RISK ASSESSMENT (RA) AND PRELIMINARY HAZARD AND OPERABILITY (HAZOP) STUDY

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1.1 *RISK ASSESSMENT*

This section on Risk Assessment (RA) aims to provide a systematic analysis of the major risks that may arise as a result of the expansion of BPCL's existing LPG storage and bottling plant in Solapur district, Maharashtra. The RA process outlines rational evaluations of the identified risks based on their significance and provides the outline for appropriate preventive and risk mitigation measures. The output of the RA will contribute towards strengthening of the Emergency Response Plan (ERP) in order to prevent damage to personnel, infrastructure and receptors in the immediate vicinity of the plant. Additionally, the results of the RA can also provide valuable inputs for keeping risk at As Low As Reasonably Practicable (ALARP) and arriving at decisions for mitigation of high risk events.

The following section describes the objectives, methodology of the risk assessment study and assessment for each of the potential risk separately. This includes identification of major hazards, hazard screening and ranking, frequency and consequence analysis for major hazards. The hazards have been quantitatively evaluated through a criteria base risk evaluation matrix. Risk mitigation measures to reduce significant risks to acceptable levels have also been recommended as a part of the risk assessment study.

1.1.1 *RA Study Objective*

The overall objective of this RA with respect to the proposed project involves identification and evaluation of major risks, prioritizing risks identified based on their hazard consequences and using the outcome to guide and strengthen both onsite and offsite ERP. Hence in order to ensure effective management of any emergency situations that may arise from LPG storage and bottling activities, the following specific objectives need to be achieved.

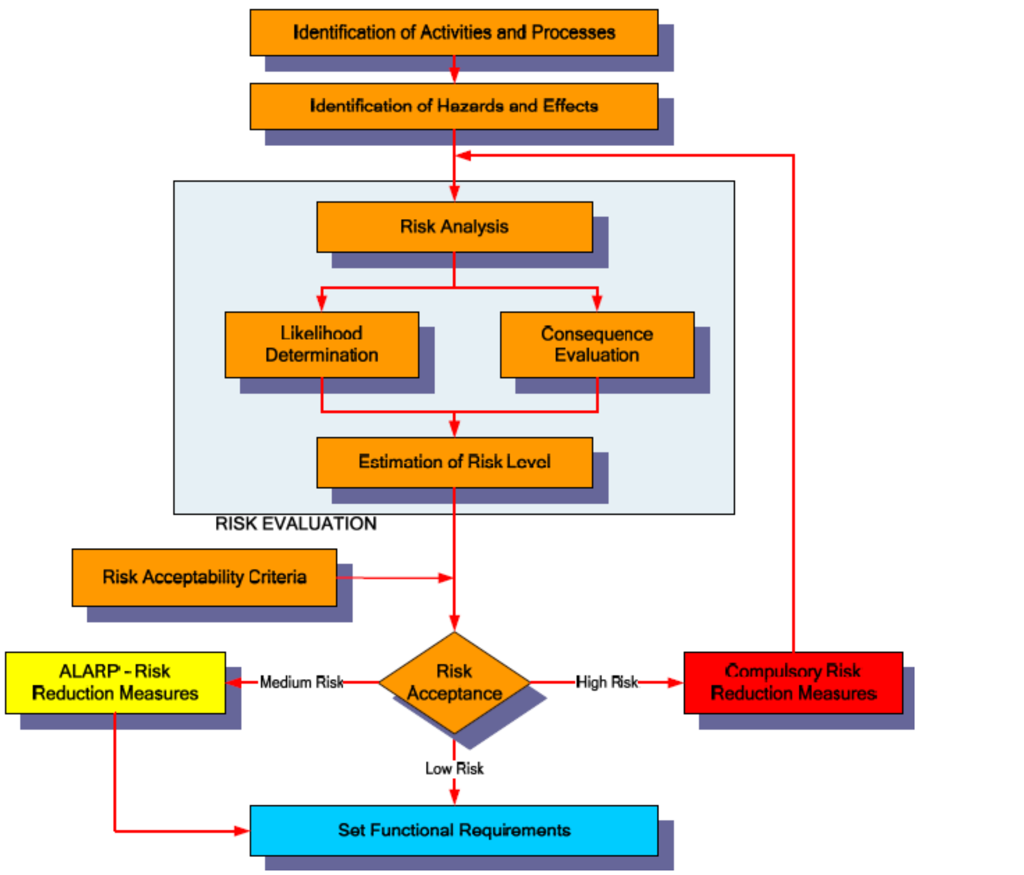
- Identify potential risk scenarios that may arise from storage of LPG in pressurised vessels including its loading and unloading operations;
- Review existing information and historical databases to arrive at possible likelihood of such risk scenarios;
- Predict the consequences of such potential risk scenarios and if consequences are observed to be high, establish the same through application of quantitative simulations; and
- Recommend feasible preventive and risk mitigation measures as well as provide inputs for strengthening of the project Emergency Response Plan (ERP).

1.1.2 RA Methodology

The risk assessment process is primarily based on likelihood of occurrence of the risks identified and their possible hazard consequences particularly being evaluated through hypothetical accident scenarios. With respect to the proposed project, major risks viz. leaks and rupture of storage tanks and pipeline/flanges/compressors have been assessed and evaluated through a risk matrix generated to combine the risk severity and likelihood factor. Risk associated with the proposed expansion project have been determined semi-quantitatively as the product of likelihood/probability and severity/consequence by using order of magnitude data (*risk ranking = severity/consequence factor X likelihood/probability factor*). Significance of such project related risks was then established through their classification as high, medium, low, very low depending upon risk ranking.

The risk matrix is widely accepted as standardized method of risk assessment and is preferred over purely quantitative methods, given that it's inherent limitations to define a risk event is certain. Application of this tool has resulted in the prioritization of the potential risks events for the existing operations and proposed expansion thus providing the basis for drawing up risk mitigation measures and leading to formulation of plans for risk and emergency management. The overall approach is summarized below in ***Figure 1.1.***

Figure 1.1 Risk Assessment Methodology



1.1.3 *Hazard Identification*

Hazard identification for the purposes of this RA involves the qualitative review of the project design and operations including relevant information provided by BPCL. Available literature related to LPG bottling plant and tankage failure risk assessment worldwide, terminal design and configuration, work procedures were reviewed in light of the proposed project activities. Information (including historical data) related to possible hazards associated LPG storage and bottling activities were also sourced from veritable secondary sources viz. UKHSE, OGP etc.

Based on the result of this exercise, potential hazards that may arise due to proposed project were identified and a qualitative understanding of their probability and significance were obtained.

Taking into account the applicability of different risk aspects the following hazards have been identified with respect to the proposed project which has been dealt in detail in the subsequent sections.

- Release of LPG from failure of loading/unloading line or hose including pumps and compressors leading jet fire (from immediate ignition) or flash fire/VCE (from delayed ignition);and
- Accidental release of LPG from failure of mounted storage vessels (MSVs) and spherical tanks leading to jet fire, flash fire or vapour cloud explosion (VCE).

Hazards from LPG

Liquefied Petroleum Gas (LPG) is a colourless and odourless gas. LPG at atmospheric pressure and temperature is a gas which is 1.5 to 2.0 times heavier than air. It is readily liquefied under moderate pressures. Since LPG vapour is heavier than air, it would normally settle down at ground level/ low-lying places, and accumulate in depressions. LPG has an explosive range of 1.8% to 9.5% volume of gas in air. This is considerably narrower than other common gaseous fuels. This gives an indication of hazard of LPG vapour accumulated in low lying area in the eventuality of the leakage or spillage. The auto-ignition temperature of LPG is around 410-580°C and hence it will not ignite on its own at normal temperature. As the gas disperses, it mixes with the surrounding air and warms up. The vapour cloud will only ignite if it encounters an ignition source while concentrated within its flammability range.

The hazards effects of LPG in the event of an accidental release from tanks, piping or equipment, including the characteristics of the possible hazardous effects have been described below.

Jet Fire

Jet fires result from ignited releases of pressurized flammable gas or superheated/pressurized liquid. The momentum of the release carries the material forward in a long plume entraining air to give a flammable mixture. Jet fires only occur where the LPG is being handled under pressure or when handled in gas phase and the release is subjected to immediate ignition.

Flash Fire

Upon release, LPG can form a vapour cloud that spreads horizontally. The maximum dispersion distance of flammable vapour cloud is defined by the lower flammability limit of the vapour material. If little or no wind is present and atmospheric conditions are very stable, the spreading cloud mixes slowly with oxygen. It can burst into flames if ignited and flash back to the source of the release. As such, when a flammable vapour cloud encounters an ignition source in a non-congested and unconfined space, the cloud can catch fire and burn rapidly in a flash fire (which is the non-explosive combustion of a vapour cloud resulting from the release of flammable material into the air) because that portion of the cloud where the concentration is in the flammable range (i.e., between the Lower and Upper Explosive Limits, LEL and UEL) is already pre-mixed to the right mixture of fuel and air for burning to occur. Following the rapid burning, the part of the cloud where the fuel-air concentration is above the UEL may continue to slowly burn as air mixes with the cloud. Possible hazards associated with a flash fire include thermal radiation, smoke, and toxic by-products from the fire.

Vapour Cloud Explosion

When a flammable chemical is released into the atmosphere, it forms a vapour cloud that will disperse as it travels downwind. If the cloud encounters an ignition source, the parts of the cloud where the concentration is within the flammable range will burn. In some situations, the cloud will burn so fast that it creates an explosive force (blast wave).Due to its chemical/combustion properties, the release and dispersion of LPG, if ignited, may also result in an explosion if there is sufficient mass within the cloud (e.g., >1 ton). The effects of an explosion, defined by blast overpressure, can be significant.As such, if the vapour cloud is ignited in a confined or congested space, an explosion could also occur.

As part of LPG transportation, storage and bottling for local distribution, BPCL has opted for MSVs for storage of LPG. Hence in this case, there is no possibility of Boiling Liquid Expanding Vapour Explosion (BLEVE) as the mounding or burying of LPG tanks gives protection from fire engulfment and significantly reduces the possibility of a BLEVE. Therefore, from MSV, release of LPG is possible only from leakage in piping, valves or flanges, etc. However such scenario is considered for the aboveground spherical vessels and bulk tank trucks carrying LPG.

1.1.4 *Frequency Analysis*

The frequency analysis of the hazards identified with respect to the proposed expansion project was undertaken to estimate the likelihood of their occurrences during the project life cycle. Hazard frequencies in relation to the proposed project were estimated based on the analysis of historical accident frequency data and professional judgment. Based on the range of probabilities arrived at for different potential hazards that may be encountered with respect to the existing and proposed storage and bottling of LPG, the following frequency categories and criteria have been defined (Refer ***Table 1.1***).

Table 1.1 Frequency Categories and Criteria

Likelihood Ranking	Criteria Ranking (cases/year)	Frequency Class
5	Likely to occur often in the life of the project, with a probability greater than 10^{-1}	Frequent
4	Will occur several times in the life of project, with a probability of occurrence less than 10^{-1}, but greater than 10^{-2}	Probable
3	Likely to occur sometime in the life of a project, with a probability of occurrence less than 10^{-2}, but greater than 10^{-3}	Occasional/Rare
2	Unlikely but possible to occur in the life of a project, with a probability of occurrence less than 10^{-3}, but greater than 10^{-6}	Remote
1	So unlikely it can be assumed that occurrence may not be experienced, with a probability of occurrence less than 10^{-6}	Improbable

Source: Guidelines for Developing Quantitative Safety Risk Criteria – Centre for Chemical Process and Safety

Frequency Analysis – LPG Storage Tanks

An effort has been made to understand the causal factors for failure of LPG storage tanks. Review of veritable literature[1] reveals such failure can be attributed to the following causal factors:

- Maintenance/hot work (sparks, welding, etc.)
- Operational Error (high inlet temperature, overfilling, etc.)
- Equipment failure (thermostat failure, discharge valve rupture, corrosion, etc.)
- Lightning (poor grounding, rim seal leaks, etc.)
- Static Electricity (rubber seal cutting, poor grounding, improper sampling procedures, etc.)
- Tank rupture (subsidence, poor fabrication, high pressure transfer from downstream)

The failure frequency of LPG storage tanks is established based on review of the *UK HSE Database - Failure Rate and Event Data for use within Risk*

[1]J.I. Chang, C.-C. Lin / Journal of Loss Prevention in the Process Industries 19 (2006) 51–59

Assessments (28/06/2012). The LPG pressurised vessel failure rates based on the type of has been presented in ***Table 1.2*** below

Table 1.2 LPG Pressure Vessel - Failure Rates based on Type of Release

Sl. No	Type of Release	Failure Rate (per vessel per year)	Frequency
1.	Catastrophic	2.0 x 10-6	Remote
2.	BLEVE	1 X 10^{-5}	Remote
3.	50mm dia hole	5.0 x 10-6	Remote
4.	25mm dia hole	5.0 x 10-6	Remote
5.	13mm dia hole	1.0 x 10-5	Remote

Source: UK HSE Database

1.1.5 Event Tree Analysis

Event tree analysis (ETA) is used to model the evolution of an event from the initial release through to the final outcome such as jet fire, fireball, flash fire etc. This may depend on factors such as whether immediate or delayed ignition occurs, or whether there is sufficient congestion to cause a vapour cloud explosion.

1.1.6 Storage Vessel Scenarios

Immediate ignition is assigned a probability of 0.3 for large releases following Cox, Lees and Ang (Lees, 1996), see ***Table 1.3***. Immediate ignition results in a fireball.

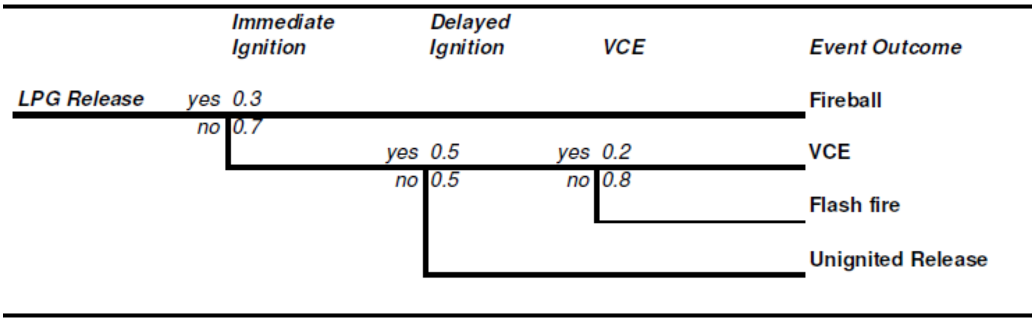
Table 1.3 Ignition Probabilities from Cox, Lees and Ang

Sl. No	Leak Rate	Probability of Ignition	
		Gas Release	Liquid Release
1	Minor (< 1kg/s)	0.01	0.01
2	Major (1-50 kg/s)	0.07	0.03
3	Massive (>50 kg.s)	0.3	0.08

Delayed ignition is assigned a probability of 0.5 (ENSR, 2008).

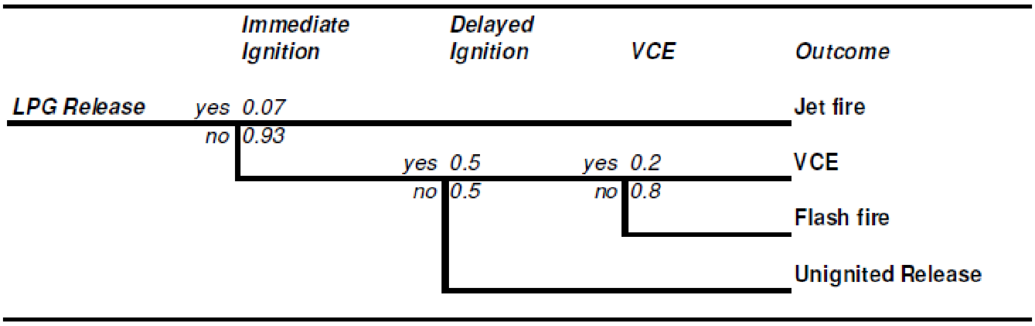
Delayed ignition may produce a flash fire or vapour cloud explosion (VCE).To achieve a VCE, a dispersing vapour cloud must accumulate in a confined and/or congested area and subsequently be ignited. Given the fairly open nature of the surroundings, an explosion probability of 0.2 was assumed (Refer ***Figure 1.2)***

Figure 1.2 *Even Tree for Catastrophic Rupture of LPG Storage Vessel*



For smaller leaks, a lower immediate ignition probability of 0.07 is applied from ***Table 1.2***. In other aspects, the event tree (***Figure 1.3***) is similar. Immediate ignition results in a jet fire, while delayed ignition may produce a flash fire or VCE.

Figure 1.3 *Even Tree for Partial Failure of LPG Storage Vessel*



1.1.7 Consequence Analysis

In parallel with the frequency analysis, hazard prediction / consequence analysis exercises were undertaken to assess the likely impact of project related risks on onsite personnel, infrastructure and environment. In relation to the proposed project as well as the existing activities have been considered, the estimation of the consequences for each possible event has been based either on accident frequency, consequence modeling or professional judgment, as appropriate. Overall, the consequence analysis takes into account the following aspects:

- Nature of impact on environment and community;
- Occupational health and safety;
- Asset and property damage;
- Corporate image; and
- Timeline for restoration of property damage.

The following criteria for consequence rankings (Refer ***Table 1.4)*** have been drawn up in context of the possible consequences of the risk events that may occur during the proposed project operations:

Table 1.4 Severity Categories and Criteria

Consequence	Ranking	Criteria Definition
Catastrophic	5	• Multiple fatalities/permanent total disability to more than 50 persons. • Net negative financial impact of >10 crores • International media coverage • Loss of corporate image and reputation
Major	4	• Single fatality/permanent total disability to one or more persons • Net negative financial impact of 5 -10 crores • National stakeholder concern and media coverage.
Moderate	3	• Short term hospitalization & rehabilitation leading to recovery • Net negative financial impact of 1-5 crores • State wide media coverage
Minor	2	• Medical treatment injuries • Net negative financial impact of 0.5 – 1 crore • Local stakeholder concern and public attention
Insignificant	1	• First Aid treatment • Net negative financial impact of <0.5 crores. • No media coverage

Risk Evaluation

Based on ranking of likelihood and frequencies, each identified hazard has been evaluated based on the likelihood of occurrence and the magnitude of consequences. The significance of the risk is expressed as the product of likelihood and the consequence of the risk event, expressed as follows:

Significance = Likelihood X Consequence

The ***Table 1.5*** below illustrates all possible product results for the five likelihood and consequence categories while the ***Table 1.6*** assigns risk significance criteria in three regions that identify the limit of risk acceptability. Depending on the position of the intersection of a column with a row in the risk matrix, hazard prone activities have been classified as low, medium and high thereby qualifying for a set of risk reduction / mitigation strategies.

Table 1.5 Risk Matrix

			Likelihood →				
			Frequent	**Probable**	**Unlikely**	**Remote**	**Improbable**
			5	**4**	**3**	**2**	**1**
Consequence →	**Catastrophic**	**5**	25	20	15	10	5
	Major	**4**	20	16	12	8	4
	Moderate	**3**	15	12	9	6	3
	Minor	**2**	10	8	6	4	2
	Insignificant	**1**	5	4	3	2	1

Table 1.6 Risk Criteria and Action Requirements

S.N.	Risk Significance	Criteria Definition & Action Requirements
1	**High (16 - 25)**	**"Risk requires attention"** – Project HSE Management need to ensure that necessary mitigation are adopted to ensure that possible risk remains within acceptable limits
2	**Medium (10 – 15)**	**"Risk is tolerable"** – Project HSE Management needs to adopt necessary measures to prevent any change/modification of existing risk controls and ensure implementation of all practicable controls.
3	**Low (5 – 9)**	**"Risk is acceptable"** – Project related risks are managed by well-established controls and routine processes/procedures. Implementation of additional controls can be considered.
4	**Very Low (1 – 4)**	**"Risk is acceptable"** – All risks are managed by well-established controls and routine processes/procedures. Additional risk controls need not to be considered

Consequence Analysis – Tankages

Consequence analysis comprise of physical effects modelling to determine the effects zone of the various hazardous outcomes such as jet fires and fireballs. In this study, consequence analysis is performed using ALOHA risk model.

LPG is generally a mixture of 60% Butane and 40% propane mix. Vessels are conservatively assumed to be full at time of failure; 300 metric tonnes (MT) for each proposed MSV and 650 metric tonnes (MT) for each of the existing LPG sphere. LPG is stored in liquid form by pressurisation to moderate pressures of about 14.5kg/cm^2, at a temperature varying within -27°C to 55°C. A significant portion of LPG flashes upon release, forming a vapour cloud. Liquid droplets may be entrained with the vapour or rainout to the ground forming a liquid pool. In the current study, pool fires were not found to be significant compared to jet fires. The more serious jet fire consequences were therefore used in the analysis.

Taking into account the earlier discussion related to LPG hazards and frequency analysis the following hypothetical risk scenarios (Refer ***Table 1.7***) have been considered for modelling with respect to the storage of LPG in tanks.

Table 1.7 LPG Sphere & MSV – Risk Modelling Scenarios

Scenario	Tank	Tank Diameter (m)	Tank Height (m)	Tank Volume (MT)	Accident Scenario
1.	Existing LPG Sphere	14.0	-	650	50mm leak
2.		14.0	-	650	100mm leak
3.		14.0	-	650	300mm leak
4.		14.0	-	650	Catastrophic failure leading to VCE
5.		14.0	-	650	Catastrophic failure leading to BLEVE
6.	Proposed LPG MSV	5.0	37.5	300	50mm leak
7.		5.0	37.5	300	100mm leak

8.		5.0	37.5	300	300mm leak
9.		5.0	37.5	300	Catastrophic failure leading to VCE
10.	LPG Bulk Tanker Truck	1.8	9.2	17.0	50mm leak
11.		1.8	9.2	17.0	100mm leak
12.		1.8	9.2	17.0	300mm leak
13.		1.8	9.2	17.0	Catastrophic failure leading to VCE
14.		1.8	9.2	17.0	Catastrophic failure leading to BLEVE

The storage vessel failure risk scenarios have been modeled using ALOHA and interpreted in terms of Thermal Radiation Level of Concern (LOC) encompassing the following threshold values (measured in kilowatts per square meter) to create the default threat zones:

Red: 10 kW/ (sq. m) -- potentially lethal within 60 sec;

Orange: 5 kW/ (sq. m) -- second-degree burns within 60 sec; and

Yellow: 2 kW/ (sq. m) -- pain within 60 sec

For vapour cloud explosion, the following threshold level of concern has been interpreted in terms of blast overpressure as specified below:

Red: 8.0 psi – destruction of buildings;

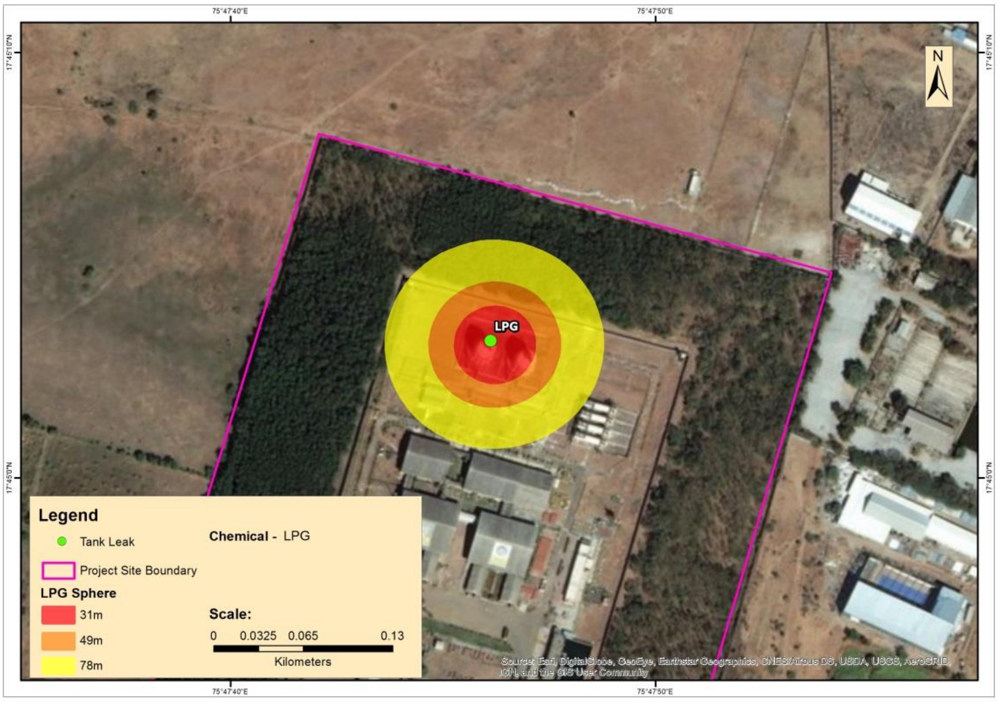
Orange: 3.5 psi – serious injury likely; and

Yellow: 1.0 psi – shatters glass

Scenario 1: LPG Storage Sphere Leak (50mm dia)

The jet fire threat zone plot for release and ignition of LPG from storage sphere leak of 50mm dia is represented in ***Figure 1.4***.

Figure 1.4 ***Threat Zone Plot – LPG Storage Sphere Leak (50mm dia)***



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 31 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 49 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

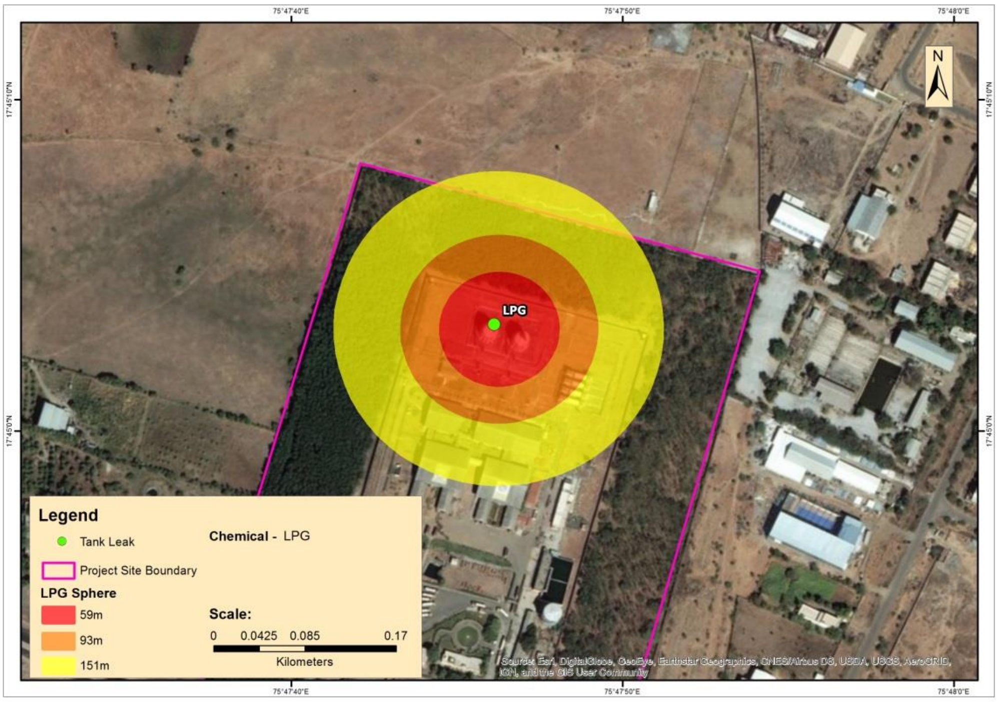
Yellow: 78 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the storage sphere leak (50mm) will be experienced to a maximum radial distance of 31m from the source with potential lethal effects within 1 minute.

Scenario 2: LPG Storage Sphere Leak (100mm dia)

The jet fire threat zone plot for release and ignition of LPG from storage sphere leak of 100mm dia is represented in ***Figure 1.5***.

Figure 1.5 Threat Zone Plot – LPG Storage Sphere Leak (100mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 59 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 93 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

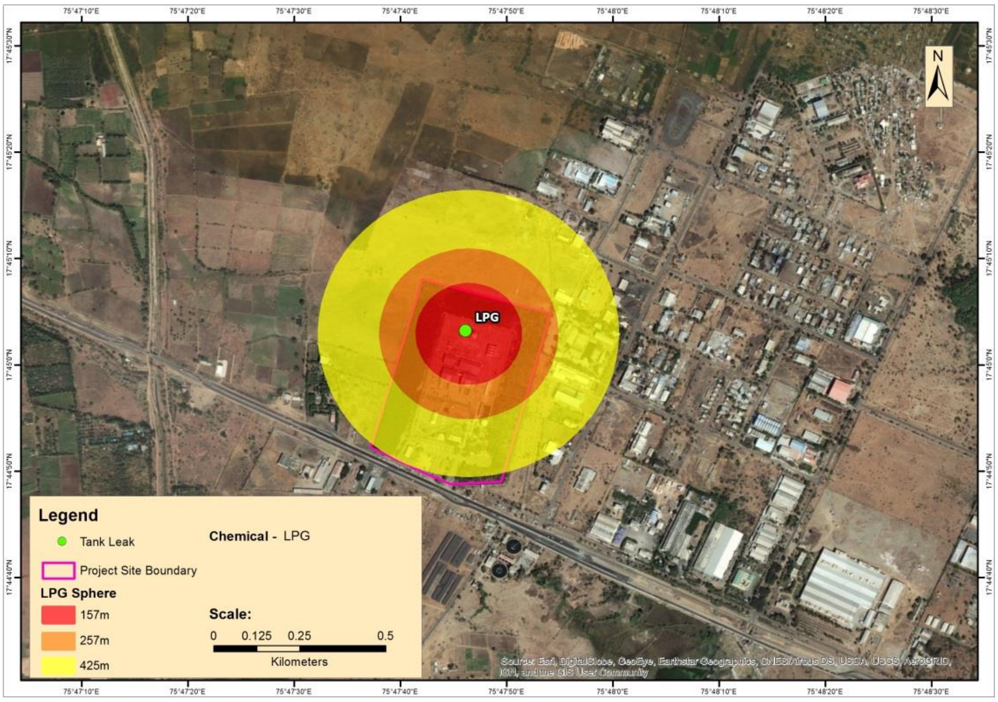
Yellow: 151 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the storage sphere leak (100mm) will be experienced to a maximum radial distance of 59m from the source with potential lethal effects within 1 minute.

Scenario 3: LPG Storage Sphere Leak (300mm dia)

The jet fire threat zone plot for release and ignition of LPG from storage sphere leak of 300mm dia (worst case) is represented in ***Figure 1.6*** below.

Figure 1.6 Threat Zone Plot – LPG Storage Sphere Leak (300mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 157 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 257 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

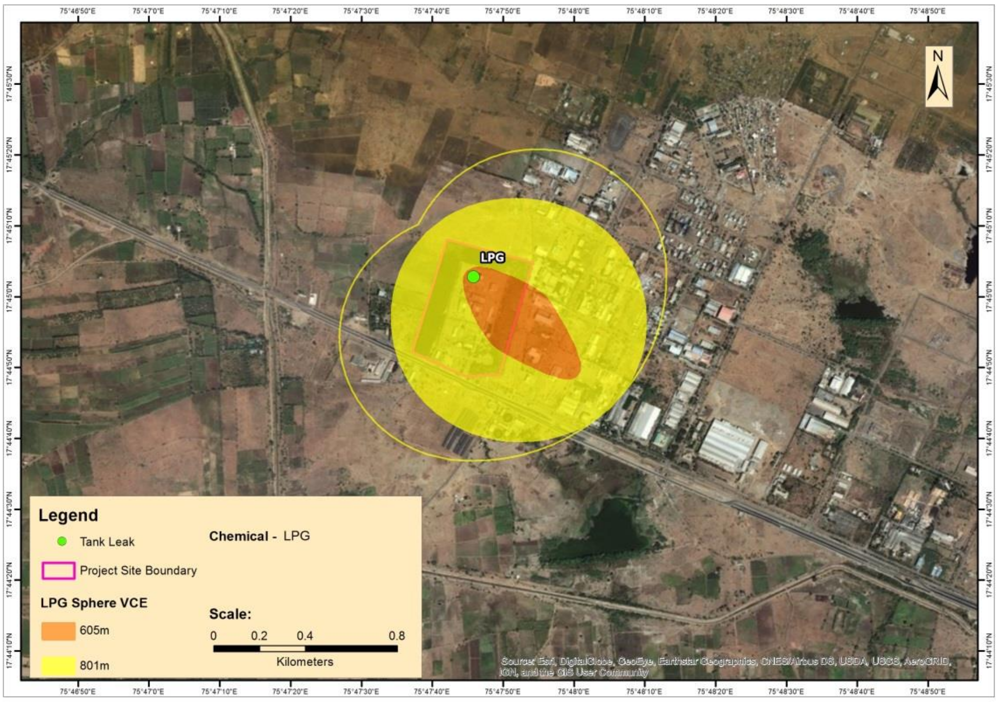
Yellow: 425 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the storage sphere leak (300mm) will be experienced to a maximum radial distance of 157m from the source with potential lethal effects within 1 minute.

__Scenario 4: LPG Storage Sphere Catastrophic Failure causing VCE__

The blast overpressure threat zone plot for VCE resulting from storage sphere failure (worst case) is represented in ***Figure 1.7*** below.

Figure 1.7 Threat Zone Plot – LPG Storage Sphere Failure leading to VCE



Source: ALOHA

THREAT ZONE:

Threat Modeled: Overpressure (blast force) from vapor cloud explosion

Level of Congestion: uncongested

Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)

Orange: 605 meters --- (3.5 psi = serious injury likely)

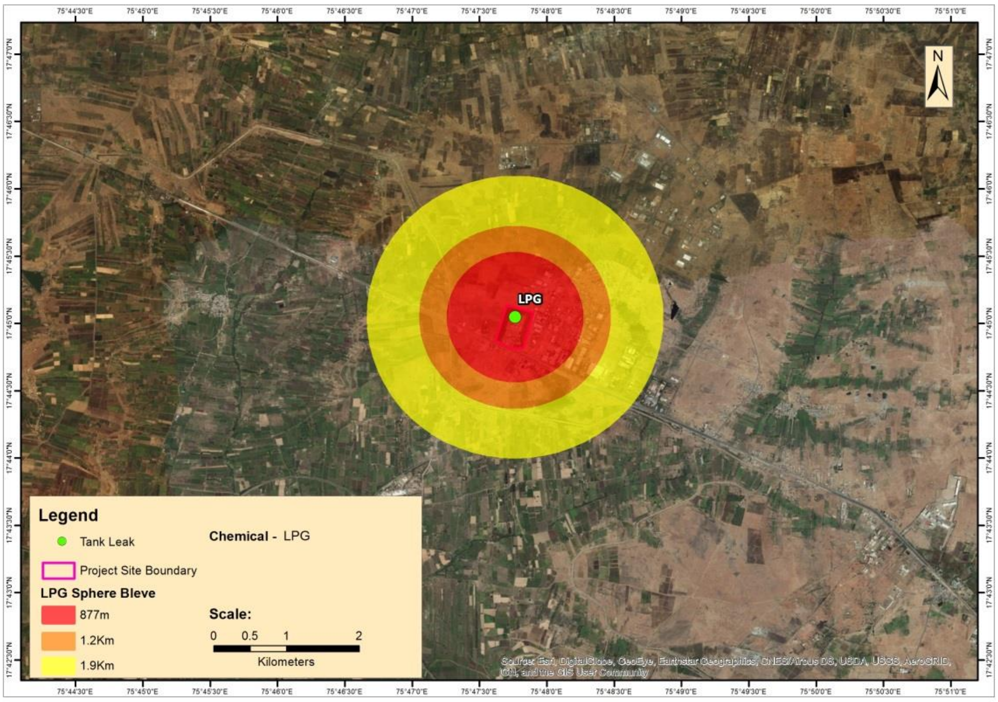
Yellow: 801 meters --- (1.0 psi = shatters glass)

For congested conditions, the blast overpressure of 3.5 psi and 1.0 psi is likely to be experienced within a radial distance of 605 m and 801m respectively. The LOC was never exceeded for the maximum blast overpressures of 8.0 psi.

__Scenario 5: LPG Storage Sphere Catastrophic Failure causing BLEVE__

The fireball threat zone plot from catastrophic failure of LPG storage sphere causing BLEVE (worst case) is represented in ***Figure 1.8*** below.

Figure 1.8 Threat Zone Plot – LPG Storage Sphere failure leading to BLEVE



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from fireball

Red : 877 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 1.2 kilometers --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

Yellow: 1.9 kilometers --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from catastrophic failure LPG storage sphere failure leading to BLEVE will be experienced to a maximum radial distance of 877m from the source with potential lethal effects within 1 minute.

For calculating the risk significance of LPG storage sphere failure, the likelihood ranking is considered to be "2" as the probability (BLEVE) for such failure is computed to be ~1 $x10^{-5}$per year. With respect to consequence ranking, for the aforesaid incident it has been identified to be as "5" given for a worst case scenario lethal effects (BLEVE) is likely to be experienced within a maximum radial zone ~877 meters. For a VCE scenario, the worst effect of blast overpressure is computed to be experienced within a radial zone of ~605 meters. However, considering the isolated LPG storages will be equipped appropriate state of the art process safety controls in the form of safety relief valves, remote operate safety valves (ROSVs), excess flow check valves (EFCVs), automation gauges, gas monitoring/detection system and automated alarm and trip system, the risk is considered to less significant. Further all processes will be monitored by PLC based automation system.

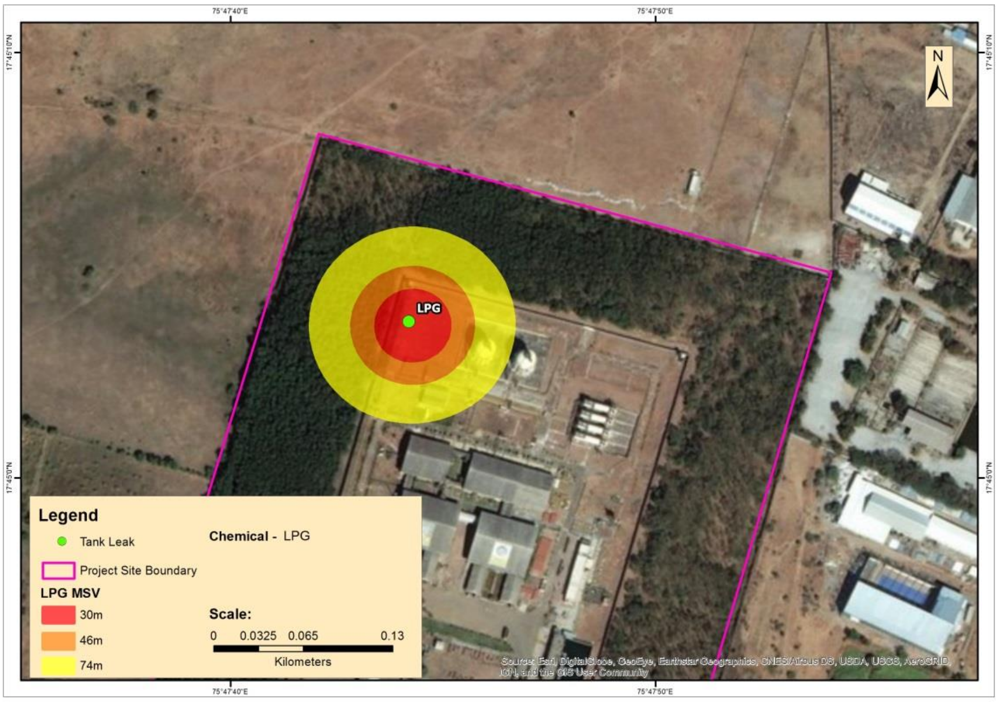
Risk Ranking – LPG Storage Sphere Failure (Worst Case Scenario)

Likelihood ranking	2	Consequence ranking	5
Risk Ranking & Significance = 10 i.e. "Medium" i.e. Risk is Tolerable and can be managed through adoption of necessary controls.			

Scenario 6: LPG MSV Leak (50mm dia)

The jet fire threat zone plot for release and ignition of LPG from MSV leak of 50mm dia is represented in ***Figure 1.9*** below.

Figure 1.9 Threat Zone Plot – LPG MSV Leak (50mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 30 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 46 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

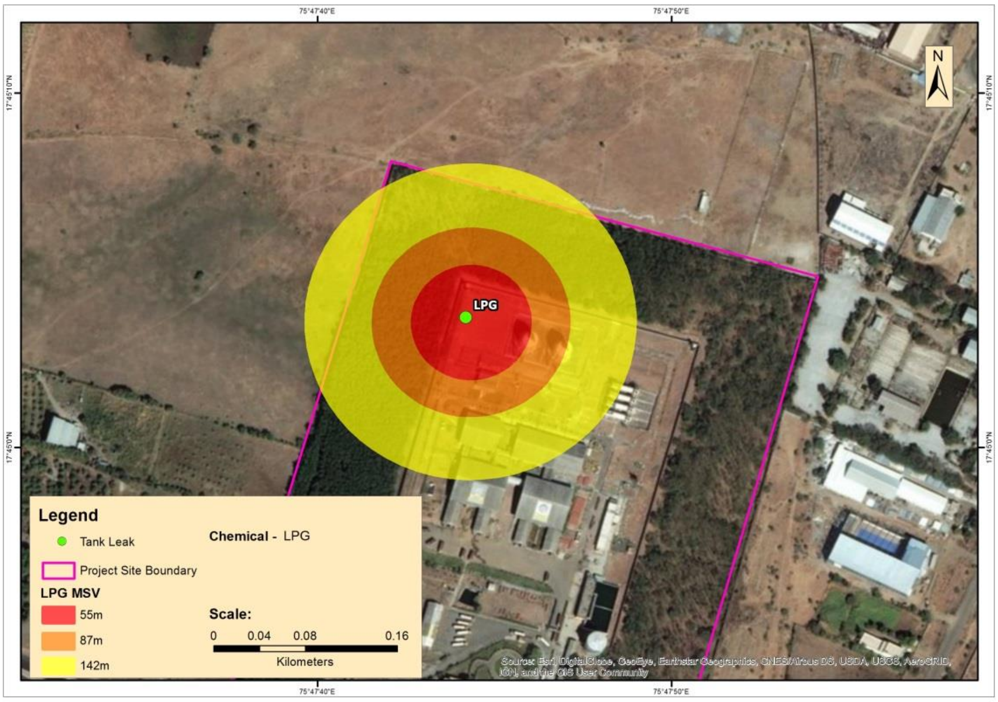
Yellow: 74 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the MSV leak (50mm) will be experienced to a maximum radial distance of 30m from the source with potential lethal effects within 1 minute.

Scenario 7: FSU LNG Storage Tank Leak (100mm dia)

The jet fire threat zone plot for release and ignition of LPG from MSV leak of 100mm dia is represented in ***Figure 1.10*** below.

Figure 1.10 ***Threat Zone Plot – LPG MSV Leak (100mm dia)***



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 55 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 87 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

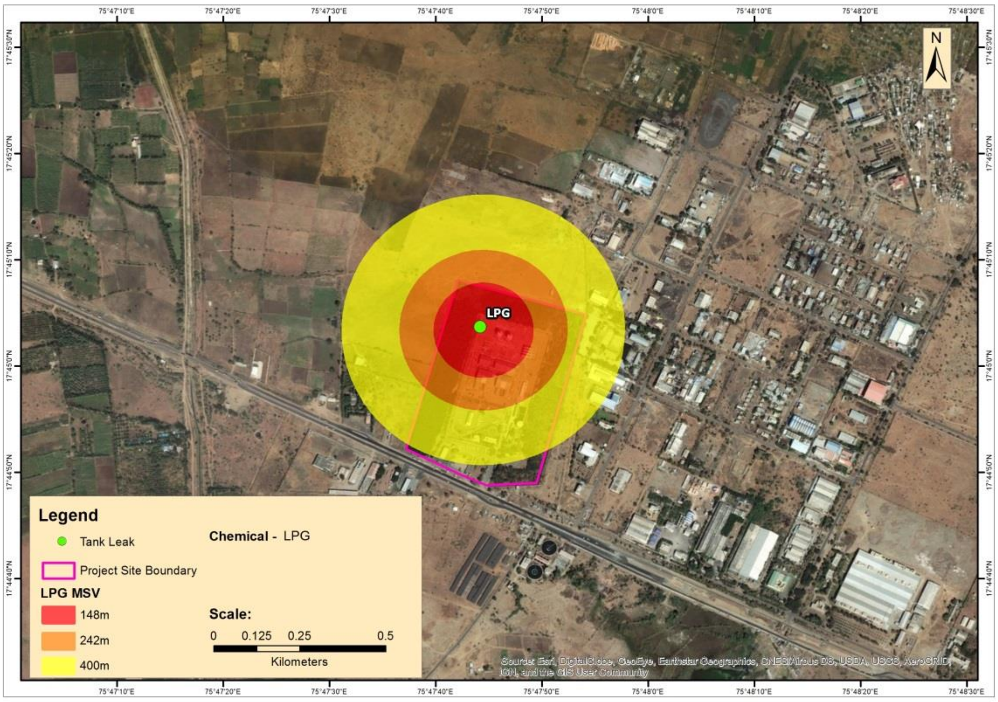
Yellow: 142 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the MSV leak (100mm) will be experienced to a maximum radial distance of 55m from the source with potential lethal effects within 1 minute.

Scenario 8: LPG MSV Leak (300mm dia)

The jet fire threat zone plot for release and ignition of LPG from MSV leak of 300mm dia (worst case) is represented in ***Figure 1.11*** below.

Figure 1.11 Threat Zone Plot – LPG MSV Leak (300mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 148 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 242 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

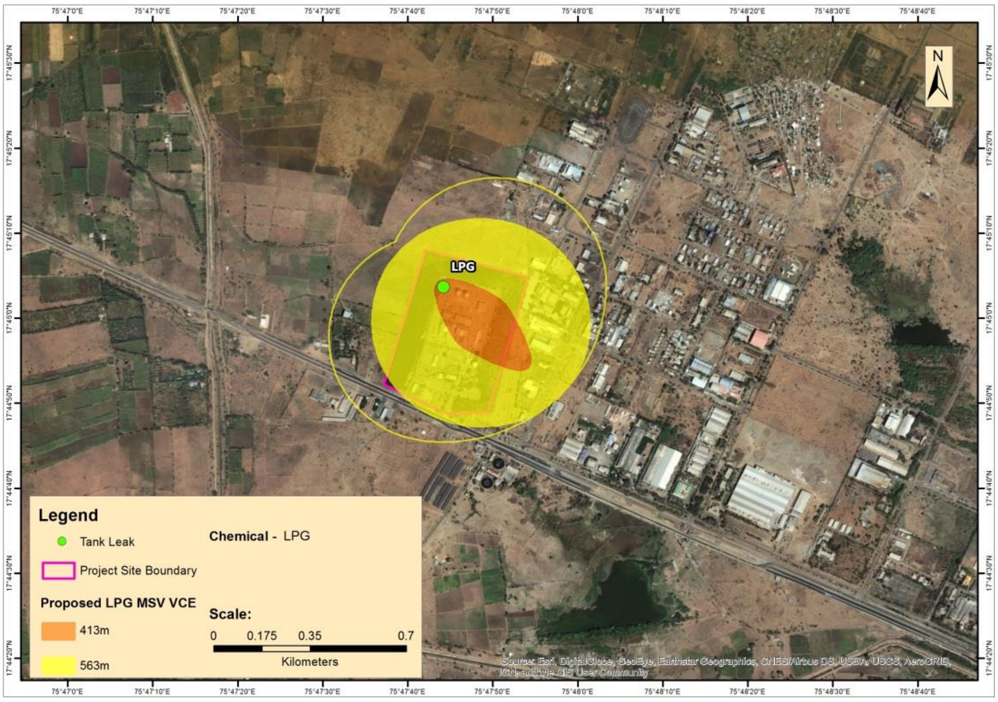
Yellow: 400 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the MSV leak (300mm) will be experienced to a maximum radial distance of 148m from the source with potential lethal effects within 1 minute.

Scenario 9: LPG MSV Catastrophic Failure causing VCE

The blast overpressure threat zone plot for VCE resulting from LPG MSV catastrophic failure (worst case) is represented in ***Figure 1.12*** below.

Figure 1.12 Threat Zone Plot – LPG MSV Failure leading to VCE



Source: ALOHA

THREAT ZONE:

Threat Modeled: Overpressure (blast force) from vapor cloud explosion

Level of Congestion: uncongested

Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)

Orange: 413 meters --- (3.5 psi = serious injury likely)

Yellow: 563 meters --- (1.0 psi = shatters glass)

For congested conditions, the blast overpressure of 3.5 psi and 1.0 psi is likely to be experienced within a radial distance of 413m and 563m respectively. The LOC was never exceeded for the maximum blast overpressures of 8.0 psi.

For calculating the risk significance of LPG MSV failure, the likelihood ranking is considered to be "2" as the failure probability for such failure is computed to be ~2 $x10^{-6}$per year. With respect to consequence ranking, for the aforesaid incident it has been identified to be as "5" given for a worst case scenario (VCE) serious effects is likely to be experienced within a maximum radial zone ~413 meters. However, considering the isolated LPG storages will be equipped appropriate state of the art process safety controls in the form of safety relief valves, remote operate safety valves (ROSVs), excess flow check valves (EFCVs), automation gauges, gas monitoring/detection system and automated alarm and trip system, the risk is considered to less significant. Further all processes will be monitored by PLC based automation system.

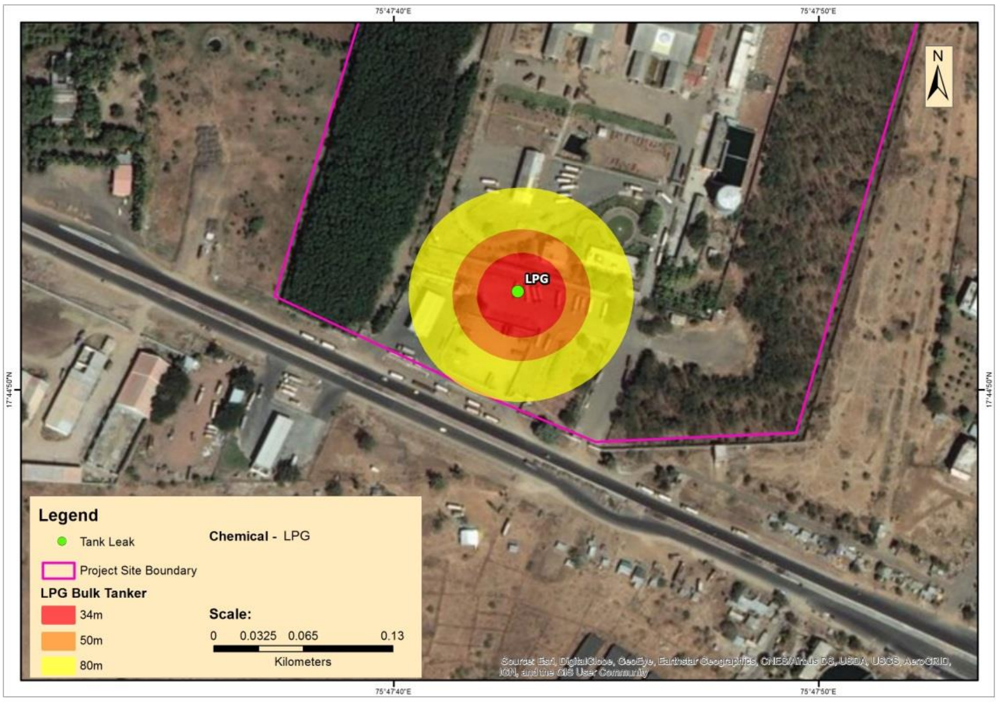
Risk Ranking – LPG MSV Failure (Worst Case Scenario)

Likelihood ranking	**2**	**Consequence ranking**	**5**
Risk Ranking & Significance = 10 i.e. "Medium" i.e. Risk is Tolerable and can be managed through adoption of necessary controls.			

__Scenario 10: LPG Bulk Tank Truck (50mm dia)__

The jet fire threat zone plot for release and ignition of LPG from bulk tank truck leak of 50mm dia is represented in ***Figure 1.13*** below.

Figure 1.13 Threat Zone Plot – LPG Bulk Tank Truck Leak (50mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 34 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 50 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

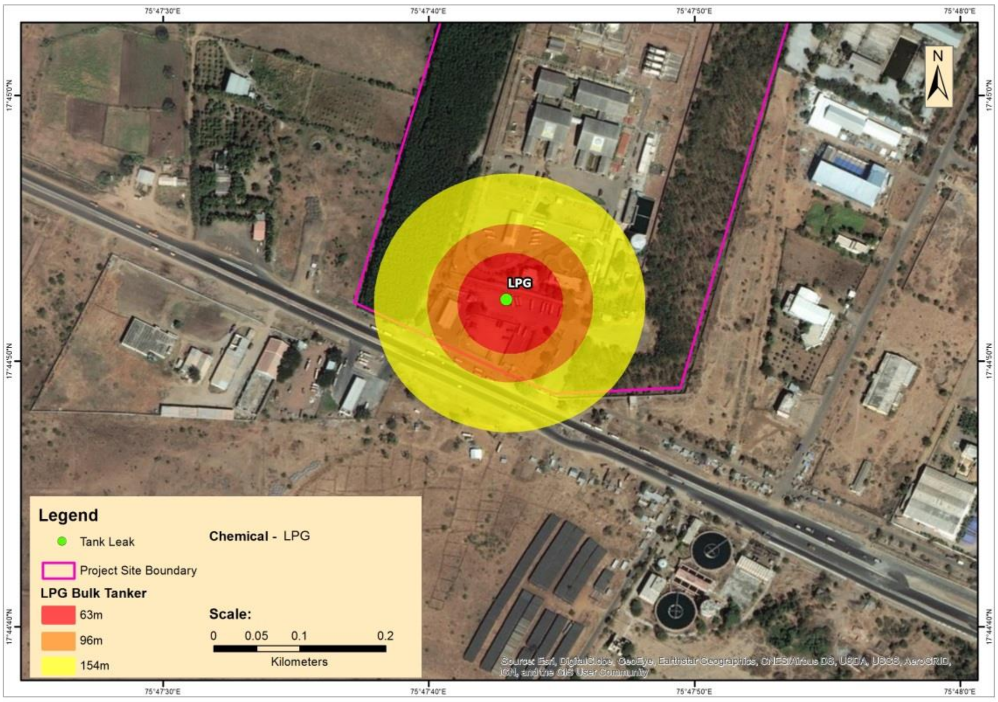
Yellow: 80 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the bulk tank truck leak (50mm) will be experienced to a maximum radial distance of 34m from the source with potential lethal effects within 1 minute.

Scenario 11: LPG Bulk Tank Truck (100mm dia)

The jet fire threat zone plot for release and ignition of LPG from bulk tank truck leak of 100mm dia is represented in ***Figure 1.14*** below.

Figure 1.14 Threat Zone Plot – LPG Bulk Tank Truck Leak (100mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 63 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 96 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

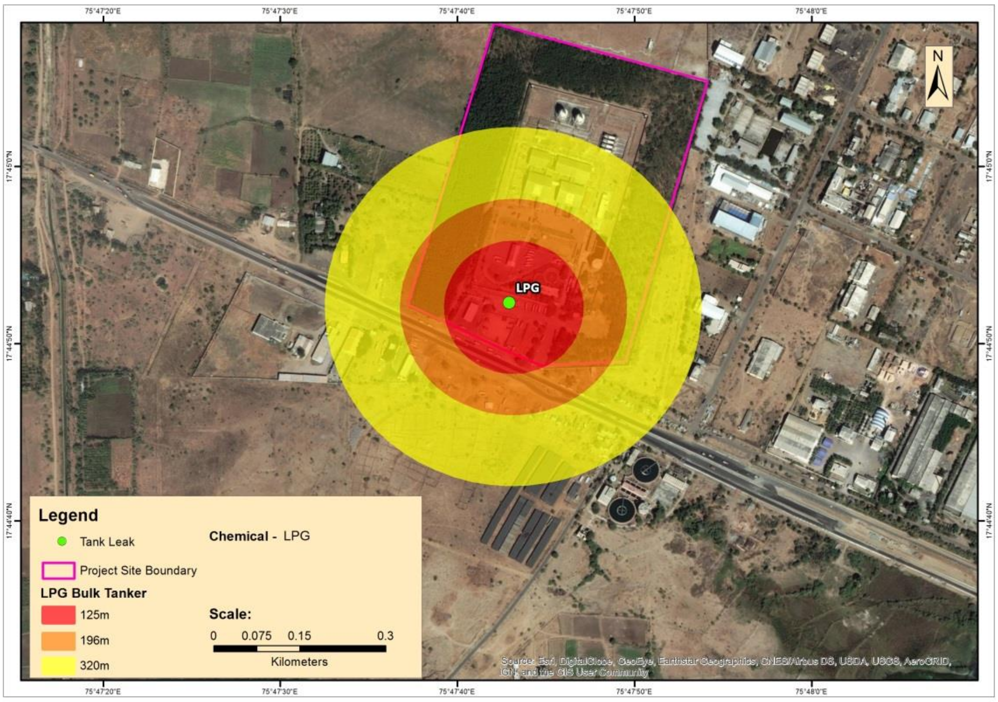
Yellow: 154 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the bulk tank truck leak (100mm) will be experienced to a maximum radial distance of 63m from the source with potential lethal effects within 1 minute.

Scenario 12: LPG Bulk Tank Truck (300mm dia)

The jet fire threat zone plot for release and ignition of LPG from bulk tank truck leak of 300mm dia is represented in ***Figure 1.15*** below.

Figure 1.15 Threat Zone Plot – LPG Bulk Tank Truck Leak (300mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 125 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 196 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

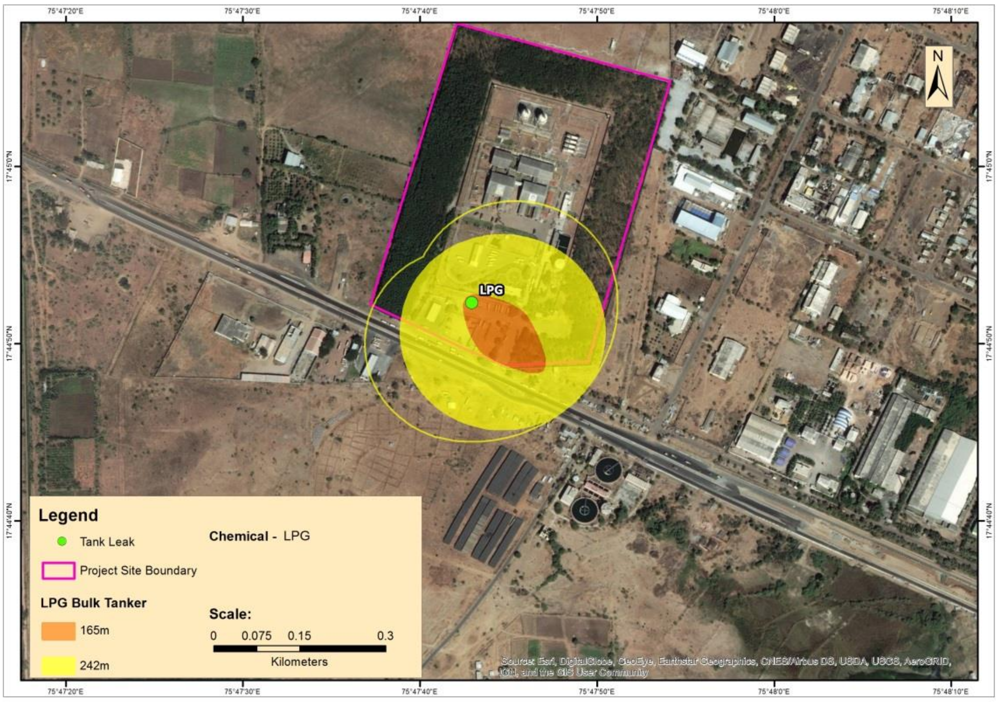
Yellow: 320 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from release and ignition of LPG from the bulk tank truck leak (300mm) will be experienced to a maximum radial distance of 125m from the source with potential lethal effects within 1 minute.

Scenario 13: LPG Bulk Tank Truck Catastrophic Failure causing VCE

The blast overpressure threat zone plot for VCE resulting from LPG bulk tank truck catastrophic failure (worst case) is represented in ***Figure 1.16*** below.

Figure 1.16 Threat Zone Plot – LPG Bulk Tank Truck Failure leading to VCE



Source: ALOHA

THREAT ZONE:

Threat Modeled: Overpressure (blast force) from vapor cloud explosion

Level of Congestion: uncongested

Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)

Orange: 165 meters --- (3.5 psi = serious injury likely)

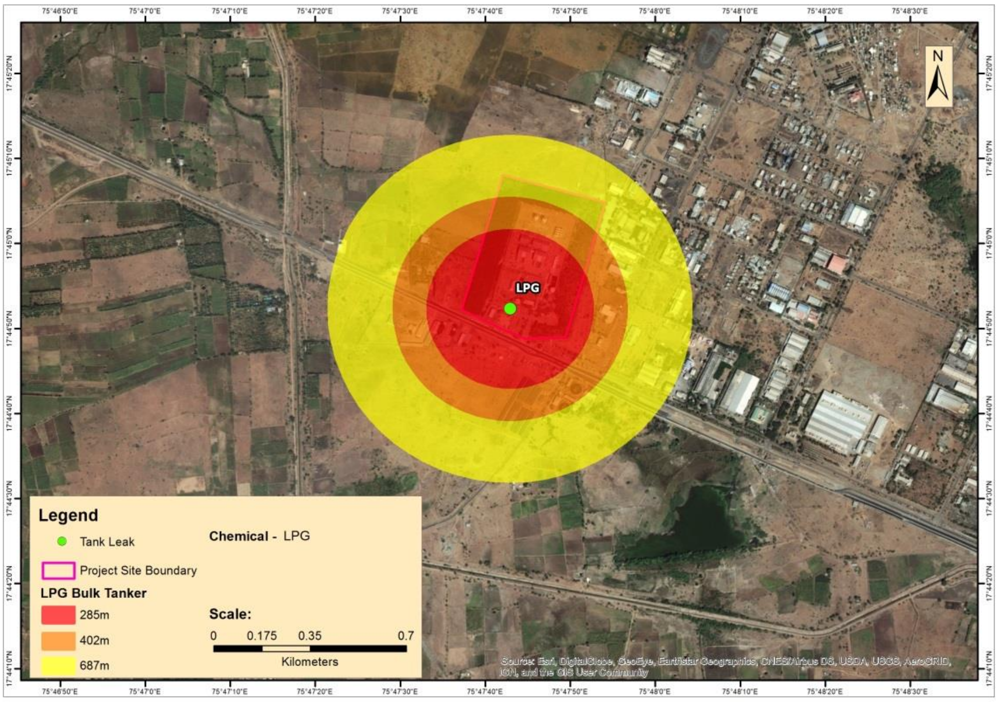
Yellow: 242 meters --- (1.0 psi = shatters glass)

For congested conditions, the blast overpressure of 3.5 psi and 1.0 psi is likely to be experienced within a radial distance of 165m and 242m respectively. The LOC was never exceeded for the maximum blast overpressures of 8.0 psi.

__Scenario 14: LPG Bulk Tank Truck Catastrophic Failure causing BLEVE__

The fireball threat zone plot for catastrophic failure of LPG bulk tank truck leading to BLEVE (worst case) is represented in ***Figure 1.17*** below.

Figure 1.17 Threat Zone Plot – LPG Bulk Tank Truck failure leading to BLEVE



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from fireball

Red : 285 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 402 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

Yellow: 627 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The maximum effect from catastrophic failure LPG storage sphere failure leading to BLEVE (worst case) will be experienced to a maximum radial distance of 285m from the source with potential lethal effects within 1 minute.

For calculating the risk significance of LPG bulk tank truck failure, the likelihood ranking is considered to be "2" as the failure probability for such failure is computed to be ~1 x10^{-5} per year. With respect to consequence ranking, for the aforesaid incident it has been identified to be as "5" given for a worst case scenario (BLEVE) the fatal effects is likely to be experienced within a maximum radial zone ~285 meters. For a VCE scenario, serious effects of blast overpressure (3.5 psi) is likely to be experienced within a radial zone of ~165 meters. However, considering the inherent risks BPCL shall make necessary provision of appropriate safety controls for the LPG bulk carriers in the form of automated internal excess flow check valves (EFCVs), emergency trips button and filter regulatory, earthing interlocks etc. In addition the truck vehicles prior to onsite entry and during loading operations will be subjected to 3-tier inspection and periodic maintenance. BPCL to all consider the implementation of a robust Vehicle Tracking System (VTS) and risk assessment of the existing transportation routes. In view of the above discussion the risk is considered to less significant.

Risk Ranking – LPG Bulk Tank Truck Failure (Worst Case Scenario)

Likelihood ranking	**2**	**Consequence ranking**	**5**
Risk Ranking & Significance = 10 i.e. "Medium" i.e. Risk is Tolerable and can be managed through adoption of necessary controls.			

1.2 *PRELIMINARY HAZARD AND OPERABILITY (HAZOP) STUDY*

1.2.1 *Introduction*

M/s. Bharat Petroleum Corporation Limited (A Govt. of India Enterprise), working under the aegis of Ministry of Petroleum has an establishment for storage and bottling of Liquefied Petroleum Gas (LPG) in Mohol taluka of Solapur district of Maharastra. The Solapur LPG Bottling plant has a bottling capacity of 132000 MTPA. Also, LPG storage capacity at the plant is 1800 MT (4 X 125 MT Bullets, 2 x 650 MT spheres). Currently, BPCL intends to enhance capacity of the LPG storage facility to 1900 MT with addition of mounded storage vessels (MSV) of 600 MT (2 x 300 MT). On commissioning of the MSV, existing LPG Bullets of 4 nos. X 125 MT will be decommissioned. Thus the final storage of 1900 MT would be as follows (2 x 650 MT spheres + 2X300 MT MSV). No expansion or modification of the bottling plant or associated facilities is being proposed under the present scope. ERM India Private Limited (ERM), has been engaged by BPCL to carry out the Preliminary HAZOP study of the upcoming storage facility (MSV).

1.2.2 *Brief description of the facility*

Summary of the existing and proposed storage tanks and other associated facilities within the plant are provided at ***Table 1.8*** and ***Table 1.9***.

Table 1.8 Facilities at the Solapur LPG Bottling Plant

Sl. No	Facility	Quantity/Capacity	
		Existing	Proposed
1.	Storage	4 nos bullets x 125 MT and 2 nos sphere x 650 MT	MSV 2 nos x 300 MT After commissioning of the MSV, existing 4 LPG bullets (4 x 125 MT) will be decommissioned. Then total capacity of the LPG storage facility will be 1900 MT.
2	LPG Unloading Gantry	6 Nos (for receiving of LPG)	Existing capacity will be used no expansion envisaged
3.	Unloading Cylinder	2 Nos Fingers	Existing capacity will be used, no expansion envisaged
4.	Loading Cylinder	2 Nos Fingers	Existing capacity will be used, no expansion envisaged
5.	No. of Carousel	Two electronic Carousel (2 x 24 filling stations)	Existing capacity will be used, no expansion envisaged
6.	LPG Pumps	3 Nos (50 m^3/Hr)	Existing capacity will be used ,no expansion envisaged
7.	LPG Compressor	4 Nos	Existing capacity will be used, no expansion envisaged

Source: BPCL

Table 1.9 *Details of Existing / Proposed Storage Tanks with proposed product allocation*

Vessel No.	Product	Tank diameter (m)	Tank/ length (m)	Class	Tank type	Tank Capacity
Existing LPG Storage Bullets						
1	LPG	4.0	23.0	A	Bullet	125 MT
2	LPG	4.0	23.0	A	Bullet	125 MT
3	LPG	4.0	23.0	A	Bullet	125 MT
4	LPG	4.0	23.0	A	Bullet	125 MT
Existing LPG Storage Sphere						
1	LPG	14.0	-	A	Sphere	650 MT
2	LPG	14.0	-	A	Sphere	650 MT
Proposed LPG Storage Bullets						
MSV001	LPG	5.0	37.5	A	MSV	300 MT
MSV002	LPG	5.0	37.5	A	MSV	300 MT

Source: BPCL; *Note:* The 4x125 MTs LPG Storage Bullets would be decommissioned after commissioning of proposed MSV

Existing operational process at the Solapur LPG plant is receipt of LPG by bulk tankers, storage of LPG in different type of storage vessel (MSV, Sphere etc.), bottling of LPG using electronic carousel, quality checking of LPG cylinder and finally dispatch to different distribution centre. Under this proposed expansion project, there will not be any changes in the existing operational process.

1.2.3 HAZOP Study Methodology

HAZOP study is a technique widely used in process plants for hazard identification. It follows a structured approach of creative brainstorming by a team of specialists using a set of guidewords. The documents consisting mainly of process flow diagrams, safety instrument interlock logic diagrams, operating instructions, MSDS for the chemicals used etc. form the basis for HAZOP Study.

The typical procedure for HAZOP study is given below:

1. Select the node (line, equipment or a system) on the P&ID;
2. List out intention & process parameters for the node;
3. Apply first guideword;
4. Develop meaningful deviations;
5. Develop various causes of the deviations;
6. Examine consequences of the deviations;
7. Identify safeguards already provided in the system;
8. Suggest remedial actions if required;
9. Repeat step 4-8 for all guidewords;
10. Mark node as having HAZOP;
11. Repeat step 1-10 for all the nodes; and
12. Repeat step 1-11 for all the P&IDs.

A flow diagram of the HAZOP process is given in ***Figure 1.18***.

1.2.4 *Assumptions*

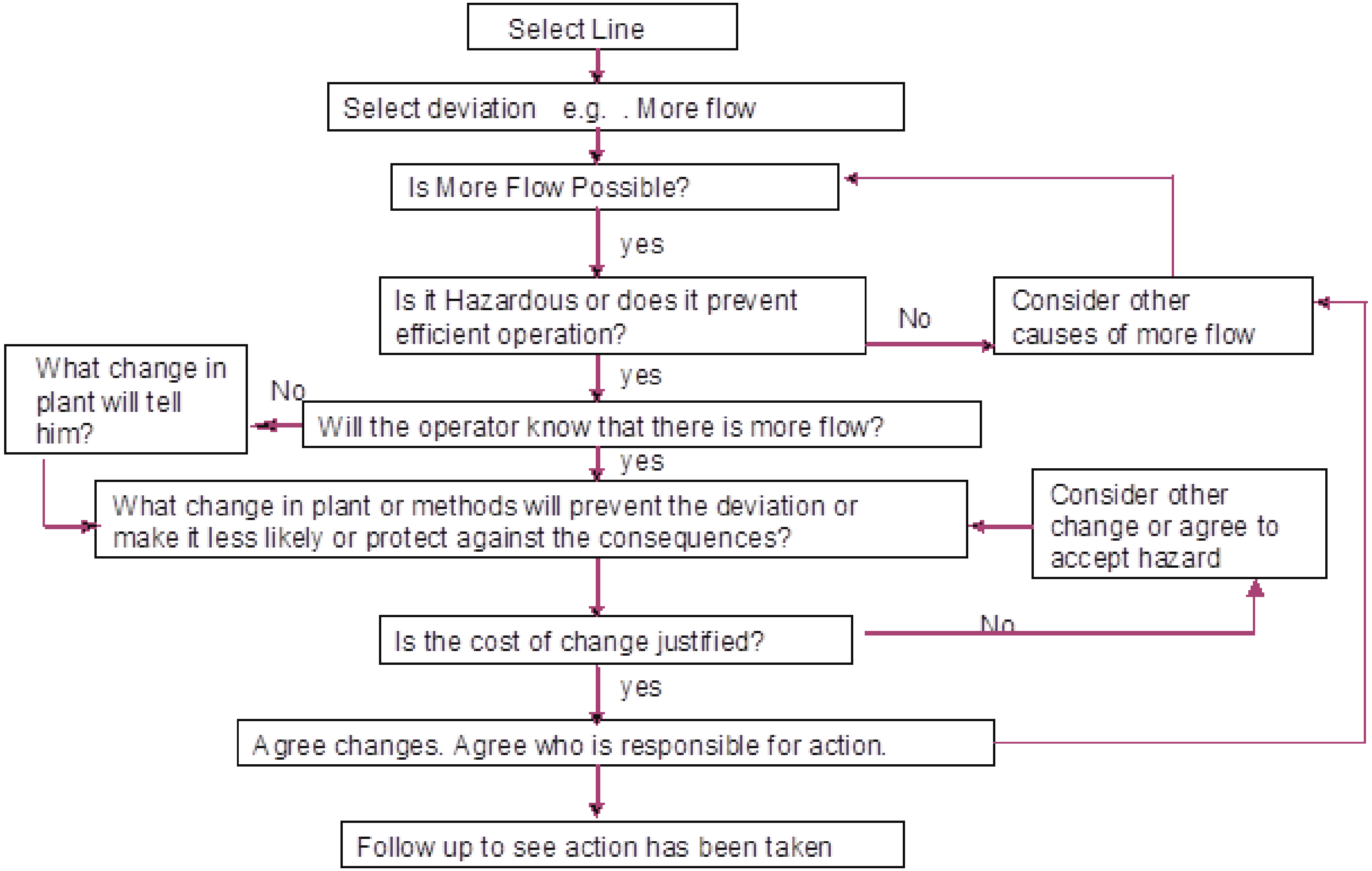
In a HAZOP study 'operability' is as important as 'hazard' and in most cases more operating problems are identified than hazards. The HAZOP technique can therefore enable companies to use resources more effectively and become more efficient as well as safer. It must be remembered, however, that the use of the HAZOP technique comes too late for fundamental change in design. All that can usually be done is to add on equipment or procedures to control the hazards that have been identified.

The technique assumes a good level of general management competence, in particular that the plant will be operated and maintained in the manner assumed by the design team and in accordance with good management and engineering practices.

1.2.5 *Limitation*

This is a preliminary HAZOP study which was conducted based on the information provided by BPCL like process and flow diagram (PFD and limited information on process controls and operating conditions. Available information is applicable to the existing facility and process conditions. BPCL is yet to generate specific piping and instrumentation diagram (P&ID), Controls and Interlock description for the proposed MSV etc. ERM HAZOP team has assumed that proposed design of MSV will be in compliance with OISD and SMPV requirements. Preliminary HAZOP Study report does not address specific process deviation due to limited availability of process related information.

Figure 1.18 HAZOP Process Flow Chart



1.2.6 *Parameter and Guidewords*

The HAZOP chairman has prepared pre-selected combinations of parameters and guidewords that give meaningful deviations, as shown in ***Table 1.10***. Some additional deviations came up during the analysis.

Table 1.10 Preliminary list of parameters and guidewords applied during HAZOP Study

Parameter	Guide Words
Flow	More
	Less / None
	Reverse
	Misdirected flow
Pressure/ vacuum	High
	Low
Temperature	High
	Low
Level	High
	Low
Others	Corrosion
	Leakage
	Design
	Layout
	Inspection and Testing at Installation and Operation Phase

1.2.7 *HAZOP STUDY TEAM*

Desk-top based preliminary HAZOP was performed by ERM team members wherein telephonic discussions were done with BPCL team members to understand proposed control measures for the MSV Bullets at site. Following ***Table 1.11*** presents the ERM Team and BPCL key members involved during the HAZOP Study.

Table 1.11 The HAZOP study team

Sl. No.	Name	Designation	Role/Represents
1.	V.K Singh	Principal Associate (ERM)	HAZOP Chairman
2.	Rekha Sharma	Senior Consultant (ERM)	HAZOP Scribe
3.	Chandan Kumar Tandi	Executive Operation (BPCL)	Process
4.	P Suman	Executive Operation (BPCL)	Instrumentation Engineer
6.	Kaustubh Prasad	Deputy Manager (BPCL)	Maintenance Engineer
7.	Nageshwar Rao	Assistant Manager (BPCL)	Safety Person

1.2.8 *LIST OF NODES CONSIDERED*

The facility under consideration was analysed as **Three Nodes**, based on the process and operating conditions.

Table 1.12 List of Nodes for HAZOP Study

Sr. No.	Node Number	Node Description	Intention
1.	Node 1	Global	To review requirements of Static and Mobile Pressure Vessel Rules and OISD 150 for consideration in the current design
2.	Node 2	LPG vapour from MSVs through compressor to LPG tanker and then LPG from tanker to MSV	To transfer LPG from tankers to Mounded Storage Vessel (MSV) by Differential (Vapour) Pressure Method
3.	Node 3	MSVs including LPG line through LPG pumps to bottling plant	To transfer LPG to bottling plant

1.2.9 *REFERENCE DOCUMENTS*

Following documents provided by BPCL have been referred:

1. Process and flow diagram (refer ***Table 1.13***);
2. Cross Section Drawing of MSV
3. General Process Description;
4. Process Interlock Description;
5. Brief para on Operating Procedure :

Table 1.13 Process & Flow Diagram (PFD)

Sr. No.	Drawing No.	Title	Rev. No.	Remarks
1.	BPCL/P&ID/1415/12/R3	AS BUILT P & I LAYOUT OF LPG BOTTLING PLANT AT SOLAPUR	R-3	These drawings are for the existing facility. Proposed MSV Bullet Drawings are yet to be prepared by BPCL
2.	E&P/STD/MSV/004	Cross Section Drawing of MSV	Not Available	-

1.2.10 *OBSERVATIONS AND RECOMMENDATIONS OF HAZOP STUDY*

Recommendation of the HAZOP study is summarized below:

- Tunnel Requirement to be followed as per SMPV and OISD for safe access to the bottom connection.

- All safety fittings and instrumentation to be provided on dome or Manhole Cover.
- Minimum two numbers of Manhole to be provided on top of the Vessels according to OISD 150.
- For the Liquid Line from the vessel the minimum distance of 3 mtr from the Vessel to ROV should be maintained with 1.5 degree (minimum) proper slope.
- All the safety fittings and instrumentation should be provided on domes of storage bullets and to be represented accordingly in the P&IDs.
- Safety Distances between equipment and other installation should be as per SMPV Rules and OISD 150.
- Mounded Bullets and associated systems to be inspected and certified as per the provisions of SMPV Rules.
- Material selection to be considered suitable for traces of Hydrogen Sulphide (As per NACE RP 169).
- Design to consider minimum corrosion allowance of 1.5 mm and stress relieving of complete vessel.
- Cathodic Protection for the LGP storage bullet to be considered for at least 15 years.
- Monitoring of the Cathodic Protection should be done on yearly basis and records maintained.
- Flange Connection should be minimum. Flange Joints of valves should be of either Spiral wound metallic Gaskets or Ring Joints.
- LGP Mounded Vessels to be provided with Fire Safe Remote Operated Valves (ROVs) on the first flange on the liquid line with the closing time not exceeding 30 seconds.
- Hazardous Area Classification to be performed as per IS 5572 & OISD 113.
- Provide Fire Proofing (2 hours rating of all exposed portion) of the Vessel including piping upto the First ROV or auto actuated fixed Fire Spray System.
- Adequate numbers of Gas Leak Detectors (Auto Fire Detection Systems), their position and actions should confirm to OISD 150.
- Fire Fighting Facilities are to be provided with Fire Hydrant and Monitor with Water Sprinklers as per Table A of Schedule 3 of SMPV Rules.
- Provide differential pressure indicator across the strainer
- Provide high/high-high level alarm with interlock to trip compressor
- Provide suitable TSV between ROV and block valve
- Provide standby compressor
- Provide flow monitoring (FI) instrumentation on discharge line
- Provide a pressure /flow control valve on discharge line along with minimum flow line recirculating to mounded bullet.
- Standard Operating Procedure (SOP) to be prepared and followed.

1.3 HAZOP STUDY WORKSHEETS

HAZOP Worksheets are attached as ***Annexure A***.

Annexure A: HAZOP Worksheets

Company	Bharat Petroleum Corporation,
Facility	LPG Bottling Plant, Solapur
Project	HAZOP Study for proposed LPG Mounded Storage Bullets (2 Nos.)
Reference P&ID	P&ID (under preparation)
Date	25-01-2017

	PRESSURE kg/cm2	**TEMPERATURE Deg C**	**PRODUCT**	**CAPACITY**	**PHASE**
DESIGN	14.5 kg/cm^2 g	(-27 to 55)	LPG	2 LGP Bullet each of 300 MT (Category 2 as per SMPV Rules Schedule 3)	LIQUID

	Deviation	**Cause**	**Consequences**	**Safeguards**	**Recommendations**
Intention	**To review requirements of Static and Mobile Pressure Vessel Rules and OISD 150 for consideration in the current design**				
Node 1	**Global**				
	1.Design	1.1 Deviations from the requirements of SMPV and OISD while designing the system	1. Project is at the Conceptual Stage. In case of deviation from the mandatory statutory requirement of SMPV rules and OISD Std. Obtaining approval from the authorised /relevant agencies would be difficult process.	1. Vessel is considered to be designed, constructed and tested in accordance to the IS 2825, ASME Section VIII or any other code accepted by Chief Controller.	

	Deviation	Cause	Consequences	Safeguards	Recommendations
		1.2 Minimum Requirement for design of Mounded Bullets not followed.	1.Follow consequence mentioned in point no. (1.1) 1 (given above).	(Information not available)	1. Design features/fixtures as minimum but not limited to following be ensured while designing the system; a). Tunnel Requirement to be followed as per SMPV and OISD for safe access to the bottom connection. b). All safety fittings and instrumentation to be provided on dome or Manhole Cover. c).Minimum two numbers of Manhole to be provided on top of the Vessels according to OISD 150. d). For the Liquid Line from the vessel the minimum distance of 3 mtr from the Vessel to ROV should be maintained with 1.5 degree (minimum) proper slope. e). All the safety fittings and instrumentation should be provided on domes of storage bullets and to be represented accordingly in the P&IDs
	2. Layout	Inadequate Safety Distances between the Storage facility and LPG Dispensing	In case of Fire/ Explosion emergency, there would be fast escalation of the Heat Radiation or Blast Overpressure in the LPG Dispensing Area.	Information not available	2.Safety Distances between equipment and other installation should be as per SMPV Rules and OISD 150.
	3 Inspection and Testing at Installation and Operation Phase	Improper Inspection and Testing Plans	Integrity and Reliability of the LPG System not achieved	Information not available	3.Mounded Bullets and associated systems to be inspected and certified as per the provisions of SMPV Rules.
	4. Corrosion	Presence of H_2S and other external factors	Failure of Vessels/ Pipeline or fittings leading to loss of containment.	Information not available	4.Material selection to be considered suitable for traces (if there any) of Hydrogen Sulphide (As per NACE RP 169)

	Deviation	Cause	Consequences	Safeguards	Recommendations
					5. Design to consider minimum corrosion allowance of 1.5 mm and stress relieving of complete vessel.
					6.Cathodic Protection for the LGP storage bullet to be considered for at least 15 years.
					7.Monitoring of the Cathodic Protection should be done on yearly basis and records maintained.
	5. Leakage of LPG	Loose fittings/flange Joints/ mechanical impact vessels or associated pipings and fittings	Fire and Explosion Hazards	Information not available	8.Flange Connection should be minimum. Flange Joints of valves should be of either Spiral wound metallic Gaskets or Ring Joints.
					9.LGP Mounded Vessels to be provided with Fire Safe Remote Operated Valves (ROVs) on the first flange on the liquid line with the closing time not exceeding 30 seconds.
					10.Hazardous Area Classification to be performed as per IS 5572 & OISD 113.
					11.Adequate numbers of Gas Leak Detectors (Auto Fire Detection Systems), their position and actions should confirm to OISD 150.
					12. Provide Fire Proofing (2 hours rating of all exposed portion) of the Vessel including piping upto the First ROV or auto actuated fixed Fire Spray System.
					13. Fire Fighting Facility are to be provided with Fire Hydrant and Monitor with Water Sprinklers as per Table A of Schedule 3 of SMPV Rules.

	Deviation	Cause	Consequences	Safeguards	Recommendations
Intention	**To transfer LPG from tankers to Mounded Storage Vessel (MSV) by Differential (Vapour) Pressure Method**				
Node 2	**LPG vapour from MSVs through compressor to LPG tanker and then LPG from tanker to MSV**				
1.No flow/Less flow	1.1 Compressor trips resulting in loss of differential pressure between mounded bullet and tanker.	1. Filling of LPG from tanker Vessel delayed		(Information not available)	1.Provide standby compressor
	1.2 ROV on liquid inlet line stuck close during the product transfer due to error or operational upsets	1. Line gets pressurized at the upstream of ROV	1. The line (class 300 #) is considered to withstand high pressure		
		2. High pressure/ temperature in compressor discharge line	2.High pressure /temperature alarms and trips provided.		
		3. High pressure in KOD	3. PRV provided on KOD		
		4.High pressure in tanker Vessel	4. PRV provided on tanker		
	1.3 Strainer blocked Located after ROV	1. Same as 1.1 (1) above			2. Provide differential pressure indicator across the strainer
2. More Flow	2.1 Malfunctioning (e.g. overspeed, etc.) of compressor.	1. Increased pressure build up in tank car resulting in more flow of LPG.	1. Fast filling and rapid level rise in mounded bullet and subsequent high pressure	1. Compressor trips at higher discharge pressure	
				2.PRVs provided on mounded bullets	

	Deviation	Cause	Consequences	Safeguards	Recommendations
			2.High pressure in the tanker	1.PRVs provided	
3. Reverse Flow	3.1 No scenario (Since flow in the liquid line is bi-directional)				
4. Misdirected flow	4.1 Incorrect line up of valves and/or vessels	1. Potential for high level in the vessel not intended for the filling			3. Provide high/high-high level alarm with interlock to trip compressor
5. Low Pressure	5.1 Same as 1.(1.1) above				
6. High Pressure	6.1 Same as 1.(1.2), 1.(1.3),2.(2.1) & 2.(2.2) above				
	6.2. Liquid trapped between ROV and block valve	1. High pressure due to expansion of LPG			4. Provide suitable TSV between ROV and block valve
7. Low Temperature	No scenario				
8. High Temperature	6.1 Same as 1.(1.2), 1.(1.3),2.(2.1) & 2.(2.2) above				
9. Low Level (KOD)	9.1 No issue				
10. High Level (KOD)	9.2 Excessing liquid entrainment in gases or lack of regular drainage	1. Carry over of liquid resulting in damage to compressor	1. High/high-high level alarms along with interlock to trip the compressor provided		
11.	11.1 Refer to				

	Deviation	Cause	Consequences	Safeguards	Recommendations
Corrosion	global node				
12. Leakage	12.1 Refer to global node				

	Deviation	Cause	Consequences	Safeguards	Recommendations
Intention	**To transfer LPG to bottling plant**				
Node 3	**MSVs including LPG line through LPG pumps to bottling plant**				
	1.No flow/Less flow	1.1 Loss of level in LPG vessel	1. Low suction pressure with potential for cavitation of the pump and subsequent damage	1. Low level/low-low level alarms with interlock to trip at low-low level (low -low pressure) provided	
		1.2 LPG pump trips	1. Loss of supply of LPG to bottling plant		1.Provide standby pump 2. Provide flow monitoring (FI) instrumentation on discharge line 3. Provide running indication with alarm on pump
		1.3 Valve on transfer line closed at bottling station	1.High pressure and temperature due to churning of LPG in pump and potential for major leakage		4.Provide a pressure /flow control valve on discharge line along with minimum flow line recirculating to mounded bullet.
		1.4 Choking of suction/discharge line	1. Low suction pressure with potential for cavitation of the pump and subsequent damage	1. Provide strainer in suction line to avoid choking	

	Deviation	Cause	Consequences	Safeguards	Recommendations
			2. Inadequate supply of LPG to bottling plant (if discharge line choked).		
			3. Pressure build-up in pump and potential for leakage (If discharge line choked).		
	2. More Flow	2.1 Excessive withdrawal of LPG in bottling plant	1. Uncontrolled flow of LPG may lead to operational upset.		5. Same as 3. above
			2. Low level in bullet (owing to high rate of withdrawal) and potential for pump cavitation	1. Low level/low-low level alarms with interlock to trip the pump at low-low level (low -low pressure) provided	
	3. Reverse Flow	3.1 Tripping of the running pump	1. Backflow of LPG from bottling plant	1. Non-return valve (NRV) provided at pump's discharge	
	4. Misdirected flow	4.1 Incorrect line up of valves and/pumps	1.Loss of transfer of LPG to the destination		6. Standard Operating Procedure (SOP) to be prepared and followed.
	5. Low Pressure	5.1Same as 1.1, 1.2 & 1.4 above	1. Same as 1.1 (1) & 1.4 (1) above		
	6. High Pressure	6.1 Samea 1.3 & 1.4 above	1. Same as 1.3 (1) & 1.4 (3) above		
	7. Low Temperature	7.1 Opening of PSV advertently	1. Low temperature of the vessel shell due to rapid vaporisation	1. Suitable low-temperature material is considered to be used	

	Deviation	Cause	Consequences	Safeguards	Recommendations
		7.2 Leakage from pipe	1.Low temperature of piping due to rapid vaporisation	1. Suitable low-temperature piping material is considered to be used	
	8. High Temperature	Same as 1.3 above			
	9. Low Level (MSV)	Same as 2.1 above	1. Same as 2.1 (2) above		
	1o. High Level (MSV)	9.1 No scenario from current node			
	11. Corrosion	11.1 Refer to global node			
	12. Leakage	12.1 Refer to global node	1. Double mechanical seal provided in LPG pumps		