# HYDROGEN RISK ASSESSMENT IN SÃO PAULO STATE - BRAZIL

**Tomaz, S.R.[1], Michelino, G.G.[2] and Neves Jr., N.P.[3]**
**[1] Risk Analysis Section, CETESB, Av. Prof. Frederico Hermann Jr., 345, São Paulo, 05459-900, Brazil, sandrot@cetesbnet.sp.gov.br**
**[2] Risk Analysis Section, CETESB, Av. Prof. Frederico Hermann Jr., 345, São Paulo, 05459-900, Brazil, giuseppem@cetesbnet.sp.gov.br**
**[3] Hydrogen Laboratory, Universidade Estadual de Campinas, P.O.Box 6039, Campinas, 13083-970, Brazil, nevesjr@ifi.unicamp.br**

**ABSTRACT**

São Paulo State Environmental Protection Agency – CETESB, Brazil, adopts a so called Reference Distance (RD) from hazardous substances storage facilities to populated places as a decision making tool for the application of a simplified or a full Risk Analysis (RA). As for hydrogen, RD was set up based on instantaneous release scenarios, where consequences reaching off-site population were estimated for delayed ignition ending up in vapor cloud explosion (VCE) with a 0.1 bar blast wave overpressure as a chosen endpoint, corresponding to a 1% of death probability range. Procedures for RD evaluation and further adoption by CETESB are presented in this paper.

## 1.0 INTRODUCTION

The Mission Statement of São Paulo State Environmental Protection Agency – CETESB is to promote and ensure environmental quality. Hence, one of CETESB's task is to establish preventive and corrective actions related to accidental release of chemicals which may affect population.

Public concern about hazardous substances increased in São Paulo State mainly after a gasoline pipeline leakage followed by fire in Cubatão City, in 1984, which brought about to hundreds of injured people, massive property destruction and 93 deaths [1]. This accident induced CETESB to carry out research on preventive actions related to accidental releases of chemicals. As a result, a facility Risk Analysis (RA) became a compulsory part of the environmental licensing process, when appropriate.

Two levels of RA were set up: a simplified one, enclosing a Risk Management Program, mostly based on API 750 [2], and a full Quantitative Risk Analysis (QRA), encompassing detailed consequence and frequency analysis, Societal Risk (SR) and Individual Risk (IR) estimation [3], in order to be compared to the São Paulo State risk acceptability criteria [4]. The adopted flowchart to choose the RA required for each case and for QRA undertaking is presented in Fig. 1.

Since a full QRA study is time-consuming, expensive and subject to uncertainties [3], facilities under licensing process have to check the need of QRA submission based on their inventories of toxic and flammable chemicals and the surrounding population. In order to address this topic, a Reference Distance (RD) was developed by CETESB as a decision making tool.

This work aims to exhibit current methods of risk assessment related to hydrogen storage in São Paulo State, Brazil. Under the prospect of increased hydrogen consumption in Brazil as a chemical and also as an energy vector in association with renewable sources of energy and with compressed natural gas, CETESB should be led to refine risk assessment models for these fuel gases to the extent of their increasing participation in the Brazilian energy mix.

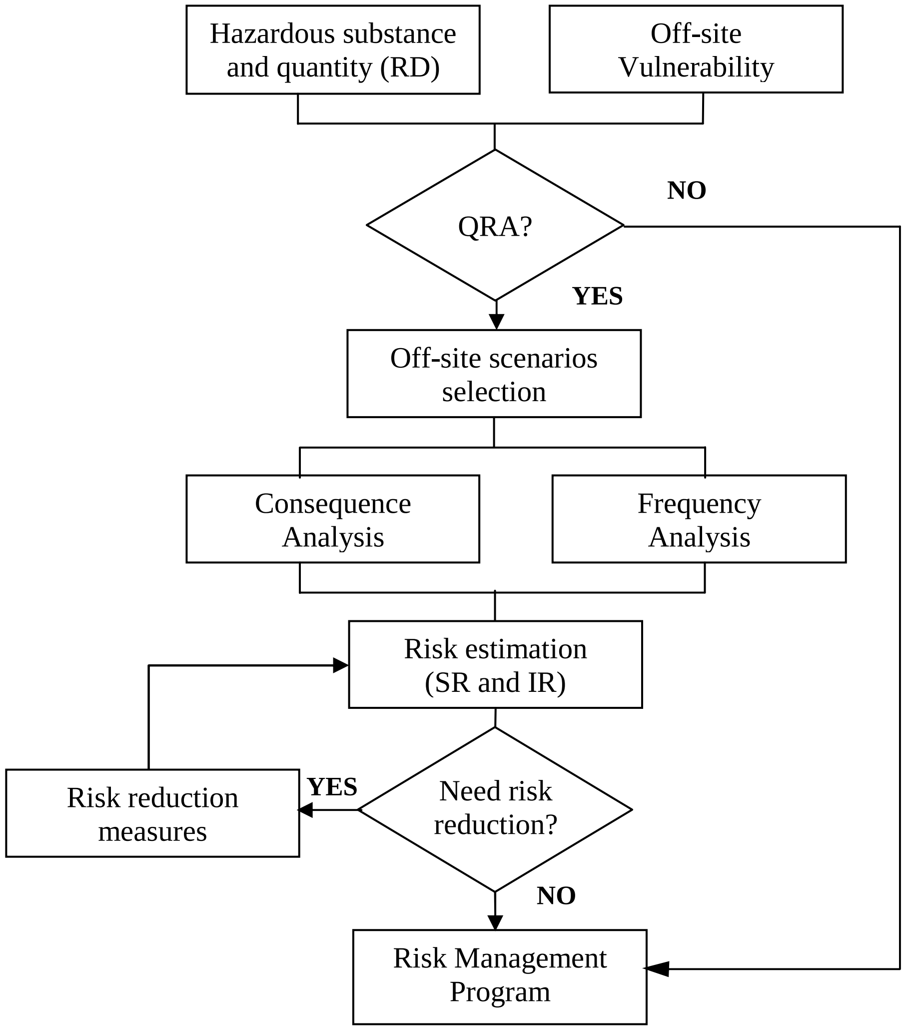


Figure 1. CETESB Risk Analysis flowchart.

## 2.0 METHODOLOGY

This work presents and discusses the methodology adopted on the RD determination and a further example application concerning some amount of hydrogen stored within a facility.

### 2.1 Accident Scenario

The accident scenario assumption refers to a hydrogen instantaneous release corresponding to 20% of the total amount contained in the larger storage vessel (details in section 3.1, item a). Despite not being the worst case scenario, this release was adopted based on practical experience of CETESB Emergency Response Branch [5]. Storage conditions were taken from manufacturers and set up to 168 bar gauge and 25 ºC. Weather conditions assumptions are presented in Table 1.

Table 1. Weather conditions

| Parameter | Value |
|---|---|
| Pasquill Atmospheric Stability | D |
| Wind Speed | 2 m/s |
| Ambient Temperature | 25ºC |
| Relative Humidity | 80% |

### 2.2 Consequences

In this work, it was considered that the system hydrogen-air can form explosive mixtures in the range of hydrogen concentration from 4.0% to 74.5% mol/mol (20°C, 1.013 bar) [6]. The usual detonation range considered is around 18.3% to 59.0% mol/mol although dry mixtures can present stable detonation for hydrogen concentrations as low as 15%mol/mol [7]. The minimum ignition energy is 0.02 mJ and autoignition temperature is 570°C (1.013 bar) [6].

Technically, many types of outcomes may be possible for a hydrogen instantaneous release, like jet flare, fireball, flash fire, vapor cloud explosion (VCE), physical explosion and confined explosion [8]. In this case, the chosen outcome was a VCE resulting in shock wave, since its consequences can reach population located outside facility's boundaries with no given time to reaction, therefore often being the worst case scenario. The release consequences were estimated running the PHAST 6.54 software, which code encloses discharge, dispersion and explosion models [9]. The program performs the late (or delayed) explosion modeling at regular intervals during the dispersion of the cloud and finds the conditions which give the greatest downwind effect distance for each overpressure of interest, set in the Explosion Parameters. This is described as the "Worst Case" explosion for that overpressure.

#### 2.2.1 Blast wave modeling

After dispersion, the flammable mass within the cloud is calculated between lower flammability limit (LFL) and upper flammability limit (UFL). Although some experimental studies have demonstrated there is a minimum flammable material mass required to produce a VCE [7], it is assumed that any amount of flammable material is able to explode. There are some empirical models available to estimate VCE effects, as TNT equivalence model, TNO model ("Yellow Book"), Multi-energy method, Baker-Strehlow, etc. [10]. The chosen model is TNT equivalence, which estimates a hypothetical mass of TNT per unit mass of fuel, whose detonation would result in the same blast wave at the same distance. The empirical explosion efficiency was set up to 10%.

Criteria for deadly injuries are based on a 0.1 bar overpressure from VCE. CETESB assumes that a 0.1 bar blast wave overpressure may cause serious structural damage to buildings thus leading to serious wounds caused by flying glass and debris, indirectly corresponding to a 1% death probability [4].

Hence, RD is a circumference with a radius determined by the distance corresponding to 0.1 bar overpressure isocurve originated from a VCE plus the distance from leak source to the cloud center, as illustrated in Fig. 2.

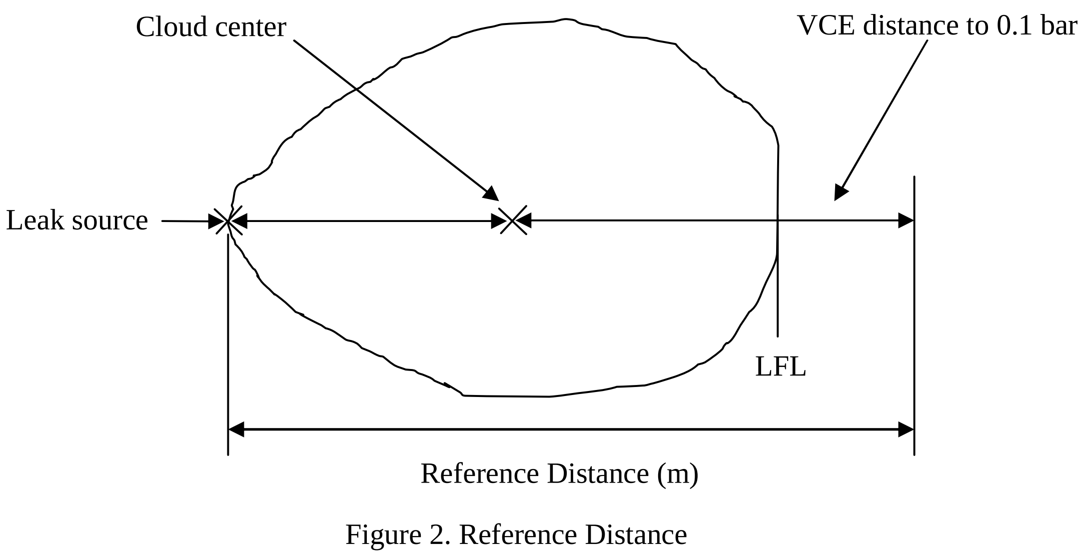


Figure 2. Reference Distance

## 3.0 RESULTS

Simulations were done for several amounts of hydrogen. For each amount the matching RD was obtained, as shown in Table 2.

Table 2. Hydrogen RD

| Mass (kg) | RD (m) |
|---|---|
| 10 | 18 |
| 50 | 30 |
| 100 | 38 |
| 500 | 65 |
| 1,000 | 81 |
| 1,500 | 93 |
| 10,000 | 175 |
| 100,000 | 378 |

### 3.1 RD Application

In a facility under licensing process, in order to check the need of a QRA or just a Simplified RA submission to CETESB, the owner or operator is asked to adopt the following procedure:

a) Determine the hydrogen amount, in kilogram, corresponding to the larger vessel capacity on site. For a set of interconnected vessels, sum up all capacities indicating the facility inventory.

b) From Table 2 - Hydrogen RD, determine the matching RD for the hydrogen inventory.

c) Upon a facility aerial photo, plot a circumference with radius equal RD and center on the facility inventory.

d) Check out if local population within the circle delimited by RD exceeds 25 people.

e) If the answer is “YES”, a full QRA must be submitted to CETESB.

f) If the answer to this question is “NO”, a Simplified RA may be submitted to CETESB.

### 3.2 Example of RD Application

In a virtual facility, whose surrounding vulnerability is shown in Fig. 3, a hydrogen amount of 1,000 kg is stored within four interconnected vessels, each one having a 250 kg storage capacity. For the total stored mass of hydrogen Table 2 indicates a RD of 81 meters. Then, a circumference with radius equal 81 m and center on the storage site center is plotted, obtaining the circle shown in the same figure. It can be seen that local population within the circle delimited by RD exceeds 25 people, due to the several buildings settled. Therefore, the facility must submit a full QRA to CETESB.

## 4.0 DISCUSSION

The methodology for hydrogen risk assessment adopted by CETESB may be very conservative in some cases since it does not take into account the whole facility and process data, such as passive or active systems, devices or procedures that can mitigate the risk. However, it fits conveniently as an initial procedure aiming to identify those facilities for which a QRA can effectively contribute to a risk reduction, thus to the off-site population safeguard, and encompasses most of licensing cases. For quite different situations involving hydrogen release, as for instance a continuous hydrogen generation process, this methodology may not be directly applied and further efforts will be necessary to evaluate the off-site risk.


Figure 3. Example of RD application

## 5.0 CONCLUSION

Although there might be worse cases than the chosen scenario, it can be considered conservative, mainly due to the explosion model adopted. It is a very simple methodology, practical, easy to apply and, above all, it avoids the submission of unnecessary studies and additional expenses to the facility owner. The described methodology can also contribute to reduce the time of the licensing process, yet keeping the focus on the off-site population safeguard.

## ACKNOWLEDGEMENT

The authors would like to thank MSc. Cristiano da S. Pinto for his critical reading of the manuscript and suggestions that improved the final version of the paper.

## REFERENCES

1. http://www.cetesb.sp.gov.br/gerenciamento-de-riscos/analise-de-risco-tecnologico/50-vila-soco
2. American Petroleum Institute, API 750 Management of Process Hazards (with errata February 1990) (1st Edition), 1990, American Petroleum Institute.
3. Center for Chemical Process Safety (CCPS), Guidelines for Chemical Process Quantitative Risk Analysis (2nd Edition), 2000, Wiley-AIChE, New York.
4. CETESB, Norma P4.261- Manual de orientação para a elaboração de estudos de análise de riscos, 2003, CETESB, São Paulo.

5. CETESB, Banco de Dados - Sistema de Informações para Emergências Químicas (SIEQ), 2011, São Paulo.
6. L'Air Liquide, Gas Encyclopaedia, 1976, Elsevier, Amsterdam.
7. Lewis, B. and Elbe, G., Combustion, flames and explosions of gases, 1987, Academic Press, Orlando.
8. TNO, Methods for the calculation of physical effects – due to releases of hazardous materials (liquids and gases) – 'Yellow Book'(3rd edition 2nd revised print), 2005, The Hague.
9. Det Norske Veritas (DNV) Software, PHAST Risk Micro v. 6.54 Technical Manual, 2010, London.
10. Center for Chemical Process Safety (CCPS), Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs, 1994, Wiley-AIChE, New York.
11. Lees, F.P., Loss Prevention in the Process Industries (2nd Edition), Elsevier, 1996, pp. 17-1 – 17-212.