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Identification and Safety Assessment of the Hazardous Zones (Unwanted Energy Flows) in an Construction Project at the National Petrochemical Company by Application of ET and BA Method

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Abstract: In this study, the safety assessment has been conducted qualitatively with the goal of determining the potential existing hazards in construction sites, with the application of ET and BA technique and assessment of the identified risks. In other words, in order to determine the risk factor, the possibilities of conversion of potential hazards into accidents and the risk factor standards were classified qualitatively. For this purpose, the risk matrix presented in MIL-STD-882E standard (The 5th Version of US Military Standard) was used. According to the results of this study, a total of 144 hazardous zones were identified. Based on the MIL-STD-882E standard, 68% of the cases were in the high-risk zone, 30% were in the important risk zone and 2% were in the average risk zone. Meanwhile, working on scaffoldings has had the most number of high risks (23 cases) and the other sections including excavation, electrical, welding and cutting operations are placed in the next level of importance with, respectively 21, 13 and 11 high-risk cases. With due to the results, nearly the majority of identified points are in the high-risk zone (68%) and important zone (30%), which is unacceptable according to the MIL-STD-822E. Hence, the necessity of conducting appropriate controlling measures including the establishment of supervision and inspection systems, preventive repairing and applying standard and safe techniques and methods are some of the proposals which leads to a drop in the possible risks. By comparing the results of this research with other similar projects, including the study which was conducted by the Ugandan Employment Office in 2005, one can realize similar results in developing countries, especially regarding high risks and control-related priorities.

Key words: Construction, ET and BA, risk assessment and accidents

INTRODUCTION

The construction phase in industries is a dynamic process, which is dangerous in nature. The more complicated the construction phase, the higher the number of accidents, such that the OSHA international organization has announced the number of deadly and fatal accidents in these industries at an average of over 2,000 death cases per year. According to statistical figures on construction industry, released by the US Employment Office, one in every six construction workers suffers from job-related harms and illnesses every year, in average. Meanwhile, one in every 16 construction workers is also seriously hurt. The construction workers lose almost 1.2 days per year due to occupational injuries. In regard to the comparison of bitter accidents in different industries, the report released by this center shows that the rate of fatal accidents among construction workers is six times more than the rate of fatal accidents among production-units workers. Therefore, the heavy burden of materialistic and moral costs, which rests on the shoulders of industries and communities, has made the specialists and experts think of a solution to prevent the occurrence of accidents (Steve, 2004).

The construction phase in the industrial projects, studied in this research, is faced with a vast range of challenges. One of these challenges is the recurrence of accidents in workplaces. From the very beginning of the construction phase of this project, (less than 4 years ago) numerous accidents have taken place and a significant number of these accidents (almost 50 cases) have led to deaths, with a numerous other accidents leading to the workers' debilitating injuries. If in the study of these fatal accidents, the pyramids for investigating the accidents are used the importance of the studied topic would be doubled. The Tye/Pearson (1975-1974) Pyramid considers the occurrence of 30 minor accidents; 50 accidents in need of first aid; 80 accidents that inflict damages on the

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equipment and properties and 400 semi-accidents (near miss); for every fatal or severe accidents. With a simple calculation, we realize that during this period following at least 50 fatal accidents; 1500 minor accidents, 2500 accidents in need of first aid, 4000 accidents that inflicted damages on equipment and properties and 20,000 semi-accidents have occurred (James and Fullman, 1994).

These figures go to show that the construction phase in the studied projects is one of the high-risk zones. For the same reason, there is need to develop an appropriate strategy in order to strongly sense a fall in the accidents of these projects. Hence, a precise assessment of the nature of energies and their resulting hazards should be made so that appropriate controlling solutions are taken into account for them.

On this basis, with due regard to the numerous varieties of energies used and the necessity to identify potential hazards and to prevent the occurrence of accidents, this study aims to benefit from the energy trace and barrier analysis technique (ET and BA). This technique is one of the most applicable and educational tools accessed by the researchers for studying the safety of the systems. In this technique, the accident is defined as the release of an unwanted flow of energy, which takes place due to the inappropriateness of the barriers.

The general goal of this study is the safety assessment of one of the ongoing projects in the construction phase and the minor goals of the study is the risk assessment in order to determine the existing potential hazards in construction sites with the application of the ET and BA technique.

Two studies have been registered, to date, throughout the history of application of this method in Iran, with the first one: Identification of hazards in an industrial unit by adoption of the method for detecting energy and analyzing its barriers, from Tehran Medical Sciences University and the second one: Assessment of the safety of glucose production line by adoption of the ET and BA method in a company, producing glucose and presenting the controlling ways and methods in order to prevent the occurrence of accidents, from Tarbiat Moalem University.

One of the most recent published studies worldwide is a research which was conducted by the Ugandan Employment Office in 2005. In addition to the above-said studies, numerous accredited organizations have recommended the application of the ET and BA method in their adopted standards and reference books. Some of these documents include DOE-NE-STD-1004-92 and NASA-STD-8719/7 and the system's safety guidance booklets released by the U.S. Federal Aviation Organization (Taylor and Francis, 2002; Ringdahl *et al*., 2001).

MATERIALS AND METHODS

The viewpoint and topic of studying energy as the source of injuries was first presented by Gibson. Thereafter, Hayden and McFarland presented their models of energy on its basis. The standpoint, which calls for studying a system based on its existing energies is based on a model of methods for studying accidents and is founded on three main components:

- The vulnerable target, which is usually humans, but it can be tools or installations
- Energy, which can lead to an accident
- Obstacles, which prevent an injury, including the devices' barriers

The ET and BA method is one of the simplest extended versions of the energy model. This technique is based on the logic that the damages resulting from the accident occur due to the unwanted flow of energy from the barrier to the connected targets. This method is used as a means for fundamental analysis of the reasons behind the accident, which has its roots in the Management Oversight and Risk Tree (MORT) Technique (Vincdi and Reinhold, 1993).

Prior to starting the analyses, one has to go through a preparation phase. One of the main points at this stage is to gain some information about the studied installations. This information can include the technical maps of the installations and a number of photos. In regard to the existing installations, one could easily gain access to these data by attending the site and observing it. Moreover, at this stage, the structure of the studied subject should be divided into several sections. The method adopted for implementation of ET and BA technique includes five major steps (Kandel and Avni, 2000).

- The first stage is to identify the types of energy within the system. This step usually calls for a significant expertise for identification of different types of energy. At this stage, the sources and reservoirs of energy in each section are identified. In order to be assured that all energy sources have been identified, an appropriate checklist of the types of energy which might be present within the system should be prepared. Table 1 show the checklist used in this study (Vincoli and Reinhold, 1993).

- The 2nd step is to trace energies within the system. As soon as different types of energy are identified in the system, the sources of each of these energies within the system should be identified and later on the flow of that energy within the system should be traced. At this stage, in order to assess the potential energy release from the source and its contact with potential targets, several tests are applied. These tests include a group of what if questions which are presented in the path of the energy flow. These questions have been rendered in the checklist for the discovery of hazards in the ET and BA technique. This checklist is presented in Table 2.
- At the 3rd stage, the existing barriers and obstacles on the way of unwanted energy flow (which have been considered for controlling the energy flows) are identified. In order to assess the effectiveness and performance of these barriers, several tests are applied. These tests include a group of what…if questions which are presented for each barrier. They have been shown in the checklist for discovery of hazards in the ET and BA technique Table 2.
- At the 4th stage, the risk factor of each of the identified energies in the system is assessed. The main goal behind the risk assessment is to pave the ground for decision-making in regard to whether the system has an acceptable risk factor and is safe under the current conditions, or is it necessary to make changes in order to optimize its safety. In the current study, qualitative risk assessment has been applied. In other words, in order to determine the level of risk, qualitative classification of the possible rate of transformation of hazards into accidents and the related risk-susceptibility standards have been used. For this purpose, the risk matrix presented in the MIL-STD-882E (www.safetycenter.navy.mil/) has been used. Table 3 and 4, respectively show the qualitative classification of the intensity and possibility of occurrence of accidents, while Table 5 and 6 show the risk matrix and risk-acceptance standards.

Table 1: Checklist of different types of energy (Vincoli and Reinhold, 1993)

1-electrical energy	4-6-ventilation	9-2-displacement	14-1-earthquake
1-1-common AC or DC currents	4-7-movement of ground/excavation	9-3-hamraft	14-2-flood/drowning
1-2-stored electrical energy/electrical discharge	5-linear kinetic energy	9-4-heating cycle	14-3-avalanche
1-3-electromagnetic radiations/RF pulses	6-1-sound	9-5-production of heat	14-4-landslide
1-4-inducted currents/voltages	6-2-vibration	10-etiological factors	14-5-compactness
1-5-controller of voltages/electrical currents	7-dampness	10-1-virus	14-6-debris
2-mass/gravity/height	8-energy resulting from chemicals (acute and chronic)	10-2-bacteria	14-7-underground water currents
2-1-individual's free fall/individual hitting the ground	8-1-chemical suffocation	10-3-fungus	14-8-frost
2-2-fall of objects	8-2-abrasion	10-4-worm	14-9-volcano
2-3-suspended objects	8-3-lubricants, solvents, solutions	10-5-biological poisoning	15-atmospheric conditions
3-circular kinetic energy	8-4-degenerating material	11-radiation energy	15-1-direction, intensity and speed of wind
3-1-wheels	8-5-precipitations	11-1-ionization	15-2-rain (warm, cold, freezing)
3-2-Fan pressure	8-6-explosives	11-2-non-ionization	15-3-snow/hail
4-Pressure/volume/kinetic displacement	8-7-oxidating material/combustible material and self-incinerating material	12-magnetic fields	15-4-electrostatic/electrical
4-1-Pressure rise and rupture/explosion	8-8-material which can be polymerized	13-objects or live animals	15-5-smug/powders
4-2-Increase of vacuum	8-9-cancerous material	13-1-actions and reactions of individuals	15-6-sun lights
4-3-Fall o f liquid/floating position/rise and/or fall of the liquid level	8-10-wastes/pollutants	13-2-animals reactions	15-7-acid rain/steam clouds/gas
4-4-expansion o f fluids	9-heating energy	13-3-interference of trees, bushes, etc	15-8-weather (mild/cold/freezing)
4-5-exit of object from looping state	9-1-radiation energy	14-natural disasters	

Table 2: Checklists for discovery of hazards ET and BA

Changes in energy flow	Changes in barriers
Flow is either too large or too low, or doest not exist	The barrier is either too strong or too weak
Energy flows either too soon or too late and/or does not take place at all	The barrier's design is faulty
Energy flows either too swiftly or too slowly	The barrier acts too quickly or too late
The energy flow stops, increases or is released	The barrier is either shattered or completely out or order
A wrong shape or kind of energy enters the system	The barrier stops the flow or increases its intensity
The release of energy has serial effects	A wrong type of barrier has been selected

Table 3: Example mishap severity categories

Description	Category	Environmental, safety and health result criteria
Catastrophic	I	Could result in death, permanent total disability, loss exceeding $1M, or irreversible severe environmental damage that violates law or regulation.
Critical	II	Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, loss exceeding $200K but less than $1M, or reversible environmental damage causing a violation of law or regulation.
Marginal	III	Could result in injury or occupational illness resulting in one or more lost work days(s), loss exceeding $20K but less than $200K, or mitigatible environmental damage without violation of law or regulation where restoration activities can be accomplished.
Negligible	IV	Could result in injury or illness not resulting in a lost work day, loss exceeding $2K but less than $10K, or minimal environmental damage not violating law or regulation.

Source: (MIL-STD-882E, www.saftycenter.navy.mil/)

Table 4: Example mishap probability levels

Description	Level	Specific individual item	Fleet or inventory
Frequent	A	Likely to occur often in the life of an item, with a probability of occurrence greater than 10^{-1} in that life.	Continuously experienced.
Probable	B	Likely to occur several times in the life of an item, with a probability of occurrence less than 10^{-1} but greater than 10^{-2} in that life.	Will occur frequently.
Occasional	C	Possible to occur some time in the life of an item, with a probability of occurrence less than 10^{-2} but greater than 10^{-3} in that life.	Will occur several times.
Remote	D	Unlikely but possible to occur in the life of an item, with a probability of occurrence less than 10^{-3} but greater than 10^{-6} in that life.	Unlikely, but can reasonably be expected to occur.
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced, with a probability of occurrence less than 10^{-6} in that life.	Unlikely to occur, but possible.

Table 5: Example Mishap Risk Assessment Matrix (MRAM)

Severity probability	Catastrophic	Critical	Marginal	Negligible
Frequent	1	3	7	13
Probable	2	5	9	16
Occasional	4	6	11	18
Remote	8	10	14	19
Improbable	12	15	17	20
Designed Out	21	22	23	24

Table 6: Example Mishap Risk Acceptance Levels (MRALs)

Mishap risk index	Mishap risk category	Mishap risk acceptance level
1-5	High	Component acquisition executive
6-9	Serious	Program executive officer
10-15	Medium	Program manager
16-24	Low	As directed

- Finally, at the 5th stage, the options for risk control are studied, with the appropriate options being selected. Following risk assessment at the 4th stage, the high-risk, important-risk, medium-risk and low-risk zones are specified. At this stage, one has to find a way to lower the risk of high-risk, medium-risk and important risk zones. At this stage, questions such as Can one lower the risk and, if so, how? Can one eliminate or lower a particular type of energy? Is it possible to install safety equipment? are presented. (Ringdahl *et al*., 2001).

By responding to these questions, one can find solutions or take measures to lower the risk, up to an acceptable level.

In order to help improve the analyses, one can use worksheets for registration of ET and BA results (Roland and Moriarty, 2000; Kletz, 1988).

Present study has been carried out in the construction Phase in Petrochemical Projects (a case study of Assaloyeh) during 2003-2005.

RESULTS AND DISCUSSION

The results of this study are the worksheets or completed tables for ET and BA technique, which amount to more than 36 in numbers due to the identification of 10 different types of energy. In this article, due to their high volume only one worksheet has been presented in Table 7 as an example. By applying this method, a total of 144 hazardous zones were identified and in accordance to the MIL-STD-882E standard, 68% of them were in the high-risk zone, 30% were in the serious risk zone and 2% were in the medium-risk zone (Table 8). Meanwhile, working on scaffolding has had the most number of high risks (23 cases) and the other section including excavation, electrical, welding and cutting operations are placed in the next level of importance with respectively 21, 13 and 11 high-risk cases.

In regard to the credibility of achieved results by implementation of the ET and BA technique in the construction phase, one should say since the risk assessment and presented proposals have been based on consultations and interviews with an eight-member team of managers, engineers and project caretakers and the study of the existing deeds and documents and also with due regard to the potential and advantages of this technique, the results credibility is at an acceptable level.

Table 7: An example of the completed worksheet for ET and BA method

First stage (identification of kinds of energy and the existing hazards)				Second stage (risk assessment)						Third stage (decision-making)		
Type of operations	State of energy	Type of energy	Description of risk	Existing controls and obstacles	Vulnerable targets	Intensity of risk	Possibility of occurrence	Primary risk assessment score	Standard adopted for decision-making	Proposed controls and obstacles	Risk assessment score following controlling measures	Standards for decision making
Confined spaces	Inner space	9-8, 1-8	Shortage of oxygen, combustible and poisonous confined spaces	-	Human	I	C	4	High	The atmosphere of confined spaces should be checked prior to worker's entry. Issuance of permission for activity in confine space. Implementation of engineering control methods (industrial ventilation, PPE,...). Provision of tools and emergency equipment. To guard the safety officer outside confined areas.	19	Low
	Outer commun-ication		Non-discharge by blocking energy sources in a confined spaces	-	-Human -material -tools and equipment	I	D	8	Serious	While entering the confined area, all energy sources should be blocked and/or discharged. Establishment of regular inspections to be assured of discharge and blockage of all energy sources	18	Medium

Table 8: Figures and types of indentificated risks

Type of operations	Risks types: High	Serious	Moderate	Low	Total	Percentage
Scaffolding and work at scaffold	23	10	0	0	33	23.0
Work at height (except scaffolds)	19	2	1	0	22	15.0
Excavation	21	7	2	0	30	21.0
Electrical activities	13	0	0	0	13	9.0
Welding and cutting operations	11	3	0	0	14	10.0
Chemical material store and transmission	5	0	0	0	5	3.3
Machinery guarding	0	10	0	0	10	7.0
Cranes	0	5	0	0	5	3.3
Confined spaces	1	1	0	0	2	1.5
Cables	3	2	0	0	5	3.3
Vehicles	1	1	0	0	2	1.5
House keeping	1	2	0	0	3	2.0
Total	98	43	3	0	144	100.0
Percentage	68	30	2	0	100	

As it's evident from the results and has been specified in the matrix of risk assessment prior to control, the majority of identified points are in the high-risk and serious-risk zones (98%) which according to the MIL-STD-882E standard is unacceptable working in the scaffoldings has the highest risk factor (23%). Since this part of the operations, in addition to working at height (19%) is the most important part of construction projects, starting preventive measures to lower the risk in this field is an overriding priority.

Excavation operations, electrical activities and welding and cutting operations with respectively 21, 13 and 11% are at the next levels of importance.

Meanwhile, to lower the risk up to an appropriate level, the proper and necessary measures have been mentioned in the ET and BA worksheets, within 5 classifications as follows:

1st Group: Establishing supervision systems and conducting regular inspections.
2nd Group: Establishing appropriate service and maintenance systems.
3rd Group: Using standard and safe material, devices and equipment.
4th Group: Using safe and standard techniques and methods for implementing the job.
5th Group: Using equipment for individual protection and appropriate and high-quality protective equipment.

With the presentation of proposals and methods for lowering the risk factor, the results are expected to change as follows:

- 0% at high-risk zone.
- 0% at serious risk zone.
- 25% at medium-risk zone.
- 75% at low-risk zone.

The important point in this section is that the fate of risk factors within the high and low risk zone is clear but the way to face risk factors at the serious and medium zones is not that vivid because defining risk-acceptability is a difficult task. The risks, which are acceptable in one particular zone, might be unacceptable in other zones. Moreover, numerous elements have an impact on acceptance of a risk factor in a particular group, including the zone in which the risk exists, the nature of the system regarding the level of necessity and advantages of activity and its continuation; perceiving of the risk factor for those who work in that system and the cost of lowering the risk factor (Roland and Moriarty, 2000).

Many risk factors are in the gray zone and between two different zones. The results of this study show that 32% of the existing hazards at the middle zone are located between the certainly acceptable and certainly unacceptable risk factors. Now the question that always springs to mind is whether the risk factor of hazards located in this zone acceptable? Answering this question especially in large and highly complex systems is difficult. Under these conditions usually the two following general principles are valid:

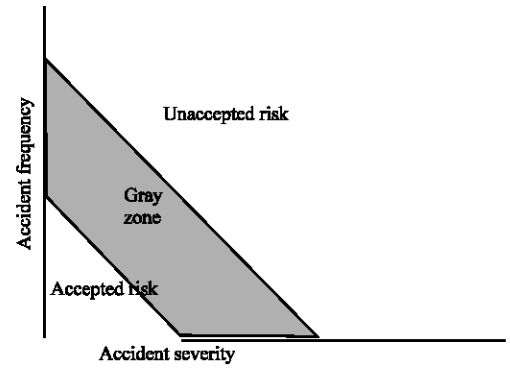

Fig. 1: Relationship between accident frequency, accident severity and risk-acceptability (Lars Harms, 2003)

- The lowest level which is reasonably achievable(as low as reasonably achievable).
- The lowest level which is reasonably practicable(as low as reasonably practicable).

The application of the As Low As Reasonably Practical (ALARP) principle means the best possible job that can be done under the current circumstances, should be conducted. The officials should in practice lower the risk, unless it's proved that this job is not logically practical.

The principle of As Low As Reasonably Achievable (ALARA) is also similar to the above-mentioned principle but it is less precise and strict. In this principle, the risk factor is lowered up to the level, which is logical (not up to a level that is feasible). When this principle is used the authorities form a kind of balance between the costs of safety equipment and facilities. The majority of accidents, also, occur due to lack of attention to the hazards, which are located in the gray zone. Negligence of the risks within these two groups by the manager results in an accident. Therefore, it's strictly recommended that the risk factors in the important risk and medium risk zones would be attended to, with the same sensitivity as the high-risk zones.

By comparison of the results of this study with similar studies including a study, which was conducted in 2005 by the Employment Office of an African country, one realizes the similarity of results in regard to high-risk zones and the set priorities regarding controlling measures, such that working in an altitude, excavation and electrical operations are the major threatening hazardous zones facing workers in these sites. However, these hazards have been appropriately controlled in the developing countries.

Finally, since the human errors are not considered in the ET and BA technique, its better to conduct this method concurrently with other existing methods regarding analyses of human errors, in order to achieve more conducive results.

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