isolation
Aw	Wet area, [ft^2]

To obtain the discharge flow, it is necessary to use the heat of absorption and the latent heat, see A.2.3.2.

$$W=\frac{Q}{\lambda} \quad \text{A.2.3.2.}$$

Where:

W	Discharge flow, [lb/h]
λ	Latent heat, [Btu/lb]

The results of PSV-101 and PSV-105 are shown in the next table:

Table A.2.3.1. Results of the relieve load or PSV 10/102 and PSV 105.

Item	Product	Q [Btu/h]	F	Aw [ft^2]	W [lb/h]	λ [Btu/lb]
PSV-101/102	Chlorine	$2{,}09\cdot10^6$	0,30	1,190	16.926	123,8
PSV-105	Caustic Soda	$1{,}15\cdot10^6$	0,30	571,5	12.660	90,71

Next step is to determinate the area that will have the orifice, following the formula of the General Catalogue of Safety Valves (Ref. 14).

There are different expressions to determine the minimum area that safety valve should have to discharge the fluid flow requested, for both PSV, taking into account that the physical state of the fluid is gas and vapour, it should be used equation A.2.3.3.

$$A=\frac{W}{387.2\cdot C\cdot P\cdot K\cdot K_1\cdot K_2}\cdot\sqrt{\frac{Z\cdot T}{M}} \qquad \text{A.2.3.3.}$$

Where:

A	Orifice area, [cm^2]
W	Discharge flow, [kg/h]
C	Expansion coefficient as function of (k)
P	Discharge pressure (set pressure + overpressure + 1.033), [kg/cm^2a]
T	Relieving temperature, [K]
Z	Compressibility factor at P and T
K	Discharge coefficient
K_1	Correction coefficient by back pressure for conventional valves
K_2	Correction coefficient by back pressure for balanced valves
M	Molecular weight

Table A.2.3.2. Results from the Orifice area of PSV.

Item	Product	C	P [kg/cm^2a]	Z	K	K_1	K_2	M [g/mol]	T [K]	A [cm^2]
PSV-101/102	Chlorine	1,34	16,45	0,29	0,95	1,00	1,00	70,9	333	1,13
PSV-105	Caustic Soda	1,34	3,19	1,00	0,95	1,00	0,90	40,0	383	12,63

Finally, the orifice area is calculated, it has been chosen a valve according to the General Catalogue of Safety Valves (Ref. 14).

Table A.2.3.3. PSV real size.

Item	Product	Valve PSV
PSV-101/102	Chlorine	1” E 2”
PSV-105	Caustic Soda	3” L 4”

A.3. QRA

AG2.CL.2.G1 Full bore rupture of the pipe of chlorine 3”-CS-Cl_2-1

Flash determination.

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (23/04/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	0,0666
Filling degree (%)	100
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	94,828
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,246
Total mass in cloud (kg)	35,867
Rainout mass (as liquid) (kg)	58,961
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	1,667
Representative density (kg/m3)	8,8534

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database

Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	63,45
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	4,46
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	2
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,10334
Purple book representative evaporation duration (s)	385,15

Representative temperature (°C)	-38,914
Representative pool diameter (m)	2,383
Density after mixing with air (kg/m3)	1,2956
Total evaporated mass (kg)	39,801
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	4,46

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	63,45
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	4,46
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120

Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	2
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,079459
Purple book representative evaporation duration (s)	437,78
Representative temperature (°C)	-34,03
Representative pool diameter (m)	2,383
Density after mixing with air (kg/m3)	1,3391
Total evaporated mass (kg)	34,786
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	4,46

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZI.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters

No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.12 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 7.2 kilograms/min
Total Amount Released: 216 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 2.3 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 320 mg/(cu m)
Indoor: 70 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.22e+08 ((mg/(cu m))^2.75)-min

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.13 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 7.8 kilograms/min
Total Amount Released: 234 kilograms

Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 904 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 321 mg/(cu m)
Indoor: 69.5 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.25e+08 ((mg/(cu m))^2.75)-min
Indoor: 3.52e+06 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZA.</u>**

ITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.12 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 7.2 kilograms/min
Total Amount Released: 216 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 6.2 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:

Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 320 mg/(cu m)
Indoor: 70 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.22e+08 ((mg/(cu m))^2.75)-min
Indoor: 3.42e+06 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.13 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 7.8 kilograms/min
Total Amount Released: 234 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 2.2 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 321 mg/(cu m)
Indoor: 69.5 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.25e+08 ((mg/(cu m))^2.75)-min
Indoor: 3.52e+06 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 320 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.12 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 7.2 kilograms/min
Total Amount Released: 72.0 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 320 mg/(cu m)
Max Threat Zone for LOC: 201 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 320 mg/(cu m)
Indoor: 25.1 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.78e+07 ((mg/(cu m))^2.75)-min
Indoor: 228,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 317 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.13 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 7.8 kilograms/min
Total Amount Released: 78.0 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 317 mg/(cu m)
Max Threat Zone for LOC: 124 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 321 mg/(cu m)
Indoor: 24.3 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.91e+07 ((mg/(cu m))^2.75)-min
Indoor: 211,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.2.G2 Leak of the pipe of chlorine 3”-CS-Cl_2-1 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (23/04/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	0,0666
Filling degree (%)	100
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	94,828
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,246
Total mass in cloud (kg)	35,867
Rainout mass (as liquid) (kg)	58,961
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	1,667
Representative density (kg/m3)	8,8534

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	6,34
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,45
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,011098
Purple book representative evaporation duration (s)	375,59
Representative temperature (°C)	-40,427

Representative pool diameter (m)	0,75694
Density after mixing with air (kg/m3)	1,2678
Total evaporated mass (kg)	4,1684
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,45

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	6,34
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,45
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete

Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,0081561
Purple book representative evaporation duration (s)	441,47
Representative temperature (°C)	-34,03
Representative pool diameter (m)	0,75694
Density after mixing with air (kg/m3)	1,2816
Total evaporated mass (kg)	3,6007
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,45

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZI.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)

Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.012 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 720 grams/min
Total Amount Released: 21.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 739 meters

TIME DEPENDENT INFORMATION:
Concentration Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 57.2 mg/(cu m)
Indoor: 12.5 mg/(cu m)
Note: Indoor graph is shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 780 grams/min
Total Amount Released: 23.4 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:

Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 270 meters

TIME DEPENDENT INFORMATION:
Concentration Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 34.3 mg/(cu m)
Indoor: 7.44 mg/(cu m)
Note: Indoor graph is shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.012 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 720 grams/min
Total Amount Released: 21.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 1.9 kilometers

TIME DEPENDENT INFORMATION:
Concentration Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 57.2 mg/(cu m)
Indoor: 12.5 mg/(cu m)
Note: Indoor graph is shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 780 grams/min
Total Amount Released: 23.4 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 669 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 34.3 mg/(cu m)
Indoor: 7.44 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 481,000 ((mg/(cu m))^2.75)-min
Indoor: 7,550 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 320 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.012 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 720 grams/min
Total Amount Released: 7.20 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 320 mg/(cu m)
Max Threat Zone for LOC: 65 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 65 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 317 mg/(cu m)

- **<u>Vulnerabilty: Toxic dispersionl 4,1D.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 317 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 10 minutes

Release Rate: 780 grams/min
Total Amount Released: 7.80 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 317 mg/(cu m)
Max Threat Zone for LOC: 39 meters
Note: Footprint was not drawn because effects of near-field patchiness make dispersion predictions unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 39 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 312 mg/(cu m)
Indoor: 23.8 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.49e+07 ((mg/(cu m))^2.75)-min
Indoor: 199,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.1.E1 Overfilled of the chlorine storage tank T-101.

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (09/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	82
Filling degree (%)	100
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	1,1675E05
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,246
Total mass in cloud (kg)	44160
Rainout mass (as liquid) (kg)	72595
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	17,867
Representative density (kg/m3)	8,8534

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	7259,4
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	141,41
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	4,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	3,0552
Purple book representative evaporation duration (s)	484,61
Representative temperature (°C)	-35,97

Representative pool diameter (m)	13,418
Density after mixing with air (kg/m3)	1,457
Total evaporated mass (kg)	1480,6
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	141,41

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	7259,4
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	141,41
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete

Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	4,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	2,3259
Purple book representative evaporation duration (s)	476,2
Representative temperature (°C)	-34,03
Representative pool diameter (m)	13,418
Density after mixing with air (kg/m3)	1,6424
Total evaporated mass (kg)	1107,6
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	141,41

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZI.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)

Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 9.21 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 553 kilograms/min
Total Amount Released: 16,578 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 25,800 mg/(cu m)
Indoor: 5,650 mg/(cu m)
Note: Indoor graph is shown with a dotted line.

- **<u>Analysis of consequences: Toxic dispersion 4,1D. ZI.</u>**

ITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 9.83 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 590 kilograms/min
Total Amount Released: 17,694 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:

Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 8.6 kilometers

TIME DEPENDENT INFORMATION:
Concentration Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 9,440 mg/(cu m)
Indoor: 2,050 mg/(cu m)
Note: Indoor graph is shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

ITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 9.21 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 553 kilograms/min
Total Amount Released: 16,578 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 25,800 mg/(cu m)
Indoor: 5,650 mg/(cu m)
Note: Indoor graph is shown with a dotted line.

- Analysis of consequences: Toxic dispersion 4,1D. ZA.

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 9.83 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 590 kilograms/min
Total Amount Released: 17,694 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 9,440 mg/(cu m)
Indoor: 2,050 mg/(cu m)
Note: Indoor graph is shown with a dotted line.

- Vulnerabilty: Toxic dispersionl 1,5F.

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 340 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm

Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 9.21 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 553 kilograms/min
Total Amount Released: 5,526 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 340 mg/(cu m)
Max Threat Zone for LOC: 1.6 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 1600 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 355 mg/(cu m)
Indoor: 33.1 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 7.79e+07 ((mg/(cu m))^2.75)-min
Indoor: 316,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 330 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 9.83 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 590 kilograms/min
Total Amount Released: 5,898 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 330 mg/(cu m)
Max Threat Zone for LOC: 1.1 kilometers

TIME DEPENDENT INFORMATION:
Concentration Estimates at the point:
Downwind: 1100 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 309 mg/(cu m)
Indoor: 24.3 mg/(cu m)
Note: Indoor graph is shown with a dotted line.

AG2.CL.1.G1 Failure of the chlorine storage tank T-101. Instantaneous release of the complete inventory.

AG2.CL.1.G2 Failure of the chlorine storage tank T-101. Continuous release of the complete inventory in 10 minutes at a constant rate of release.

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (22/04/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	82
Filling degree (%)	90
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	1,0523E05
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,022
Total mass in cloud (kg)	39898
Rainout mass (as liquid) (kg)	65335
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	17,273
Representative density (kg/m3)	8,806

Other information	
Main program	Effects 8.1.8.6673

Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	6533,5
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	141,41
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	4,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	3,043

Purple book representative evaporation duration (s)	477,47
Representative temperature (°C)	-36,069
Representative pool diameter (m)	13,418
Density after mixing with air (kg/m3)	1,4564
Total evaporated mass (kg)	1453
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	141,41

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2nd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	6533,5
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	141,41
Wind speed at 10 m height (m/s)	1,46

Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	4,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	2,3268
Purple book representative evaporation duration (s)	474,29
Representative temperature (°C)	-34,03
Representative pool diameter (m)	13,418
Density after mixing with air (kg/m3)	1,6425
Total evaporated mass (kg)	1103,6
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	141,41

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZI.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 8.46 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 508 kilograms/min
Total Amount Released: 15,228 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 23,600 mg/(cu m)
Indoor: 5,160 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 3.03e+13 ((mg/(cu m))^2.75)-min
Indoor: 4.59e+11 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:

Direct Source: 9.05 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 543 kilograms/min
Total Amount Released: 16,290 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 8.2 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 8,820 mg/(cu m)
Indoor: 1,910 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.04e+12 ((mg/(cu m))^2.75)-min
Indoor: 3.2e+10 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 8.46 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 508 kilograms/min
Total Amount Released: 15,228 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 23,600 mg/(cu m)
Indoor: 5,160 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 3.03e+13 ((mg/(cu m))^2.75)-min
Indoor: 4.59e+11 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 9.05 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 543 kilograms/min
Total Amount Released: 16,290 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters

Max Concentration:
Outdoor: 8,820 mg/(cu m)
Indoor: 1,910 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.04e+12 ((mg/(cu m))^2.75)-min
Indoor: 3.2e+10 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 340 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 8.46 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 508 kilograms/min
Total Amount Released: 5,076 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 340 mg/(cu m)
Max Threat Zone for LOC: 1.6 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 1600 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 326 mg/(cu m)
Indoor: 30.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.13e+07 ((mg/(cu m))^2.75)-min
Indoor: 249,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 330 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 9.05 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 543 kilograms/min
Total Amount Released: 5,430 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 330 mg/(cu m)
Max Threat Zone for LOC: 1.0 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 1000 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 336 mg/(cu m)
Indoor: 26.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 7.9e+07 ((mg/(cu m))^2.75)-min
Indoor: 258,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.1.G3 Failure of the chlorine storage tank T-101. Continuous release from a hole with an effective diameter of 10 mm.

- **Release.**

Case description: Release

Model: Liquefied Gas Bottom Discharge (TPDIS model)
version: 5.06 (23/04/2014)
Reference: Yellow Book (CPR-14E), 3rd edition 1997, Chapter 2 and Modelling source terms for the atmospheric dispersion of hazardous substances, Jaakko Kukkonen

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Type of release	Release through hole in vessel
Pipeline length (m)	
Pipeline diameter (mm)	
Hole diameter (mm)	10
Hole rounding	Sharp edges
Discharge coefficient (-)	0,62
Height difference between pipe entrance and exit (m)	
Height leak above tank bottom (m)	0
Initial temperature in vessel (°C)	15
Vessel volume (m3)	82
Vessel type	Horizontal cylinder
Length cylinder (m)	12,41
Filling degree (%)	90
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
Type of calculation	Calculate until specified time
Time t after start release (s)	120

Results

Initial mass in vessel (kg)	1,0523E05
Initial (vapour) pressure in vessel (bar)	5,888
Time needed to empty vessel (s)	61479

Massflowrate at time t (kg/s)	1,872
Total mass released at time t (kg)	223,71
Pressure in vessel at time t (bar)	5,8865
Temperature in vessel at time t (°C)	14,992
VapourMass fraction at time t (%)	0
Liquid mass in vessel at time t (kg)	1,0486E05
Vapour mass in vessel at time t (kg)	156,85
Height of liquid at time t (m)	2,4406
Fillingdegree at time t (%)	89,807
Exit pressure at time t (bar)	6,2259
Exit temperature at time t (°C)	14,992
Maximum mass flow rate (kg/s)	1,8726
Representative release rate (kg/s)	1,8723
Representative outflow duration (s)	120
Representative temperature (°C)	14,997
Representative pressure at exit (bar)	6,2275
Representative vapour mass fraction (%)	0

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Flash determination.</u>**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (22/04/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	82

Filling degree (%)	90
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	1,0523E05
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,022
Total mass in cloud (kg)	39898
Rainout mass (as liquid) (kg)	65335
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	17,273
Representative density (kg/m3)	8,806

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 2 i 4 (R=90%)
Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)

Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	13,91
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,98
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,023694
Purple book representative evaporation duration (s)	379,45
Representative temperature (°C)	-39,886
Representative pool diameter (m)	1,117
Density after mixing with air (kg/m3)	1,2743
Total evaporated mass (kg)	8,9904
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,98

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 i 4 (R=90%)
Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	13,91
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,98
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,017683
Purple book representative evaporation duration (s)	440,77
Representative temperature (°C)	-34,03

Representative pool diameter (m)	1,117
Density after mixing with air (kg/m3)	1,2947
Total evaporated mass (kg)	7,7942
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,98

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.027 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.62 kilograms/min
Total Amount Released: 48.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 1.1 kilometers

TIME DEPENDENT INFORMATION:

Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 102 mg/(cu m)
Indoor: 22.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 9.67e+06 ((mg/(cu m))^2.75)-min
Indoor: 149,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Analysis of consequences: Toxic dispersion 4,1D. ZI.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.029 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.74 kilograms/min
Total Amount Released: 52.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 411 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 75.4 mg/(cu m)
Indoor: 16.3 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.19e+06 ((mg/(cu m))^2.75)-min
Indoor: 65,700 ((mg/(cu m))^2.75)-min

Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.027 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.62 kilograms/min
Total Amount Released: 48.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 3.0 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 102 mg/(cu m)
Indoor: 22.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 9.67e+06 ((mg/(cu m))^2.75)-min
Indoor: 149,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:

Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.029 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.74 kilograms/min
Total Amount Released: 52.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 1.0 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 75.4 mg/(cu m)
Indoor: 16.3 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.19e+06 ((mg/(cu m))^2.75)-min
Indoor: 65,700 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Vulnerabilty: Toxic dispersionl 1,5F.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 320 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters

No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.027 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 1.62 kilograms/min
Total Amount Released: 16.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 320 mg/(cu m)
Max Threat Zone for LOC: 96 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 96 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 318 mg/(cu m)
Indoor: 25 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.83e+07 ((mg/(cu m))^2.75)-min
Indoor: 227,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 320 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.029 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 1.74 kilograms/min
Total Amount Released: 17.4 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 320 mg/(cu m)
Max Threat Zone for LOC: 57 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 57 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 323 mg/(cu m)
Indoor: 24.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 7.04e+07 ((mg/(cu m))^2.75)-min
Indoor: 213,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.4.G1 Catastrophic failure with full bore rupture of the largest connecting pipeline of the pump P-101A.

- **Release.**

Case description: Release
Model: Liquefied Gas Bottom Discharge (TPDIS model)
version: 5.06 (23/04/2014)
Reference: Yellow Book (CPR-14E), 3rd edition 1997, Chapter 2 and Modelling source terms for the atmospheric dispersion of hazardous substances, Jaakko Kukkonen

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Type of release	Release from vessel through (a hole in) pipe
Pipeline length (m)	5
Pipeline diameter (mm)	86,926
Hole diameter (mm)	86,926
Hole rounding	Sharp edges
Discharge coefficient (-)	0,62
Height difference between pipe entrance and exit (m)	0
Height leak above tank bottom (m)	0
Initial temperature in vessel (°C)	15
Vessel volume (m3)	82
Vessel type	Horizontal cylinder
Length cylinder (m)	12,41
Filling degree (%)	90
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
Type of calculation	Calculate until specified time
Time t after start release (s)	120

Results

Initial mass in vessel (kg)	1,0523E05
Initial (vapour) pressure in vessel (bar)	5,888
Time needed to empty vessel (s)	2203,9

Massflowrate at time t (kg/s)	55,864
Total mass released at time t (kg)	6702,4
Pressure in vessel at time t (bar)	5,8432
Temperature in vessel at time t (°C)	14,739
VapourMass fraction at time t (%)	1,2474
Liquid mass in vessel at time t (kg)	98365
Vapour mass in vessel at time t (kg)	241,4
Height of liquid at time t (m)	2,2767
Fillingdegree at time t (%)	84,204
Exit pressure at time t (bar)	4,5467
Exit temperature at time t (°C)	6,446
Maximum mass flow rate (kg/s)	56,543
Representative release rate (kg/s)	56,317
Representative outflow duration (s)	120
Representative temperature (°C)	6,6758
Representative pressure at exit (bar)	4,5794
Representative vapour mass fraction (%)	1,2414

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (23/04/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	0,03

Filling degree (%)	100
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	42,715
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,246
Total mass in cloud (kg)	16,156
Rainout mass (as liquid) (kg)	26,559
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	1,2779
Representative density (kg/m3)	8,8534

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 2 (R=90%)

Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)

Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	416,74
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	29,27
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	3,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,63721
Purple book representative evaporation duration (s)	394,77
Representative temperature (°C)	-37,923
Representative pool diameter (m)	6,1047
Density after mixing with air (kg/m3)	1,3523
Total evaporated mass (kg)	251,55
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	29,27

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	416,74
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	29,27
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	3,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,5071
Purple book representative evaporation duration (s)	436,96
Representative temperature (°C)	-34,03

Representative pool diameter (m)	6,1047
Density after mixing with air (kg/m3)	1,4566
Total evaporated mass (kg)	221,58
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	29,27

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.79 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 47.4 kilograms/min
Total Amount Released: 1,422 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 5.1 kilometers

TIME DEPENDENT INFORMATION:

Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 1,690 mg/(cu m)
Indoor: 370 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.16e+10 ((mg/(cu m))^2.75)-min
Indoor: 3.27e+08 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.84 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 50.4 kilograms/min
Total Amount Released: 1,512 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 2.4 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 1,430 mg/(cu m)
Indoor: 310 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 1.37e+10 ((mg/(cu m))^2.75)-min
Indoor: 2.14e+08 ((mg/(cu m))^2.75)-min

Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.79 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 47.4 kilograms/min
Total Amount Released: 1,422 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 1,690 mg/(cu m)
Indoor: 370 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.16e+10 ((mg/(cu m))^2.75)-min
Indoor: 3.27e+08 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

ITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.84 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 50.4 kilograms/min
Total Amount Released: 1,512 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 5.9 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 1,430 mg/(cu m)
Indoor: 310 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 1.37e+10 ((mg/(cu m))^2.75)-min
Indoor: 2.14e+08 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 338 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters

No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.79 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 47.4 kilograms/min
Total Amount Released: 474 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 338 mg/(cu m)
Max Threat Zone for LOC: 501 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 501 meters
Off Centerline: 0 meters
Max Concentration:
  Outdoor: 340 mg/(cu m)
  Indoor: 26.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
  Outdoor: 6.85e+07 ((mg/(cu m))^2.75)-min
  Indoor: 249,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Vulnerabilty: Toxic dispersionl 4,1D.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 317 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.84 kilograms/sec
Source Height: 0

Release Duration: 10 minutes
Release Rate: 50.4 kilograms/min
Total Amount Released: 504 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 317 mg/(cu m)
Max Threat Zone for LOC: 326 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 326 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 317 mg/(cu m)
Indoor: 24.5 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.84e+07 ((mg/(cu m))^2.75)-min
Indoor: 214,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.4.G2 Leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipeline, a maximum of 50 mm, of the pump P-101A.

Release.

Case description: Release

Model: Liquefied Gas Bottom Discharge (TPDIS model)
version: 5.06 (23/04/2014)
Reference: Yellow Book (CPR-14E), 3rd edition 1997, Chapter 2 and Modelling source terms for the atmospheric dispersion of hazardous substances, Jaakko Kukkonen

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Type of release	Release from vessel through (a hole in) pipe
Pipeline length (m)	5
Pipeline diameter (mm)	86,926
Hole diameter (mm)	8,6926
Hole rounding	Sharp edges
Discharge coefficient (-)	0,62
Height difference between pipe entrance and exit (m)	0
Height leak above tank bottom (m)	0
Initial temperature in vessel (°C)	15
Vessel volume (m3)	82
Vessel type	Horizontal cylinder
Length cylinder (m)	12,41
Filling degree (%)	90
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
Type of calculation	Calculate until specified time
Time t after start release (s)	120

Results

Initial mass in vessel (kg)	1,0523E05
Initial (vapour) pressure in vessel (bar)	5,888

Time needed to empty vessel (s)	80891
Massflowrate at time t (kg/s)	1,4146
Total mass released at time t (kg)	171,7
Pressure in vessel at time t (bar)	5,8869
Temperature in vessel at time t (°C)	14,994
VapourMass fraction at time t (%)	0
Liquid mass in vessel at time t (kg)	1,0491E05
Vapour mass in vessel at time t (kg)	156,14
Height of liquid at time t (m)	2,4421
Fillingdegree at time t (%)	89,854
Exit pressure at time t (bar)	6,2263
Exit temperature at time t (°C)	14,994
Maximum mass flow rate (kg/s)	1,4148
Representative release rate (kg/s)	1,4147
Representative outflow duration (s)	120
Representative temperature (°C)	14,998
Representative pressure at exit (bar)	6,2275
Representative vapour mass fraction (%)	0

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Flash determination</u>**.

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (23/04/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)

Vessel volume (m3)	0,03
Filling degree (%)	100
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	42,715
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,246
Total mass in cloud (kg)	16,156
Rainout mass (as liquid) (kg)	26,559
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	1,2779
Representative density (kg/m3)	8,8534

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 2 (R=90%)

Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)

Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	10,68
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,75
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,018237
Purple book representative evaporation duration (s)	379,89
Representative temperature (°C)	-40,099
Representative pool diameter (m)	0,97721
Density after mixing with air (kg/m3)	1,2718
Total evaporated mass (kg)	6,9279
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,75

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database

Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (30/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	10,68
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,75
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,013528
Purple book representative evaporation duration (s)	442,88

Representative temperature (°C)	-34,03
Representative pool diameter (m)	0,97721
Density after mixing with air (kg/m3)	1,2896
Total evaporated mass (kg)	5,9913
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,75

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

ITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.021 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.26 kilograms/min
Total Amount Released: 37.8 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 981 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 85.3 mg/(cu m)
Indoor: 18.7 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 5.87e+06 ((mg/(cu m))^2.75)-min
Indoor: 90,100 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.022 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.32 kilograms/min
Total Amount Released: 39.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 356 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 58.3 mg/(cu m)
Indoor: 12.6 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)

Outdoor: 2.06e+06 ((mg/(cu m))^2.75)-min
Indoor: 32,300 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.021 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.26 kilograms/min
Total Amount Released: 37.8 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 2.6 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 85.3 mg/(cu m)
Indoor: 18.7 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 5.87e+06 ((mg/(cu m))^2.75)-min
Indoor: 90,100 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)

Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.022 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.32 kilograms/min
Total Amount Released: 39.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 884 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 58.3 mg/(cu m)
Indoor: 12.6 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.06e+06 ((mg/(cu m))^2.75)-min
Indoor: 32,300 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Vulnerabilty: Toxic dispersionl 1,5F.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 320 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.021 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 1.26 kilograms/min
Total Amount Released: 12.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 320 mg/(cu m)
Max Threat Zone for LOC: 85 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 85 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 318 mg/(cu m)
Indoor: 25.1 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.88e+07 ((mg/(cu m))^2.75)-min
Indoor: 229,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 319 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C

Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.022 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 1.32 kilograms/min
Total Amount Released: 13.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 319 mg/(cu m)
Max Threat Zone for LOC: 51 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 51 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 320 mg/(cu m)
Indoor: 24.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.96e+07 ((mg/(cu m))^2.75)-min
Indoor: 213,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.3.G1 Full bore rupture of the pipe of chlorine 3”-CS-Cl2-3.

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (25/04/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	0,133
Filling degree (%)	100
Initial temperature in vessel (°C)	29
Pressure inside vessel determination	Use actual pressure
Initial (absolute) pressure in vessel (bar)	8,7
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	183,75
Adiabatic vapour flash fraction (%)	20,302
Liquid mass fraction in cloud (%)	60,73
Total mass in cloud (kg)	94,993
Rainout mass (as liquid) (kg)	88,753
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	2,3065
Representative density (kg/m3)	9,4133

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 1
Model: Pool evaporation
version: 5.16 (25/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	47,83
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	3,46
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	1200

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,068957
Purple book representative evaporation duration (s)	567,58
Representative temperature (°C)	-42,749

Representative pool diameter (m)	2,0989
Density after mixing with air (kg/m3)	1,2864
Total evaporated mass (kg)	39,138
... duration evaporation time (s)	1199,5
Corresponding representative pool surface area (m2)	3,46

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Evaporation 1,5D</u>**

Case description: Evaporation 1,5 F - Cas 1
Model: Pool evaporation
version: 5.16 (25/04/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	47,83
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	3,46
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete

Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	1200

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,050991
Purple book representative evaporation duration (s)	692,25
Representative temperature (°C)	-34,03
Representative pool diameter (m)	2,0989
Density after mixing with air (kg/m3)	1,3164
Total evaporated mass (kg)	35,299
... duration evaporation time (s)	1199,5
Corresponding representative pool surface area (m2)	3,46

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

ITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 8.23 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)

Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.13 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 7.8 kilograms/min
Total Amount Released: 234 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 8.23 mg/(cu m)
Max Threat Zone for LOC: 2.3 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 339 mg/(cu m)
Indoor: 74.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.6e+08 ((mg/(cu m))^2.75)-min
Indoor: 3.98e+06 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 8.23 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.14 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 8.4 kilograms/min

Total Amount Released: 252 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 8.23 mg/(cu m)
Max Threat Zone for LOC: 915 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 334 mg/(cu m)
Indoor: 72.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.51e+08 ((mg/(cu m))^2.75)-min
Indoor: 3.94e+06 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.47 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.13 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 7.8 kilograms/min
Total Amount Released: 234 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.47 mg/(cu m)
Max Threat Zone for LOC: 6.2 kilometers

TIME DEPENDENT INFORMATION:

Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 339 mg/(cu m)
Indoor: 74.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.6e+08 ((mg/(cu m))^2.75)-min
Indoor: 3.98e+06 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.47 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.14 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 8.4 kilograms/min
Total Amount Released: 252 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.47 mg/(cu m)
Max Threat Zone for LOC: 2.3 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 334 mg/(cu m)
Indoor: 72.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.51e+08 ((mg/(cu m))^2.75)-min

Indoor: 3.94e+06 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

ITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 322 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.13 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 7.8 kilograms/min
Total Amount Released: 78.0 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 322 mg/(cu m)
Max Threat Zone for LOC: 207 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 207 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 323 mg/(cu m)
Indoor: 25.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.92e+07 ((mg/(cu m))^2.75)-min
Indoor: 233,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 317 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.14 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 8.4 kilograms/min
Total Amount Released: 84.0 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 317 mg/(cu m)
Max Threat Zone for LOC: 127 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 127 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 319 mg/(cu m)
Indoor: 24.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.82e+07 ((mg/(cu m))^2.75)-min
Indoor: 208,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.3.G2 Leak of the pipe of chlorine 3”-CS-Cl_2-3 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (09/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	35
Filling degree (%)	85
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	42458
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	57,89
Total mass in cloud (kg)	16120
Rainout mass (as liquid) (kg)	26338
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	12,769
Representative density (kg/m3)	8,7785

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database

Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- Evaporation 4,1D

Case description: Evaporation 4 D - Cas 1

Model: Pool evaporation
version: 5.16 (09/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	26338
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	1500
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	1200

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	12
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	23,137
Purple book representative evaporation duration (s)	782,3

Representative temperature (°C)	-40,934
Representative pool diameter (m)	43,702
Density after mixing with air (kg/m3)	1,6956
Total evaporated mass (kg)	18100
... duration evaporation time (s)	1199,5
Corresponding representative pool surface area (m2)	1500

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 1
Model: Pool evaporation
version: 5.16 (09/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	26338
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	1500
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120

Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	1200

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	12
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	17,696
Purple book representative evaporation duration (s)	906,81
Representative temperature (°C)	-34,03
Representative pool diameter (m)	43,702
Density after mixing with air (kg/m3)	2,0029
Total evaporated mass (kg)	16047
... duration evaporation time (s)	1199,5
Corresponding representative pool surface area (m2)	1500

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 8.23 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters

No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 780 grams/min
Total Amount Released: 23.4 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 8.23 mg/(cu m)
Max Threat Zone for LOC: 746 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 60.5 mg/(cu m)
Indoor: 13.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.29e+06 ((mg/(cu m))^2.75)-min
Indoor: 35,100 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 8.23 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.014 kilograms/sec
Source Height: 0

Release Duration: 30 minutes
Release Rate: 840 grams/min
Total Amount Released: 25.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 8.23 mg/(cu m)
Max Threat Zone for LOC: 274 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 37.5 mg/(cu m)
Indoor: 8.12 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 611,000 ((mg/(cu m))^2.75)-min
Indoor: 9,590 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZA.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.47 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 780 grams/min
Total Amount Released: 23.4 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.47 mg/(cu m)
Max Threat Zone for LOC: 2.0 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 60.5 mg/(cu m)
Indoor: 13.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.29e+06 ((mg/(cu m))^2.75)-min
Indoor: 35,100 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.47 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.014 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 840 grams/min
Total Amount Released: 25.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.47 mg/(cu m)
Max Threat Zone for LOC: 679 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 37.5 mg/(cu m)
Indoor: 8.12 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 611,000 ((mg/(cu m))^2.75)-min

Indoor: 9,590 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 310 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 780 grams/min
Total Amount Released: 7.80 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 310 mg/(cu m)
Max Threat Zone for LOC: 68 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 68 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 312 mg/(cu m)
Indoor: 24.6 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.6e+07 ((mg/(cu m))^2.75)-min
Indoor: 218,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:

Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 318 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.014 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 840 grams/min
Total Amount Released: 8.40 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 318 mg/(cu m)
Max Threat Zone for LOC: 41 meters
Note: Footprint was not drawn because effects of near-field patchiness make dispersion predictions unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 41 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 319 mg/(cu m)
Indoor: 24.3 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.88e+07 ((mg/(cu m))^2.75)-min
Indoor: 211,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.6.G2 Continuous release from a hole the size of the largest connection of the road tanker TK-101.Release . AG2.CL.6.L1a Full fore rupture of the loading hose of the road tanker TK-101.

Release

Case description: Càlcul Release

Model: Liquefied Gas Bottom Discharge (TPDIS model)
version: 5.06 (12/05/2014)
Reference: Yellow Book (CPR-14E), 3rd edition 1997, Chapter 2 and Modelling source terms for the atmospheric dispersion of hazardous substances, Jaakko Kukkonen

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Type of release	Release through hole in vessel
Pipeline length (m)	
Pipeline diameter (mm)	
Hole diameter (mm)	75,166
Hole rounding	Sharp edges
Discharge coefficient (-)	0,62
Height difference between pipe entrance and exit (m)	
Height leak above tank bottom (m)	0
Initial temperature in vessel (°C)	15
Vessel volume (m3)	35
Vessel type	Horizontal cylinder
Length cylinder (m)	10
Filling degree (%)	85
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
Type of calculation	Calculate until specified time
Time t after start release (s)	120

Results

Initial mass in vessel (kg)	42458
Initial (vapour) pressure in vessel (bar)	5,888

Time needed to empty vessel (s)	486,25
Massflowrate at time t (kg/s)	101,97
Total mass released at time t (kg)	12275
Pressure in vessel at time t (bar)	5,6655
Temperature in vessel at time t (°C)	13,69
VapourMass fraction at time t (%)	0
Liquid mass in vessel at time t (kg)	30017
Vapour mass in vessel at time t (kg)	253,04
Height of liquid at time t (m)	1,2232
Fillingdegree at time t (%)	60,071
Exit pressure at time t (bar)	5,8364
Exit temperature at time t (°C)	13,69
Maximum mass flow rate (kg/s)	104,77
Representative release rate (kg/s)	103,98
Representative outflow duration (s)	120
Representative temperature (°C)	14,645
Representative pressure at exit (bar)	6,04
Representative vapour mass fraction (%)	0

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (12/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)

Vessel volume (m3)	35
Filling degree (%)	85
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	42458
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	57,89
Total mass in cloud (kg)	16120
Rainout mass (as liquid) (kg)	26338
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	12,769
Representative density (kg/m3)	8,7785

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Evaporation 4,1D</u>**

Case description: Evaporation 4 D - Cas 2 (R=90%)

Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)

Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	763,21
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	53,6
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	4
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	1,1416
Purple book representative evaporation duration (s)	398,4
Representative temperature (°C)	-37,646
Representative pool diameter (m)	8,2611
Density after mixing with air (kg/m3)	1,3825
Total evaporated mass (kg)	454,81
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	53,6

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database

Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	763,21
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	53,6
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	4
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,91811
Purple book representative evaporation duration (s)	437,22

Representative temperature (°C)	-34,03
Representative pool diameter (m)	8,2611
Density after mixing with air (kg/m3)	1,5179
Total evaporated mass (kg)	401,41
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	53,6

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.92 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 295 kilograms/min
Total Amount Released: 8,856 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 9.9 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 12,800 mg/(cu m)
Indoor: 2,800 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 5.64e+12 ((mg/(cu m))^2.75)-min
Indoor: 8.53e+10 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 5.22 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 313 kilograms/min
Total Amount Released: 9,396 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 6.2 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 5,640 mg/(cu m)
Indoor: 1,220 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)

Outdoor: 5.97e+11 ((mg/(cu m))^2.75)-min
Indoor: 9.36e+09 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.47 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.92 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 295 kilograms/min
Total Amount Released: 8,856 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.47 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 12,800 mg/(cu m)
Indoor: 2,800 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 5.64e+12 ((mg/(cu m))^2.75)-min
Indoor: 8.53e+10 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN

Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 5.22 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 313 kilograms/min
Total Amount Released: 9,396 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 5,640 mg/(cu m)
Indoor: 1,220 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 5.97e+11 ((mg/(cu m))^2.75)-min
Indoor: 9.36e+09 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 330 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm

Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.92 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 295 kilograms/min
Total Amount Released: 2,952 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 330 mg/(cu m)
Max Threat Zone for LOC: 1.2 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 1200 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 353 mg/(cu m)
Indoor: 30.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 7.13e+07 ((mg/(cu m))^2.75)-min
Indoor: 293,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 317 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 5.22 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 313 kilograms/min
Total Amount Released: 3,132 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 317 mg/(cu m)
Max Threat Zone for LOC: 801 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 801 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 317 mg/(cu m)
Indoor: 25 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.8e+07 ((mg/(cu m))^2.75)-min
Indoor: 222,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.6.G2 Continuous release from a hole the size of the largest connection of the road tanker TK-101.Release .
AG2.CL.6.L1a Full fore rupture of the loading hose of the road tanker TK-101.

Release

Case description: Release

Model: Liquefied Gas Bottom Discharge (TPDIS model)
version: 5.06 (12/05/2014)
Reference: Yellow Book (CPR-14E), 3rd edition 1997, Chapter 2 and Modelling source terms for the atmospheric dispersion of hazardous substances, Jaakko Kukkonen

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Type of release	Release through hole in vessel
Pipeline length (m)	
Pipeline diameter (mm)	
Hole diameter (mm)	75,166
Hole rounding	Sharp edges
Discharge coefficient (-)	0,62
Height difference between pipe entrance and exit (m)	
Height leak above tank bottom (m)	0
Initial temperature in vessel (°C)	15
Vessel volume (m3)	35
Vessel type	Horizontal cylinder
Length cylinder (m)	10
Filling degree (%)	85
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
Type of calculation	Calculate until specified time
Time t after start release (s)	120

Results

Initial mass in vessel (kg)	42458
Initial (vapour) pressure in vessel (bar)	5,888

Time needed to empty vessel (s)	486,25
Massflowrate at time t (kg/s)	101,97
Total mass released at time t (kg)	12275
Pressure in vessel at time t (bar)	5,6655
Temperature in vessel at time t (°C)	13,69
VapourMass fraction at time t (%)	0
Liquid mass in vessel at time t (kg)	30017
Vapour mass in vessel at time t (kg)	253,04
Height of liquid at time t (m)	1,2232
Fillingdegree at time t (%)	60,071
Exit pressure at time t (bar)	5,8364
Exit temperature at time t (°C)	13,69
Maximum mass flow rate (kg/s)	104,77
Representative release rate (kg/s)	103,98
Representative outflow duration (s)	120
Representative temperature (°C)	14,645
Representative pressure at exit (bar)	6,04
Representative vapour mass fraction (%)	0

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (12/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)

Vessel volume (m3)	35
Filling degree (%)	85
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	42458
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	57,89
Total mass in cloud (kg)	16120
Rainout mass (as liquid) (kg)	26338
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	12,769
Representative density (kg/m3)	8,7785

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 2 (R=90%)

Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)

Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	763,21
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	53,6
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	4
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	1,1416
Purple book representative evaporation duration (s)	398,4
Representative temperature (°C)	-37,646
Representative pool diameter (m)	8,2611
Density after mixing with air (kg/m3)	1,3825
Total evaporated mass (kg)	454,81
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	53,6

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database

Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	763,21
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	53,6
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	4
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,91811
Purple book representative evaporation duration (s)	437,22

Representative temperature (°C)	-34,03
Representative pool diameter (m)	8,2611
Density after mixing with air (kg/m3)	1,5179
Total evaporated mass (kg)	401,41
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	53,6

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 1.44 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 86.4 kilograms/min
Total Amount Released: 2,592 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 6.4 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 3,140 mg/(cu m)
Indoor: 687 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 1.18e+11 ((mg/(cu m))^2.75)-min
Indoor: 1.78e+09 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Analysis of consequences: Toxic dispersion 4,1D. ZI.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 1.53 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 91.8 kilograms/min
Total Amount Released: 2,754 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 3.3 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 2,210 mg/(cu m)
Indoor: 479 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)

Outdoor: 4.54e+10 ((mg/(cu m))^2.75)-min
Indoor: 7.12e+08 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 1.44 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 86.4 kilograms/min
Total Amount Released: 2,592 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 3,140 mg/(cu m)
Indoor: 687 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 1.18e+11 ((mg/(cu m))^2.75)-min
Indoor: 1.78e+09 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 1.53 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 91.8 kilograms/min
Total Amount Released: 2,754 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 8.1 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 2,210 mg/(cu m)
Indoor: 479 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.54e+10 ((mg/(cu m))^2.75)-min
Indoor: 7.12e+08 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 343 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)

Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 1.44 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 86.4 kilograms/min
Total Amount Released: 864 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 343 mg/(cu m)
Max Threat Zone for LOC: 667 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 667 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 350 mg/(cu m)
Indoor: 27.3 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.85e+07 ((mg/(cu m))^2.75)-min
Indoor: 259,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 317 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 1.53 kilograms/sec

Source Height: 0
Release Duration: 10 minutes
Release Rate: 91.8 kilograms/min
Total Amount Released: 918 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 317 mg/(cu m)
Max Threat Zone for LOC: 441 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 441 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 316 mg/(cu m)
Indoor: 24.7 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.86e+07 ((mg/(cu m))^2.75)-min
Indoor: 219,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.6.L2a Leak of the loading hose of the road tanker TK-101 with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm.

Release.

Case description: Càlcul Release
Model: Liquefied Gas Bottom Discharge (TPDIS model)
version: 5.06 (12/05/2014)
Reference: Yellow Book (CPR-14E), 3rd edition 1997, Chapter 2 and Modelling source terms for the atmospheric dispersion of hazardous substances, Jaakko Kukkonen

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Type of release	Release through hole in vessel
Pipeline length (m)	
Pipeline diameter (mm)	
Hole diameter (mm)	7,5166
Hole rounding	Sharp edges
Discharge coefficient (-)	0,62
Height difference between pipe entrance and exit (m)	
Height leak above tank bottom (m)	0
Initial temperature in vessel (°C)	15
Vessel volume (m3)	35
Vessel type	Horizontal cylinder
Length cylinder (m)	10
Filling degree (%)	85
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
Type of calculation	Calculate until specified time
Time t after start release (s)	120

Results

Initial mass in vessel (kg)	42458
Initial (vapour) pressure in vessel (bar)	5,888
Time needed to empty vessel (s)	44763

Massflowrate at time t (kg/s)	1,0474
Total mass released at time t (kg)	125,97
Pressure in vessel at time t (bar)	5,886
Temperature in vessel at time t (°C)	14,988
VapourMass fraction at time t (%)	0
Liquid mass in vessel at time t (kg)	42234
Vapour mass in vessel at time t (kg)	100,17
Height of liquid at time t (m)	1,668
Fillingdegree at time t (%)	84,747
Exit pressure at time t (bar)	6,1182
Exit temperature at time t (°C)	14,988
Maximum mass flow rate (kg/s)	1,0477
Representative release rate (kg/s)	1,0475
Representative outflow duration (s)	120
Representative temperature (°C)	14,997
Representative pressure at exit (bar)	6,1201
Representative vapour mass fraction (%)	0

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (12/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	35

Filling degree (%)	85
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	42458
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	57,89
Total mass in cloud (kg)	16120
Rainout mass (as liquid) (kg)	26338
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	12,769
Representative density (kg/m3)	8,7785

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 2 (R=90%)

Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)

Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	6,81
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,48
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,011804
Purple book representative evaporation duration (s)	377,9
Representative temperature (°C)	-40,412
Representative pool diameter (m)	0,78176
Density after mixing with air (kg/m3)	1,2683
Total evaporated mass (kg)	4,4606
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,48

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	6,81
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,48
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,0086784
Purple book representative evaporation duration (s)	443,52
Representative temperature (°C)	-34,03

Representative pool diameter (m)	0,78176
Density after mixing with air (kg/m3)	1,2825
Total evaporated mass (kg)	3,8491
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,48

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 780 grams/min
Total Amount Released: 23.4 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 766 meters

TIME DEPENDENT INFORMATION:

Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 60.5 mg/(cu m)
Indoor: 13.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.29e+06 ((mg/(cu m))^2.75)-min
Indoor: 35,100 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.014 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 840 grams/min
Total Amount Released: 25.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 281 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 37.5 mg/(cu m)
Indoor: 8.12 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 611,000 ((mg/(cu m))^2.75)-min
Indoor: 9,590 ((mg/(cu m))^2.75)-min

Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 780 grams/min
Total Amount Released: 23.4 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 2.0 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 60.5 mg/(cu m)
Indoor: 13.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 2.29e+06 ((mg/(cu m))^2.75)-min
Indoor: 35,100 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.014 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 840 grams/min
Total Amount Released: 25.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 697 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 37.5 mg/(cu m)
Indoor: 8.12 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 611,000 ((mg/(cu m))^2.75)-min
Indoor: 9,590 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Vulnerabilty: Toxic dispersionl 1,5F.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 310 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)

Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.013 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 780 grams/min
Total Amount Released: 7.80 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 310 mg/(cu m)
Max Threat Zone for LOC: 68 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 68 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 312 mg/(cu m)
Indoor: 24.6 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.6e+07 ((mg/(cu m))^2.75)-min
Indoor: 218,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 318 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.014 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 840 grams/min
Total Amount Released: 8.40 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 318 mg/(cu m)
Max Threat Zone for LOC: 41 meters
Note: Footprint was not drawn because effects of near-field patchiness make dispersion predictions unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 41 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 319 mg/(cu m)
Indoor: 24.3 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.88e+07 ((mg/(cu m))^2.75)-min
Indoor: 211,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

AG2.CL.5.G1 Full bore rupture of ten pipes simultaneously of chlorine of heat exchanger E-102.

- **Release.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (08/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	0,0063
Filling degree (%)	100
Initial temperature in vessel (°C)	55
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	16,308
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	8,1665
Adiabatic vapour flash fraction (%)	28,676
Liquid mass fraction in cloud (%)	62,982
Total mass in cloud (kg)	6,3263
Rainout mass (as liquid) (kg)	1,8403
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	0,93489
Representative density (kg/m3)	9,9859

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **<u>Flash determination.</u>**
- Evaporation 4,1D

Case description: Evaporation 4 D - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (08/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	0,19
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,014
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,00037718
Purple book representative evaporation duration (s)	358,46

Representative temperature (°C)	-42,809
Representative pool diameter (m)	0,13351
Density after mixing with air (kg/m3)	1,2561
Total evaporated mass (kg)	0,1352
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,014

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (08/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	0,19
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,014
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120

Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,00026826
Purple book representative evaporation duration (s)	428,41
Representative temperature (°C)	-34,03
Representative pool diameter (m)	0,13351
Density after mixing with air (kg/m3)	1,2585
Total evaporated mass (kg)	0,11493
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,014

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/201

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZI.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 8.80 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters

No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.0013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 78 grams/min
Total Amount Released: 2.34 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 8.80 mg/(cu m)
Max Threat Zone for LOC: 217 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 10 mg/(cu m)
Indoor: 2.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 16,400 ((mg/(cu m))^2.75)-min
Indoor: 253 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 8.80 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.0013 kilograms/sec
Source Height: 0

Release Duration: 30 minutes
Release Rate: 78 grams/min
Total Amount Released: 2.34 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 8.80 mg/(cu m)
Max Threat Zone for LOC: 77 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 3.49 mg/(cu m)
Indoor: 0.757 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 896 ((mg/(cu m))^2.75)-min
Indoor: 14.1 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZA.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.57 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.0013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 78 grams/min
Total Amount Released: 2.34 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:

Model Run: Heavy Gas
User-specified LOC: 1.57 mg/(cu m)
Max Threat Zone for LOC: 565 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 10 mg/(cu m)
Indoor: 2.2 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 16,400 ((mg/(cu m))^2.75)-min
Indoor: 253 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.57 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.0013 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 78 grams/min
Total Amount Released: 2.34 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.57 mg/(cu m)
Max Threat Zone for LOC: 188 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:

Outdoor: 3.49 mg/(cu m)
Indoor: 0.757 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 896 ((mg/(cu m))^2.75)-min
Indoor: 14.1 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 260 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.0013 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 78 grams/min
Total Amount Released: 780 grams
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 260 mg/(cu m)
Max Threat Zone for LOC: 11 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 11 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 129,000 mg/(cu m)
Indoor: 10,200 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 1.08e+15 ((mg/(cu m))^2.75)-min
Indoor: 3.43e+12 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 260 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.0013 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 78 grams/min
Total Amount Released: 780 grams
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 260 mg/(cu m)
Max Threat Zone for LOC: 11 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 11 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 129,000 mg/(cu m)
Indoor: 10,200 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 1.08e+15 ((mg/(cu m))^2.75)-min
Indoor: 3.43e+12 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

2.G2: Overfilled of the chlorine storage tank T-101.

Flash determination.

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (12/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	41
Filling degree (%)	100
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	58377
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,246
Total mass in cloud (kg)	22080
Rainout mass (as liquid) (kg)	36297
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	14,181
Representative density (kg/m3)	8,8534

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 2 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	3629,7
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	70,71
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	3,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	1,5747
Purple book representative evaporation duration (s)	480,16
Representative temperature (°C)	-36,163

Representative pool diameter (m)	9,4885
Density after mixing with air (kg/m3)	1,4054
Total evaporated mass (kg)	756,1
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	70,71

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	3629,7
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	70,71
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete

Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	3,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	1,1708
Purple book representative evaporation duration (s)	482,87
Representative temperature (°C)	-34,03
Representative pool diameter (m)	9,4885
Density after mixing with air (kg/m3)	1,5436
Total evaporated mass (kg)	565,33
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	70,71

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Analysis of consequences: Toxic dispersion 1,5F. ZI.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)

Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.62 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 277 kilograms/min
Total Amount Released: 8,316 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 9.7 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 11,900 mg/(cu m)
Indoor: 2,600 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.58e+12 ((mg/(cu m))^2.75)-min
Indoor: 6.92e+10 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE   Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm   IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.94 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 296 kilograms/min
Total Amount Released: 8,892 kilograms

Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 6.0 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 5,410 mg/(cu m)
Indoor: 1,170 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 5.32e+11 ((mg/(cu m))^2.75)-min
Indoor: 8.35e+09 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.62 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 277 kilograms/min
Total Amount Released: 8,316 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters

Off Centerline: 0 meters
Max Concentration:
Outdoor: 11,900 mg/(cu m)
Indoor: 2,600 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.58e+12 ((mg/(cu m))^2.75)-min
Indoor: 6.92e+10 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.94 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 296 kilograms/min
Total Amount Released: 8,892 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 5,410 mg/(cu m)
Indoor: 1,170 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 5.32e+11 ((mg/(cu m))^2.75)-min
Indoor: 8.35e+09 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 340 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.62 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 277 kilograms/min
Total Amount Released: 2,772 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 340 mg/(cu m)
Max Threat Zone for LOC: 1.2 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 1200 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 333 mg/(cu m)
Indoor: 28.5 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.06e+07 ((mg/(cu m))^2.75)-min
Indoor: 249,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm

Footprint Level of Concern: 316 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76%   Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.49 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 269 kilograms/min
Total Amount Released: 2,694 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 316 mg/(cu m)
Max Threat Zone for LOC: 746 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 746 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 317 mg/(cu m)
Indoor: 25 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.83e+07 ((mg/(cu m))^2.75)-min
Indoor: 223,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

Failure of the chlorine storage tank T-101. Instantaneous release of the complete inventory. Alternative (two tanks of 41m^3)

- **Flash determination.**

Case description: Flash determination
Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (12/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	41
Filling degree (%)	90
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	52617
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,022
Total mass in cloud (kg)	19949
Rainout mass (as liquid) (kg)	32668
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	13,709
Representative density (kg/m3)	8,806

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database

Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 4,1D**

Case description: Evaporation 4 D - Cas 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	3266,8
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	70,71
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	3,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	1,5678
Purple book representative evaporation duration (s)	473,09

Representative temperature (°C)	-36,272
Representative pool diameter (m)	9,4885
Density after mixing with air (kg/m3)	1,4049
Total evaporated mass (kg)	741,71
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	70,71

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	3266,8
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	70,71
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120

Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	3,5
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	1,1719
Purple book representative evaporation duration (s)	480,46
Representative temperature (°C)	-34,03
Representative pool diameter (m)	9,4885
Density after mixing with air (kg/m3)	1,5438
Total evaporated mass (kg)	563,04
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	70,71

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters

No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.25 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 255 kilograms/min
Total Amount Released: 7,650 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 9.4 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 10,800 mg/(cu m)
Indoor: 2,360 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 3.51e+12 ((mg/(cu m))^2.75)-min
Indoor: 5.3e+10 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.55 kilograms/sec
Source Height: 0

Release Duration: 30 minutes
Release Rate: 273 kilograms/min
Total Amount Released: 8,190 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 5.8 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 5,070 mg/(cu m)
Indoor: 1,100 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.45e+11 ((mg/(cu m))^2.75)-min
Indoor: 6.98e+09 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.25 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 255 kilograms/min
Total Amount Released: 7,650 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 10,800 mg/(cu m)
Indoor: 2,360 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 3.51e+12 ((mg/(cu m))^2.75)-min
Indoor: 5.3e+10 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.55 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 273 kilograms/min
Total Amount Released: 8,190 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: greater than 10 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 5,070 mg/(cu m)
Indoor: 1,100 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.45e+11 ((mg/(cu m))^2.75)-min

Indoor: 6.98e+09 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 1,5F.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 340 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.25 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 255 kilograms/min
Total Amount Released: 2,550 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 340 mg/(cu m)
Max Threat Zone for LOC: 1.1 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 1100 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 366 mg/(cu m)
Indoor: 30.7 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 7.79e+07 ((mg/(cu m))^2.75)-min
Indoor: 318,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Vulnerabilty: Toxic dispersionl 4,1D.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 316 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 4.55 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 273 kilograms/min
Total Amount Released: 2,730 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 316 mg/(cu m)
Max Threat Zone for LOC: 750 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 750 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 317 mg/(cu m)
Indoor: 25 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.81e+07 ((mg/(cu m))^2.75)-min
Indoor: 223,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

Failure of the chlorine storage tank T-101. Continuous release from a hole with an effective diameter of 10 mm Alternative (two tanks of 41m^3)

Release.

Case description: Release

Model: Liquefied Gas Bottom Discharge (TPDIS model)
version: 5.06 (12/05/2014)
Reference: Yellow Book (CPR-14E), 3rd edition 1997, Chapter 2 and Modelling source terms for the atmospheric dispersion of hazardous substances, Jaakko Kukkonen

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Type of release	Release through hole in vessel
Pipeline length (m)	
Pipeline diameter (mm)	
Hole diameter (mm)	10
Hole rounding	Sharp edges
Discharge coefficient (-)	0,62
Height difference between pipe entrance and exit (m)	
Height leak above tank bottom (m)	0
Initial temperature in vessel (°C)	15
Vessel volume (m3)	41
Vessel type	Horizontal cylinder
Length cylinder (m)	6,205
Filling degree (%)	90
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
Type of calculation	Calculate until specified time
Time t after start release (s)	120

Results

Initial mass in vessel (kg)	52617
Initial (vapour) pressure in vessel (bar)	5,888
Time needed to empty vessel (s)	30580

Massflowrate at time t (kg/s)	1,8716
Total mass released at time t (kg)	224,34
Pressure in vessel at time t (bar)	5,8851
Temperature in vessel at time t (°C)	14,983
VapourMass fraction at time t (%)	0
Liquid mass in vessel at time t (kg)	52316
Vapour mass in vessel at time t (kg)	79,895
Height of liquid at time t (m)	2,4346
Fillingdegree at time t (%)	89,614
Exit pressure at time t (bar)	6,2237
Exit temperature at time t (°C)	14,983
Maximum mass flow rate (kg/s)	1,8726
Representative release rate (kg/s)	1,8722
Representative outflow duration (s)	120
Representative temperature (°C)	14,995
Representative pressure at exit (bar)	6,2269
Representative vapour mass fraction (%)	0

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Flash determination.**

Case description: Flash determination

Model: Liquefied Gas Instantaneous Release (AMINAL model)
version: 7.02 (12/05/2014)
Reference: AMINAL- Belgium, "Nieuwe richtlijn voor het berekenen van flash en spray" doc.97/001 which is original source of CPR 18E, table 4.8, pg. 4.14

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Vessel volume (m3)	41

Filling degree (%)	90
Initial temperature in vessel (°C)	15
Pressure inside vessel determination	Use vapour pressure
Initial (absolute) pressure in vessel (bar)	5,888
X-coordinate of release (m)	0
Y-coordinate of release (m)	0

Results

Initial mass in vessel (kg)	52617
Adiabatic vapour flash fraction (%)	15,792
Liquid mass fraction in cloud (%)	58,022
Total mass in cloud (kg)	19949
Rainout mass (as liquid) (kg)	32668
Temperature jet/cloud (°C)	-34,03
Temperature of the pool (°C)	-34,03
Radius of the Fire Ball (m)	13,709
Representative density (kg/m3)	8,806

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **<u>Evaporation 4,1D</u>**

Case description: Evaporation 4 D - Cas 2 i 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)

Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	13,95
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,98
Wind speed at 10 m height (m/s)	4,05
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,023681
Purple book representative evaporation duration (s)	380,32
Representative temperature (°C)	-39,899
Representative pool diameter (m)	1,117
Density after mixing with air (kg/m3)	1,2743
Total evaporated mass (kg)	9,0063
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,98

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010

Chemical source date	14/09/2010

- **Evaporation 1,5D**

Case description: Evaporation 1,5 F - Cas 2 i 4 (R=90%)
Model: Pool evaporation
version: 5.16 (12/05/2014)
Reference: Yellow Book CPR14E 2rd Edition - Chapter 5: Evaporation

Parameters

Inputs

Chemical name (DIPPR)	CHLORINE (DIPPR)
Use which representative step	Second 20% average (toxic)
Evaporation from land or water	Land
Type of release	Instantaneous
Mass flow rate of the source (kg/s)	
Duration of the release (s)	
Total mass released (kg)	13,95
Type of pool growth on Land	Spreading in bunds
Type of pool growth on Water	
Temperature of the pool (°C)	-34,03
Maximum pool surface area (m2)	0,98
Wind speed at 10 m height (m/s)	1,46
Solar heat radiation flux (W/m2)	120
Type of subsoil	Heavy concrete
Subsoil roughness description	flat sandy soil, concrete, tiles, plant-yard
Maximum evaluation time for evaporation (s)	600

Results

Heat flux from solar radiation (kW/m2)	0,12
Time pool spreading ends (s)	1
Time until pool has totally evaporated (s)	
Purple book representative evaporation rate (kg/s)	0,017667
Purple book representative evaporation duration (s)	441,67
Representative temperature (°C)	-34,03

Representative pool diameter (m)	1,117
Density after mixing with air (kg/m3)	1,2947
Total evaporated mass (kg)	7,8031
... duration evaporation time (s)	599,5
Corresponding representative pool surface area (m2)	0,98

Other information	
Main program	Effects 8.1.8.6673
Chemical database	DIPPR database
Chemical source	DIPPR Jan2010
Chemical source date	14/09/2010

- **Analysis of consequences: Toxic dispersion 1,5F. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.027 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.62 kilograms/min
Total Amount Released: 48.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 1.1 kilometers

TIME DEPENDENT INFORMATION:

Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 102 mg/(cu m)
Indoor: 22.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 9.67e+06 ((mg/(cu m))^2.75)-min
Indoor: 149,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZI.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 7.85 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.029 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.74 kilograms/min
Total Amount Released: 52.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 7.85 mg/(cu m)
Max Threat Zone for LOC: 411 meters

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 75.4 mg/(cu m)
Indoor: 16.3 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.19e+06 ((mg/(cu m))^2.75)-min
Indoor: 65,700 ((mg/(cu m))^2.75)-min

Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 1,5F. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.027 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.62 kilograms/min
Total Amount Released: 48.6 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 3.0 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 201 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 102 mg/(cu m)
Indoor: 22.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 9.67e+06 ((mg/(cu m))^2.75)-min
Indoor: 149,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **Analysis of consequences: Toxic dispersion 4,1D. ZA.**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 1.40 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.029 kilograms/sec
Source Height: 0
Release Duration: 30 minutes
Release Rate: 1.74 kilograms/min
Total Amount Released: 52.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 1.40 mg/(cu m)
Max Threat Zone for LOC: 1.0 kilometers

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 124 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 75.4 mg/(cu m)
Indoor: 16.3 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 4.19e+06 ((mg/(cu m))^2.75)-min
Indoor: 65,700 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Vulnerabilty: Toxic dispersionl 1,5F.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 320 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)

Wind: 1.46 meters/sec from N at 10 meters
No Inversion Height
Stability Class: F (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.027 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 1.62 kilograms/min
Total Amount Released: 16.2 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 320 mg/(cu m)
Max Threat Zone for LOC: 96 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 96 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 318 mg/(cu m)
Indoor: 25 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 6.83e+07 ((mg/(cu m))^2.75)-min
Indoor: 227,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

- **<u>Vulnerabilty: Toxic dispersionl 4,1D.</u>**

SITE DATA INFORMATION:
Location: TARRAGONA, SPAIN
Building Air Exchanges Per Hour: 0.5 (user specified)
Time: September 17, 2012 1119 hours ST (user specified)

CHEMICAL INFORMATION:
Chemical Name: CHLORINE Molecular Weight: 70.91 kg/kmol
TLV-TWA: 0.5 ppm IDLH: 10 ppm
Footprint Level of Concern: 320 mg/(cu m)
Boiling Point: -34.03° C
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC INFORMATION: (MANUAL INPUT OF DATA)
Wind: 4.05 meters/sec from W at 10 meters
No Inversion Height
Stability Class: D (user override)
Air Temperature: 17.4° C
Relative Humidity: 76% Ground Roughness: urban or forest
Cloud Cover: 5 tenths

SOURCE STRENGTH INFORMATION:
Direct Source: 0.029 kilograms/sec
Source Height: 0
Release Duration: 10 minutes
Release Rate: 1.74 kilograms/min
Total Amount Released: 17.4 kilograms
Note: This chemical may flash boil and/or result in two phase flow.

FOOTPRINT INFORMATION:
Model Run: Heavy Gas
User-specified LOC: 320 mg/(cu m)
Max Threat Zone for LOC: 57 meters
Note: Footprint was not drawn because effects of
near-field patchiness make dispersion predictions
unreliable for short distances.

TIME DEPENDENT INFORMATION:
Concentration/Dose Estimates at the point:
Downwind: 57 meters
Off Centerline: 0 meters
Max Concentration:
Outdoor: 323 mg/(cu m)
Indoor: 24.4 mg/(cu m)
Max Dose:(in the first hour) (Dose exponent: 2.75)
Outdoor: 7.04e+07 ((mg/(cu m))^2.75)-min
Indoor: 213,000 ((mg/(cu m))^2.75)-min
Note: Indoor graphs are shown with a dotted line.

RISK CURVES

```
Riskcurves Report Generator

Version         : 7.6.9.6454

Owner           : Fundacio - RISC/B/31

Directory       : C:\Documents and Settings\Administrador\Escritorio\Cristina Núñez\PFC -
15.05.14\Risk curves

Report created : 16 may 2014  15:33:49


-------------------- PROJECT SETTINGS & FILENAMES --------------------------

Calculate FN-data (Y/N) .............................. YES

Data for day, night or both (D/N/B) .................. BOTH

Skip unchanged scenario definitions (Y/N) ............ NO



Release (scenario) file .............................. PFC.scn
```

```
Population grid day file ............................ malla_dia_Day.pop

Population grid night file .......................... malla_nit_Night.pop

Ignition points file name ...........................

Population concentrations file ......................

Dispersion & wind parameters data file .............. PFC_Purple Book (1999).DPF

Weather & wind probability distribution file ......... actual (1).prb

Environment definition file ......................... PFC.Env

Program parameters file ............................. PFC_Purple Book (1999).SPF

Database file ....................................... PFC_Purple Book (1999).RDB

Onsite population probability of presence............


Include ignitionpoint calculations .................. NO

Include Population concentrations ................... NO

Perform Onsite Societal Risk (OSR) calculations....... NO

Perform Personal Individual Risk (PIR) calculations... NO

Perform injury risk calculations..................... NO

Perform location bounded societal risk (Dutch VROM)... NO

Risk hotspots........................................ NO

Perform FR pair based risk calculations.............. NO




------------------- PROGRAM PARAMETERS -------------------------------------

File : PFC_Purple Book (1999).SPF


Output message level                                    : 350

Population distribution 1/5                             : NO


Default standard pipe roughness                     [m] : 4.5E-05

Default coefficient of contraction for holes        [-] : 0.62

Default coefficient of contraction for pipes        [-] : 0.82

Default evacuation time                             [s] : 1E09

Default exposure duration                           [s] : 1800

Ventilation rate during day time                  [1/s] : 0.00027778
```

```
Ventilation rate during night time                       [1/s] : 0.00027778

Toxic inhalation heigth                                    [m] : 1.5

Fraction CO2 in the atmosphere                         [Vol %] : 0.03

Ambient pressure                                       [N/m^2] : 1.0151E05

Pressure below which turbulent free jet will NOT occur  [N/m2] : 2E05

Response matrix boundary is set to lethal fraction of      [-] : 0.01

Lowest significant frequency                               [-] : 1E-21

Default averaging time  (for toxics)                       [s] : 600

Maximum number of accident locations in transport routes       : 1000

Minimum accident distance in transport routes              [m] : 10

Number of responsegrid calc. per sector FN calc.               : 9

Number of responsegrid calc. per sector FX calc.               : 9

FX transport factor                                            : 0.333

FN transport factor                                            : 0.333

Related lethal fraction for peak overpressure              [-] : 0.025

Lethal fraction for presence in poolfire                   [-] : 1

Lethal fraction for presence in flashfire                  [-] : 1




------------------- ENVIRONMENT PARAMETERS --------------------------

File : PFC.Env


Environment temperature                          : 9 °C

Ground temperature                               : 9 °C

Water temperature                                : 9 °C

Humidity                                         : 83 %

CO2 Fraction                                     : 0.03 %

Ambient pressure                                 : 1.0151E05 Pa

Roughness lenght decription                      : Average subsoil

Solar Radiation Flux                             : 120 kW/m2

Location latitude                                : 51 Deg

Cloud cover                                      : 75 %

Subsoil type                                     : Average subsoil
```

------------------- STABILITY CLASS & WINDSPEED PARAMETERS --------------------------

File : PFC_Purple Book (1999).DPF

Riskcurves dispersion parameter editor

Software library version 7.6.9.6454

	Sigma parameters			
	a	b	c	d
Stab. class				
Very Unstable	0.527	0.865	0.280	0.900
Unstable	0.371	0.866	0.230	0.850
Lightly Unstable	0.209	0.897	0.220	0.800
Neutral	0.128	0.905	0.200	0.760
Stable	0.098	0.902	0.150	0.730
Very Stable	0.065	0.902	0.120	0.670

------------------- GENERAL POPULATION GRID INFORMATION --------------------------

DAY population file : malla_dia_Day.pop

Population grid info

File version	: 210
Read only	: FALSE
Type (True=Day, False=Night)	: TRUE
Ventilation rate [1/s]	: 0.000E+0000
Grid cell width [m]	: 142
Nr of rows	: 103
Nr of columns	: 199
Angle with pos. X-axis [degrees]	: 0.00
X coordinate left upper corner	: 316649.0
Y coordinate left upper corner	: 4550033.0

Percentage of people inside houses [%] : 93.00

Maximum Nr. of people in one grid cell : 95.00

NIGHT population file : malla_nit_Night.pop

Population grid info

File version : 210

Read only : FALSE

Type (True=Day, False=Night) : FALSE

Ventilation rate [1/s] : 0.000E+0000

Grid cell width [m] : 142

Nr of rows : 103

Nr of columns : 199

Angle with pos. X-axis [degrees] : 0.00

X coordinate left upper corner : 316649.0

Y coordinate left upper corner : 4550033.0

Percentage of people inside houses [%] : 99.00

Maximum Nr. of people in one grid cell : 95.00

------ STABILITY CLASS & WIND DIRECTION PROBABILITY DISTRIBUTION ---------

File : actual (1).prb

	Probability [%]		Probability of wind to sector [%]												
Stability class	Day	Night	1	2	3(W)	4	5	6(N)	7	8	9(E)	10	11	12(S)	Total [%]
A3	0.0	0.0	13.7	5.1	9.9	11.6	10.4	1.9	2.1	1.9	1.3	0.2	17.6	24.3	100.0
B1.5	0.0	0.0	10.6	4.7	4.4	4.6	5.5	2.2	2.6	3.0	3.3	18.9	21.4	18.7	100.0
C6	0.0	0.0	8.2	5.5	5.1	3.6	1.0	2.0	0.2	17.8	16.8	15.3	13.4	11.0	100.0
D4	51.8	10.1	6.4	10.7	15.4	15.7	11.5	6.2	4.5	4.9	7.5	5.7	5.6	5.8	100.0

```
E5                    0.0     0.0      5.3  11.2  18.1  16.5   6.6  10.2   7.1   6.1   7.1
3.8   3.8   4.3   100.0

F2                    3.6    34.5      6.5   3.6   4.3   8.1  14.8  19.1  14.8   9.9   4.4
1.6   5.6   7.3   100.0

                      ----------- +

                     55.4    44.6

                      ----------- +

                         100.0  Both day and night cumulated
```

NOTE: Explanation of the meaning of "Probability of wind to sector"

Sector 3 means wind blowing in the direction of 3 'o clock (West wind)

Sector 6 means wind blowing in the direction of 6 'o clock (North wind)

Sector 9 means wind blowing in the direction of 9 'o clock (East wind)

Sector 12 means wind blowing in the direction of 12 'o clock (South wind)

Etc.

------------------- TOXICITY PARAMETERS --------------------------

Database File : PFC_Purple Book (1999).RDB

Materials used:

UN number   Material

Probit parameters used:

-------------- CHEMICAL DATABASE PROPERTIES OF ALL CHEMICALS INVOLED IN THIS PROJECT ------------------

-------------- OLD STYLE RISKCURVES 4.X/5.X/6.X SCENARIOS (BACKWARD COMPATIBILITY ONLY) ------------------

Scenario 1: "AG2.CL.1.G1 Failure of the chlorine storage tank T-101. Instantaneous release of the complet" (Tank T-101)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 2: "AG2.CL.1.G2 Failure of the chlorine storage tank T-101. Continuous release of the complete i" (Tank T-101)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 3: "AG2.CL.1.G3 Failure of the chlorine storage tank T-101. Continuous release from a hole with " (Tank T-101)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 4: "AG2.CL.1.E1 Overfilled of the chlorine storage tank T-101." (Tank T-101)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 5: "AG2.CL.2.G1 Full bore rupture of the pipe of chlorine 3”-CS-Cl2-1." (Pipeline 1)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 6: "AG2.CL.2.G2 Leak of the pipe of chlorine 3”-CS-Cl2-1 with an effective diameter of 10% of th" (Pipeline 1)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 7: "AG2.CL.3.G1 Full bore rupture of the pipe of chlorine 3"-CS-Cl2-5/30." (Pipeline 5/32)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 8: "AG2.CL.3.G2 Leak of the pipe of chlorine 3"-CS-Cl2-5/30 with an effective diameter of 10% of" (Pipeline 5/32)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 9: "AG2.CL.4.G1 Catastrophic failure with full bore rupture of the largest connecting pipeline o" (Pump P-101A/B)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 10: "AG2.CL.4.G2 Leak with an effective diameter of 10% of the nominal diameter of the largest co" (Pump P-101A/B)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 11: "AG2.CL.6.G1 Instantaneous release of the complet inventory of the road tanker TK" (Road tanker)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 12: "AG2.CL.6.G2 Continuous release from a hole the size of the largest connection of the road ta" (Road tanker)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 13: "AG2.CL.6.L1a Full fore rupture of the loading hose of the road tanker TK-101." (Road tanker)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 14: "AG2.CL.6.L2a Leak of the loading hose of the road tanker TK-101 with an effective diameter of" (Road tanker)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 15: "AG2.CL.7.G1 Full bore rupture of the pipe of chlorine 3”-CS-Cl2-32." (Pipeline 32)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Scenario 16: "AG2.CL.7.G2 Leak of the pipe of chlorine 3-CS-Cl2-32 with an effective diameter of 10% of th" (Pipeline 32)

This scenario is modelled with (an) external interface file(s)

Please use the scenario definition printout for details.

Different models used in this project:

Different model executables (.exe) used in this project:

Different scenarios used in this project:

------ TRANSPORT FILENAMES ---

TRANSPORT SUMMARY

TRANSPORT DETAILS

---------------------- End of summary report ----------------------------