European Online Journal of Natural and Social Sciences 2016;
Vol.5, No.3 pp. 851-863
ISSN 1805-3602

Analysis of Gas Leak Events through the Combination of Tripod Beta and RCA Methods (Case Study: Fifth Refinery of South Pars Gas Complex)

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Received for publication: 25 February 2016.
Accepted for publication: 17 July 2016.

Abstract

Nowadays, concerns about the consequences of events caused by hazardous substances have become a global issue, therefore, the purpose of this study is to analyze gas leak events in gas refinery by the combination of Tripod Beta and RCA methods. The case study is (phases of 9 and 10) the fifth refinery of South Pars Gas Complex. In order to gather information, library and field methods were used. The information was gathered by visiting the site and interviewing with operators and safety personnel. The questionnaire was used in this study. The statistical population included 15HSE and professional health care experts working at safety and operation units in the refinery. The gathered information was analyzed by a combination of Tripod Beta and RCA methods and library studies were used to make a conceptual research model and a theoretical framework. Based on the obtained results, the average age of participants in this study was 4.35 years. The results show that the dangers to human health with the average of 78.3 are the most important danger compared to equipment and environmental dangers. The most important threat to the equipment is the detectors' breakdown and massive explosion, and the most important environmental danger is the increase of hydro-sulfur in the atmosphere. The death and injury to vital and sensitive parts of body have the highest frequency among other dangers. In fact, experts believed that death or serious injury to personnel should take the first priority. Corrective actions can include current processes and procedures, use of equipment, rules and regulations and the training of human resources.

Keywords: gas leak, gas refinery, Tripod Beta, RCA

Introduction

In order to meet the requirement of life, the society has to use industrial material and productions and go towards the use of new technologies, materials and energy. The progressive development of science and technology along with the discovery and the use of different types of chemical compounds will provide many human needs, but they will also have side effects and disastrous consequences which will eventually lead to the destruction of economic, human and environmental sources in the form of events such as explosion, fire, gas leak and dispersion of poisonous materials (Adl et al, 2007). The huge gas and oil sources and significant cost savings regarding this issue ensure the necessity of priority and investment in this industry so that the South Pars gas field in Assaluyeh region of Iran having more than 14 trillion cubic meters of gas reserves has the priority in development projects(Arzandeh, 2009). On the other hand, the numbers of refineries and their products have increased and as a result, the numbers of people working in these industries and populations living in the surrounding have also increased (Habibiet al., 2011).

Nowadays, the concerns about the consequences of events caused by hazardous substances have become a global issue (Hosseini Jenabet al., 2012). Today, human life has found the close and inevitable relationship with different chemical industry. One of the most important industries is oil, gas and petrochemicals industry. Due to the priority and investment in this area, these kinds of studies are very important in our country (Abbaspouret al., 2009). On the other hand, the increase in the industrial complexes in this field leads to the growth of population of people working in this industry or living in the surroundingwhichcauses that the relevant health and safety become more important (Habibi, et al., 2011). According to the statistics, the average of 6000 people die of work-related accidents or diseases every day, i.e. more than 2.2 million people die due to their work-related activities which is meant to state that3000 people die while they are working. It is estimated that the costs which are due to the loss of manpower, equipment and time exceed $ 5000000 each year (Somavia, 2005).One of the incidents that can alwaysincur in the industrial processing unit is the release or the leak of poisonous material in the environment which can incur due to failure of a deviceor personnel' mistake. The gas and oil leak is one of the most important events in the phases of construction, pre-commissioning, commissioning and the production of oil, gas and petrochemical (Abbaspour et al., 2009). Natural gas leak is more important than other chemical leaks such as ammonia and chlorine. Gas leak can cause not only respiratory dangers but also explosion and fire in the whole complex. Dealing with gas leak incidents requires the application of new knowledge and technologies among which modeling is one of them. Modeling includes the prediction of the effect of chemical release and broadcast in the environment by mathematical modeling. It evaluates the effects of the incident as damage to property, infrastructure, human health and the environment and usually uses a four-stage model scenarios, situation analysis, incident modeling and damage assessment (Hosseini Jenab, 2012;Chavoshi et al., 2011). The main outcome of flammable and toxic chemical release is fire, explosion and the release of toxic substances (Rezaiet al., 2012). The purpose of this study is to evaluate gas leak events in gas refinery With the Combination of Tripod Beta and RCA; a case study of (phases 9 and 10) of South Pars Gas Complex in fifth refinery.

The Scope of the Study

The scope of the study is the South Pars gas field which is one of world's largest independent gas resources which is on the borderline of Iran and Qatar and it is considered as on the most important energy resources of the country (Ghasemi,2013). The total area of this field is 9700 square kilometers and Iran has 3700 square kilometers of this field. The gas reserve is about 9% of the total global gas reserve and it is 48% of the gas reserves in Iran (Public Relations Department of National Petrochemical Company, 2010). Today, 25 thousand people are working directly in the field of South Pars and this figure will exceed 60 thousand people in the near future (Ghanbariet al., 1999).

Methodology

To gather information, library and field methods were used. The internet and library were used to write the literature review. The information was gathered by visiting the site and interviewing with operators and safety personnel. The questionnaire was used in this study. The statistical population of this study involved 15 HSE and professional health care experts working at safety and operation units in the refinery. After being edited by some experts, the questionnaire was given to the participants; the received results were analyzed, and then the final questionnaire was designed in the larger scale. Cronbach's alpha was used to measure the reliability of the questionnaire and the alpha coefficient was calculated using the following equation:

Equation (1):$R_a = \frac{j}{j-1}(1 - \frac{S_{j2}}{S_2})$

Where J is the numbers of sub-questions in the questionnaire, Sj2 is the variance of each section of the questionnaire, and S2 is the variance of the total questionnaire.

Using the reliability test in the statistical software, Cronbach's alpha was used to analyze the questionnaire. The descriptive statistics were presented using central tendency and dispersion and it was used with factor analysis results as an inferential statistics andall statistical operations were conducted by SPSS software (version 20).

After studying the documents and the existing conditions in phases 9 and 10 of South Pars Gas Complex in fifth refinery, the information received from the reports and observations, the incidents of fifth refinery were analyzed by the combination of Tripod Beta and RCA methods; the library studies were used to make a conceptual research model and a theoretical framework.

To investigate the core, direct and intermediary causes, the incidents were evaluated by RCA and Tripod Beta techniques, and then the two results were compared to each other and finally, according to the received information, some practical solutions were presented to prevent and reduce the incidents. Tripod Beta is based on three pillars of danger, goal and incident and the analysis of the incidents are based on the following factors:

1. To illustrate a chart and the determination of danger, goal and incident
2. To determine the protective systems (control and defense)
3. To identify surface problems (unsafe acts and conditions)
4. To use the attached checklist in order to determine the preconditions and hidden problems (Mohammadi et al., 2013)
5. To determine an effective pre-conditions and invisible problems in incidents based on the above mentioned checklist and entering them in the table to manage the invisible problems.

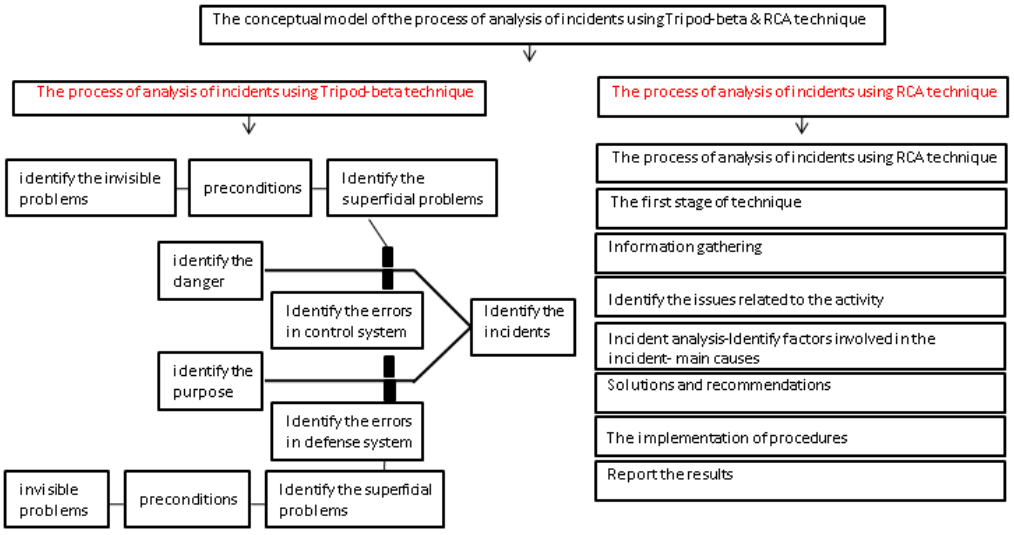

Figure 1. The Process of the Stages

"What", "How" and "Why" an incident happened is determined by RCA method and the purpose of the RCA is to achieve a systematic method in order to determine the main reason of incident and to ensure that the same incident will not incur anymore and it can be mentioned that a combined Tripod Beta and RCA methods can realize the ability of the immune system and the

management of gas refinery under study. The stages of this study were schematically shown in Figure 1.

The Prioritization of Criteria and the Validity and Reliability of the Questionnaire and the Individual Characteristics of Experts

In this section, the questionnaire was used to survey the members of the panel of experts. By surveying the statistical population, the prioritization of gas refinery dangers were taken into account and at the end, the prioritization of gas leak incident and weighting events were manipulated.The reliability of the questionnaire was determined by Cronbach's alpha. Regarding the fact that Cronbach's alpha coefficient is higher than 7.0 for each variable, it shows that the questionnaire has a good validity. The statistical population of this study involved 15 HSE and professional health care experts working at safety and operation units in the refinery. The individual characteristics results of the panel of experts such as age, gender, marital status and educational degree is shown in Table 1.

Table 1. **The frequency distribution of the individual characteristics of the panel members**

Variable	Ranges	Frequency	percentage
Age	20-30	2	13.33
	31-40	11	73.33
	41-50	2	13.34
Sex	Male	15	100
	Female	0	0
Marital Statues	Single	3	20
	Married	12	80
Education	Diploma	0	0
	Associate degree	3	20
	BA/BS	10	66.66
	MA/BA and above	2	13.33

The panel members have been graduated from different fields of study such as engineering (4individuals), HSE (4individuals), health professionals (3individuals), environmental health (1individual), environmental pollution (1 individual), disaster management (1 individual) and civil engineering (1 individual). The average work experience was 9.7 years which was in the range of 1-16 years.

Table 2. The results of the central indexes and dispersion of factors (dangers)

NO	Factors	Average	Standard deviation	The coefficient of variation
1	Danger to the human health	3.78	0.042	1.11
2	Danger to the instruments	3.40	0.03	0.88
3	Danger to the environment	3.16	0.03	0.94

Central Indexes and Danger Dispersion

According to the results in Table 2, human danger with the average of 3.78 is the most important gas refinery danger which regarding preservation of human life and health in comparison with equipment and environment dangers has more importance. Based on the participants' priorities,

the environmental dangers with an average of 16.3 are less effective than other options in terms of danger. This selection is based on the extent and degree of deterioration, the consequences of the accident as well as the likelihood of incident.

The Results of Frequency and Danger Priority

The dangers which are given too much importance by experts are mentioned here. The results of frequency, percentage and prioritization of items regardless of the defined factors have been investigated. In Table 3, the frequency and prioritization of dangers in the gas refinery is provided. The highest frequency rate belongs to death or injury to vital and sensitive organs. Extensive gas leak equipment dangers, fires in the units as well as the damage to the furnace achieve the fourth or fifth rate. The final priority is often related to environmental dangers.

Table 3. The results of frequency, percentage and prioritization of items

No	Dangers	Frequency	Percentage	Priority
1	Death or damage to vital and sensitive organs	14	93	1
2	Explosion and damage to the personnel working in the naked tower	13	86	2
3	Burn caused by fire or explosion	13	86	2
4	Gas poisoning (inlet gas, sulfur, etc)	11	73	3
5	Extensive gas leak and fire at units	10	66	4
6	Damage to the furnace and disorder in the naked tower	9	60	5
7	Freezing and burning caused by spreading propane	8	53	6
8	The overflow of soluble materials from V51003 container and the destruction of Plantair	8	53	6
9	Personnel fall from height	8	53	6
10	The release of hydro-sulfur into the atmosphere	7	46	7
11	The disorder in the process of Klaus	6	40	8
12	The sulfuric acid leakage in a closed space caused by the increase of the flow	5	33	9
13	The increase of release of ethanol amine into the environment and the increase of groundwater nitrate	3	20	10
14	Greenhouse gas emissions resulting from the combustion of fossil fuels and hydrocarbons	1	6	10
15	Sour water production and the release of water resources without any control	1	6	10

The Factor Analysis Dangers and a Summary of the Records of Incidents from Gas Leaks at Refineries

In order to set the data to factor analysis, K.M.O factor and Bartlett's test were used.In this study, the value of MSA (which is described by KMO) was equal to 0.725 and showed data for analysis at the good level. Bartlett's value is equal to 627.2264 which was at the meaningful level of

1% and in fact the meaningful sphericity is between different levels of data. And, these indexes showed that the data are suitable for factor analysis and the Kaiser criterion was used to determine the number of components; five components were found appropriate. In this study, the gas leak incidents were reviewed in fifth South Pars Refinery from 2011 to 2013. 15, 12 and 8 gas leak incident occurred in South Pars gas of fifth refinery in 2011, 2012, and 2013, respectively which 12of them were related to human damage. It should be noted that in order to analyze the gas leak incidents using Tripod Beta and RCA, the main incident regarding some criteria such as human damage, damage to equipment and environmental dangers were selected. The weight of the different criteria was considered which are as follows (Table 4):

Table 4. The criteria for selecting incidents with their weight

The code of criteria	The description of criteria	Weight
A	The death of personnel (official [full time], part time, etc)	5
B	Damage (burning, poisoning, etc.) to some personnel	4
C	Damage (burning, poisoning, etc.) to one employee	3
D	Damage to instruments caused by explosion, fire, etc.	2
E	Environmental dangers (gas or fluid leak, etc.)	1

According to these cases, the choice of incidents was based on the weight of the criteria and it was found that the incident number (i.e. 322) had the highest points (i.e. 8) and regarding the fact that two of the people died in this incident, it has been a remarkable incident in recent records of the refinery. It was analyzed based on the considered method and the corrective actions have been proposed to prevent the bitter and harmful recurrence of such incidents.

The Analysis of Incident Based on a Combined Tripod Beta and RCA Methods

*The Data Gathering Phase.*The incident took place on May 1, 2012 at 2:45 a.m. It happened at the Cold Box second floor, on the 105STR-0006 flange downstream of the filter, 16-inche line between the demethanaizer tower and Cold Box of the fourth row of gas treatment in the phases 9 and 10 of the fifth refinery in South Pars Gas Complex. The conditions prior to accident were as follows:

At the beginning of the night shift dated 30.04.2012 in order to continue overhaul, a group of fitter was asked to install the hose who was discharged after working the surrounding units at 23:45. According to the research team, after being discharged, two victims who were the members of the group and were hired temporarily for the overhaul period separated from the group and went to the place without checking out with their supervisor.

Based on the available evidences on the safety department, both victims took part in the introductory instructions of safety regulation and H2S classes in the gas refinery. However, despite the fact that they knew the regulations, they secretly brought the forbidden items (lighters, cigarettes and drugs) into the refinery and tried to use these items at the incident place.

According to the 901825 license to work on 1054-STR-0003 filter on the southern side of the incident place, the place was checked by safety personnel for the presence of the gas at 1:00 A.M and the amount of gas was zero. It should be noted that by the time of the incident, no activity was started on this case.Only two activities were started in the fourth gas row before the incident and they are described in details in the following:

- 901832 permit license for Hydrostatic test on the 105-E-405 adapter

- 968575 permit license for De-spading operations of 1044CC0014 coupon corrosion

It should be noted that no hot naked flame work was done in the fourth row of the gas in the refinery at that night.

According to research group studies, the evidence indicates that the creation of ignition source in the vicinity of the downstream STR0006 flange (only fixed with plastic cover, and tied with wire) and heat (which causes gradual emission of gas of hydrocarbons trapped in a blind spot system (based on the existing design) and the likelihood of the destruction or opening of the plastic cover are the main causes of the incident.

In addition, during the two days before the incident the pressure of the demethanaizer tower has been fixed on zero which indicates that the flammable gases are not transmittable into other adjacent systems. The inactivation of three infrared gas detectors in the vicinity of the place of incident confirms this issue.

In a visit conducted by the research team from the incident site, some evidences showed the presence of two victims in the region including 2 caps, 2 pairs of shoes, 2 work clothes, cans of food, tea flasks, lighters, cigarette packets, some cigarette filters and tablets of methadone, tramadol and sildenafil (Viagra) as well as crystal which handed over to the security office.The overall overview of the incident was reported as follows:

The fire incident was reported by one of the operating personnel to the control room and the announcement to emergency control team via central control room recorded at 02:43 a.m. at the fire control center.Due to the presence of the firefighters in the south of the area, the firefighting operation started immediately; after the establishment of emergency control teams (firefighting, safety, emergency, security and the head of shift operations), they asked for the crisis team in the refinery because of the extent of incident. Immediately after the arrival, the emergency control teams found one of the victims in the east of the fourth gas row and he was sent quickly to the clinic; the second victim was found in the west of the fourth gas row and he was sent to the clinic. After initial medical treatment, they were sent to the special zone clinic and then to Ganaveh harbor. According to the initial medical report, the victims suffered from the second and third degree burn and were hospitalized in ICU and their consciousness was monitored. Both victims were part-time workers of Petropi Contractors Company who was hired for the overhaul period. The fire station report also showed that the place was on the downstream filter STR0006 flange which was opened to clean the filter based on the license number 901852 on April 26th, 2012 and the filter was transferred to the workshop, the entry toward the filter was blinded and the exit toward Cold Box was tied with plastic cover and wire.

According to the available evidences, regarding installation authority emphasis on the installation of blind and the emphasis of the safety personnel on blinding the place to maintenance supervisor (with this explanation that the place should be ruptured) the mentioned place was not blinded,and only the entry to Strainer was blinded and the exit from Strainer to Cold Box was not blinded.Based on the movies from CCTV system, the severity of fire was direct and according to the officials at the scene, it has been low and upward. Due to lack of blockage of the downstream STR0006 flange and the heat, the gas (which according to the instruction was prepared in the system) was emitted from the system and caused the fire. The fire was completely extinguished after 2:35 minutes at 5:20 a.m. and after immunization and gas and heat test, the STR-0006 exit was blinded at 6:20 a.m.

In the incident, two people working at Petropi Contractors Company were severely burned and were immediately sent to hospital. The damages to the equipment consist of a number of precise instruments and a number of cables and destruction of the cold box body color and the destruction of a number of the lighting system. Furthermore, the truck (vehicle) in the first refinery (the first phase

of South Pars) leaked in the gearbox (fire equipment). The consequences of this incident were estimated based on human and financial losses. The human losses include the death of two people. The definite financial loss was estimated over 5.2 billion Rials while the possible loss was not estimated.

The Appraisal and the Analysis of Incident

After gathering information, the results from the review of the process of the incident are as follows:

- Phase 9 is in the state of producing 23.5 million cubic meters per day
- Gas treatment unit No. 4 is in a state of full pressure discharge and is also under overhaul
- The temperature is 33 ° C
- Wind direction: West to East

Furthermore, from Monday(30.04.2012) the stop timeline and the establishment of the refineries are as follows:

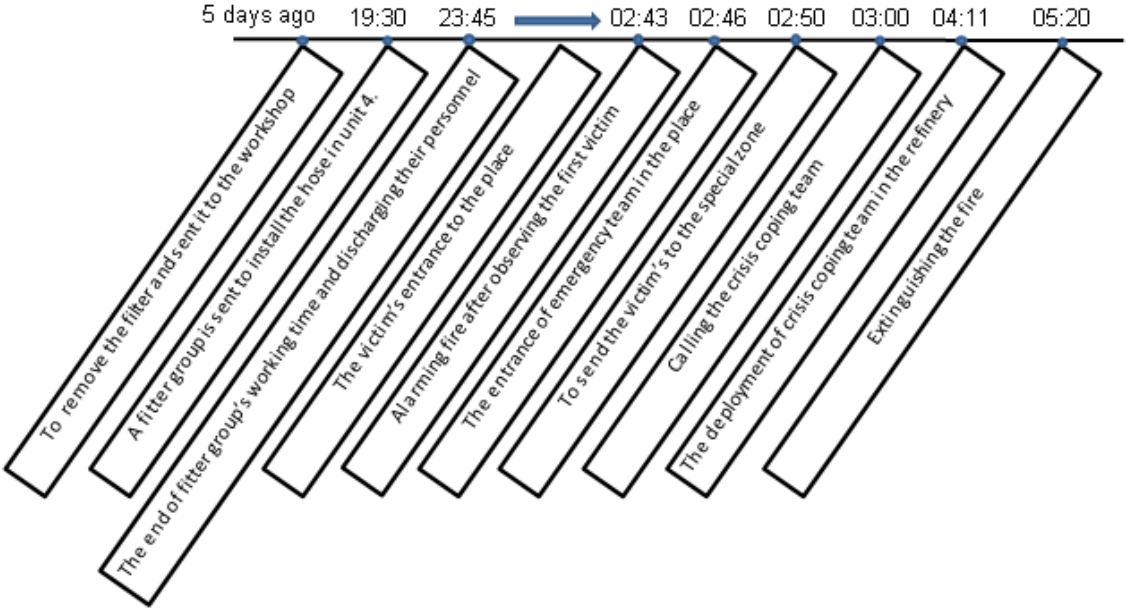

Figure 2.The stop timeline and the establishment of the refineries

Due to these facts, events and causal factor (E&CF) can be drawn by RCA method (Figure 3).
As shown, the direct causes of the incident are:

A. Ignition sources
B. Flammable materials

Furthermore, the main causes of A include are:

a. Lack of Handover of activities due to the end of the shift
b. The concurrency of launch phase 9
c. The preparation of phase 10
d. Not following the HSE instructions from involved individuals
e. The lack of proper supervision on the workers
f. The lack of spade of the lines due to the pressure on propane cycle to accelerate the cycling launch
g. Thinking about doing something else from the repair team

The main causes of the B are:

a. The lack of control on the personnel by the relevant authorities

b. Lack of control on the personnel at the time of entrance by the security guards

c. Use of part time uncommitted and unfamiliar personnel who are not familiar with the dangers to overhaul the process.

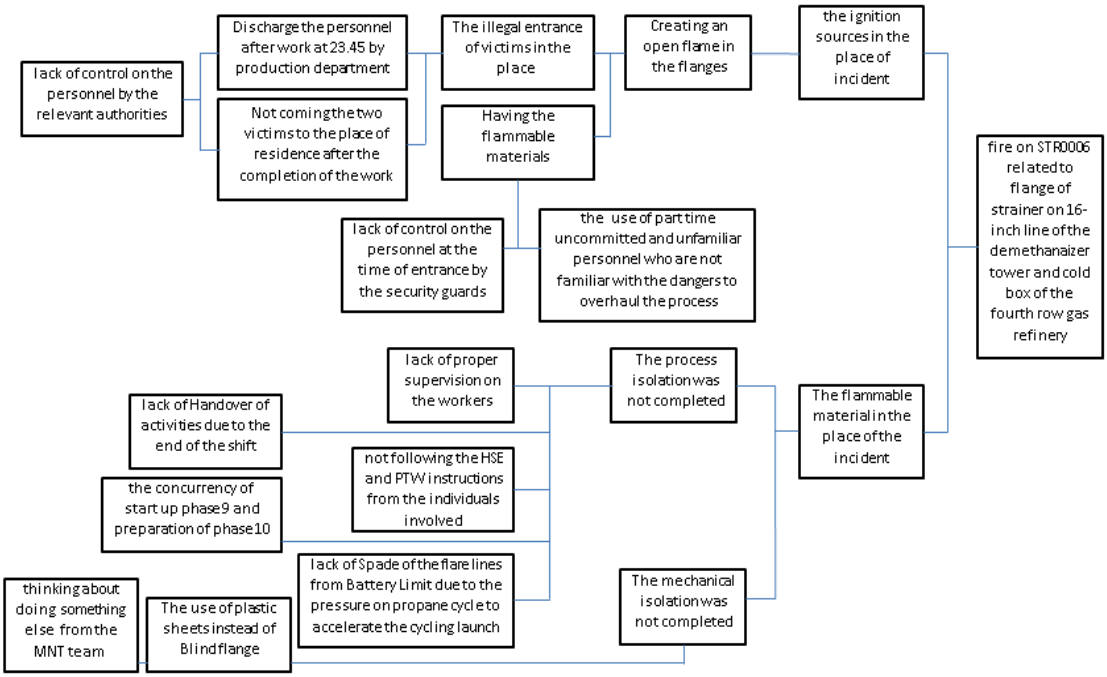

Figure 3. E & CF incident table based on RCA method

Figure 4 shows the three items of incident, danger, and goal in the Tripod Beta method.

Based on this table, three recognitions can be perceived which include:

A. Incident recognition: fire on STR0006 flat flange on 16-inch line of the demethanaizer tower and cold box of the fourth row of gas (gas train 4)

B. Goal recognition: 1. Personnel: Two dead individuals 2. Equipment (the damage to a number of precise instruments, body color of the cold box, parts of cables, lighting system and gearbox of fire truck) 3. The environment (the emission of the toxic gas)

C. Danger recognition: The failure in the immune system: the ignition sources in the place of incident; (2) The failure of control system: The flammable material in the place the incident. These two items are the superficial failures (or direct causes). Furthermore, the pre-conditions and invisible items in the figure are intermediate and main causes of RCA method, respectively.

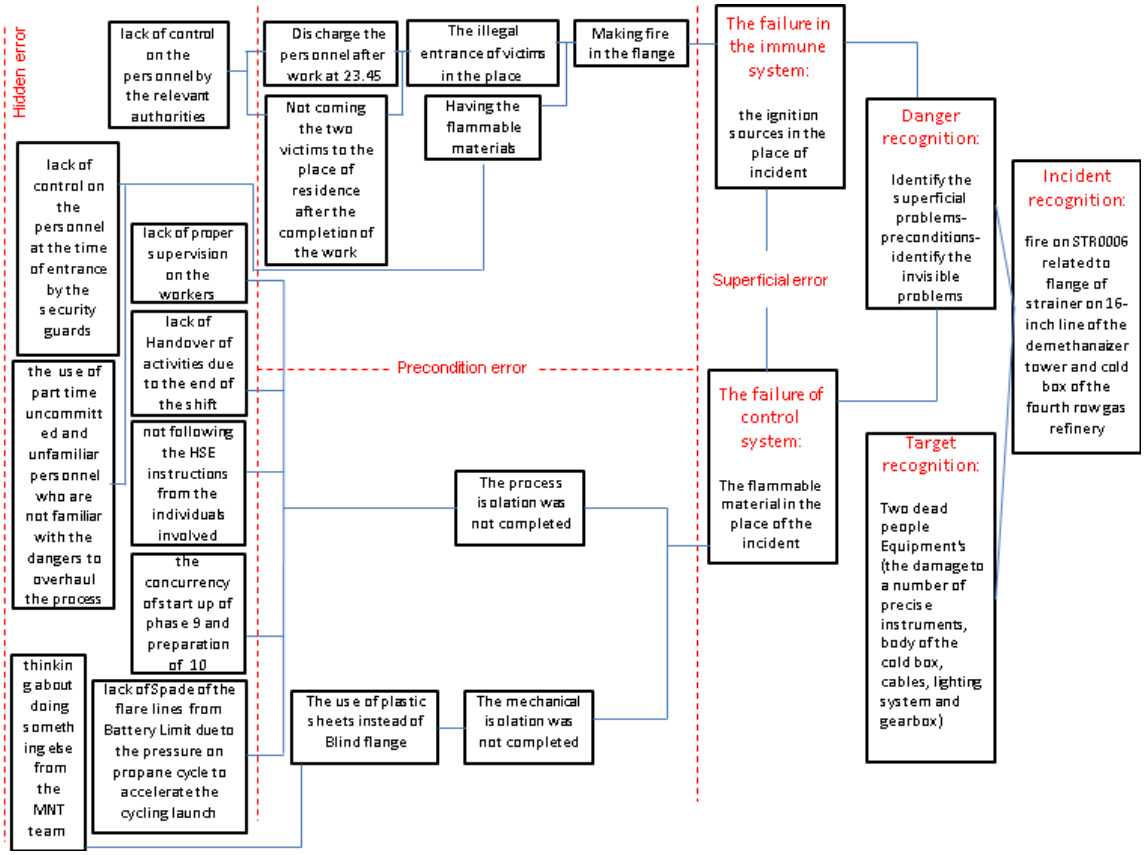

Figure 4. The table of event, danger and goal based on Tripod Beta method

A tree diagram of Tripod Beta and RCA methods is shown in Figure 5.

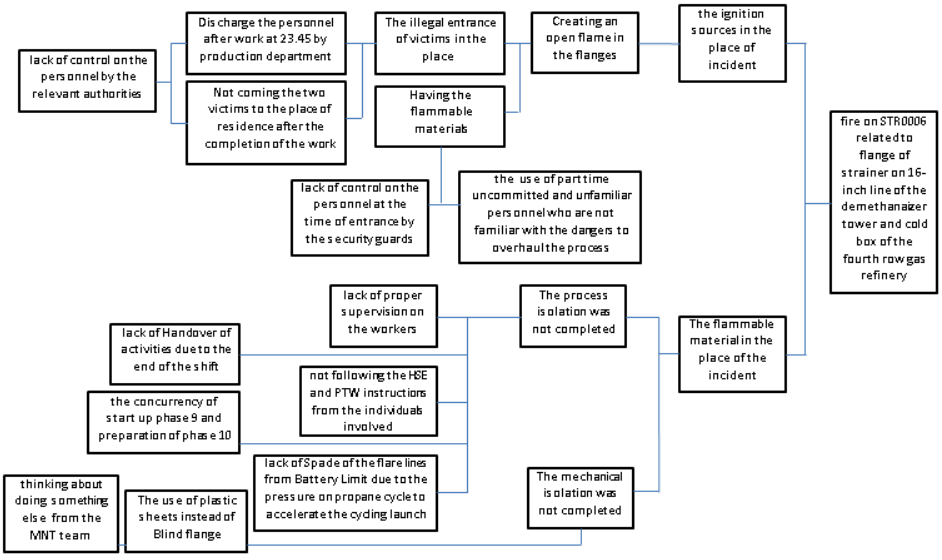

Figure 5. A tree diagram of Tripod Beta and RCA methods

In this diagram, events and causal factors of RCA and the event, danger and goal items have been combined together by Tripod Beta methods

The Suggested Corrective Actions Phase

Based on RCA method, the "sparks" and "gas" was determined that any corrective actions are presented in the following figures:

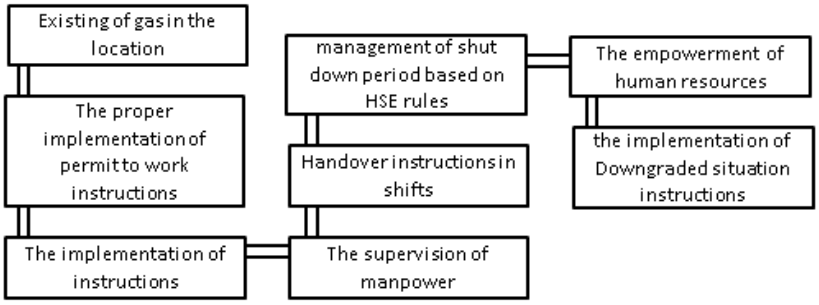

Figure 6.Corrective actions in gas issues

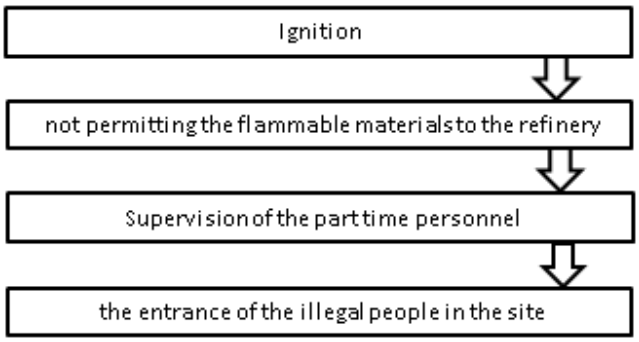

Figure 7.Corrective actions in spark issues

The corrective actions can be categorized into four groups:

- The current methods and processes
- Use the standard equipment
- The rules and regulation
- Manpower Training

The Recommended Solutions

It is recommended to give the responsibility of any corrective actions to the relevant sections, on this basis, the recommended tasks that each section should take are listed in the followings:

- The control and continuous monitoring of detectors in each unit regarding the importance and sensitivity of the accident caused by gas leakage or the increase of temperature of naked tower through repair unit or the analysis of systems
- Prevention of presence of addicted people (or people with the habit of using drugs) in the refinery by the working group on security, administrative services and safety, as well as preventing from the entrance of the spark-generating devices into the industrial site

- The employment of the manpower in the works related to repairing and the establishment of the above instructions by the repair team or the manager of refinery; the supervisor of the part-time workers in the overhaul and the preparation of the instructions
- The proper revision and implementation of the gas license instructions by working group on security, maintenance, operation, engineering and the supervisor of the full time worker
- The establishment of handover instructions in shifts by the working group on safety, maintenance, operation and security, and the implementation of downgraded situation instructions
- The empowerment of human resources by 1) determination of the indexes, 2) how to measure, and 3) determination of the distance and 4) bridging the gaps.
- The necessity of wastewater treatment as well as reducing sulfur and greenhouse gas emissions before entering into the environment should be followed by operation and safety units.

Some experiences can be gained from this incident including:

1. Manpower training
2. The revision of the overseas rules and regulation
3. The management of addiction

In addition, it is necessary to provide some instructions related to the prevention of flammable materials, manpower training and empowerment in the relevant profession and its obligations should be regarded (Haqjoe, 2013).

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