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Comparison Of Brazilian Risk Assessment Guidelines With International Risk Assessment Approaches

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Abstract

In Brazil, as well as in some European countries, risk assessment is applied as a feasibility and decision-making tool for the permit of hazardous developments. Therefore, to assess whether different approaches lead to very divergent results, the Quantitative Risk Assessment (QRA) methods used in Brazil (state of São Paulo), the United Kingdom, France, Belgium (Walloon region) and the Netherlands will be compared. When evaluating the methodologies adopted by European countries, the report from the National Institute for Public Health and the Environment (Gooijer et al, 2012) will be used, which contains a summary of the four approaches and the different results of the calculations (safety distances obtained) for the same fictitious LPG plant. In order to compare the results obtained in Europe and Brazil, the same LPG plant will be analyzed based on the guidelines defined by the environmental agency of the state of São Paulo, P.4261 - Risk of accident of technological origin - Method for decision making and reference terms (P4.261/11 2ª ed.).

Keywords: risk assessment, LPG plant, Brazilian guidelines

1. Introduction

Brazilian risk approaches have been developed based on international references, especially British and Dutch publications (Green Book, Yellow book, and Purple Book/BEVI manual). The most complete Brazilian risk approach has been developed by the state of São Paulo (CETESB P4.261/11 Standard, 2nd edition). It was approved on April 2014 and is available at the following address: https://cetesb.sp.gov.br/wp-content/uploads/2013/11/P4261-revisada.pdf. P4.261/11 has been adopted as a reference by most of the state environmental agencies in Brazil and by the federal environmental agency IBAMA – Brazilian Institute for the Environment and Renewable Natural Resources.

A comparison of the quantitative risk assessment (QRA) methods for land use planning and licensing used in France, the United Kingdom, The Netherlands and the Walloon Region of Belgium, a benchmark exercise have been performed by Gooijer et al, 2012. The authors based their evaluation on a fictitious LPG storage plant. Each of the representatives of these countries used their own quantitative risk assessment approach to perform the exercise. An overview of these methodologies has been presented by Gooijer et al, 2012, therefore they will not be described in this work.

In this paper, we present an extension of the study performed by Gooijer et al, 2012 in order to evaluate P4.261/11 risk assessment methodology and criteria regarding to industrial plants. The premises and criteria for risk assessment of industrial plants are established in part II of standard P4.261/11.

2. LPG fictitious plant

The fictitious LPG plant is illustrated in Figure 1. It consists of an unloading area, three storage vessels and a loading station. It is supposed that all the equipment is located at exactly the same location (Gooijer et al, 2012).

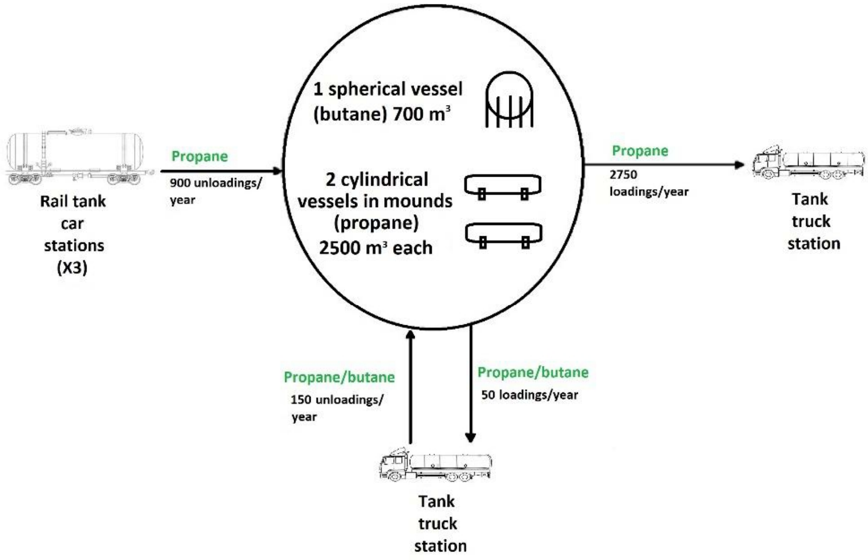

Fig. 1. Illustration of fictitious LPG plant (Gooijer et al, 2012).

The LPG depot that is studied is based on:

- 2 cylindrical propane vessels in mounds with a capacity of 2500m^3 per vessel[1];
- 1 spherical butane vessel with a capacity of 700m^3;
- rail tanker unloading stations;
- 2 road tanker stations: 1 loading station with one arm for propane and 1 loading/unloading station for both propane and butane with two arms;
- A piping system equipped with pumps and a compressor.

Based on the process description by Gooijer et al, 2012 we have drawn a process flowchart, as shown in Figure 2.

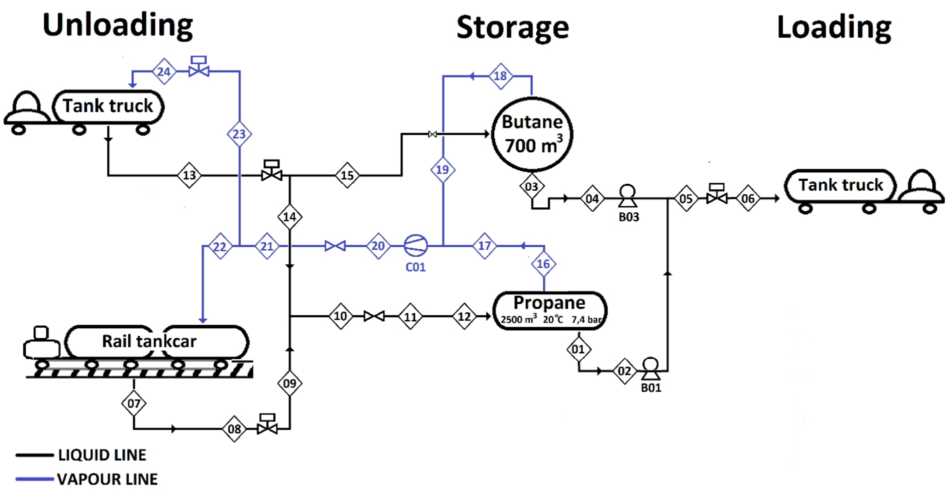

Fig. 2. Process flowchart based on the description by Gooijer et al, 2011.

[1] In this study, the vessels have been considered aboveground, since it is not common in Brazil to design mounded vessels.

3. Population

A fictitious population has been defined in the surroundings of the facility, which is illustrated in Figure 2. A blue dot can also be seen where the plant would be located.

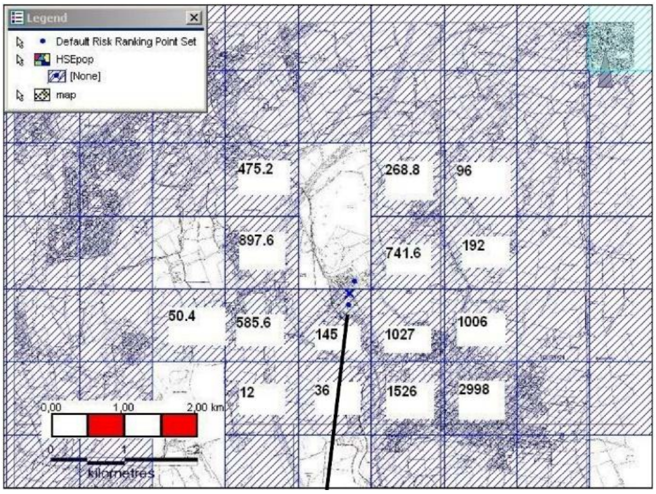

Fig. 3. Illustration of fictitious population (Gooijer et al, 2011).

4. Hazards identification

Based on the structured hazard identification methodology, scenarios capable of giving rise to accidents have been identified and their consequences have been assessed. Large and small leaks scenarios have been considered for the fictitious LPG plant. Theses scenarios have been described in Table 1 and represented in Figure 4.

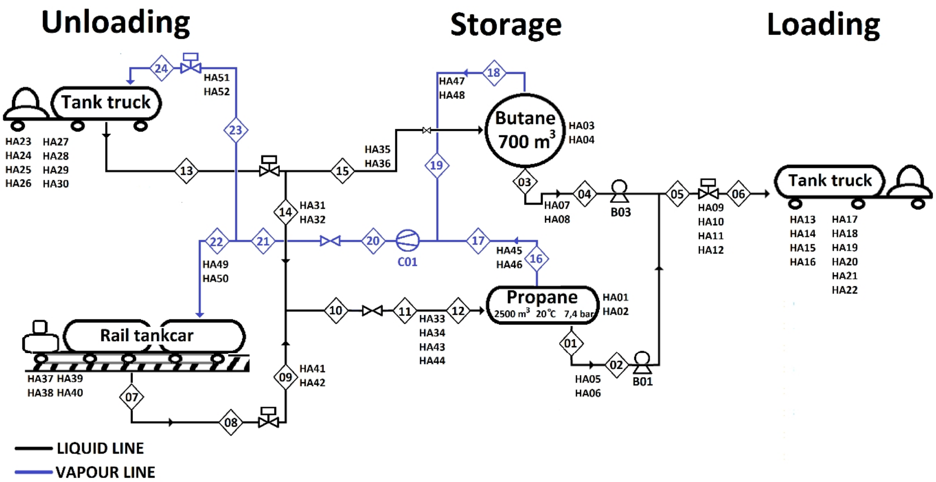

Fig. 4. Scenarios capable of giving rise to accidents for the fictitious LPG plant.

Table 1. Scenarios capable of giving rise to accidents at the LPG plant.

HA01/HA02	Catastrophic propane storage vessel rupture/ Hole in propane storage vessel
HA03/ HA04	Catastrophic butane sphere rupture/ Hole in the butane sphere
HA05/HA06	Large/small release of propane due to rupture/hole in 14" and 10" line during tank truck loading, from the storage vessel to the pump suction (B01/02).
HA07/ HA08	Large/small release of butane due to rupture/hole in 4" and 6" line during tank truck loading, from the storage sphere to the pump suction (B03).
HA09/ HA10	Large/small release of propane due to rupture/hole in 6" and 3" line from the pump discharge (B01/02) to the tank truck loading station.
HA11/ HA12	Large/small release of butane due to rupture/hole in 6" and 3" line from the pump discharge (B03) to the tank truck loading station.
HA13/ HA14	Large/small release of propane due to rupture/hole in 3" arm between the loading island and the tank truck
HA15/ HA16	Large/small release of butane due to rupture/hole in 3" arm between the loading island and the tank truck
HA17/ HA18	Catastrophic rupture of tank truck storage vessel (propane)/ Hole in tank truck storage vessel (propane)
HA19/ HA20	Catastrophic rupture of tank truck storage vessel (propane)/ Hole in tank truck storage vessel (propane)
HA21/ HA22	Catastrophic rupture of tank truck storage vessel (butane)/ Hole in storage vessel tank truck storage vessel (butane)
HA23/ HA24	Catastrophic rupture of tank truck storage vessel (butane)/ Hole in storage vessel tank truck storage vessel (butane)
HA25/ HA26	Catastrophic rupture of tank truck storage vessel (propane)/ Hole in tank truck storage vessel (propane)
HA27/ HA28	Large/small release of propane due to rupture/hole in 3" arm between the loading island and the tank truck
HA29/ HA30	Large/small release of butane due to rupture in 3" arm between the loading island and the tank truck
HA31/ HA32	Large/small release of propane due to rupture in 3" and 4" line between the tank truck unloading station and the storage vessel.
HA33/ HA34	Large/small release of propane due to rupture in 8" and 10" section of line, the tank truck unloading station and the storage vessel.
HA35/ HA36	Large/small release of butane due to rupture in 3" and 4" line during tank truck unloading, from the unloading station to the sphere.
HA37/ HA38	Catastrophic rupture of tank car storage vessel (propane)/ Hole in tank car storage vessel (propane)
HA39/ HA40	Large/small release of propane due to rupture in 3" arm between the tank car and the unloading island
HA41/ HA42	Large/small release of propane due to rupture in 3" and 4" line between the tank car unloading station and the storage vessel.
HA43/ HA44	Large/small release of propane due to rupture in 8" and 10" line section between the tank car unloading station and the storage vessel.
HA45/ HA46	Large/small vapor release due to rupture/hole in 6" and 4" line from the storage vessel to the compressor.
HA47/ HA48	Large/small vapor release due to rupture/hole in 3" and 2" line from the storage sphere to the compressor.
HA49/ HA50	Large/small vapor release due to rupture/hole in 3" and 2" line from the compressor to the tank car unloading station.
HA51/HA52	Large/small vapor release due to rupture/hole in 2", 3" and 4" line from the compressor to the tank truck unloading station.

The hole sizes assumptions for consequence calculations have been based on the Manual Bevi Risk Assessments (RIVM, 2009) as below:

Lines: 100% of the pipe diameter for ruptures; 10% of the nominal pipe diameter (up to a limit of 50 mm) for leaks.

Equipment: Catastrophic rupture; 10mm hole for leaks.

5. Frequency estimation

Table 2. Failure frequencies for lines and equipments.

Equipment	Rupture	Hole	Source
Process vessel	5×10^{-6} year^{-1}	1×10^{-4} year $^{-1}$ (10 mm)	(BEVI, 2009) , Table 31 Page 45/130
Pressurised storage tank	5×10^{-7} year^{-1}	1×10^{-5} year $^{-1}$ (10 mm)	(BEVI, 2009), Table 13 Page 32/130
Line ND < 75mm	1×10^{-6} m^{-1}.year^{-1}	5×10^{-6} m^{-1}.year^{-1} (10% ND)	(BEVI, 2009), Table 27 Page 42/130
75mm ≤ Line ND ≤ 150mm	3×10^{-7} m^{-1}.year^{-1}	2×10^{-6} m^{-1}.year^{-1} (10% ND)	(BEVI, 2009) , Table 27 Page 42/130
Line ND > 150mm	1×10^{-7} m^{-1}.year^{-1}	5×10^{-7} m^{-1}.year^{-1} (10% ND)	(BEVI, 2009), Table 27 Page 42/130

5.1. Event trees

The event tree schematically describes the sequences of facts that develop after the occurrence of an accident, defining the possible consequences that can be generated by it .

Figures 5 and 6 present the event trees for continuous and instantaneous butane/propane releases according to P4.261/11.

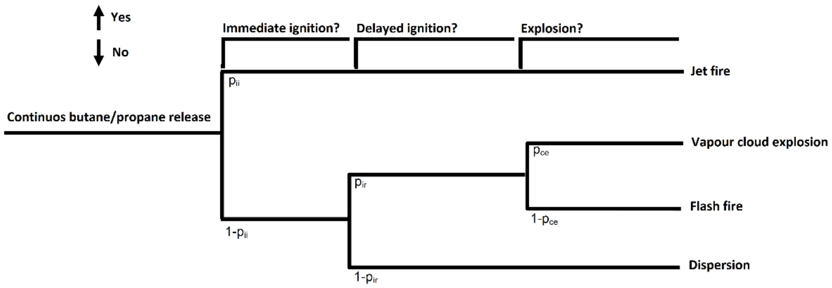

Fig. 5. Event Tree for continuous butane/propane releases (CETESB, 2011).

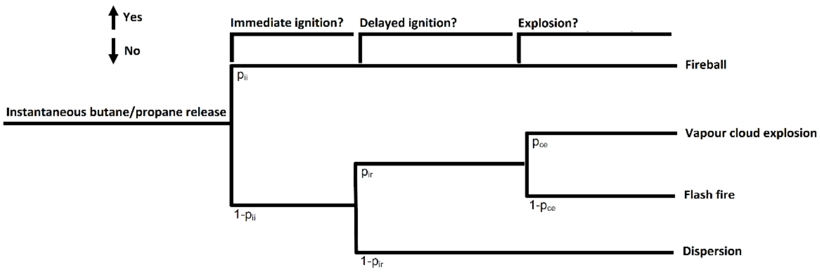

Fig. 6. Event tree for instantaneous butane/propane release (CETESB, 2011).

In the case of lines, regardless of the size of the release hole, only the horizontal direction (0º in relation to the ground) was adopted with 100% probability, in accordance with CETESB P4261/11.

The immediate ignition probabilities (p_{ii}) are presented in Table 3.

Table 3. Probability of immediate ignition (CETESB, 2011).

Continuous release	Instantaneous release	Probability of immediate ignition
<10 kg/s	<1000kg	0.2
10-100kg/s	1000-10000kg	0.5
>100kg/s	>10000kg	0.7

The probability of delayed ignition (p_{ir}) is considered to be equal to 0,5.

The probabilities of explosion (p_{ce}) and flash fire ($1 - p_{ce}$) are presented in Table 4.

Table 4. Probability of explosion and flash fire (CETESB, 2011)

Accidental typology	Probability
Explosion	0.4
Flash fire	0.6

5.2. Calculation of Consequences

The consequences have been calculated using the software PHAST (Process Hazard Analysis Tool) version 9.

The fatality levels for a given thermal dose emitted by jet fire and fireball have been estimated using the probit model proposed by Tsao and Perry as suggested by CETESB, 2011.

$$Pr = -36{,}38 + 2{,}56\ln(\mathrm{tI}^{4/3}). \tag{1}$$

In (1), *Pr* represents the probit, I is the thermal radiation intensity (W/m^2) and *t* is the exposure time (*s*). An exposure time of 20s has been considered (CETESB, 2011).

Furthermore, a probability of fatality equal to 100% has been also considered for people subjected to radiation intensity equal to or greater than 35 kW/m^2 (CETESB, 2011).

For thermal radiation values below 35 kW/m^2, the probability of fatality for people not sheltered is also affected by the protection offered by clothing. An exposure factor equal to 0.2 has been used (CETESB, 2011).

The time exposure limit is equal to 20 seconds in case of jet fire. In the case of the fireball, the exposure's time is equal to its duration.

In the case of the flash fire typology, it has been considered that within the flame envelope (region delimited by the reach of the lower flammability limit) the probability of fatality is equal to 100%.

The modeling of the vapor cloud explosion effects have been done considering the multienergy model with unconfined explosion strength equal to 6 and unconfined explosion efficiency equal to 12,5%. Overpressure levels of 0.1 bar and 0.3 bar have been considered with probabilities of 0,25 and 0,75 (CETESB, 2011).

6. Risk assessment

6.1. Individual risk

Individual risk can be defined as the expected frequency, expressed on an annual basis, that an individual located in a certain position in relation to the installations under analysis will suffer certain damage (generally fatalities) as a result of accidents that may eventually occur in these facilities.

6.1.1. Individual risk criteria

The individual risk criteria defined by CETESB P4.261 is presented in Figure 7.

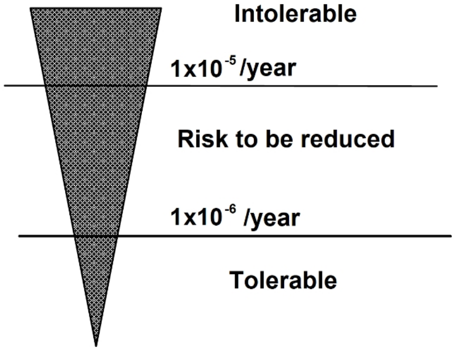

Fig. 7. Individual risk tolerability criteria (CETESB, 2011).

As can be seen in Figure 7, the individual risk criteria established by CETESB delimits three risk regions: tolerable, risk to be reduced and intolerable:

- Tolerable risk: IR < 1.0E-6/year;
- Risk to be reduced: 1.0E-6/year ≤ IR ≤ 1.0E-5/year;
- Intolerable risk: IR > 1.0E-5/year.

The "risk to be reduced" region, indicated in Figure 7, represents the region of risks that must be reduced as much as possible without, however, being considered intolerable.

The way in which individual risk results are assessed is illustrated in Figure 8.

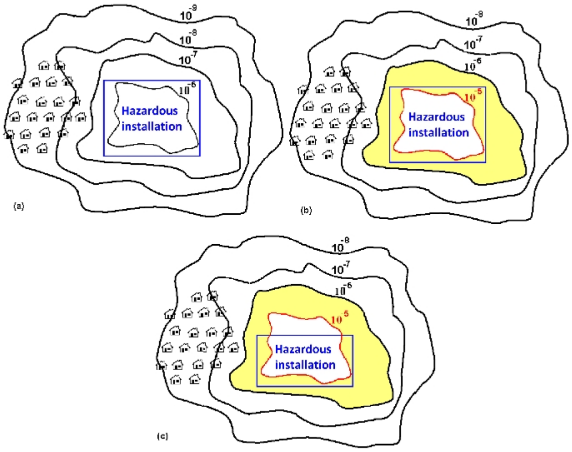

Fig. 8. Individual risk assessment method for installations (CETESB, 2011).

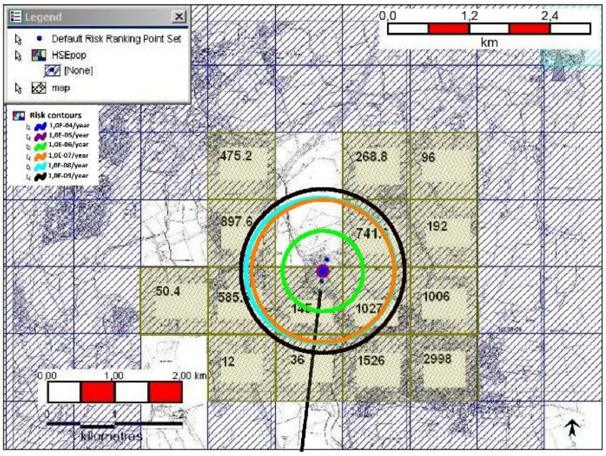

Fig. 9. Individual risk results.

As shown in Figure 8(a), the iso -risk contour of 1.0E-6/year located entirely within the limits of the project, indicates the presence of residual risk which must be managed. In this case the risks are considered tolerable. If the iso -risk contours corresponding to 1.0E-5/year are completely within the limits, but those corresponding to 1.0E-6/year are located outside the limits of the project, as in Figure 8Fig. 8(b) , therefore in the “risk to be reduced” region, there will be a need to implement mitigating measures to reduce risk. In turn, if the iso -risk contour of 1.0E-5/year lies totally or partially outside the limits of the project, as in Figure 8 (c), the risk is considered intolerable, which indicates the unfeasibility of the project, as proposed.

CETESB also considers that in cases where the individual risk is greater than the maximum tolerable risk, but the societal risk is considered met (tolerable), they may consider the project approved, since the main focus in risk assessment is on groups of people possibly impacted by major accidents.

6.1.2. Individual risk results

In order to evaluate if the individual risk criteria have been met, it is necessary to zoom in to the 1,0E-5/year curve, since this contour must be integrally inside the perimeter of the installation area. This would result in a minimum area of approximately 14448 m2. This process is illustrated in Figure 10.

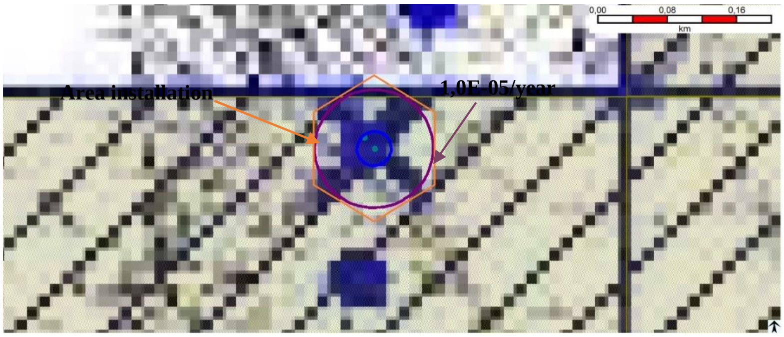

Fig. 10. Area required to meet individual risk criteria.

6.2. Societal risk

Societal risk refers to the population present within the reach of the physical effects generated by the different accident scenarios (Casal, 2018).

6.2.1. Societal risk criteria

The tolerability limit values for societal risk proposed by P4.261/11 are shown in Figure 11.

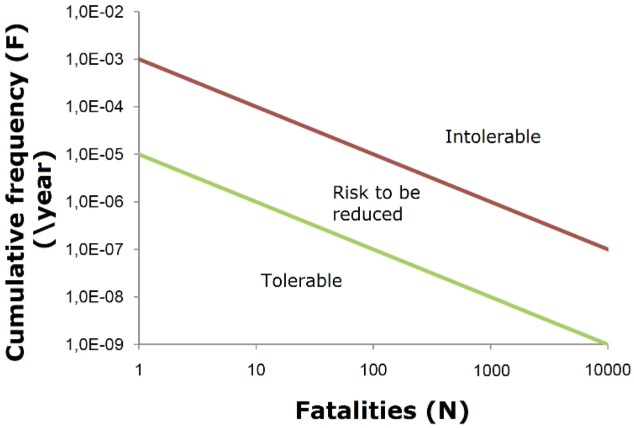

Fig. 11. Societal risk criteria (CETESB, 2011).

The societal risk criterion defines three regions where the risk results must be evaluated: tolerable, "risk to be reduced", and intolerable. The interpretation of these regions are as follows:

- the FN curve situated totally in the region of tolerable risk indicates the presence of residual risk that must be managed through a Risk Management Program;
- the FN curve situated totally or partially in the "risk to be reduced" region requires the implementation of measures to reduce the risk;
- the FN curve located totally or partially in the region of intolerable risk indicates that the plant operation is unfeasible without the implementation of mitigating measures for risk reduction. The adoption of measures to reduce risk should aim to place the FN curve entirely in the "risk to be reduced" region or, preferably, in the region of tolerable risk.

6.2.2. Societal risk results

Figure 12 presents the societal risk results LPG plant.

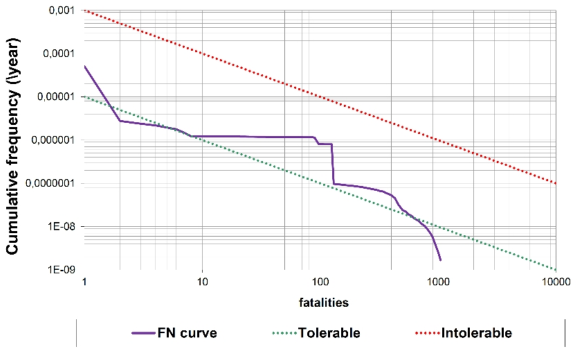

Fig. 12. Societal risk results.

According to the risk results presented in Figures 12, it is observed that the societal risk is in the "risk to be reduced" region, in which it is necessary to evaluate mitigating measures to reduce the risk.

7. Comparison with international approaches

7.1. Individual Risk safety distances

Table 6 summarizes the safety distances that are most relevant for policy decision-making based on risk results. Individual Risk distances based on P4.261/11 are on the same order of magnitude as the other institutions. Comparing São Paulo IR results, it is possible to see that 10^{-5} distance is smaller whereas 10^{-6} distance is larger than the distances of the other institutions.

Table 5. Safety distances relevant for policy decision-making.

Institution	Criteria	Distance (m)
United Kingdom (HSE)	Inner zone (used for housing, hotels)	280
	Middle zone (used for hospitals, schools)	380
France (INERIS)	Alea VH (limit value for expropriation)	270
Netherlands	(RIVM) IR 10^{-6} per year (limit value for houses, schools, hospitals)	250
Walloon Region (FPMs)	IR 10^{-5} per year (limit value for houses)	200
	IR 10^{-6} per year (limit value for schools, hospitals)	375
São Paulo (CETESB)	IR 10^{-5} per year (IR contour must be inside the installation area)	70
	IR 10^{-6} per year (It is necessary to evaluate mitigation measures)	595

7.2. FN curves

CETESB FN curves are compared to HSE and RIVM results as only these institutions calculated societal risk. The FN curves with the guide lines are shown in Figure 13.

Comparing the CETESB curve with the RIVM curve, it is observed that it is lower up to approximately 20 fatalities and higher above this. When compared to the HSE curve, the CETESB curve is lower up to 90 fatalities, but higher above this number of fatalities. It also can be seen that CETESB methodology has given a maximum number of fatalities higher than RIVM and HSE.

Taking into consideration societal risk results the conclusion is:

- RIVM: FN curve exceed the SR guide line;
- HSE: FN curve is in the acceptable region;
- CETESB: FN curve is in the "Risk to be reduced" region requiring the evaluation of mitigation measures.

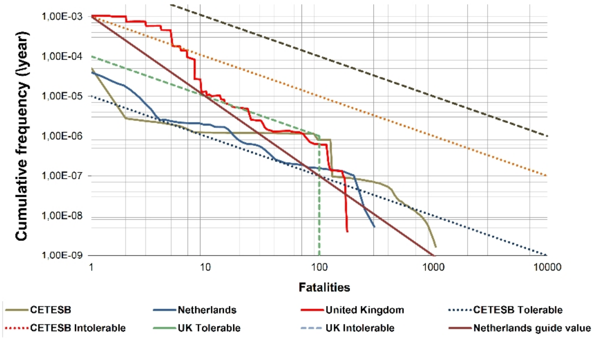

Fig. 13. Comparison of societal risk results.

8. Conclusion

This article presented an extension of the study performed by Gooijer et al, 2012 in order to evaluate P4.261/11 risk assessment methodology and criteria regarding to industrial plants.

Based on the results, the following considerations may be taken:

- Individual Risk distances based on P4.261/11 are on the same order of magnitude as the other institutions. CETESB IR 10^{-5} distance is smaller whereas 10^{-6} distance is larger than the distances of the other institutions.
- CETESB FN curve lower than the RIVM curve up to approximately 20 fatalities and higher above this. When compared to the HSE curve, the CETESB curve is lower up to 90 fatalities, but higher above this number of fatalities.
- CETESB methodology gives a maximum number of fatalities higher than RIVM and HSE.
- CETESB: FN curve is in the “Risk to be reduced” region requiring the evaluation of mitigation measures.

Acknowledgements

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