Application of Quantitative Risk Assessment for a CNG Refueling Station

N.Badry, B.Abdolhamidzadeh, D.Rashtchian*
Sharif University of Technology, Chemical and Petroleum Engineering Department, Tehran, Iran.
Rashtchian@sharif.edu

Abstract
This paper outlines the quantitative risk assessment (QRA) for a fast-fill CNG station. Methane (CH₄) is the major material used in this plant. Methane is a flammable chemical that can lead to fire and explosion. A systematic procedure including a detailed HAZOP study of the entire station has been used. Fault tree analysis (FTA), event tree analysis (ETA) technique and historical data have been used to identify the most credible scenarios obtained from HAZOP studies and to calculate their probabilities. Consequence analysis of the credible scenarios has been carried out by using PHAST 6.5 software package containing several models for performing consequence analysis through risk assessment. The risk which has been estimated in term of fatality is monitored by the F-N curve and iso-contours. These results form the basic inputs for the risk management decisions.

Keywords: Quantitative Risk Assessment (QRA); CNG station; Consequence Analysis

1. Introduction
Risk assessment is a measure to weigh up whether it has been taken enough precautions or should be done more to prevent fatality and injury chiefly in process industries. Risk assessment may be the most important step in the risk management process, and may also be the most difficult and prone to error. Therefore it is critically essential to use correct data through study. The need for risk assessment of process plants has become exceedingly critical due to the trend towards larger and more complex units that process toxic, flammable or other hazardous chemicals under extreme temperature and pressure conditions. Moreover, the potential damage has been magnified by the proximity of many such operations to densely populated areas. The qualitative and quantitative results obtained from risk assessment can conduct process industries toward such modifications that can lead to reducing major sources of risk and in result the fewer number of fatalities and injuries.

This paper presents the QRA study carried out for a fast-fill CNG station processing Methane as a fuel for natural gas vehicles. The flammable nature of methane [1], high pressure condition and vicinity to densely populated areas are the most significant reasons which emphasize on importance of risk assessment study in CNG stations. A recent survey revealed several CNG station accidents with considerable number of injuries and fatalities occurred throughout the world; gas cylinder explosion due to
high pressure gas leakage in Pakistan (2006), fire incidents in India (2003) and China (1998) [2-4]. The main purpose of this paper is to quantify these hazards and their consequences to estimate the risk to surrounding population. In the end, the results of this study can be used in CNG station layout design and also they are broadly helpful in subsequent risk management steps such as emergency response planning.

2. Risk Assessment
The present study was aimed to follow a systematic procedure for the QRA of a CNG station and Fig. 1 summarizes the main steps of the methodology [5].

Risk can be described in different ways: individual risk, societal risk, maximum individual risk, average individual risk of exposed population, average individual risk of total population and average rate of death. Two popular measures are individual risk (IR) and societal risk (SR). The former is usually shown on a risk contour plot, while the latter is presented with a frequency–number (F–N) curve. The individual risk is defined as the probability of death at any particular location due to all undesired events. It can be expressed as the probability of a person at a specific location becoming a casualty within a year. With the risk of multiple fatalities being concerned, the societal risk is defined as the relationship between the frequency of an incident and the number of resulting casualties. It is usually expressed in the form of a graph of cumulative frequency (F) of N or more casualties plotted against N (F–N curve) [6]. The individual and societal risks of CNG station will be discussed in more detail in the following sections.

Fig. 1. Flow diagram of the procedure used for QRA
2.1. CNG station description

Fast-fill CNG stations (Fig. 2) are designed to refuel a vehicle in a similar time to a liquid fuel station and are analogous to these stations in many aspects of their operation. For the CNG stations fed by public distribution pipeline, five main components can be distinguished as follows [7,8]:

- **Measurement Unit:** A metering unit is required at the CNG station inlet to record gas flow. This is a conventional displacement meter which records the total flow of gas into the filling station at low pressure (20 bar).
- **Dryer:** The moisture content of CNG must be controlled at the filling station as water can cause operational problems in the filling station or the vehicle if not reduced to levels at which condensation does not take place. For this reason a dryer unit which uses molecular sieve is incorporated in low pressure section at the station inlet.
- **Compressor:** This station uses two large reciprocating compressors which are electrically powered. These compressors are housed in acoustically shielded enclosures and are operated automatically by the CNG station control system. These compressors are been designed to pressurize gas to 250 bar through three stages.
- **Cylinders:** Compressed gas is stored in cylinders mounted vertically in “cradles” each holding several cylinders. The cylinders are configured in “banks” to maximize the utilization efficiency of the gas storage system. Gas is stored at
three pressure levels; Low (160 bar), Medium (200 bar) and High (250 bar). There are 36 cylinders at Low, 27 cylinders at Medium and 12 cylinders at High pressure level. This classification leads to reducing refueling time remarkably. Both compressors and cylinders are located in a room with reinforced concrete walls.

- **Dispensers:** The dispenser is the interface of the CNG filling station with the vehicles. It is therefore usually designed to be similar in appearance and operation to conventional garage forecourt dispensers for liquid fuel. In this station eight dispensers are connected to gas cylinders by pipeline conveying gas at three pressure levels.

### 2.2. Hazard identification and scenario selection

This step is so critical, because a hazard omitted is a hazard not analyzed. Preliminary Hazard Analysis (PHA) and Hazard and Operability (HAZOP) studies [9] have been used to identify the hazardous sections of the station. The major causes which may lead to hazards identified from HAZOP studies are “corrosion through dryer section due to moisture content of gas” and “high pressure in cylinders and dispensers”. This step also includes the identification and tabulation of all scenarios regardless to importance or initiating event. Scenarios begin with an incident, which usually results in the loss of containment of material from the process. Typical incidents might include the rupture or break of a pipeline, a hole in a cylinder or pipe, fire external to vessels, etc. [10].

Although release of gas through small hole sizes in dryer section is frequent to occur due to numerous former incidents and HAZOP studies results, these incidents can be ignored in comparison with rupture scenarios because of low pressure and consequently small content of discharged gas. Two compressors used in this station are strongly protected against gas release by using an electrical powered ventilator for each one and gas detectors located in suitable places. All of the equipments in this section, mainly electrical engines are explosion proof to avoid any hazard due to unlikely gas release. Therefore, no credible scenario could be identified in the compression section. Storage and dispensing sections including cylinders and pipeline with highly pressurized gas are worthy to investigate through different credible scenarios. To sum up, the most significant credible scenarios in the CNG station are listed as below:

- Sc-01: Rupture in dryer pipeline.
- Sc-02: 5mm hole diameter in cylinders.
- Sc-03: 25mm hole diameter in cylinders.
- Sc-04: 5mm hole diameter in dispenser pipeline.
- Sc-05: Rupture in dispenser pipeline.

### 2.3. Consequence analysis
In this paper, consequence analysis is supposed to be carried out through several steps to estimate the number of fatalities in each scenario. Once the scenario is defined, source models are selected to describe how materials are discharged. The source model provides a description of the discharge rate and the total quantity discharged. A dispersion model is subsequently used to describe how the material is dispersed to some concentration levels. Then, fire and explosion models convert the source model information on the release into hazard potentials such as thermal radiation and explosion overpressures [5]. All of the mentioned steps have been modelled using PHAST 6.5 software package developed by DNV. Finally, effect models convert results obtained by software into effects on people (death).

2.3.1. Source and Dispersion models
Source models are used to quantitatively define the release scenario by estimating discharge rates and total quantity released. Discharge rate models are based on a mechanical energy balance. A typical form of this balance is Eq. 1 and total quantity released depends on discharge duration.

\[
\int_{p_1}^{p_2} \frac{dp}{\rho} + \frac{g}{g_c} (z_2 - z_1) + \frac{1}{2g_c} (v_2^2 - v_1^2) + \sum e_f = 0
\]

(1)

In Eq. 1, \( P, \rho \) and \( v \) are the pressure, density and velocity of the discharged fluid, \( z \) is elevation of the source point and \( e_f \) is frictional loss term. Dispersion models convert the source term outputs to concentration fields downwind from the source. Typically, the dispersion calculations provide an estimate of the area affected and the average gas concentrations expected. The minimum required data to estimate the release rate of the gas (or the total quantity released) are the atmospheric conditions, surface roughness, temperature, pressure and sometimes release diameter. More complicated models may require additional detail on the geometry, discharge mechanism, and other information on the release. Source and dispersion models are highly coupled, with the results of the source model being used to select the appropriate dispersion model [5].

2.3.2. Fire and Explosion
The evaluation of the consequence of jet fire, flash fire and vapor cloud explosion (VCE) has been performed assuming that risk assessment has to be always as conservative as possible, whatever the finality of the assessment: “worst case” should always be considered when uncertainties are faced [11].

Jet fires typically result from the ignition of a flammable material as it is being released from a pressurized source and the main concern is always local radiation effects. In this paper, a relatively simple method, API 521(1996a), has been used to simulate jet fire assuming that release hole can be approximated as a nozzle and the
flame direction is vertical which provides a conservative result, since the vertical flame will provide the largest radiant heat flux at any receptor point [12]. A flash fire is the non-explosive combustion of a vapor cloud resulting from a release of flammable material into the open air. Flash fire is non-explosive since the flame speed has not accelerated sufficiently to produce damaging overpressures; the main consequence of a flash fire is direct flame contact and thermal radiation. Flash fires do not create a blast; however, a delayed ignition of a flammable vapor which has accumulated in a congested area, such as a process plant, may result in a vapor cloud explosion and resulting overpressure which affects humans and buildings through a blastwave covering large distances [13]. The mass of flammable vapor between the lower and upper flammability limits (LFL, UFL) has been used for evaluating the field of overpressure due to vapor cloud explosion by means of the TNO multi-energy method through the total combustion energy. The TNO multi-energy explosion model calculates the distance to various overpressure levels specified by the user for an unconfined vapor cloud explosion. It takes into account the variability of the blast strength by expressing the explosion as a number of fuel–air charges, each with individual characteristics, by modeling the vapor cloud explosion as the number of smaller blasts in each centre on confined sections of the cloud, this model is appropriate for estimating near field damage [14, 15].

2.3.3. Effect models
For the evaluation of consequences of flash fire, the typical cut-off criterion of lower flammability limit (LFL) has been used; any person within the cloud identified by the LFL border is in fact dead. In the other cases, the vulnerability of individuals exposed to VCE or jet fire, has been evaluated by probit functions (Eq. 2) based on experimental dose-response data. In risk studies, probit equations are commonly used to quantify the expected rate of fatalities for the exposed population [5].

\[ Y = k_1 + k_2 \ln(V) \]  \hspace{1cm} (2)

Where \( Y \) is probit variable, \( k_1 \) and \( k_2 \) are constants and \( V \) represents the dose of hazard (radiation or overpressure). A useful expression for performing the conversion from probit variable to probability of fatality (\( P \)) is given by Eq. 3.

\[ P = 0.5 \left[ 1 + \frac{Y - 5}{Y - 5} \text{erf} \left( \frac{Y - 5}{\sqrt{2}} \right) \right] \]  \hspace{1cm} (3)

Probit equations are available for a variety of exposures, including exposures to radiation and overpressure. The physiological effects of fire on humans depending on the rate at which heat is transferred from the fire to the person, and the time the person is exposed to the fire. Even short-term exposure to high heat flux levels may be fatal.
The combination of radiation and time is referred to dose. Therefore, all combinations of radiation and time that result in an equal dose also result in equal values for the probit and produce equal expected fatality rates for the exposed population. Eisenberg et al. (1975) develop a probit model to estimate fatality levels for a given thermal dose (Eq. 4) [16].

\[ Y = -14.9 + 2.56 \ln(tI^{1/2}) \]  
(4)

Where \( Y \) is the probit variable, \( t \) is the duration of exposure (sec) (Exposure time is considered 20s for jet fires), and \( I \) is the thermal radiation intensity (kW/m\(^2\)). The physiological effects of VCE depend on the peak overpressure that reaches the person. In the event of a VCE, the overpressure levels necessary to cause fatality to the public are typically defined as a function of peak overpressure, regardless to exposure time. Persons who are exposed to explosion overpressures have no time to react or take shelter; thus, time does not enter into the relationship. In this paper, the following relationships (Table 1) between overpressure and percentage affected have been used [17].

<table>
<thead>
<tr>
<th>Overpressure (psi)</th>
<th>Percentage affected (fatality)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>5</td>
<td>50%</td>
</tr>
<tr>
<td>7</td>
<td>95%</td>
</tr>
</tbody>
</table>

Table 1. The relationship between overpressure and percentage affected.

In the end, the following equation (Eq. 5) has been used to predict the total number of fatalities caused by jet fire and VCE.

\[ N = \int_A P(x, y) p(x, y) dA \]  
(5)

Where, \( P(x, y) \) means the probability of fatality in a place located in \((x, y)\), \( p(x, y) \) means the population distribution in \((x, y)\) and \( A \) is the total area where exposed to fire or explosion.

### 2.3.4. Computational tools

The software mainly used in this work was “PHAST 6.5” developed by DNV, which is a fully integrated family of consequence models for performing offsite consequence modelling and emergency response planning through QRA. There are several models in this package to model gas release, thermal radiation flux and overpressure levels at various specified distances. Models used in this task were announced before.
Consequently, MATLAB software package has been used to solve effect models and to calculate and present the risk.

2.3.5. Consequence estimation

There is significant information needed for the risk analysis. For example, site location, process flow diagrams (PFDs), piping and instrumentation diagrams (P&IDs), layout drawings, process chemistry, and physical property data. This information is fed to the analysis database for using throughout QRA. But the most essential information mainly in consequence estimation is atmospheric condition, population density and surface roughness [5].

Consequence estimation in general requires the dispersion modeling of flammable clouds for several realistic scenarios in a range of representative atmospheric conditions. These conditions comprise wind data, such as average velocity and direction, atmospheric stability [18], ambient temperature and humidity. In this paper, all of the scenarios have been investigated in two different atmospheric conditions (Table 2) corresponding day and night.

<table>
<thead>
<tr>
<th>Table 2. Atmospheric conditions corresponding day and night.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Wind Velocity (m/s)</td>
</tr>
<tr>
<td>Atmospheric Stability</td>
</tr>
<tr>
<td>Ambient Temperature (°C)</td>
</tr>
<tr>
<td>Humidity</td>
</tr>
</tbody>
</table>

The continuous change of wind direction requires the use of meteorological data in order to ascertain the major winds. In this case, assuming the uniform population density throughout the CNG station area has led to ignoring the wind direction, because in this state the wind direction has no effect on the final consequence. According to the area of CNG station and average number of people present there, the population density has been calculated 0.0076/m² for day and 0.0038/m² for night.

The surface roughness parameter (SRP) describes the roughness of the surface over which the cloud is dispersing and is a measure of the root mean square fluctuating velocity as a fraction of the mean velocity 10 m above ground. Typical value for the surface roughness parameter in urban area is assumed 0.33 [19]. Results obtained from consequence analysis are described in following sections. In this case, Calculations show that among flash fire, jet fire and vapor cloud explosion only flash fire has considerable consequences to study and following sections has been allotted to flash fire results.

2.3.5.1. Sc-01

The results obtained from simulating Sc-01 incident outcome cases are demonstrated in Fig. 3-4. These figures demonstrate the area limited to LFL concentration which
has been used to determine the number of fatalities due to flash fire effects assuming all people locating in this area will be killed.

2.3.5.2. Sc-04
The results obtained from simulating Sc-04 incident outcome cases are demonstrated in Fig. 5-6.

2.3.5.3. Sc-05
The results obtained from simulating Sc-05 incident outcome cases are demonstrated in Fig. 7-8.
Because of highly protected concrete walls used to construct the storage room, overpressure and radiation due to explosion and fire can not damage the walls. Therefore, a couple of scenarios (Sc-02 and Sc-03) related to high pressure gas cylinders have no consequence on people and are not credible to investigate. Thus, there is no need to involve these scenarios in QRA process. Finally, the number of fatalities due to Sc-01, Sc-04 and Sc-05 which have been determined by using Eq. 5 are shown in Fig 22-24.

2.4. Frequency estimation
Frequency estimation is the methodology used to estimate the number of occurrence of a scenario through a year. Estimates may be obtained from historical incident data on failure frequencies or from failure sequence models, such as FTA [5]. Depending on scenario type both techniques have been used in this paper.

2.4.1. Fault tree analysis
FTA technique has been used for probabilistic analysis. FTA gives all possible minimum combinations of basic human, instrument and equipment failures called minimum cut sets, which could lead to the occurrence of the critical event, commonly known as the ‘top event’. The fault tree is performed to obtain the set of basic events whose combination would lead to the occurrence of the unwanted top event. This method can be quantified and be used for estimating of top event occurrence frequency [20]. To determine the frequency of the Sc-01, FTA has been performed as shown in Fig. 9.
In quantification of the developed fault tree, almost all of the failure rates are generic data from technical handbooks such as OREDA, [21-23]. For estimation of human error probabilities, TESEO method has been used which considers the operator quality and training, type of activity, ergonomic factors and level of anxiety [24]. In the developed fault tree there is just one undeveloped event (External fire) that its probability has been determined from the frequency estimation done in dispenser section.

### 2.4.2. Historical data

In many cases, the incident frequency information required in risk assessment can be obtained directly from the historical records. This is a straightforward technique that provides directly the top event frequency without the need for detailed frequency modelling. A number of criteria have to be satisfied for the historical likelihood to be meaningful. These include sufficient and accurate records and applicability of the historical data to the particular process under review [5]. In this study some scenario frequencies determined from historical incident data on failure frequencies. With the uniform conditions assumed along the pipeline section of interest, failure frequencies in pipeline can be obtained from different equations which have been correlated.
versus hole leakage diameter as follows: (f is the frequency and d is the hole diameter (m)) [25].

Frequency of leakage per 1m length of pipes:
\[ f = 5.8 \times 10^{-5} d^{-1.25} + 8.8 \times 10^{-7} \]
(6)

Frequency of leakage per number of flanges:
\[ f = 2 \times 10^{-3} d^{-1.25} + 1.8 \times 10^{-5} \]
(7)

Frequency of leakage per number of instruments:
\[ f = 6.8 \times 10^{-4} d^{-1.25} + 1.5 \times 10^{-4} \]
(8)

To determine the frequency of leakage in a pipeline after determining the length of pipe, the number of flanges and the number of instruments, the values obtained from Eq. 6-8 must be aggregated. By using Eq. 6-8 and adding the frequencies of leakage in pipes, flanges and instruments the frequencies of Sc-04 and Sc-05 have been determined in Table 4.

<p>| Table 4. The estimated frequency for Sc-04 and Sc-05 in dispensing section. |
|----------------|----------------|----------------|----------------|----------------|</p>
<table>
<thead>
<tr>
<th>Hole Diameter (mm)</th>
<th>Pipe length (m)</th>
<th>No. Flanges</th>
<th>No. Instrument</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc-04</td>
<td>5</td>
<td>100</td>
<td>230</td>
<td>6.8 \times 10^{-2}</td>
</tr>
<tr>
<td>Sc-05</td>
<td>19*</td>
<td>100</td>
<td>230</td>
<td>1.7 \times 10^{-2}</td>
</tr>
</tbody>
</table>

* In rupture scenarios the hole diameter equals pipe diameter.

Due the nature of dispersed gas (Methane) scenarios may lead to incident outcomes such as jet fire, flash fire and VCE and according what atmospheric condition is accompanied with incident outcome, there are two incident outcome cases for each incident outcome.

An event tree would commonly be used to identify and quantify the various consequence types (Jet fire, flash fire, VCE, or unignited safe dispersal) that might arise from a single release of hazardous material. Event trees are pictorial representation of logic models. Their theoretical foundation is based on logic theory. The frequency of an incident outcome is defined as the product of the scenario frequency and all succeeding conditional event probabilities leading to that incident outcome. The event tree has been provided to illustrate the relationship between an incident, incident outcomes, and incident outcome cases for a selected scenario [5].
In these event trees, different conditional event probabilities are used which must be determined carefully and according to historical, plant and process data. Immediate ignition probability in all scenarios has been estimated 0.05 because of the few number of electrical devices in CNG station. Delayed ignition probability depends to the discharge gas flow and differs in each scenario. In all scenarios the probability of flash fire in delayed ignition condition set at 0.4 and 0.6 for vapor cloud explosion [11]. Event trees related to Sc-01, Sc-04 and Sc-05 with the number of fatality due to any incident outcome case are shown in Fig 10-12.

<table>
<thead>
<tr>
<th>Incident</th>
<th>Incident outcome</th>
<th>Incident outcome case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rupture</td>
<td>Immediate ignition</td>
<td>Delayed ignition</td>
</tr>
<tr>
<td></td>
<td>YES (0.05)</td>
<td>YES (0.4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig 10. Sc-01: Rupture in dryer pipeline.
Incident | Incident outcome | Incident outcome case |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Leakage</td>
<td>Immediate ignition</td>
<td>Fatality</td>
</tr>
<tr>
<td></td>
<td>Delayed ignition</td>
<td>Frequency</td>
</tr>
<tr>
<td></td>
<td>Flash fire rather than VCE</td>
<td></td>
</tr>
<tr>
<td>YES (0.05)</td>
<td>Jet Fire</td>
<td>Day</td>
</tr>
<tr>
<td></td>
<td>NO (0.95)</td>
<td>Night</td>
</tr>
<tr>
<td>6.8(\times)10(^{2})</td>
<td>YES (0.4)</td>
<td>Flash fire</td>
</tr>
<tr>
<td>YES (0.1)</td>
<td>NO (0.6)</td>
<td>VCE</td>
</tr>
<tr>
<td>NO (0.9)</td>
<td>Safe Dispersion</td>
<td></td>
</tr>
</tbody>
</table>

Fig 11. Sc-04: 5mm hole diameter in dispenser pipeline.
### Incident Outcome Cases

<table>
<thead>
<tr>
<th>Incident Outcome</th>
<th>Incident outcome case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate ignition</td>
<td>Day: $4.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Delayed ignition</td>
<td>Night: $4.3 \times 10^{-4}$</td>
</tr>
<tr>
<td>Flash fire rather than VCE</td>
<td>Day: $6.6 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>Night: $6.6 \times 10^{-4}$</td>
</tr>
<tr>
<td>Safe Dispersion</td>
<td>Day: $9.9 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>Night: $9.9 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

**Fig 12. Sc-05: Rupture in dispenser pipeline.**

### 2.5. Frequency and consequence combination to estimate risk

Typical measures for probabilistic analysis of industrial risks include individual risk (IR) and societal risk (SR).

#### 2.5.1. Societal Risk

Societal risk is the relationship between the number of fatalities $N$ and the cumulative frequency $F$ at which the number $N$ or more fatalities are predicted to occur for all incident outcome cases [26-28]. The F-N curve is a method that is commonly used to present the results of a QRA. The number of people affected by all incident outcome cases (Eq. 5) must be determined, resulting in a list of all incident outcome cases, each with a frequency and the number of people affected (Tables 5-7). This information must then be put in cumulative frequency form in order to plot the F-N curve.
$F_N = \sum_i F_i \text{ for all incident outcome case } i \text{ which } N_i > N$

(9)

Where $F_N$ is the frequency of all incident outcome cases affecting $N$ or more people, $F_i$ the frequency of incident outcome case $i$, and $N_i$ is the number of people affected by incident outcome case $i$. The result is a data set giving $F_N$ as a function of $N$, which is then plotted (usually by a logarithmic plot) to give the F-N curve. The F-N curve for the CNG station is shown in Fig. 13 in comparison with risk margins which are acceptable in this country as low and high risk measures.

![Fig. 13. F-N Curve for CNG Station](image)

### 2.5.2. Individual Risk

Individual risk (IR) is intended as the annual probability of fatal injuries at any point $(x, y)$ within the analysed area, without taking into account the probability of presence of human in the same area. For the goals of the paper we have shown local risk in terms of iso-contour. Estimation of the individual risk at a specified location from a pipeline is complicated because the failure position is unknown. It can be estimated by integrating along the pipeline the probability of an accident multiplied by the fatality at the location from all accident scenarios, and can be written as the following equation [29]:
Where the subscript $i$ denotes the accident scenarios, $f_i$ the failure rate per unit length of the pipeline associated with the accident scenario $i$, $l$ the pipeline length, $P_i$ the fatality at the location associated with the accident scenario $i$ and $0 \leq L$ represent the ends of the interacting section of the pipeline in which an accident pose hazard to the specified location (Fig. 14). Eq. 10 can be implemented to all scenarios involving pipeline and all scenarios (Sc-01, Sc-04 and Sc-05) supposed to contribute in risk assessment involves pipeline.

Fig. 14. The relation among variables to determine individual risk

Fig. 15 presents the individual risk contours for QRA. The individual risk contours will not be affected by the number of persons living or working in the area around the station. Thus, a person located on the $1.0 \times 10^{-6}$ individual risk contour for one year has one chance in a million of being fatally injured by the hazards associated with releases of methane in the CNG station, regardless of how many other persons are located in the same area.
3. Conclusion
PHA and HAZOP studies of CNG station identified the dryer and dispensing sections of the station to be the most hazardous sections. Methane is a flammable chemical which may lead to fire and explosion. Hence discharge of methane was considered as the top event for the fault tree analysis in all selected scenarios. The basic events responsible for the top event occurrence were identified using the probabilistic fault tree analysis technique and historical data. Finally, the results from F-N curve reveal that measured risk is located in ALARP region meaning there is a need to reduce the risk. Also, the results from iso-contours confirm this finding. Hence appropriate offsite and onsite emergency plans need to be formulated to aid evacuation in the event of dangerous methane release.

Results obtained from QRA considering to PHA and HAZOP studies revealed several options which can be modified to reduce risk, they mainly include installing gas detectors in dryer section and protecting it against unwanted high pressure condition and reducing the length of high pressure pipeline and the number of connections in dispensing section to decrease the probability of likely accidents.
References


