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Root Cause Analysis of Some Reported Radiological Events

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Abstract
Lessons learned from past events are a way for improving the national infrastructure related to safety regulation and emergency preparedness. Root cause analysis is a tool required to identify factors that lead to the occurrence of the events and to develop the effective strategies to avoid the recurrence of such events. The aim of this work is to investigate the root cause analysis for most reoccurred international reported radiological events. The study covered 26 reported overexposure events in industrial radiography during the period from 2012 to 2016. The results of the analysis showed that the most common and repeated cause of overexposure to the workers in industrial radiography is related to human error. More investigations were focused on this type of error in this study. The concluded investigations help the regulatory bodies and licensee for enhancing and improving their radiological regime in industrial radiography field.

Keywords: Root cause analysis, Radiological events, Radiation safety

Introduction

Industrial radiography is one of the important tools for non-destructive testing that used in different applications e.g. weld inspection on oil and gas pipelines, detection of flaws in aircraft components, etc. As the effective engineering control are not fully present in site radiography, a significant number of industrial radiography incidents have been reported worldwide, in which persons affected were not only those directly connected with the activity but also members of the population involved by chance [**Currivan, L** et al. 2004 & Palacios, E., 1990].

Despite the best efforts of individuals and organizations to prevent harm in radiation application, events still take place. When these occur, the first priority of safety is to ensure that the public and workers condition are managed appropriately. However, it is essential that for both individuals and organization including such applications to use the past codes of practices for decreasing the recurrence of such events [**Siegle RL**., 2004]. Root cause analysis is an accepted structured process for achieving this goal. IAEA identified that globally a key root cause of nuclear or radiological accidents was the lack in many countries of an effective regulatory infrastructure and a critical mass of appropriate radiological protection expertise. In this issue, the IAEA developed the model Project [**IAEA**, 2008].

IAEA and many of international publications [**IAEA**, 1999; **IAEA,**1998; **IAEA**,2012;**P. Zuniga Bello**et al., &**John Croft**,2004] were focused on the lessons learned from the major radiological accidents that had effects on the environment or the public. The causes identified in the review of these accidents are failure to follow procedures, insufficient training, lack of regulatory control, insufficient maintenance, and in a few cases willful violation [**Jean Claude N´enot**, 2009]. The causes of accidents in radiotherapy application can be summarized as deficiencies in education and training, insufficient procedures and protocols, deficient communication and transfer of essential information, insufficient defense in depth, deficiencies in design, manufacture, testing and maintenance of equipment as well as inattention and unawareness [**P. Ortiz** et al., 2000].

Despite all of these analyses and concluded lessons, the events and accidents at the national level still occurred, which means that it is important to go through defining the causes in a deep manner or to define the root causes of these events.

For nuclear events investigation; there are four accepted main methodologies for establishing the strategy of an inquiry and describing an integrated system of event investigation activities [**Dusic M**.,2009]. These methodologies are, Root Cause Analyses; Probabilistic Safety Analysis Based Methodology (Precursor Analyses); Deterministic Transient Analyses; and Safety Culture Impact Assessment.

A problem is a result of multiple causes at different levels. These levels of problem causes are visible problem, first level cause, and higher level cause. The highest level of the cause of a problem is called a Root Cause [**P. ORTIZ**, 1995].

The root cause is the most fundamental reason for an event or adverse condition, which if corrected will effectively prevent or minimize recurrence of the event or condition [**Bojorn Andersen and Tom Fagerhaug**, 2006].

Root cause analysis consists of three fundamental components: (a) consideration and identification of factors most directly associated with the adverse event; (b) analysis and prioritization of these factors to plan the introduction of effective strategies to prevent them from recurring; and (c) introduction, management, and, wherever possible, dissemination of effective countermeasures that are shown to have a beneficial effect [**Siegle RL.**, 2004]. In addition to providing a process for formally investigating an adverse event, the principles of root cause analysis can be applied to any real or perceived safety risk, near misses, and less severe or minor patient safety events.

There are many tools that can be considered for getting the proper root cause of an event or issue such as Pareto chart, Cause and Effect analysis, Scatter diagram, Flowchart, Control Chart,….etc).

The main role of these different quality tools is to provide the means for making decisions and can:-

- Help for identifying and prioritizing problems quickly,
- Assist in the decision making process,
- Powerful tools for use in continuous improvement activity,
- Provide a means of communicating problems and decisions throughout the business,
- Provide a way of extracting information from data collected

Cause and Effect analysis is considered as the most common quality tool and used to identify root cause by examining the relation between cause and effect. This tool is often used in addressing events initiated by both human performance and equipment failure [**IAEA**, 2015].

The ‘5 Why’ is a questions-asking technique used to explore the cause/effect relationships underlying a particular problem [http://www.mapwright.com.au] and it is currently one of seven basic quality control tools used to determine components needed for the desired outcome [**Stanislovas Ziedelis and Marc Noel**, 2011].

The aim of this work is to carry out a comprehensive investigation of the most common re-occurring radiological events including overexposure to radiographer in industrial radiography application. The investigation is based on Cause &Effect analysis and 5 whys tool. The study covers the incidents related to overexposure of radiographer in radiography industry occurred in the period from 2011 to 2016. The investigation is comprehensively determine the root causes of such events and introducing suggestions about the preventive actions taken by the regulatory authorities as well as the licensee to eliminate and/or prevent the reoccurring of such events in this field.

Literature Review

Industrial radiography using x-rays and gamma rays is considered one of the most applications of ionizing radiation all over the world. This application accounts for approximately half of all the reported accidents for the nuclear related industry in both developed and developing countries. 43 reported accidental conditions in industrial radiography were analyzed in detailed manner and lessons learned were identified through the IAEA report [IAEA,1998]. The report covered the accident occurred from 1970 to 1998. Based on the analysis carried out and the detected deficiencies in the safety, the regulatory system, the design and the personnel performance; several measures were identified to improve safety performance in this industrial application.

In addition to the radiological accidents described in IAEA documents, there are many of publications represent the national events related to the industrial radiography and the calculation of corresponding doses as well as their health effect on the workers and the public. These comprehensive studies aimed at identifying the lessons learned to reach the highest degree of safety and reduce the frequency of such incidents to a minimum.

Overexposure of the workers or member of the public is associated with the applications of ionizing radiation in many sectors mostly in industry and medical sectors. A systematic survey on the reported overexposure radiation accidents over the period 1980 till 2013 was carried out to evaluate the impact of past lessons learned to prevent the recurrence of the accidents and potential remaining needs for more actions to prevent such events. Among the 634 reported radiation accidents identified, 27% of them were occurred in the industrial sector while in the medical sector through the use of radiation therapy the percentage was (32%) or fluoroscopy was (31%). The number of overexposed people in radiation therapy is the most (47%), followed by accidents in the industrial sector (22%), fluoroscopy (17%) and orphan sources (9%). The study showed that the number of deaths resulting from radiation overexposure, was the greatest for accidents reported in radiation therapy (51%), followed by those reported in the industrial sector (24%) and accidents involving orphan sources (19%) [**Karen Coeytaux**, 2015]

A study carried out in South Africa highlighted tow early documented cases of radiation overexposure and reviewed more recent not so well documented cases and trends that are evident. It is concluded that a lack of education and training significantly causes of these incidents. Further unrealistic workload and service provides appetite to profits have also been major factors [Elihah A Mosokotso et al., 2012].

The importance of periodically review the license conditions taking into account experience from inspections and reported incidents as well as hiring and maintaining a well- trained workforce are concluded **[Currivan, L.,** et al. 2004]

Lessons learned from accident in the radiography industry showed that there are some important aspects should be considered; proper implementation of the code of practice, reducing human error by repeating educational training programs, minimizing the probability of source malfunction by repeated maintenance, stringent supervision over logistics involved importing, licensing, transporting and recording off sources and formulation of a proper system for dealing with spent sources [**El Sayeda Farid Salem**, 2017].

The study carried out by Iran Nuclear Regulatory Authority [**F Mianji** et al., 2016] for investigating overexposure cases in industrial radiography over a period of three years showed that the main causes of overexposures were the difficult working conditions and ignoring safety principles while device failures were a minor contribution. Also, the study was indicating that personal monitoring instructions were not being implemented appropriately.

Through the investigation conducted for a 1999 incident in Taiwan [Ting CY et al., 2015] it was found that two operators were overexposed to an unshielded (Ir) source while conducting industrial radiography. The effective doses for the two operators were estimated to range from 6.9 to 18.9 Sv and from 2.5 and 11.5 Sv. This study indicated a major flaw in the control and regulation of radiation safety for conducting NDT industrial radiography in 1999. The suggestion for modifying the Ionizing Radiation Protection Act in Taiwan, continuous educations of NDT workers in radiation safety and requiring medical care to report acute radiation exposure events are the main recommendations raised from this study.

In Iran, There are more than 1000 radiation workers engaged in about 70 private industrial radiography companies using 312 mobile gamma radiography devices (GRDs). The business is carried out sing Ir-192 point source. Survey on the overexposure accident in these companies during the period 1998 to 2004 was carried out. The study showed that, these accidents led to acute radiation syndrome in 13 workers and overexposure of 36 workers. According the founding of this study, the main factors of such events is insufficient implementation of the monitoring program and training [M R Deevband, 2004].

During the 45-y period of study, overexposure events accounted for 50% (n = 3,796) of all the radiation-related incidents recorded in Texas for the time period from 1965 to 2001 (n = 7,534). Of the overexposure events, 65% (n = 2,342) resulted in the actual deposition of energy in the individual exposed. The predominant sources reported as involved in the events included Ir-192. Co-60, and Cs-137. The results of the analysis helped in training the health care provider in defining the common causes and sources of overexposures and related treatments [Maness, K et al., 2004

Description f The Selected Events

Statistical survey for the radiological accidents/events reported on the IAEA USIE web site [**IAEA USIE**] was carried out. Table (1) represents the total number of reported radiation source events and the numbers of different types of these events while figure (1) illustrates the percentage of each type of events.

Among 79 reported events, there are 26 (32.9%) events are related to overexposure in industrial radiography while the remaining events distributed between stolen/theft, missing of radioactive sources as well found orphan sources and overexposure of member of the public.

Table (1): Description of the total numbers of the reported radiation source events/year and their types

Type of events	No. of Events					
	2012	2013	2014	2015	2016	Total (all

						years)
Total/year	21	15	16	18	7	78
Theft/Stolen	4	3	5	3	1	16
Loss/ missing	2	3	1	5	1	12
Dispersion/leakage	--	--	1	1	2	4
Overexposure of radiographer	8	4	7	5	2	26
Overexposure of member	1	1	--	1	1	4
Others*	6	4	3	3	--	16

- others: include found orphan sources, sources in scrap, damage of sources without dispersion, defect in devices and overexposure of workers.

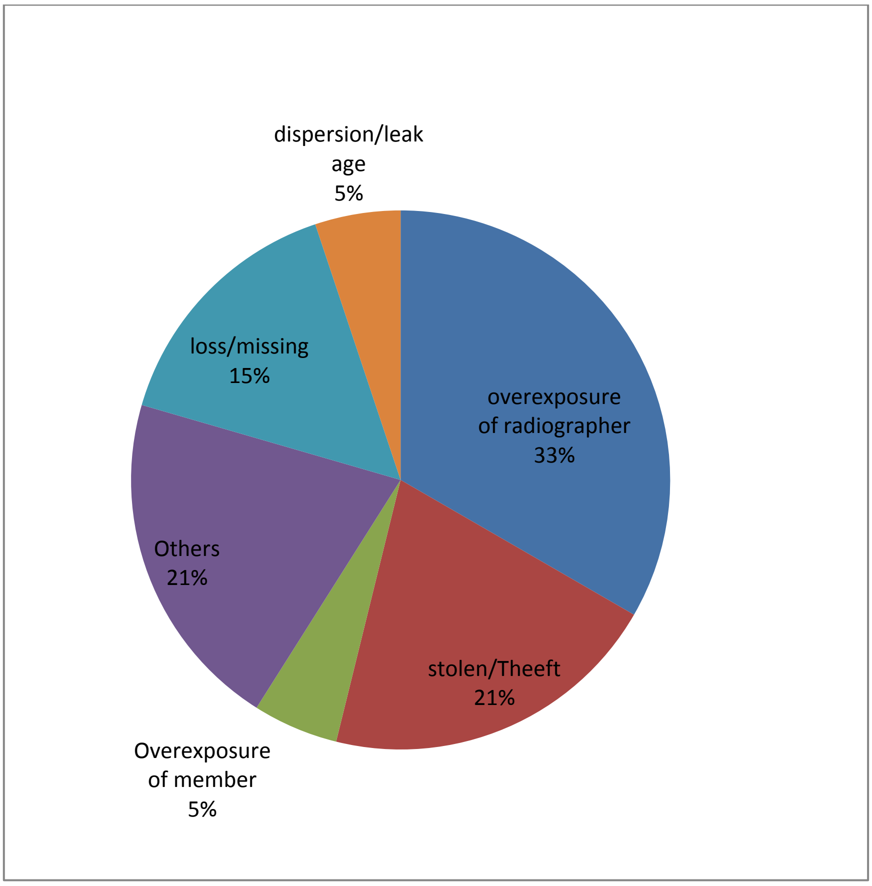

Figure 1: The percentage of the different types of events under radiation source accidents (2012-2016)

The study focused on the analysis of overexposure of radiographer incidents which are highly percentage events occurred in the selected period. Figure (2) shows the countries that reported the events related to overexposure of radiographer during the selected period.

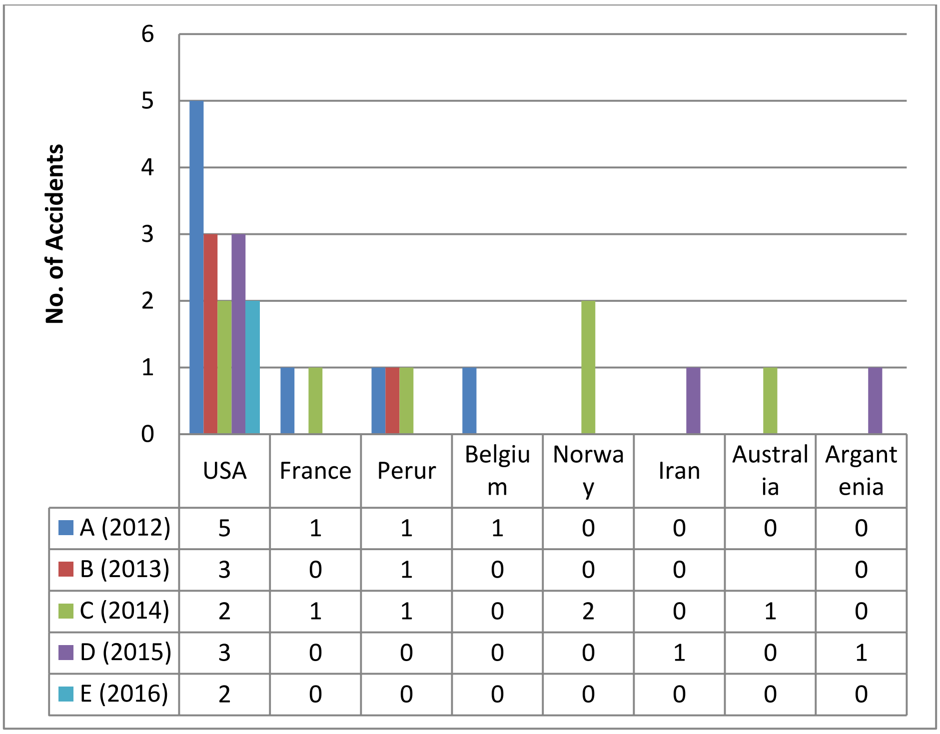

Figure (2): The Countries that reported the events related to overexposure of radiographer (2012-2016)

Analysis Methodology Of The

The analysis was covered 26 events occurred in the period from 2012 to 2016 represent overexposure to radiographer [**https://www-news.iaea.org**, **http://www.climatesceptics.org**. &**http://** **www.nrc.gov/**].The steps to reach the root cause of the selected events are described in figure (3). The more detailed on the analysis of the selected events are described in table (2)

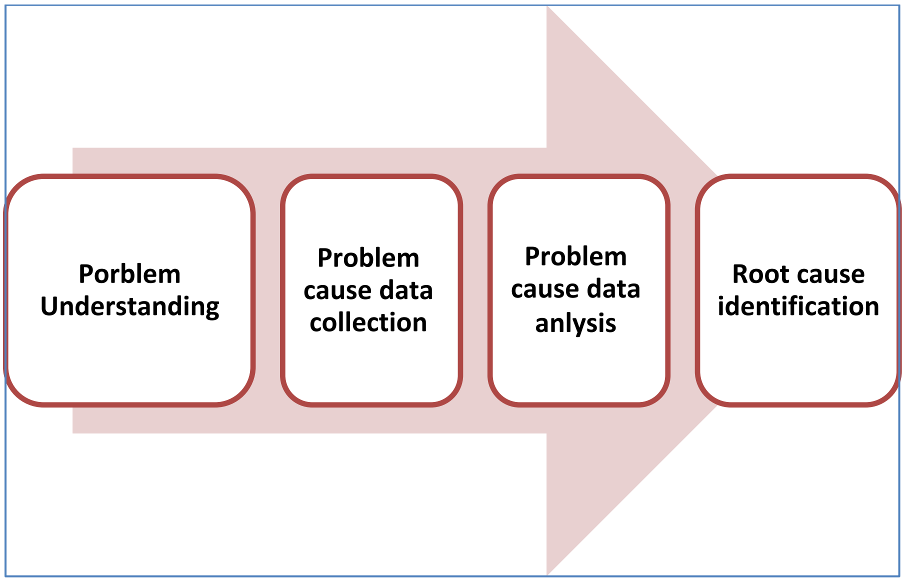

Figure (3): The Steps for root cause identification

From the 26 event's reports, there are 22 available data. The analysis of these events showed that, the failure in retract the source to its correct position, dealing with the camera while the source is exposed and dealing with the guide tube while the source is present are the main predominant causes tend to overexposure to radiographer in the radiography industry. Figure (4) illustrates the number of recurrence of the defined main cause of the selected events.

Table (2): Summary of the analyses of the selected events related to overexposure of radiographers

Date	Country	Problem	Whole body Dose	Main cause

24/3/2012	Pasadena, Texas /USA	Overexposure of radiographer	290.0mSv	Failure to retract the source to the camera
31/12/2012	Seiling, Oklahoma/ USA	Overexposure of radiographer's assistance	51 mSv	Not enough monitoring of the assistant's exposure
19/9/2012	Belgium	Overexposure of radiographer	< 200mSv	Thought the irradiation was finished
18/12/2012	Pakistan	Overexposure of worker	2.02 Sv ,0.81 Sv	Stuck of Ir-192 source in the guide tube
12/1/2012	Peru	Severe Overexposure of radiographer,	1 to 3 Gy	Fixing the collimator while the source is uncovered
20/3/2013	Oklahoma/ USA	Overexposure of worker	67mSv	Failure to retract the source to the camera
15/1/2013	Oklahoma / USA	Overexposure to Radiographer's Assistant	59.0mSv/y	Failure to retract the radiation source
2/5/2013	Peru	Overexposure of radiographers	29,65 mSv,44,6 mSv	Failure to retract the radiation source
9/4/2014	Marietta, Ohio / USA	Overexposure to radiographer	130 mSv	Failure to retract the source to the camera
13/3/2014	La Porte, Texas/USA	Overexposure to radiographer trainee	60 mSv,33 mSv	Handling the guide tube where the source in it
28/2/2014	Australia	Overexposure of Radiographer	0.18 to 2.7 mSv	Unloading of radioactive sources from the logging tools.
18/4/2014	France	Exposure of a worker during radiographic inspection	5.3mSv	Unknown exposed to a radiation source, where it is not in its protection position
8/9/2014	Norway	Overexposure of radiography worker	32 mSv	Exposure to unsecure Ir-192 source
17/7/2014	Norway	Overexposure to workers to radiographic source	30 mSv	Three workers were exposed to doses while working in a bunker.Se-75 (1,5 TBq)
14/2/2014	Perue	Exposure to workers	0,5 Gy,15 mSv,85 mSv,17 mSv	Failed to retract the source to the camera
17/3/2015	Alabaster, Alabama /USA	Overexposure to radiographer	112mSv,200 mSv,50 mSv,50 mSv	Unknowingly Exposure to the radiation source
11/11/2015	Pecos, Texas/ USA	Overexposure to radiographer	114.5 mSv	The radiographer believed he had cranked the source back inside the camera.
16/1/2015	Baton Rouge, Louisiana / USA	Overexposure to radiographer	64 mSv	disconnect the guide tube from the radiography camera, without ensuring the source was in the shielded position

27/8/2015	Argentina	Overexposure to radiographer	160 mGy,1.85 mSv	Performing test while the source is exposed
23/9/2015	Iran	Overexposure of two industrial radiographers	1.6 Gy,3.4 Gy	dismantled the guide tube without noticing that the source/holder was detached and stocked in the guide tube
24/8/2016	Texas/USA	Overexposure to radiographer	0.064Sv	Incorrect distance between the radiographer and the source
11/5/2016	Texas/USA	Overexposure to radiographer	9.37 mSv	Dealing with guide tube in the presence of the radioactive source out of the camera.

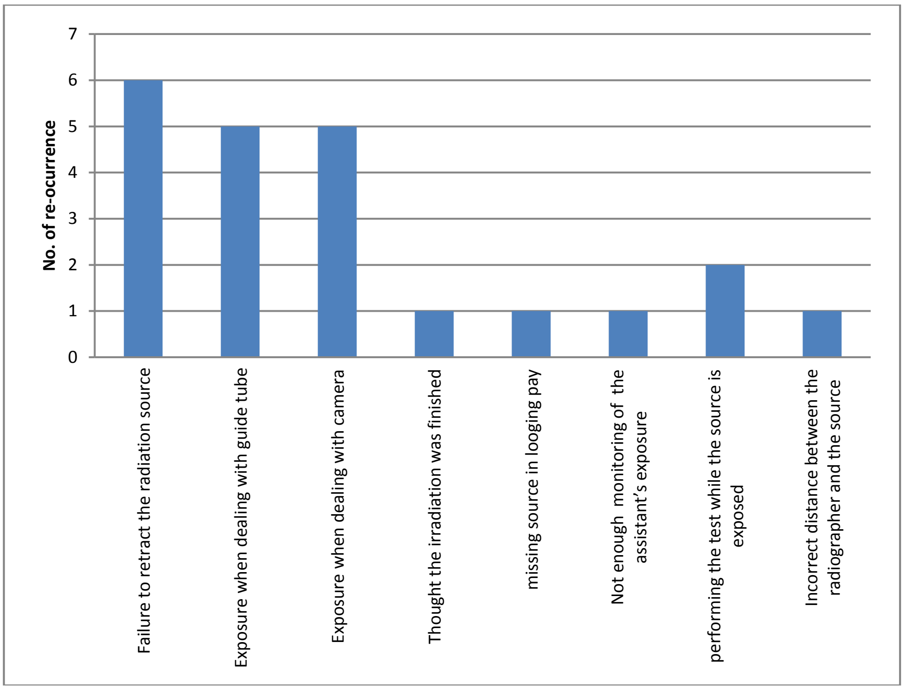

Figure (4): The number of recurrence of the main causes related to overexposure to radiographer

Upon the analysis of the reported information for each event, it is found hat human errors (human failure), managerial error, instrumentation/maintenance failure and the environmental effect are factors that contribute in occurring the accident. Figure (5) illustrates the percentage of each factor in respect to the occurred events.

Some terms are refereed to human errors such as 'lack of competence', 'inadequate procedures', 'inadequate tools or equipment'. The Energy Institute, London [**Energy Institute**, 2008] considered the root cause in those cases would be the system deficiencies that led to poor competence, procedures, and equipment.

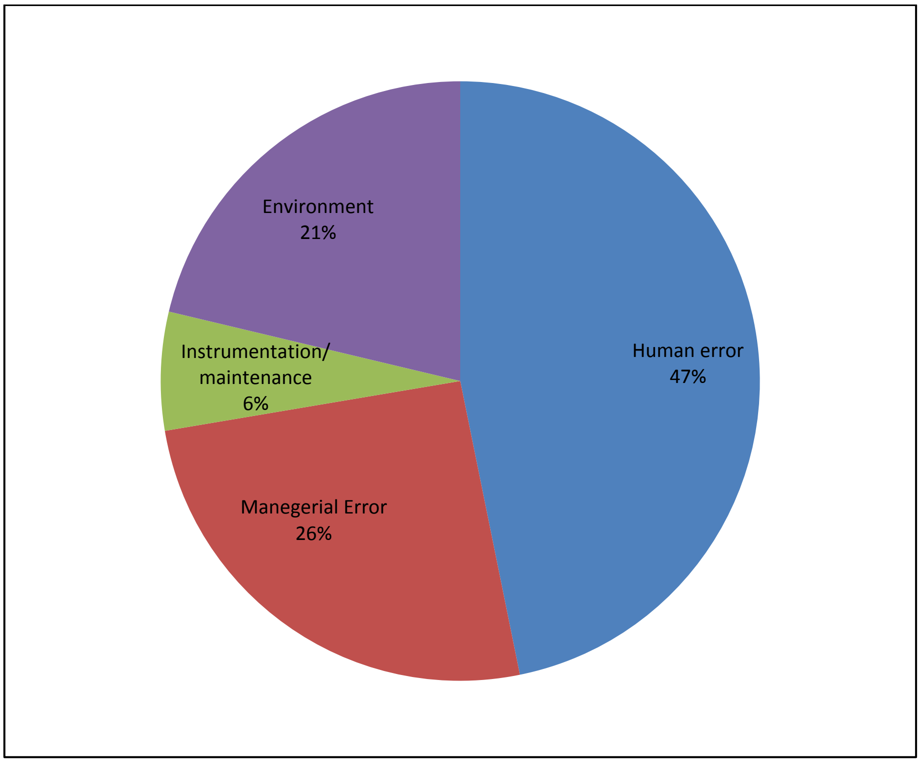

Figure (5): The percentage of the defined factors contributed in causing the studied events.

To discuss and investigate the root cause of the described events it is important to understand very well the human and organization factors of the incident. To develop appropriate recommendations for improvement, in the area of human failure, at least the types of human errors and factors influencing the human performance must be known and understood. Figure (6) describes the types of human errors.

It is noticed that there are general behaviors in all studied incidents regarding human failure (figure7). There are:-

- Failure to follow Safety procedure,
- Failure to use survey meter/personal dosimeter,
- Failure to perform inspection prior to use (after each shot),
- Inattention to details

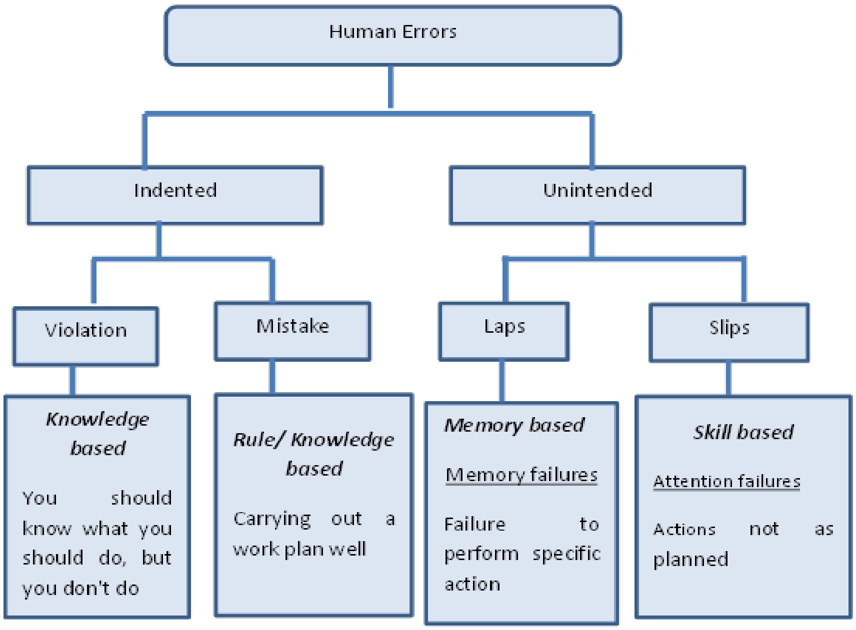

Figure (6): Types of Human Errors

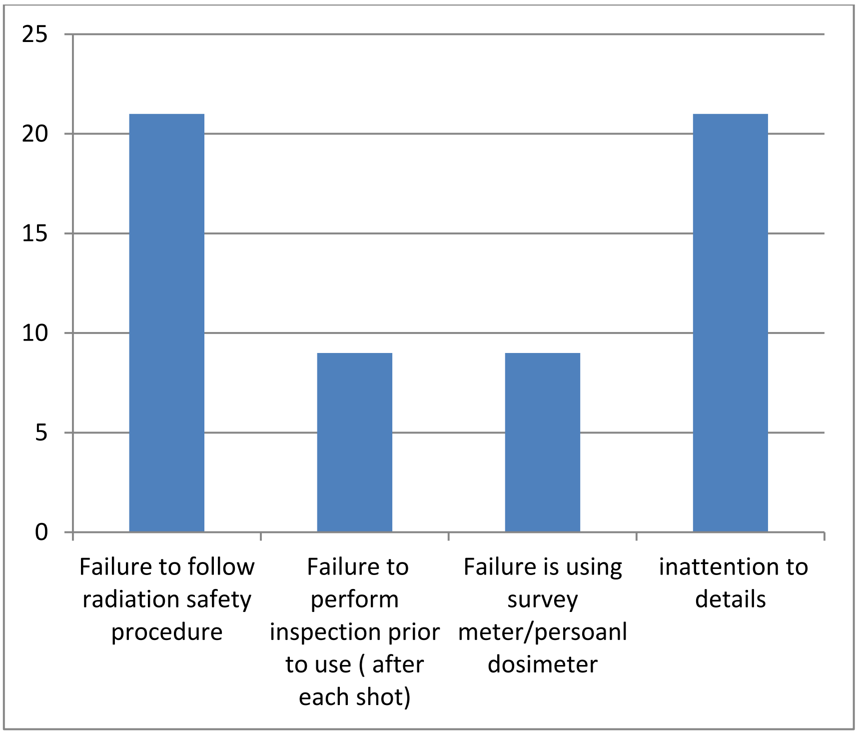

Figure (7): The contribution of main human error elements in the analyzed events (22 of 26 available information reports)

Other factors which play an important role in overexposure of radiographer and the trainee in radiography industry are the lack of training and deficiency in safety culture which is the responsibility of the licensee and they are the main managerial errors that contribute to the overexposure of the workers. The environment (e.g. lighting, noising,..) that surround the radiographer during their job is considered as another root cause influencing the human behavior in this industry.

Generic lesson learned from deep investigations of 43 industrial radiography incidents showed that; accidents were rarely due to a single human error or isolated equipment failure. In most cases there was a combination of elements such as: a) unawareness of the potential for an accident, b) poor education, c) an unbalanced striving for resuming or finishing work, which led to ignoring warnings and was often tolerated by management, d) poor maintenance program. This combination points primarily to an overall managerial failure [**P. ORTIZ**, 1995].

As the results of the current study, the human errors with their different elements are considered as major root causes of the investigated events. The radiographer doesn't use the survey meter during the work course, don't make the survey after each shot and can neglect the signal of alarm.

Conclusion and Recommendation

An analysis for 26 reported overexposures to radiographer incidents was carried out to define the root causes of these events. The analysis aimed to extract improvement steps as well as lessons learned from past literature at the levels of regulators and licensee to decrease the recurrence of such events in the future.

From the investigation carried out in this study, we concluded that it is very important to give the human behavior with their different elements in industrial radiography more deep attention taken into consideration the types of certain error or violation as it is the common contribution to the overexposure events. Knowing the environment, workload, economic situation and large numbers of safety measures required from the radiographer before, during and after his job are very important to identify his responsibility and ability to follow the required safety procedure.

It is concluded that even the human error or failure is a major causes of the incidents/accidents, the incidents/accidents occurred because the system for preventing this error failed. So the accident is system failure rather than person failure, however, it is very important to understand that system what they are, how they are intended to work and how they have failed in some areas.

Based on human factors, management of safety and safety culture concepts [http:// www.energyin.org.uk/humanfactor/bm] the following are the suggested recommendations on the regulatory and managerial levels.

The suggested steps at the regulatory level include:-

- Issuing regulatory requirements in respect to defining of the workload of the radiographer which allow him to follow the safety instructions,
- Required the monthly event report including the doses received,
- Required intensive training program including increasing the awareness of the workers and trainee with the consequences of the accidents, ways of identifying and facing unusual events,
- Let the acceptability of the license application based on the provision of defence-in-depth in accordance with systematic safety assessment,
- Setting regular meeting with the licensee and responsible companies in this field.
- Required the configuration of the site and working area including those with other interfaces (introduce clear and identified labels, lights..,),
- Required code of practice "lessons learned from past incidents at least past 5 years" including the improvement actions taken by the licensee to avoid the occurrence of similar events.
- Establishing regular inspection program including inspection of the maintenance program, radiation protection, worksheet and checklist, event records and suitability of site location in respect to radiation protection.

The suggested steps at the managerial level include:-

- Licensing appraisals and inspections should be able to identify the degree of awareness of the management, its commitment reflected in written policy, procedures and supervision,

- Taken measures to reduce the human error regarding the using of survey meters and follow the lighting and sounding alarm (e.g. establishing a network between the devices in the site and connect them to one channel in a control room under supervising of qualified person during daily work),
- Setting an administrative penalty regarding the types of human errors and their consequences.
- Setting a program for safety culture to all the workers in the company
- Ensure the direct supervision to the radiographer during his work course.

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