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QUANTITATIVE RISKS ANALYSIS OF MARITIME TERMINAL PETROCHEMICAL

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Abstract. *This work consists of the application of a computer program (RISKAN) developed for studies of quantification of industrial risks and also a revision of the models used in the program. As part the evaluation made, a test was performed with the application of the computer program to estimate the risks for a marine terminal for storage of petrochemical products, in the city of Rio Grande, Brazil. Thus, as part of the work, it was performed a Quantitative Risk Analysis associated to the terminal, both for the workers and for the population nearby, with a verification of acceptability using the tolerability limits established by the State Licensing Agency (FEPAM-RS). In the risk analysis methodology used internationally, the most used way of presenting results of social risks is in the graphical form with the use of the FN curves and for the individual risk it is common the use of the iso-risk curves traced on the map of the area where is the plant. In the beginning of the study, both a historical analysis of accidents and use of the technique of Preliminary Analysis of Risks were made in order to aid in the process of identification of the possible scenarios of accidents related to the activities in the terminal. After identifying the initiating events, their frequencies or probabilities of occurrence were estimated and followed by the calculations of the physical effects and deaths, with the use, inside the computer program, of published models of Prins Mauritz Laboratory and of American Institute of Chemical Engineers. The average social risk obtained for the external populations was of* $8.7x10^{-7}$ *fatality.year*$^{-1}$ *and for the internal population (people working inside the terminal),* $3.2x10^{-4}$ *fatality.year*$^{-1}$*. The accident scenario that most contributed to the social risk was death due to exposure to the thermal radiation caused by pool fire, with 84.3% of the total estimated for external populations and 82.9% for the people inside the terminal. The curve FN resulting from the program showed that the social risks that the terminal represents for the neighborhoods are acceptable, according to the criteria established by FEPAM. The individual risk curves, crossing areas where the population lives are less than* 10^{-6}*.year*$^{-1}$ *and for the companies installed in the proximities,* 10^{-4}*.year*$^{-1}$*, both considered acceptables.*

Keywords*: Quantitative analysis risks, historical analysis, identification of accidents, frequency analysis of accidents*

1. INTRODUCTION

Until the beginning of the decade of 70, the related subjects the safety of operations of having accomplished in chemical industries and petrochemical was just, an internal problem to the companies, not having some type of governments' interference or of populations. With the time, industrial accidents began to happen and with that, the increase of the dissatisfaction of the population and of authorities. Indeed, techniques that previously were used in the warlike industries, aeronautics and nuclear they began her they are implanted and adapted for studies of analysis of risks related to chemical industries and petrochemical. Among these techniques implemented in this section this Quantitative Analysis of Risks. The analysis of risks possesses a wide group of methods and techniques that look for the improvement of work conditions, of the public in general and of the environment. Among them, it is the Quantitative Analysis of Risks. A methodology developed to act as a tool, in the administration aid and evaluation of the safety of the industrial chemical processes, according to AIChE (2000).

The objective principal of this work is to accomplish an application of a program computational (RISKAN) destined for quantitative evaluation of industrial risks, through a study of the employed models in the same and of a concrete practical application, where a quantification of the risks associated to a terminal marine located petrochemical was accomplished in the city of Rio Grande, in Brazil, for the populations that live in your outskirts, employees of neighbouring companies and for to the workers of the own terminal. The methodology used in the study and in the program it is the same used internationally, based on the methods of calculation of social and individual risk of the work proposed by Haag and Ale (1999), known like Purple Book. The calculation of the social risks will be presented in the graph form, through curves FN (Function Cumulative Distribution) and a medium social risk, already for individual risks, they will also be expressed graphically, in iso-risk that present the same risk value.

2. METODOLOGIA

The risk is a measure of the economical damages, deaths or damages to people, so much in terms of probability as of magnitude, result of the combination of the hypothetical scenery of the accident, of the estimate of your frequency or probability of occurrence of the accident and of your consequences. For the cases that will be studied in this work they will be appraised the social and individual defined for:

Social Risk - it is the expected number of fatalities, in a period of one year, that are caused by accidents with origin in the installation, with your unit usually expressed in deaths a year. It can be defined as the sum of a combination of the product of the frequency of occurrence of the scenery by your consequence, as display the equation (1).

$$R_S = \sum_{i=1}^{n} f_i \cdot C_i \qquad (1)$$

Where is the social risk in the unit of fatalities per year, it is the accident scenery, it is the frequency of the scenery, given in accident a year, it is the consequence of the scenery given in number of deaths a year and it is the number of identified sceneries.

Individual Risk - it is the probability or expected annual frequency of death due to accidents with origin in an installation for a located individual in a certain point of the proximities. It can be defined as the reason of the social risk by the exposed population, as display the equation (2).

$$R_I = \frac{\sum_{i=1}^{n} f_i \cdot C_i}{N} \qquad (2)$$

Where is the individual risk given in the unit of year-1 and, the number of people potentially exposed to the risks.

In a quantitative analysis of risks it is done in two stages. In the first stage, the accomplishment of a qualitative analysis of risks is had where is done a study of the installation with the identification of the possible events initiators of accidents, in other words, those that tend to happen for the loss of product contention with liberation of dangerous material in the atmosphere through a historical analysis of accident and for a preliminary analysis of risks. In the second quantitative stage, in the which the risks are dear through packages software for the multiplication done between the frequency and consequence by an analysis of having done for a methodology denominated Events Tree (EA) and vulnerability analysis, respectively. This is dependent of the estimates of discharge rates for the atmosphere, the dispersion of the material for influence of the wind in the area being considered conditions medium atmospheric appraised statistically, the evaluation of the frequencies of the events initiators of accidents and of the respective expressed consequences in number of deaths, as well as the combination of these results for the calculation of the social and individual risk.

The consequences are determined form models described to estimate the effects damage by release of dangerous substances as: the thermal flow originating from of a torch, pool fire and fire ball, overpressure peak generated by the explosion of a vapour cloud and concentrations of clouds of gas in an atmospheric dispersion, built as functions of the distance in relation to the liberation source. Based on the results of physical effects proposed by Roos (1989), in the work known as Green Book that proposes the estimate of your consequences through measured of probability calculated by the model of vulnerabilities of Eisenberg, which makes use of the equations of *Probit*. With the application of this model it allows to be determined, for instance, the chance that a person has to die in the proximities or inside of an industrial installation due to an explosion of a cloud of gas, the exhibition of a toxicant cloud and thermal radiation. In other words, dictates of other form, the delimitation and the extension of the possible damages they are certain for the intensity of the effect damage, and the relationship between this intensity and the corresponding damage is established being made use of the model of vulnerabilities of Eisenberg.

The equations of *Probit* are represented by a relationship (look the equation (3)) between the intensity of the effect damage and the variable of *Probit* (*Probability Unit*), which is directly, linked the probability of observing the damage. They were developed starting from experiments and of data of accidents already happened along the history.

$$Y = k_1 + k_2 \cdot \ln V \qquad (3)$$

Where the intensity of the effect caused damage it is V, and k_1 e k_2 are constant empiric and it is the variable of *Probit*. The probability of occurrence of the damage is obtained implementing the variable of *Probit* in the equation (4)

$$\Pr ob = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y-5} \exp(-\frac{u^2}{2}) du \qquad (4)$$

The modelling of the physical effects as exhibition to the thermal radiation, pressure peak in the shock wave and dispersion of inflammable and toxicant cloud.

The estimate of the frequency of the sceneries of accidents is accomplished the work accordingly presented by Schüller, J. C. H. (1997), in the work known as *Red Book*. Based on the elaboration of a Tree of Events (AE), a graphic model that allows to identify and to quantify the possible results ends of an event initiator, based on a systematic one that it describes the propagation of the event along the time, in other words, it shows in sequence the stages one of event initiator of an accident to arrive to the scenery, like this, to break frequency of the event initiator of the accident it goes being multiplied by your unfolding probabilities. In Fig.1, a tree of events is had built with RISKAN.

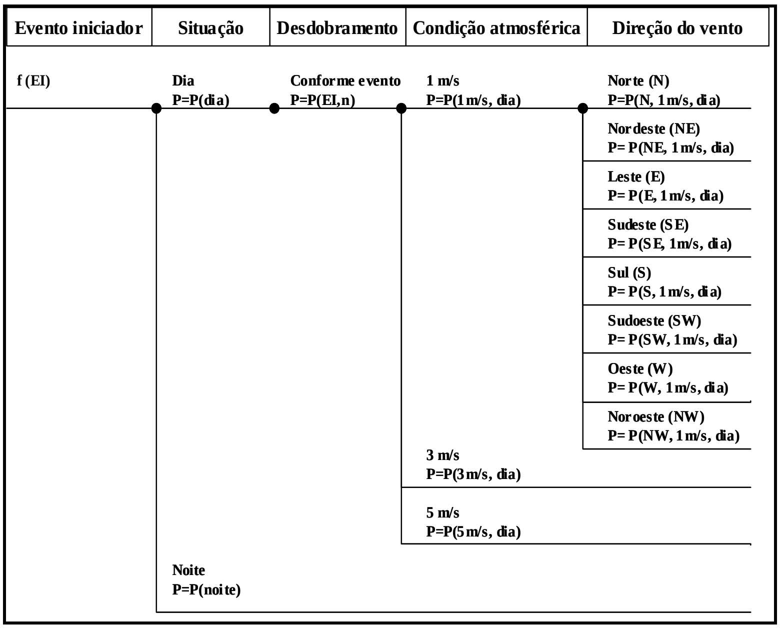

Figure 1. Tree of Events used in the software RISKAN

2.1 Execution of the calculation risk

The estimate of the risk accomplished by the program it begins starting from the definition and construction of a grating or calculation mesh that it is traced on the area of interest, in the case, the map or lay-out of the installation. Each element of the mesh is called cell and the individual risk is certain for each one of points, separately. In other words, dictates in another way, they are had a group of cells drawn on the map, where in each cell, the calculation of the probability is made of happening the individual's death when this be positioned in the central point of the cell. The iso-risk curves would be the contour lines drawn that they present results of death probability, in common, in the central points of the cells. The individual risk for each element of the mesh is calculated by the multiplication of the frequency of the accident scenery (done with the use of a Tree of Events) with the death probability. This last one calculates starting from the evaluation of the vulnerability.

In the calculation of the social risk, first, it is made the selection of the cells in the map in the area that correspond the population. Soon after, the program divides the number of people distributing them for each cell of the selected area and, the calculation of the fraction of deaths of the population is accomplished with the use of the technique of vulnerability analysis being multiplied this value by the number of people present in the cell, as outline can be shown. in the Fig. 2.

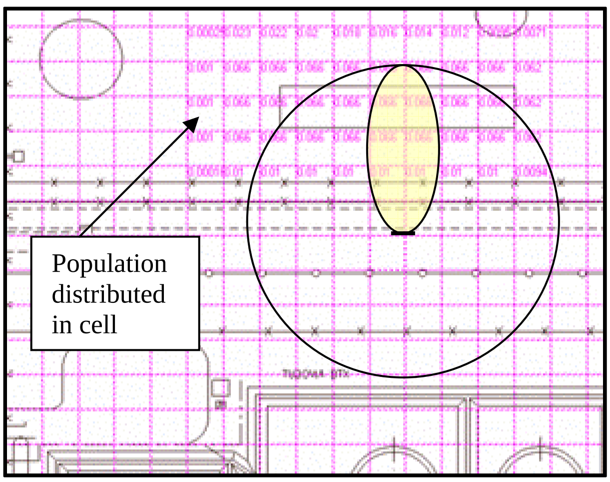

Figure 2. Outline of execution of the calculation social risk

The result, then, fatality/year is supplied. Later, for the construction of the curves FN, are made the calculations of the frequencies of all the sceneries of accidents and the determination of the number of dead caused by the same ones, being generated a list with the number of fatalities with your respective occurrence frequencies. They are organized the data for they be worked in the form of accumulated frequency, making possible the construction of the curve FN, following the model presented in the equation (5).

$$F_N = \sum f_i \text{ , with } N_i \geq N \quad (5)$$

Where f_i it is frequency of occurrence of the scenery i (with unit year-1), N_i it is the number of fatalities caused by the scenery i, F_N it is the frequency accumulated of occurrence of all the sceneries i that it cause N or more deaths.

3. DESCRIPTION OF THE FACILITIES AND OF THE METEOROLOGY

The terminal locates in the city of Rio Grande, in Brazil, to the edge of the Ponta da Mangueira, close to the sea and it has capacity to receive, to store and to send chemical products and petrochemical. The terminal is divided in 3 (three) areas and a pier, the area A100 is a terminal of gases where it have been installing pressure vases that store butylene, the area A300, that presents a park of storage of liquids, like benzene, toluene and MTBE (Methyl-terc-butyl-ether) and, the area A00, of storage of MTBE. In Fig. 3, it is had suitable the area of the terminal studied in red, with the placed letter her on the area A300, the letter B on the area A100 and the letter C on the area A00. In the surroundings of the installation they are the terminals of a state subsidiary company, shown in the blue area in Fig 3 and, a terminal of storage of ammonia, shown with the green color.

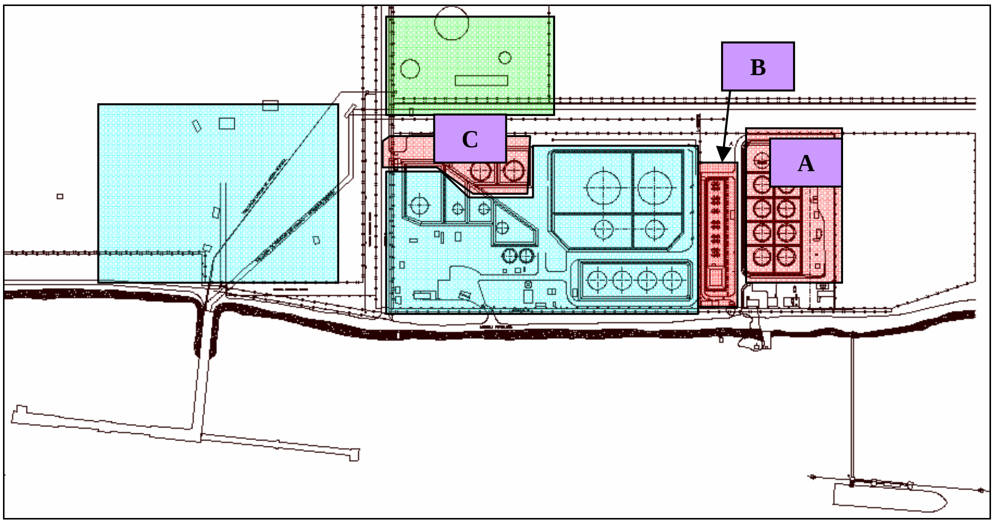

Figure 3. Lay-out of the facilities with the identification of the area of neighbouring companies

In the area A100 it have been installing 16 (sixteen) vases with capacity of 150 m^3, 2 vases with 130 m^3, 2 vases with 60 m^3, 2 vases with 45 m^3, with 3 relief valves gauged for opening when verified a pressure of 17 $kgf.cm^{-2}$ each one, storing the gases in the liquefied form. The area A300 is endowed with 9 (nine) tanks, where 8 (eight) they possess capacity of 4208 m^3 and 1 (one) of residues. The products are sent for the ships with the bombs of the own terminal, while the greeting of the products is made with the centrifugal bombs of the ship. The gases are transported it a leak of 160 $m^3.h^{-1}$ and the liquids to 220 $m^3.h^{-1}$. In the terminal it also accomplishes provisioning for road-tank, that it can be correspondents to the same ones until a leak of 60 $m^3.h^{-1}$ (gases) and 90 $m^3.h^{-1}$ (liquids).

3.1 Population data

For the calculation of the risks are necessary the inclusion of the population data in the software. The estimative are made for it can to know which are the exhibition probabilities to the dangers that the terminal represents for external populations, that for the case of work, the inhabitants of the village Ponta da Mangueira were considered and of the neighboring companies. Initially, it is drawn the polygons on the map of the installation inserted in the program and soon after this task, it opens up a window of the program where they are typed the number of inhabitants with the percentile of sheltered persons, during the night and the day. In Tab. 1. have the presentation of the number of inhabitants of the proximities of the installation is had, where the informed area is shown in Fig. 4 that shows the population areas that were drawn in the program RISKAN.

Table 1. Residents around terminal inserted into RISKAN

Region	Number total of persons		Percentage of sheltered persons (%)	
	Day	Night	Day	Night
1	25	4	84,3	100
2	11	1	27,3	0
3	1	0	0	0
4	9	6	0	0
5	1	0	100	0
6	20	3	90	90
7	400	600	20	99

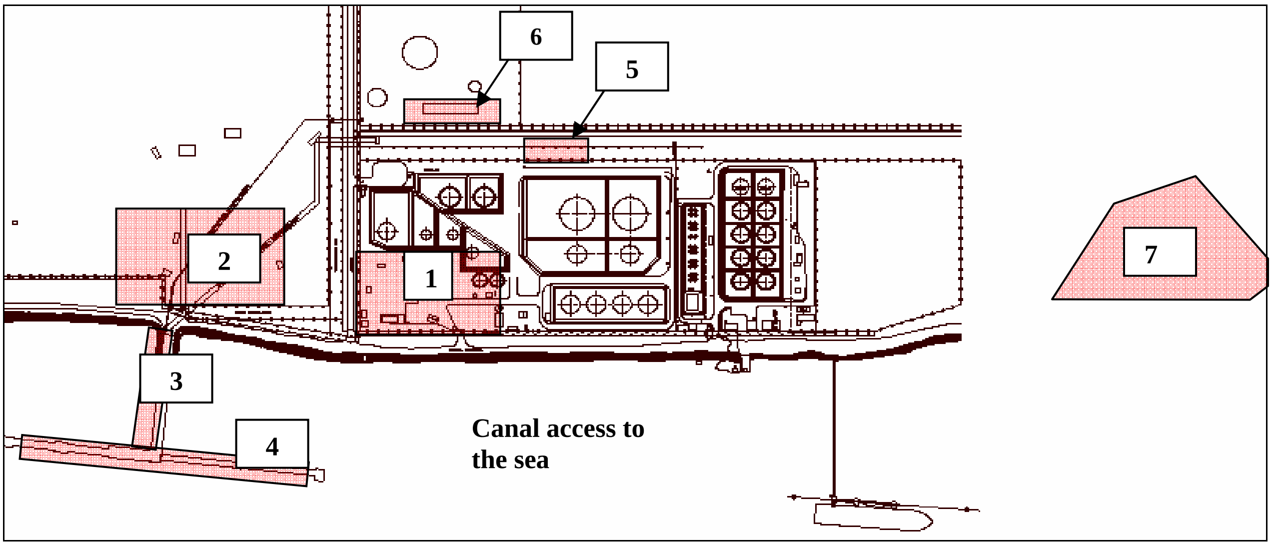

Figure 4. Lay-out of the facilities with the location of the population areas

4. METEOROLOGICAL DATE

The mathematical models that they are included in the software for the evaluation of physical effects, mainly the behavior of liberation of a dangerous gas, they depend on the meteorological conditions and of the predominant atmospheric stability where it is discharge sources that for this work it is the area that locates the marine terminal.

The atmospheric stability is represented by the parameterization of the atmospheric turbulence, generated by the vertical gradient of temperature of the atmosphere and, for the mechanical turbulence caused by the presence of the soil and of obstacles to the drainage of the air. As the shift has alteration of this gradient, during the day, for instance, the originating from thermal radiation the sun heats up the close air the surface reducing your density, resulting in the movement for buoyancy among the masses of present air in the surface and with the one that it is in the atmosphere in a smaller temperature and larger density, already at night, the soil catches a cold acquiring a similar temperature the one of the atmosphere and with that, it has a calm situation, because the vertical gradient of temperature becomes small, not having great modification of the densities among the masses of air and, therefore, not happening the movement among the same ones.

In agreement with AIChE (2000), when the obtaining of data of atmospheric stability to the place is not estimable, as a good gauging of the turbulence, it is common the use of the Classes of Atmospheric Stability of Pasquill-Gifford, proposed by Gifforf, F. A. (1976), that are based on the measures of speed of the wind, heatstroke level and degree of covering of the clouds. However, as the supplied data of the meteorological station don't consist information on heatstroke levels and covering of the place, for this work, the atmospheric stability was only qualified using as criterion the speed of the wind, using collected data of the meteorological station of INMET - National Institute of Meteorology, 8° District of Meteorology - Disme, Section of Observation and Applied Meteorology.

To be considered in the study the meteorological influence, RISKAN offers a resource that through a window of the program, in that it can introduce, manually, the percentile of influence of the direction of the wind for a strip of speed to the user's criterion. In Tab. 2 and in Tab. 3 are had the presentation of the statistical analysis with the percentile of direction of the wind in each strip of speed used in the study.

Table 2. Distribution of the speed of the wind with relationship to the cardinal point at night

Direction	Speed ($m.s^{-1}$)				
	0 a 2 $m.s^{-1}$	2 a 4 $m.s^{-1}$	4 a 6 $m.s^{-1}$	> 6 $m.s^{-1}$	Total (%)
NE	2,8	7,6	7,3	3,3	20,9
E	2,7	5,2	5,5	3,8	17,2
SE	0,9	3,9	2,9	1,3	9,1
S	1,7	4,7	2,4	1,2	10,0
SW	3,2	7,1	4,6	2,6	17,5
W	4,9	3,5	2,2	1,4	12,0
NW	1,2	2,5	1,2	0,5	5,4
N	1,5	4,7	1,4	0,3	8,0
Total (%)	18,8	39,2	27,5	14,5	100

Table 3. Distribution of the speed of the wind with relationship to the cardinal point at day

Direction	Speed ($m.s^{-1}$)				
	0 a 2 $m.s^{-1}$	2 a 4 $m.s^{-1}$	4 a 6 $m.s^{-1}$	> 6 $m.s^{-1}$	Total (%)
NE	0,9	5,3	7,0	4,8	18,0
E	0,8	3,8	9,0	8,7	22,3
SE	0,5	4,0	6,9	3,8	15,2
S	0,4	2,1	4,9	3,8	11,2
SW	1,3	3,3	3,6	6,4	14,7
W	2,1	2,9	1,8	0,5	7,4
NW	1,0	2,0	0,6	0,2	3,8
N	1,1	4,0	2,0	0,4	7,5
Total (%)	8,1	27,6	35,8	28,6	100

5. A PRELIMINARY ANALYSIS RISKS (PRA)

For the study of quantification of risks is necessary that is accomplished a rising of possible accidents that you/they can happen in a certain installation. For that, together with the workers of the terminal, it was made a Preliminary Analysis Risks. It is a qualitative methodology of identification and classification of sceneries and events initiators of accidents in frequency categories, severity and risk, that they are established for an environmental organ, in the case of this work the categories were used stipulated by FEPAM, environmental organ of the state of Rio Grande do Sul.

In the identification, they were identified sceneries of accidents to be related to the loss of product contention. This argument is based on a historical research accomplished with the database MHIDAS (2005), where it was verified through a statistical analysis of the data supplied by the same, that most of the accidents in port areas has origin in the transport and in the transfer of products. In the execution of PRA, they were identified 220 sceneries of the which just those with having characterized in the category of marginal severity, critic and catastrophic they had your simulate physical effects with the program RISKAN. Among the simulate sceneries they are pool fire, fire jet, BLEVE (Boiling Liquid Expanding Vapor) followed fireball, flash fire, and explosion of cloud of gas.

6. EVALUATION OF THE FREQUENCY

In the evaluation of the areas of the terminal petrochemical, they were identified the possible events initiators that would be capable to generate sceneries of accidents with potential of causing located victims in the external zones to the enterprise. The principal events are related with ruptures or leaks associated to equipments (tubes, valves, flanges, bombs, etc.). In RISKAN, soon after the simulation of the physical effect, the program to be set up generates an event initiator where the user clicks on the same and he opens a small window in the which should be typed your flaw rate and, later, when it is already had all the mounted sceneries that can be unfolded for this event, it is clicked on the same place where the rate of flaw of the event was introduced and it interferes the unfolding probabilities.

The leak frequencies adopted for the different sizes of available area for liberation of dangerous material for these equipments they were collected of data of the works Cox and Lees (1990), and Haag and Ale (1999).

For each event initiator two possibilities were considered:

- Medium leak: leak in an equivalent hole to 10% of the area of the traverse section of the line;
- Failure catastrophic: total rupture of the line, in other words, discharge hole is same to the traverse section of the tube.

7. ANALYSIS OF VULNERABILITY

In the plan of the vulnerable areas of the physical effects, the use of the program RISKAN allows to visualize the areas where the flow of thermal radiation caused by the immediate ignition of the product it would correspond at the levels that could cart in 1%, 50% and 99% of death probability, for the sceneries of fire ball, fire in puddle and torch, the probability of death of 100% for located people in the area in that would be formed the cloud of gas with concentration same to the inferior limit of inflammability of the product in the fire sceneries in cloud (flash fire). Already the sceneries of explosion of vapor cloud, the areas where the overpressure of the shock wave that can offer a probability of 1%, 50% and 99% of death for an observer in the place.

As example, in Fig. 5 are had the presentation of a vulnerable area to the thermal radiation due to an occurrence of a BLEVE in an of the buteno-1 vases installed in the terminal, where the ray of the red circle is of 452 m, the yellow is of 299 m and the blue is of 176 m.

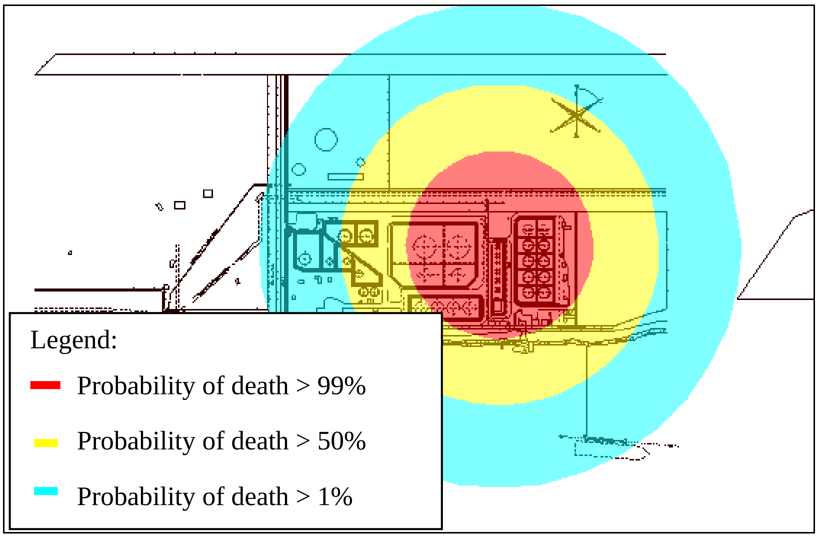

Figure 5. Area vulnerable the thermal radiation caused by fireball due to a BLEVE

8. EVALUATION OF THE RISKS

The curves FN were certain with the program RISKAN starting from the events initiators (loss of contention of dangerous material) and your possible unfolding in terms of direction of winds, at day or night, type of results of sceneries (as: fire, explosion, toxicant cloud, etc.), as display Fig. 6 where the legend presents the tolerability limits for the social risks stipulated by the environmental organ. If the curve FN be traced in the area below the straight line of blue color this risk it is considered acceptable and, if the same stays above the straight line of green color the social risks they are intolerable.

The zone among the two straight line is the area of denominated transition of area ALARA (*As Low As Reasonably Achievable*), it means that the risks should be reduced whenever the cost of the necessary measures for your reduction is reasonable when compared with the benefits obtained in terms of reduction of the risks.

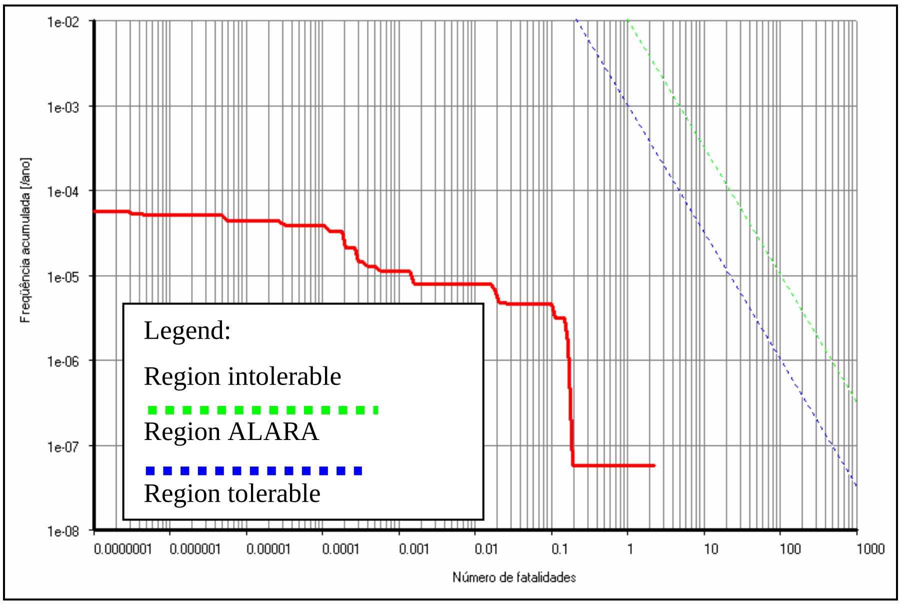

Figure 6. Curves built with RISKAN for the external populations to the marine terminal from Rio Grande

The iso-risk curves built with the program RISKAN for the external and internal populations to the installation of the marine terminal, used as case study, referring the simulations of sceneries of accidents accomplished in the area A00 (storage of MTBE), A100 (buteno-1 storage) and in the area A300 are presented in the Illustration 6-11 where the red curves, it yellows, blue and green represents the individual risk of 10^{-4}.year^{-1}, 10^{-5}. year^{-1}, 10^{-6}. year^{-1} and 10^{-8}. year^{-1}, respectively. It is important to remind that the individual risk was calculated for each one of the sceneries of accidents of EA (Events Tree) of each event initiator.

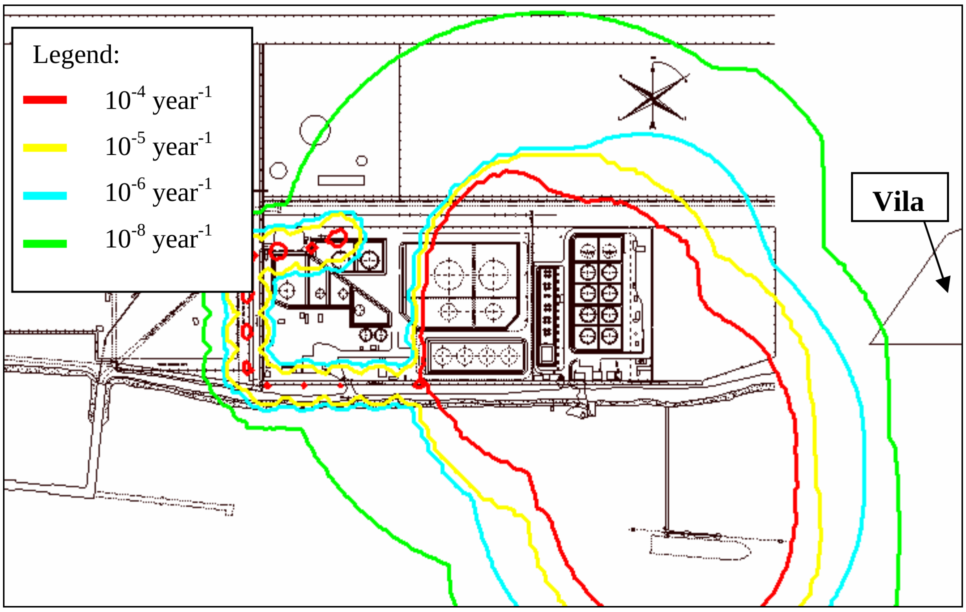

Figure 7. Curves iso–risk built for terminal with the use of program RISKAN

A part of the curve of level of 10^{-4} year^{-1} comes had been of the area of the studied terminal, however, this is not traced at the place where the employees of the neighboring company are installed., just in areas where it is had the presence of tanks, tubes and pavements of the internal roads of the company. The limit of tolerability of individual risk adopted by FEPAM for members of neighboring companies it is of up to 10-4.ano-1, being inside the individual risk of the criteria stipulated by the environmental organ.

9. CONCLUSIONS

This work had as main objective the application of program computational (RISKAN) and a revision of the models contained in the same, developed for the elaboration of works of quantitative analysis of industrial risks, being used in the test, as a case study, a marine terminal of storage of products petrochemical, located in the municipal district of Big Rio, located in Brazil. Using a methodology internationally recognized, they were dear with the tested program the social and individual risks that the terminal represents for the populations external and internal of the installation, and also as part of the work, the verification of the results with relationship your acceptability with the tolerability criteria adopted by the State Foundation Henrique Luís Roesler - FEPAM-RS.

For the simulations of the sceneries of accidents accomplished with the use of the program RISKAN, it can be ended that it is of easy application, it allows the construction of curves FN for social risks and iso-risk for individual risks, typical results of quantitative analyses of risks that are only obtained by foreign programs. It allows to the user to simulate discharges of reservoirs of gas, liquid and gaseous phase of liquefied gases and of atmospheric tanks, could be chosen the discharge it is reasonable a vertical or horizontal cylindrical tank and, spherical. He/she/you offers the possibility to simulate three types of relative sceneries involving thermal radiation as BLEVE followed by fire ball, torch and fire in puddle, three methods for the calculation of explosion effects as the Multi-energy, equivalent TNT and Shockwave. It executes simulations for neutral gases, with the use of the models Gaussian and for dense, with the code SLAB, for several speeds of the wind and atmospheric stability. Besides, it allows that they are simulate evaporations of puddles cryogenic and not cryogenic, being able to the user to adapt her as confined or not and the substratum type.

It can be ended that RISKAN with relationship to the calculation of the risks is quite adaptable, because it allows to the user to specify in the calculation mesh traced on the map, the size of the cell used for the calculations of the social and individual risks, being able to like this, offering the choice possibility in the precision of the results and in the time of execution of the calculations.

10. ACKNOWLEDGEMENTS

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