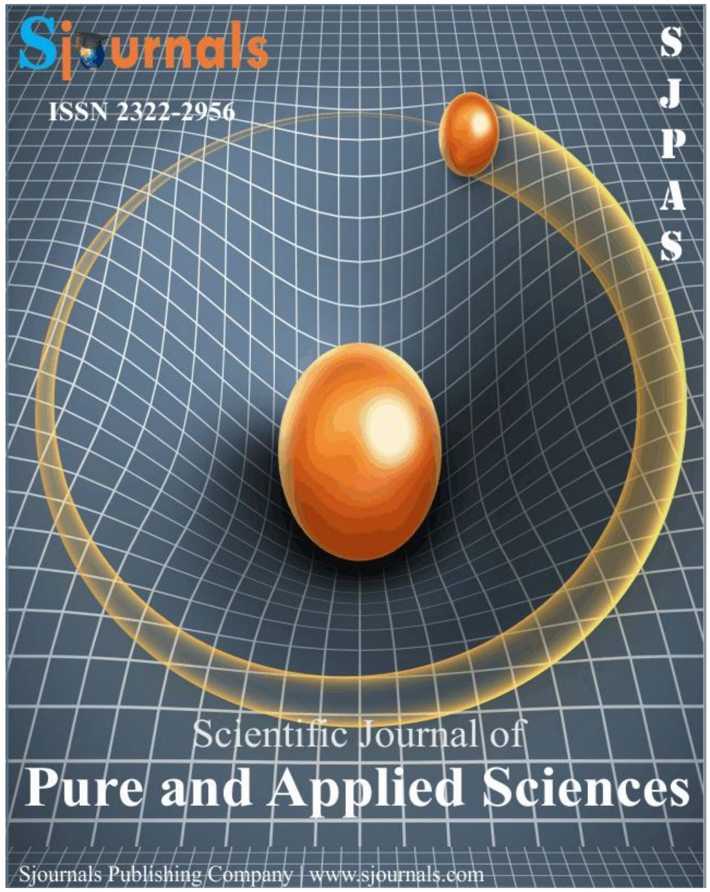
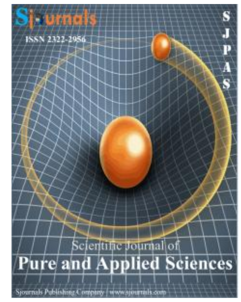

Sjournals
ISSN 2322-2956
SJPAS
Scientific Journal of
Pure and Applied Sciences
Sjournals Publishing Company | www.sjournals.com

Sjournals
Scientific Journals
Scientific Journal of Pure and Applied Sciences (2016) 5(11) 515-523
ISSN 2322-2956
doi: 10.14196/sjpas.v5i11.2270

Contents lists available at Sjournals
Scientific Journal of **Pure and Appiled Sciences**
Journal homepage: www.Sjournals.com



Case study

Layers of protection analysis to achieve safety integrity level (SIL), Case study: Hydrogen unit of refinery

Akram Delavar[a], Mahnaz Mirza Ebrahim Tehrani[a,*], Seyed Shamseddin Alizadeh[b]
[a]*Department of Environment Management, Faculty Marine Science and Technology, North Tehran Branch, Islamic Azad University, Tehran, Iran.*
[b]*Department of Occupational Health Engineering, Tabriz University of Medical Sciences, Tabriz, Iran.*

*Corresponding author; Department of Environment Management, Faculty Marine Science and Technology, North Tehran Branch, Islamic Azad University, Tehran, Iran.

A R T I C L E I N F O

Article history,
Received 05 October 2016
Accepted 06 November 2016
Available online 10 November 2016
iThenticate screening 07 October 2016
English editing 04 November 2016
Quality control 08 November 2016

Keywords,
Risk assessment
Hazard and operability study (HAZOP)
Layers of protection analysis (LOPA)
Safety integrity level (SIL)
Hydrogen unit of refinery

A B S T R A C T

To identify and evaluate hazard in process industries as oil and gas, there are various methods in which *hazard* and operability study (HAZOP) and layers of protection analysis (LOPA) are the most common methods. The present study aims to analyze layers of protection to achieve safety integrity level in hydrogen unit of refinery. After performing library studies and data collection of events in refinery, hazards of hydrogen unit as operating nodes and deviations with causes and consequences are identified using HAZOP method. The next stage is presenting corrective solutions by LOPA method and target factor. Then, frequencies are determined for the initiating event by the experts. By completing the sheets of each event, independent layers of protection and integrity level are determined. The results of evaluation of identified risks showed that 11 cases had risk higher than 15 and it is not acceptable. The analysis of consequence of hazards showed that for 6 hazardous points, independent layers of protection can reduce risk as 100% to target factor (10-5) and safety integrity level is fulfilled. Regarding the eighths scenario "elimination of repulsive system of equipment and lines with the high temperature of very hot steam", layers of protection cannot increase safety integrity level to more than 60% (10-3) and to provide safety to target factor, after eliminating the identified problems, other layers are positioned. In this study, to achieve safety integrity level in hydrogen unit of refiner. A three period plan (short-term, mid-term and long-term) is proposed.

1. Introduction

There is a challenge between performance improvement and profitability on one hand and safety improvement on the other hand. Process industries need supply maintenance and keeping safety conditions of employed at work place and the environment. This need in process industries is provided mostly by exact tool systems to keep risk at acceptable level (Berg, 2007). Despite advancement in this regard, events occur and adverse consequences are presented. Some disasters as Fizen (France), Mexico city and Payper Alpha (England) and Chernobyl (Russia) are the examples in which human consequences, environment pollution and ecosystem destruction can lead to much emphasis on safety, health and environmental issues in industrial activities (Millner, 2006; Kjellén, 2000; Craddock, 1997). The comparison of big disasters in different countries shows that despite development of these countries, there are some similarities between these disasters (Millner, 2006; Yi and Lee, 2016; Carrillo-Castrillo et al., 2015). Some factors, including human mistakes, assurance of safety of utilities, problems of design and lack of preparation under emergency conditions are common reasons in human and environmental disasters (Yi and Lee, 2016; Jarvis, 1997; Mearns et al., 2001).

Marsh (2001) reported that during 1974-2013, the economic loss of 36 billion of 100 accidents were observed in these industries (Marsh, 2002). The traditional approach to reduction of process risks is providing layers of protection or adds-on between risk and vulnerable element (human being, assets and environment). Layers of protection are costly. Various studies have shown that during 1980, 15-30% of investment on oil and chemical industries was dedicated to safety and pollution prevention sectors.

Based on the complexity of a process and potential intensity of a consequence, a scenario needs one or some layers of protection. For a definite scenario, only one layer works successfully for a consequence. No layer is effective fully; we should use adequate layers of protection to achieve an acceptable risk (summers, 2003; Chongguang and Zhang Beike, 2007). The experts should consider the performance of layers of protection. A comprehensive safety and risk management system should be established to have continuous layers of protection and prevent relevant accidents. Risk identification is one of the most important elements in risk management system affecting all the relevant results. In case of the lack of accurate identification of risks, preventive actions are not designed well (Alizadeh and Moshashaei, 2015; Tcameron and Raman, 2005; Isimite and Rubini, 2016). In process industries and in design phase, we attempt to prevent risks based on their identification in design stage as the source of risk is eliminated or by control actions, the effect is controlled (Rausand, 2013; Lees and Loss, 2012). For risk assessment in process industry, there are various methods (Alizadeh et al., 2015; Nassiri et al., 2007; Rasoulzadeh et al., 2015) and HAZOP and LOPA are the most common methods (Dunjó et al., 2010; Ouazraoui et al., 2013). LOPA is a semi-quantitative method to analyze risk as being used at any time of life cycle, but it is mostly used in design stage with the changes of safety system or process (Bridges et al., 2001). This method is used for the significance of classification of initiating event repetition, consequence intensity and failure of independent protection layers (IPLs) in estimation of the risk of a scenario. The initial aim of LOPA is to determine adequacy of layers of protection against an event scenario (Chongguang and Zhang Beike, 2007; Isimite and Rubini, 2016). LOPA is a good basis for judgment about IPLs adequacy in risk control of an event for a definite scenario. If the estimated risk is not acceptable, more IPLs are added. The recommendations of safe design can be analyzed. This method doesn’t recommend about adding or design of IPLs but it is beneficial in presenting recommendations to reduce risk (Ouazraoui et al., 2013; Wei et al., 2008). Hydrogen generation units are important sectors in process industry and in case of failure in these systems; the relevant consequences can affect the entire or part of system. Thus, safety integrity level (SIL) is of great importance in this industry (Summers, 2003; Guo and Yang, 2006; Freeman, 2007). Based on the process-oriented unit and materials with high Flammability and explosion, identification of risk is of great importance. The present study is aimed to analyze the layers of protection to achieve SIL in hydrogen unit of a refinery. The general purpose of the present study is the layers of protection analysis to achieve SIL in hydrogen sector of a refinery.

2. Study methodology

The present study is a cross section-descriptive and applied design to analyze the protection layers of hydrogen unit of an oil refinery company. LOPA method is one of the process risk analysis tools and it is a semi-quantitative risk evaluation to analyze the effectiveness of independent layers of protection in process against the identified risks. In case of the lack of effectiveness of these independent layers of protection, new independent layers of protection and their reliability are determined. Layers of protection are groups of equipment or administrative control and in case of emergency in process, definite actions are performed. The flowchart of this method is shown in Fig. 1.

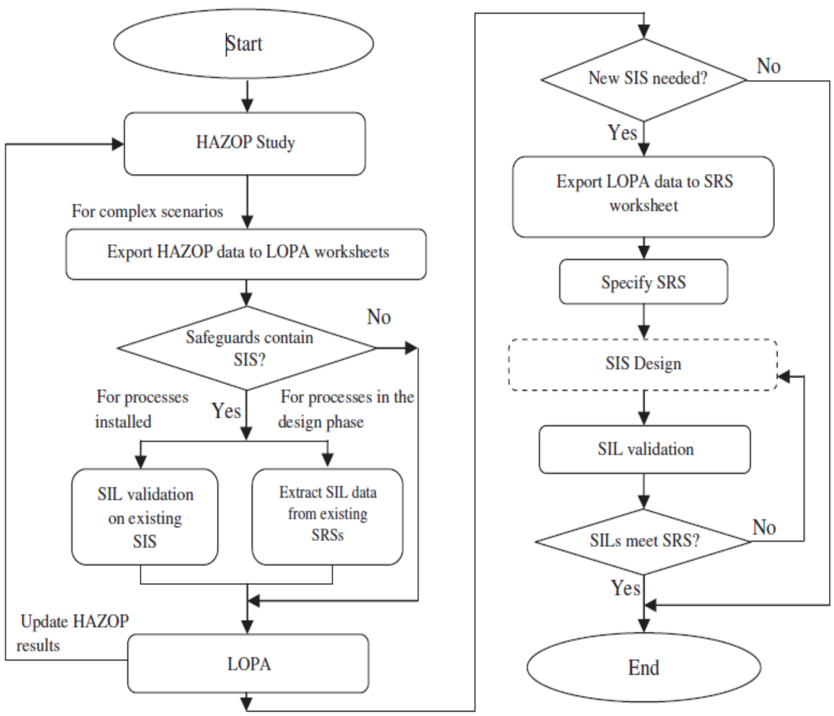


Fig. 1. Flowchart of evaluation of layers of protection process.

Risk matrix is a method defining an acceptable risk for a scenario based on the consequence frequency and event probability. This method is used extensively for risk decision making of LOPA (Hauptmanns, 2004). Thus, consequence frequency is reduced and its intensity is compared with risk matrix (Table 1) (Christopher, 2008). If the risk value is:

- It has no color in the region, the risk reduction is low and no action is required and it is at acceptable level.
- In bright region, it needs management judgment to show much reduction is required. This region is at acceptable level but it needs analysis to identify any action to reduce costs.
- In dark region, risk reduction is high and with the information of management of company, corrective measurements should be performed to reduce risk (Christopher, 2008).
- Based on the Table, obligatory or optional correction actions as layers of protection for significant scenarios (as explained in HAZOP method) are as follows (Table 2):

Table 1
Applied risk matrix for risk decision making (Studt, Christopher, 2008).

Fifth level	Fourth level	Third level	Second level	First level	
Corrective actions (informing the management of company)	Corrective actions (informing the management of company)	Corrective actions (informing the management of company)	Optional	Optional Periodical evaluation of alternatives	10^{-1}
Corrective actions (informing the management of company)	Corrective actions (informing the management of company)	Optional	Periodical evaluation of alternatives	Optional Periodical evaluation of alternatives	10^{-2}
Corrective actions (informing the management of company)	Corrective actions (informing the management of company)	Periodical evaluation of alternatives	Optional	No extra action is required	10^{-3}
Corrective actions (informing the management of company)	Optional	Optional	No extra action is required	No extra action is required	10^{-4}
Optional	Periodical evaluation of alternatives	No extra action is required	No extra action is required	No extra action is required	10^{-5}
Periodical evaluation of alternatives	No extra action is required	No extra action is required	No extra action is required	No extra action is required	10^{-6}
No extra action is required	No extra action is required	No extra action is required	No extra action is required	No extra action is required	10^{-7}

Based on the results of analysis of risky point to apply layers of protection, 11 points of hydrogen unit are evaluated as risky regions (condition: unacceptable) and their scenarios are presented in the previous sections. Of which, 6 points need obligatory and immediate revision and actions.

Table 2
Layers of protection for assessed risks.

Target factor LOPA	Reduced risk	Corrective action		PDF	Code	Risky region
		Explanation	Type			
10^{-5}	10^{-5}	Control system on FT-8006 A/B/C to regulate flow, alarming system and automatic lock	IPL	1×10^{-2}	A.6.2.1	**1**
10^{-5}	10^{-5}	Control of S/C, control system on FT-8006 A/B/C to show and regulate flow	IPL	1×10^{-2}	B.1.1.1	**2**
10^{-5}	10^{-5}	Control system on FT-8006 A/B/C to regulate flow, alarming system and automatic lock	IPL	1×10^{-2}	B.6.1.1	**3**
10^{-5}	10^{-4}	Install temperature marks on each exit, equipping convection spiral and chimney of gas with alarm	IPL	1×10^{-2}	C.6.1.1	**4**
10^{-5}	10^{-4}	Control system on FT-8006 A/B/C to regulate flow, alarming system and automatic lock	IPL	1×10^{-2}	C.7.1.2	**5**
10^{-5}	10^{-5}	PSHH software as activating by control system and install reformer alarm system	Safe guard	1×10^{-1}	C.7.2.1	**6**

10^{-5}	10^{-7}	PSHH software as activating by control system and install reformer alarm system	IPL	1×10^{-2}	C.7.3.1	**7**
10^{-5}	10^{-3}	Install temperature mark and observing TORC	IPL	1×10^{-2}	E.1.1.1	**8**
10^{-5}	10^{-4}	Install temperature mark and cooling fans	IPL	1×10^{-1}	E.1.1.2	**9**
10^{-5}	10^{-4}	Install marker and temperature regulator, heater	IPL	1×10^{-2}	F.2.1.1	**10**
10^{-5}	10^{-4}	Using AAH-8007A (CO) and AAH-8007B (CO2) safeguards	Safe guard	1×10^{-1}	L.1.1.1	**11**

3. Results

Based on the results of HAZOP method in identification of consequences and risk assessment, events consequence is calculated based on estimation of costs by groups. Based on the existing consequences, the scenarios are identified and recorded in Table 4 (Column of scenario). The data of each scenario is shown in LOPA sheet as shown in Table 3.

Table 3
The sample of LOPA sheet.

Frequency	Probability	Title:	Scenario NO.
			Consequence description/consequence intensity class
			Risk acceptance criterion
			Initiating event
		Flammability probability	Adjusting conditions
		The probability of one's presence in affected region	
		Fatal damage probability	
		Financial damage probability	
		Not reduced consequence frequency	
		Independent layers of protection	
			BPCS
			Human interference
			SIF[1]
			Safety tools
			Physical layers of protection
			Safeguards (those that are not IPL)
		Total PFD[2] for all independent protection layers	
		Reduced consequence frequency	

Is risk acceptance criterion acceptable? (YES/NO)
[1]Safety Instrumented Function
[2]Probability of Failure on Demand

Table 4
Scenarios of layers of protection.

Corrective action	Frequency	Intensity ($)	Initiating event	Scenario title	Code	No.
Optional	1×10^{-1}	0 to 10000	Flow loss in riffle due to pressure reduction	Reduction of system performance rate after the lack/shortage/ increase of flow	A.1.1.1	1
Optional	1×10^{-1}	0 to 10000	Flow loss in riffle due to pressure reduction	Reduction of system performance rate after the inverse or lost flow	A.2.1.1	2
Optional	1×10^{-3}	10000 to 100000	The failure or error of exit exchange in more closing	Damage of catalyst with high temperature of *desulfurized* feed	A.3.1.1	3 . .
Optional	1×10^{-3}	10000 to 100000	Loading unsuitable catalyst	Toxicity risk of reformer catalysts	A.7.7.1	19 . .
Obligatory	1×10^{-1}	1 to 100000 million	Failure of FV-8006 or any other factor regulating opening and closing in control loop.	Reduction of production rate and damage of reformer pipes with the lack or shortage of desulfurizated flow	B.1.1.1	22
Optional	1×10^{-3}	10000 to 100000	Failure of FV-8006 or any other factor regulating opening and closing in control loop.	Mechanical damage in convection pipes due to temperature increase	B.1.1.2	23 . .
Optional	1×10^{-3}	10000 to 100000	Low heat generation in reformer	Reduction of heat transfer in convection and dysfunction in riffle	B.6.1.2	31 . .
Optional	1×10^{-1}	0 to 10000	The main effect of flow, temperature and pressure in chamber	Reduction of system performance rate due to inverse or lost flow	C.2.1.1	35
Optional	1×10^{-1}	0 to 10000	Generation of excess heat in reformer	Damage to reformer, catalyst, convection (heat transfer) and riffle pipes due to temperature increase	C.3.1.1	36 . .
Obligatory	1×10^{-2}	1 million to 10 million	Failure in PV-8017 A/B or another factor in control loop regulating opening and closing.	Shortage of gas of chimney/steam of reformer and humane injury due to high pressure of heating chamber of reformer	C.7.1.2	45
Obligatory	1×10^{-2}	1 million to 10 million	Sudden increase of fire in launching (for any reason)	Shortage of gas of chimney/steam of reformer and humane injury due to high pressure of heating chamber of reformer	C.7.2.1	46
Optional	1×10^{-2}	1 to 100000 million	Pipes fracture	Create uncontrolled fire with high pressure of reformer heating chamber	C.7.3.1	47 . .
Obligatory	1×10^{-1}	1 million to 100000	Failure in TV-8009 or another factor in controlling closing.	Destruction of dumping system, equipment and lines with high temperature of very hot steam	E.1.1.1	57
Obligatory	1×10^{-1}	1 million to 100000	Reformer temperature increase	Destruction of dumping system, equipment and lines with high temperature of very hot steam	E.1.1.2	58
Optional	1×10^{-3}	10000 to 100000	Failure in TV-8009 or another factor in controlling closing.	Temperature fall below the acceptable point and probable disturbance for foreign consumers.	E.2.1.1	59 . .
Obligatory	1×10^{-1}	1 million to 100000	Increase of the age of absorbents	Reduction of hydrogen purity gas with the lack of good performance of PSA system	L.1.1.1	72

4. Discussion and conclusion

Control of production unit and hydrogen purification of refinery is done via a central chamber called control room. In feed gas and furnace fuel, desulfurization of feed gas of water steam hydrocarbon transformation, steam generation in furnace, periodical conversion of CO to CO2, carbon dioxide absorption, methane making and distilled water collection system, 43 workers work and based on organizational position, there are 14 control operators, 21 yard operators and 8 supervisors.

Based on HAZOP of operating nodes, their deviations and outcomes are identified in hydrogen unit of refinery with 11, 37, 72 cases. The results of identified risks evaluation based on risk degree (occurrence probability and accident intensity) showed that 11 cases had risk degree higher than 15 and it is not acceptable. The results showed that the highest risk frequency were in nodes “natural gas entrance valve and operating sector” (21 cases), “reformer heating chamber” (18 cases) and “combined stage and reformer steam”(13 cases). These results are acceptable. The majority of reforming process activities is performed in three sectors and this process with methane and synthesis gas generation has high flammability and explosion capability, thus frequency of existing risks in these operating nodes is probable and it is true. In terms of risk intensity, the highest frequency of unacceptable risks (4 cases) is observed in the node “reformer heating chamber”. In addition, the highest frequency of acceptable risks (9 cases) with alarm (11 cases) is in the node “natural gas entrance valve and operating sector”. The most dangerous type of deviation as the increase of temperature and pressure in heating chamber are higher than normal, chemical reactions can lead to accidents. In different industrial units, based on production and final product, there are different risks as different in terms of accidents. In each industry, despite differences, some indices as accident repetition coefficient and risk intensity can be used for classification of jobs and sub-units. In addition, the highest lost day and correlation coefficients between initial risk assessment codes and safety performance indices can be of great importance (Hasheminejad et al., 2012). As unacceptable risks in each project can be eliminated with exact calculation of safety conflicts. The study of Mahdavi et al. (2012) showed that many accidents were dedicated to human errors and to limit their outcomes, control actions were performed in the forms of changes. After identification of outcomes (safety, economic, health and environmental), the intensity of these outcomes can be estimated using LOPA method and by presenting suitable control methods, reduced risks are computed and compared with target factor (Habibi et al., 2013; Vi et al., 2008; Jahangiri, 2007). Based on the results of LOPA, the majority of risks are based on cases in which starting point of chain events is extensive leading to stop of production and damage to equipment (employees) or environmental pollution. The relevant scenarios are identified risks with outcomes and each one is occurred by an initiating event. To analyze, accident intensity indices (based on economic loss) and frequency (accident frequency) are used. Finally, by risk decision matrix, it was shown which corrective action of scenario is obligatory and it should be performed on time (6 scenarios) and optional cases are recommended and it is in the next rank of significance (54 scenarios). Other scenarios don’t need any action and there is no economic justification for these cases (12 scenarios). Finally, the analysis of risks outcomes is consider using LOPA method and comparison with standard as target factor of LOPA and with considering existing layers of protection in each of points (e.g. BPCS, alarms and other control measurements) and total PDF of sum of protection layers is computed. Based on the results of analysis of risky points to apply layers of protection, 11 points of hydrogen unit are risky areas (condition: unacceptable), of which 6 points need review and immediate and obligatory corrective actions. The results of corrective actions and reduced risk for scenarios showed that for 6 risky points (e.g. first, second, third, sixth, seventh and eleventh scenarios), adding independent layers of protection can reduce risk 100% (compared to target factor) and safety integrity level is provided. Regarding four other regions (e.g. fourth, fifth, ninth and tenth scenarios), risk is reduced as 80% by layers of protection. Regarding the eighths scenario, protection layers cannot increase safety integrity level to more than 60% and to provide safety to target factor, after implementation of identified failures, other layers are used. It is proposed that further studies are applied using multi-variate decision making methods including hierarchy analysis to select the best corrective solution and using RCA method is considered to analyze the causes of accidents in hydrogen unit of refinery.

References

Alizadeh, S.S., Moshashaei, P., 2015. The Bowtie method in safety management system: A literature review. Sci. J. Rev., 4(9), 133-138.

Alizadeh, S.S., Sheikh Damanab, P., Rasoulzadeh, Y., Moshashaie, P., Varmazyar, S., 2015. Failure modes and effects analysis (FMEA) technique: A literature review. Sci. J. Rev., 4(1), 1-6.

Berg, A.R., 2007. Applicability of layer of protection analysis to determine safety integrity levels in the process industry: Norw. Univ. Sci. Technol., 1002.

Bridges, W., Dowell, III.A., Gollin, M., Greenfield, W., Poulsen, J., Turetzky, W., 2001. Layer of Protection analysis: Simplified process risk assessment center for chemical process safety. AIChE, New York, NY. 1002.

Cameron, I.T., Raman, R., 2005. Process systems risk management Elsevier. San Diego, 1008.

Carrillo-Castrillo, J.A., Rubio-Romero, J.C., Guadix, J., Onieva, L., 2015. Risk assessment of maintenance operations: The analysis of performing task and accident mechanism. Int. J. Inj. Contr. Saf. Promot., 1028; 11(1), 122-22.

Chongguang, W., Zhang Beike, M.X., 2007. The Layers of Protection Analysis (LOPA) in Process Industry [J]. Automation in Petro-Chemical Industry. 1002; 40001.

Craddock, H., 1997. Safety hand in hand with quality. Quality World, 11, 25885-20.

Dunjó, J., Fthenakis, V., Vílchez, J.A., Arnaldos, J., 2010. Hazard and operability (HAZOP) analysis. A literature review. J. Hazard. Mater., 1020; 221(2), 29.

Freeman, R., 2007. Using layer of protection analysis to define safety integrity level requirements. Proc. Saf. Progr. 1002; 12(1), 258-94.

Guo, H-t., Yang, X-h., 2006. Safety integrity level of safety related system and its selection. Contr. Instrum. Chem. Indust. 1002; 11(1), 22.

Habibi, E., Zare, S., Keshavarzi, M., Mousavi, M., Yousefi, H.A., 2013. The application of the Layer of Protection Analysis (LOPA) in sour water refinery process. Int. J. Environ. Health. Eng. 1021; 1(2), 45-82.

Hasheminejad, N., Halvani, G.H., Moghadasi, M., Zolali, F., Shafizade Bafghi, M., 2012. Risk assessment and determine safety performance indices in design stage and agglomeration project in 2011. Sci. J. Med., 4(4), 63-74.

Isimite, J., Rubini, P.A., 2016. Dynamic HAZOP case study using the Texas city refinery explosion. J. Loss. Prev. Proc. Indust. 1022; 400492-802.

Jafari, M., Lajevardi, S., Mohammad-Fam, I., 2015. Semi quantitative risk assessment of a hydrogen production unit. Int. J. Occup. Hyg. 1028; 8(1), 202-5.

Jarvis, J., 1997. Occupational health and safety: Take the first step. Quality World. 2992; 11(2), 884-2.

Kjellén, U., 2000. Prevention of accidents through experience feedback. CRC Press; 1000.

Lees, F., Loss, 2012. Loss prevention in the process industries: Hazard identification, assessment and control. Butterworth-Heinemann; 1021.

MARSH., 2002. The 200 Largest Losses 2921-1002: Large property damage losses in the Hydrocarbon Industry. 1001.

Mearns, K., Whitaker, S.M., Flin, R., 2001. Benchmarking safety climate in hazardous environments. A longitudinal, interorganizational approach. Risk analysis. 1002; 12(4), 222-52.

Millner, N., Small, T., 2006. Deakin Crick R. Learning by accident 1002.

Nassir, P., Alizadeh, S.S., Golbabaei, F., Shahtaheri, S.J.A.D., 2007. Hazards identification and assessment in a production factory using Job Safety Analysis (JSA). J. Environ. Sci. Technol., 8(4).

Ouazraoui, N., Nait-Said, R., Bourareche, M., Sellami, I., 2013. Layers of protection analysis in the framework of possibility theory. J. Hazard. Mater. 1021; 1210225.

Rasoulzadeh, Y., Alizadeh, S.S., Valizadeh, S., 2015. Health, safety and ergonomically risk assessment of mechanicians using job safety analysis (JSA) technique in an Iran city. India. J. Sci. Technol., 8(28).

Rausand, M., 2013. Risk assessment: theory, methods, and applications. John Wiley and Sons; 1021.

Summers, A.E., 2003. Introduction to layers of protection analysis. J. Hazard. Mater. 1001; 204(2), 221-5.

Wei, C., Rogers, W.J., Mannan, M.S., 2008. Layer of protection analysis for reactive chemical risk assessment. J. Hazard. Mater. 1005; 289(2), 29-14.

Yi, K.H., Lee, S.S., 2016. A policy intervention study to identify high-risk groups to prevent the industrial accident in South Korea. Safety and Health at Work. 1022.

How to cite this article: Delavar, A., Mirza Ebrahim Tehrani, M., Alizadeh, S.S., 2016. Layers of protection analysis to achieve safety integrity level (SIL), Case study: Hydrogen unit of refinery. Scientific Journal of Pure and Applied Sciences, 5(11), 515-523.