Prediction of Severe Accident Occurrence in Radiation Laboratory Using Fault Tree Method

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Abstract. This paper reviews the prediction of severe accident occurrence in radiation laboratory using fault tree method. Accident can be happened everywhere either near-miss or not. Accident includes any unintended event including operating errors, equipment failures or other mishaps and the consequences or potential consequences of which are not negligible from the point of view of protection and safety. The primary benefit of fault tree (FT) method is it provides a unique insight into the operation and potential failure of a system. The FT process may lead to a single component or material that causes many paths to failure thus improving that one element may minimize the possibly of many failures. Besides that, by using the logic of a detailed failure analysis and suitable tools, FT helps the system focus on the causes of each event in a logical sequence that leads to the failure.

Keywords: Accident, Radiation, Laboratory, Fault Tree

1.0 ACCIDENT DUE TO HUMAN ERRORS

A structure, deductive methodology to determine the potential causes of an undesired event which referred as the top event, usually the top event represents a major accident causing safety hazards or economic loss is known as fault tree analysis method [1]. Fault tree analysis (FTA) which is deterministic is used to quantify the failure probabilities of all prevention barriers. The prevention barriers in this accident model were systematically analysed with FTA to establish a sequential causal relationship [2-3]. At the top of tree, top event is placed and the tree is constructing downwards. The system is continue until the primary events leading the top events. Primary events are considered as binary which consist two states and independents of fault tree analysis. The relationships between events are means of gates, which AND-gates and OR-gates are the most widely used [4-5].

In the reliability of engineering systems including in nuclear power plants or radioactive material, human being plays an essential role because they are involved in not only the specification, design, implementation, installation, start-up, and maintenance, but also the operation of these systems. This make it is hard to build a system or events in which human error is totally eliminated [5-6]. Therefore, human error, human reliability and the tendency to make mistakes are problems of fundamental importance [7]. The action performed by an individual, which was not intended by the actor, not desired by a set of rules or an external observer, or that led the task or system outside its acceptable limits is meant by human error [8].

Worker not able to understand the actual functionality and usefulness of the protective measures of the machinery or material when the worker does not receive a clear and effective information, formation and training about the risks and the operative use of the machinery or radioactive material and this will bring disaster or risk to others . The lack of respect operatives and formal procedures could be happen due to human misbehavior due to willing actions and unwilling errors during a specific task. So, adopting a misbehavior of human is more tempted to deliberately defeat and tamper with safety equipment in order to obtain a supposed higher simplicity and speed of use [9].

Human minds tend to evaluate intangible situations, not concentrated in time, infrequent, which do not induce serious consequences as less risky. The ultimate goal of the risk management is to ensure that actual risk and perceived one coincide. In contrary, human mind tends to perceive the risk in a subjective way assessing tangible situations, concentrated in time, with high frequency of occurrence or that could lead to serious consequences as riskier [10]. However, some issues are arising after enterprise implements some measures to cope with after accidence such as the relationship and root cause of the accident are not understood in depth; the improvement method is only for preventing the similar accident in the future; lots of possible latent errors may be omitted [11].

For each phase of the radioactive material, the error may fall into two main categories: normal and abnormal hazardous action. The abnormal hazardous actions can be allocated into several categories such as radiations, slips, mistakes, fixation, error in emergency, violations, rule breaking. Depending on the radiation analyzed, the designer assesses whether all the behavior categories are or not applicable to the severity composition. Then, the designer will identify the behaviors for each applicable category, which contains specific behaviors, where n depends on the particular application [12].

In nuclear power systems, the nature of incipient and human faults makes their diagnosis problematic. This largely results from the fact that the symptoms of these kinds of faults lie within the range of covered by the compensatory actions of the reactor control systems and human cannot detect or detect this problem in late period. Hardware degradation, cracks in components and leakages in valves and pipings that are not large enough to change the operating set point could remain undetected for a long time and are indicators of incipient faults. Undetected, incipient faults could result in large faults necessitating emergency shutdown, downtime costly start-up procedures and all this problem will lead to bad effect to the community as well as the country [13].

The exponential rise of electronic records even worsened the problems related with human error data, stating that data validation, compatibility, integration and harmonization are increasingly significant challenges in maritime data analysis and risk assessments. This indicates that difficulties to find usable human error and human factors data are still a major concern, which deserves to be carefully addressed by practitioners and researchers, if this problem is continuing in radioactive material, the half-life decay of radioactive material, type of source radiation and number of radioactive material need to be recorded and calculate carefully, if one is missing it is still dangerous and risk to others and death can occur [14].

Despite years of research, difficulties still exist in quantifying the contribution of human error to accidents that result in disaster and/or losses. Incorporating human errors into safety analyses is a rather difficult and complex exercise. Indeed, engineers still find it difficult both to incorporate human and organization sources and to realistically quantify them [15]. 'External exposure' is the most potential hazard to workers during decommissioning of nuclear facilities than other hazards. External exposure is an occupational exposure to workers during decommissioning of nuclear facilities in another words [16].

The exposure of abnormal environments from human errors is consist of physical errors, procedural errors, and operational errors of equipment's under radiological environments. The physical error means worker makes errors such as falling from elevation, turnover during decommissioning activities. The procedural error means that a worker commits out of order in the middle of according to precedence. The operational error means that a worker makes control error during in-tact and remote operations of equipment's. There are radiological hazards and non-radiological hazards throughout decommissioning of nuclear facilities. Radiological hazards, in general, fall into four categories which are external exposure, ingestion and inhalation of radionuclides, criticality, and breach of containment. Overall radiological risks can be lower during decommissioning of nuclear facilities [17].

In the industrial accident of the world's history, here are few of accident that occur due to the human error. Firstly, is Bhopal disaster, a combination of operator error, poor maintenance, failed safety systems and poor safety management was caused to leaked methyl isocyanate gas from a pesticide plant led to creating a dense toxic cloud and killing more than 2500 people. Next, the explosion and fire accident occurred in Piper Alpha offshore oil and gas platform which killed 167 workers was attributed mainly to human errors including deficiencies in the permit to work system, deficient analysis of hazards, and inadequate training in the use of safety procedures. Then, in the Chernobyl accident, operator error and operating instructions and design deficiencies were found to be two main factors for the explosion of a 1000 MW reactor releasing radioactive materials that spread over much of Europe [18].

Human error has been defined as any improper decision or behavior which may have a negative effect on the effectiveness, safety, or performance system [19]. The responsible individuals should assess the work procedures and check the safety at all of stages of work. Usually, permits are effective between the communication of site managers, plant supervisors and operators, and the individuals who carrying out the work. The people doing the job sign the permit to show that they understand the risks and the necessary precautions [20].

Human error incidences in refueling maintenance of any periodically inspectionable and repairable device of a nuclear power plant (NPP) can cause a failure of the component during operation, and the component can remain in a fail state until the failure is detected by periodic tests. The maintainer can make the mistake again during the periodic test and repair resulting in unavailability of that component for next period of operation. Repeated human error could occur in periodic tests causing component unavailable for a long time although the probability is low. The repetition of human error during periodic tests, and the effect of refueling maintenance error for periodic maintenance failure should be included in component reliability assessment. Our study has been conducted with consideration of these issues regarding human errors during maintenance of component [21].

2.0 Accident due to equipment error

Fault tree analysis (FTA) is the most widely used of the risk analysis tool [22]. Fault tree analysis tool that represent graphical of possible event which used to determine overall system reliability and safety [23]. When the logic gates used it allow the combination event and enables an illustration to visualize how individual faults, including operator errors or both and cause a hazard. The probability can be assumed to assign the fault conditions and identified hazards or overall system failure [22]. This risk analysis need to be done early in the development cycle, potential faults and resulting hazards to make it identifiable and easier to mitigate with error-reducing designs. Usually the design should be the primary method of control, followed by documentation and training as secondary methods. So, risk analysis tool is a must to be done to make it smooth [22].

2.1 Fault Tree Analysis to Assess the Domino Effect Frequency

Domino accident can be defined as consequence of the primary event accident which propagated to the nearby equipment and trigger one or more secondary that more severe than the primary one [24-25]. The domino effect still available until now and showing a rise tendency based on previous research [26]. However, some aspects such as active and passive safeguards, and probability of ignition source are not included. A new methodology need be proposing to assess the frequency of domino effect occurrence considering the failure frequency for each unit process, damage probability due to escalation vectors and presence of safeguards [24].

The domino effect is manifested by different accidents sequences as example from explosion to fire, fire to explosion continue with fire, fire to fire [27-29]. Domino accident can be illustrated in a general sequence of events. The primary event started with a failure of any process unit either loss of control operation or loss of containment. The domino effect may occur if a second process unit have passive safeguard fail and close enough to the primary event.

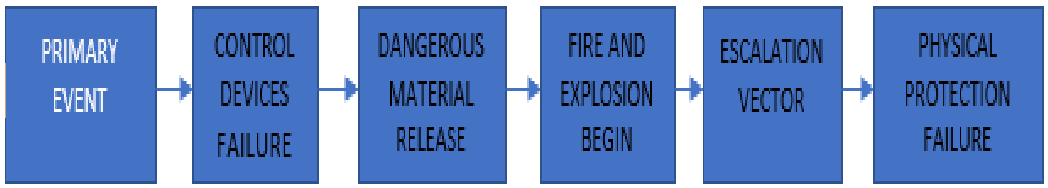

Figure 2.1 : Domino effect general sequence event

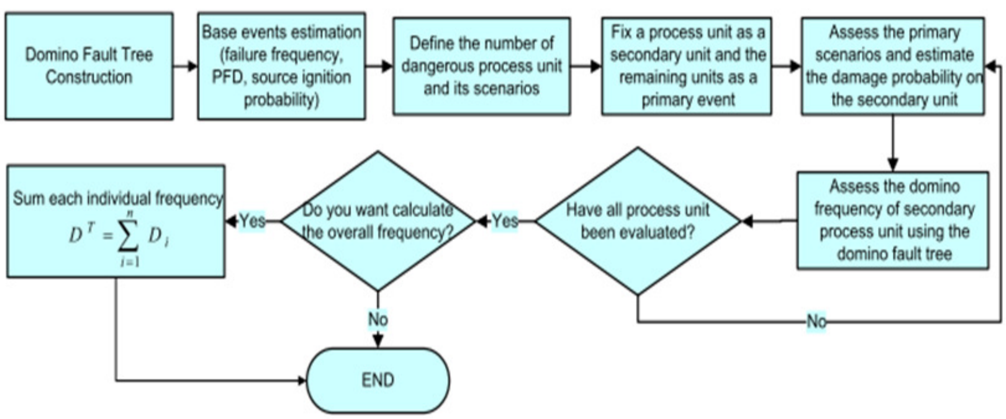

Figure 2.2: General methodology to construct fault tree method

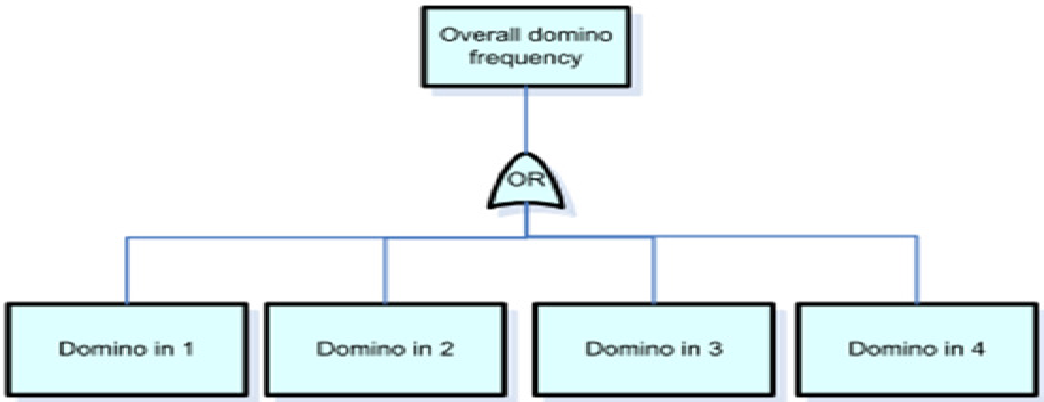

Figure 2.3: Overall Domino Frequency assed by Fault Tree

The general sequence event (Fig. 2.1) is the guide for performing a fault tree analysis method as shown in Figure 2.2. As shown in Figure 2.3, the result of domino frequency assists by fault tree analysis after solving some of the method.

2.2 Prevention High-Sulfur Natural Gas Leakage and Develop Equipment Inspection Strategy Using Dynamic Modelling with The Combination of Fault Three Method

The combination model of fault tree and event sequence diagram can be done for abnormal event at the gas gathering station with the assist of chain theory. The progress is being describe as sequential failure of safety barriers, then, the occurrence probability of the consequence of abnormal event is predicted. Consequences, the abnormal events are divided into accidents and accident precursors which include careless and incident [30].

Based on previous research, a model of accident process by using safety barrier concept are used to prevent the accident for the offshore oil and gas environment like releasing natural gas [31]. A develop from the previous model has been created by providing capability to reduce uncertainty of the probabilistic assessment by using accident precursor data [32]. The improved model is enhanced by integrating fault tree and event tree analysis to represent the cause- consequence relationship graphically which referred to System hazard identification, prediction and prevention method (SHIPP) which valid for safety assessment. However, this method has certain limitation which prevent in maintenance inspection [33].

The fault tree is employed to represent the causal relationships leading to failure of each safety barrier starting with release prevention barrier until emergency evacuation barrier as shown in Figure 2.4. In fault tree, the top event denotes the failure of the safety barrier.

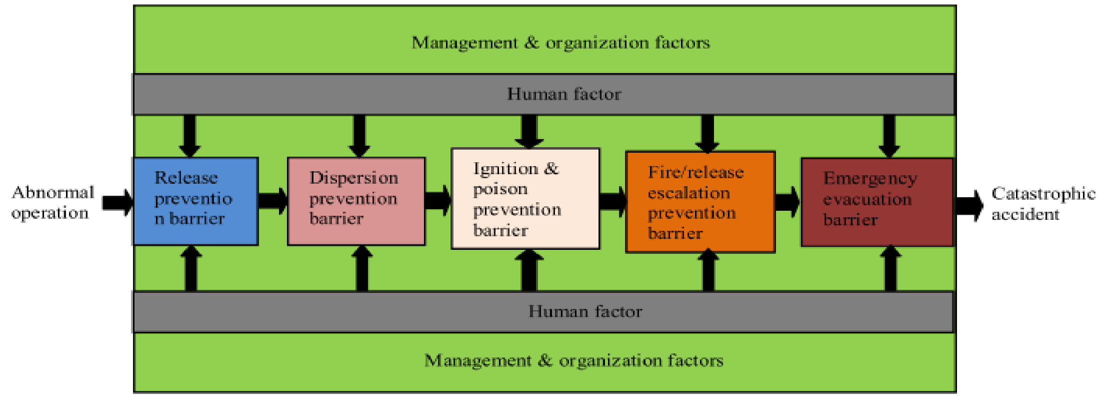

Figure 2.4: Accident model for high-sulfur natural gas gathering station

The integration of fault tree and event sequence diagram analyses provide a holistic picture of the cause consequence mechanism of potential accident scenarios. In addition, this model minimizes degree of uncertainty in prediction using Bayesian updating mechanism and plant real time data [34]. The accident sequence initiate from loss of containment. The immediate causes for release prevention barrier failure (Figure 2.5) are identified which included process disturbance, technical faults, operation error, maintenance failures and external loads.

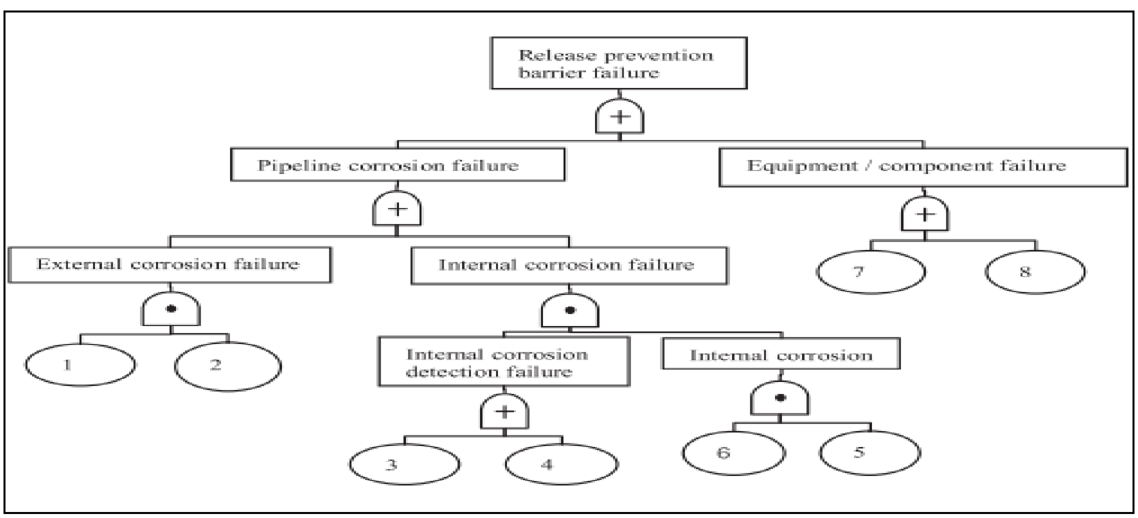

Figure 2.5: Fault tree analysis of release prevention barrier failure for the starting chain.

To prevent the spreading of material or energy dispersion prevention barrier limits are introducing to extent the hazardous events. Passive and active barriers are applied to prevent and ease the dispersion of material such as gas detection, isolation and venting. Next, the ignition prevention is important in gas processing to avoid the worse effect from the hazardous event on nearby equipment. To protect the operator, the poison prevention barrier (Figure 2.6) use and lastly emergency evacuation barrier (Figure 2.7) are used to protect the whole system by emergency shut down it.

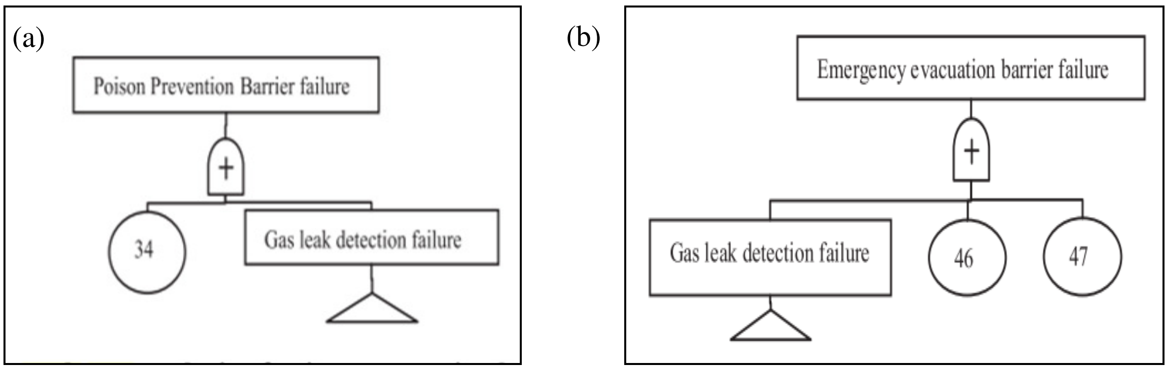

Figure 2.6 & 2.7: Fault tree analysis of (a) poison prevention barrier failure and (b) emergency evacuation barrier failure.

3.1 Violation of Radiation Safety Procedures

There is a report in Henan province in China stated that three cases had been diagnosed of acute radiation sickness caused by exposed to a Cobalt-60 radiation [35]. This accident occurred on 26 April 1999. It was reported that three persons were accidentally exposed to a high dose of Co-60 irradiation. The history of the cases begins with when a worker (case C) found the radiation source in a container. He then bought the container without knowing the radiation source and the damages it can bring to him and even his family. The radiation was put near the bed of his wife (case A) and his son (case B).

The worst begin when case A go to sleep at that night and started to felt nausea and repeatedly vomit. Case C came to her room and took care of case A and case B which he then later started to vomit too. They eventually went to rural doctor to get some help. They were diagnosed as food intoxication and get treatment for that disease. However, their symptoms were not healed for next three days. On 28 April 1999, the radiation source was reclaimed in a lead container. A doctor assures them to go to a special hospital knowing that they are being exposed to radiation for quite some times. After several days of treatment, all three of them were sent to Tianjin by plane to get treatment from clinical department of Chinese Centre for medical response to radiation emergency.

The case report covered all the details needed from the victims. For case A, is a 38 years old married female who suffered from nausea, vomiting, reddish face, conjunctiva hyperemia, hyposalivation and anorexia, headache, fatigue and weakness also trichomadesis [35]. She suffered the worst symptoms among three of them since she is exposed to the radiation source longer than her husband and son. She also almost lost her hair completely. Her armpit and pubic hair were completely depleted at that time too. Other symptoms including deposited a dark purple strip on her nailbed which then disappeared gradually when the nails grow. The radiation effect also affecting her menstruation. She only recovered from the danger on 34^{th} day from the incident.

Case B is a male 8 years old boy who is the son of the couple. The boy had faced the same symptoms as his mother except reddish face. The effects also slightly lower than case A and the symptoms started to show up quite late than the first case. He also suffered from hair lost and deposition of dark purple band on his nails. He recovered from his symptoms and entered the recovery phase on 32^{nd} day.

Meanwhile for case C, is a 37 years old male. This man is exposed to lower dose radiation source compared to other two hence his symptoms are slightly better. The symptoms faced were the same as case B and only differ in vomiting caused he had that symptoms only after 6^{th} to 10^{th} hour later than the rest of them. He only lost his hair after two to three weeks from the incident and there was no obvious loss of armpit and pubic hair. Case C and B had papules scattered on their bodies and had been given sulphur ointment as scabies [35]. He also recovered on the same day as his son.

This kind of accident could be avoiding if there is enough awareness and guidelines on the severe effects of radiation towards the society. We are grateful that this case had not cause fatal to the victims. Generally known that the most somatic risk of ionizing radiation is cancer induction [36]. In assuring the safeness for all people, Ionising Regulations 1999 has produced The Basic Safety Standards Directive that deals with the radiation safety of staff and members of the general public [37] and The Medical Exposure Directive deals with the protection of patients and had been implemented in the UK in May 2000 [38].

According to IAEA, an accident is an unintended event which includes operating errors, equipment failures or other mishaps, the consequences or potential consequences which could not be neglected from the point of view of protection and safety [39]. There are two categories of radiation accidents which are radiological and nuclear accidents [40]. In year 1944 to 2000, there are several accidents had been reported caused by radiation. It is reported among 3000 overexposed persons, 127 death cases had registered in 57 years [41].

The accidents are mainly occurring with radiation devices for instance sealed sources or x-ray devices used in medicine or research [42]. Based on previous study it shown that, during the last 5 year period which is during 1995 to 1999, the accidents became significantly less in frequency but more severe in the outcome from the sealed source. However, for unsealed radioisotopes, the number of accidents remained low than ten cases for that years.

Radiation accidents are often occurred from these three causes. The first one is accidents that depends on the population groups involved. This includes accidents happened involving workers from nuclear research jobs, accidents of public that are exposed to radiation source and accidents of patients during medical application of radiative sources involved. The second one is radiation accidents by type, time of recognition and management. This is caused by accidents from unknown origin and late recognition, critical accidents and nuclear accident with transboundary effects. The last one is radiation accidents by scale. By scale means small scale radiation which involved small source term and small number of individuals and large scale which usually involved large source team and large number of persons.

All these accidents occurred from violation of the safety procedures in handling and understanding the radiation safety regulations. The most common mistakes that lead to radiation accidents are lack of information on physical appearance of the radiation sources and its harmful effects. Next, the violation of radiation protection itself and also human error who has insufficient knowledge on radiation safety regulations. This occurrence also involving the application and handling the sources. For example, wrong application of gamma sources and x-ray machines in industrial radiography and radiotherapy.

Violations of radiation safety regulations are classified into 3 severity levels which are minor, moderate and severe. The levels are derived by Nuclear Regulatory Commission from UCSB’s safety history. Violation is differing from accident and spills of radiative source. It is about the failure to obey the condition of authorization’s approved protocol or radiation safety in that areas [43]. In minor violations, can be seen from laboratory records and radioactive material use and storage. For the records in laboratory, the radioisotope use logs not completed, survey records not maintained and the surveys not conducted with appropriate instrument.

In radioactive material use and storage, the common violations that occurred are radioactive material (RAM) are not correctly labelled and not be shielded. During using the RAM the work surfaces are not being covered properly. Next, the absence of survey meter near the RAM as well as not wearing dosimeters while in contact with RAM. The application of lab coats and gloves are being neglected while conducting the materials.

The second level of violation is moderate level. In this level, most common violations occurred are presence of food and drinks or cosmetics in a radioisotopes use area. The radioactive materials are not secured properly. There is individual use the RAM in an unauthorized area which increase the level of contamination levels outside the laboratory. Besides, the disposal and release of radioactive material are improperly thrown away for example like sink and in a container.

The highest level of violation is severe levels which the violation is a lot risky compared to other levels. In this level the violations are including falsification of radiation safety records which being made intentionally. Next, fail to immediately report whether loss or theft of radioactive material to authorized person. Besides, occur cases like external shipment of radioactive material from external source which is not being approved. The use of RAM is not according to the type of investigation taken at that time. Finally, failure to respond to a written notice from the RSO for significant actions.

All these violations could be avoiding by acknowledging lessons identified from the incidents. In a study by Turai and Veress, some general recommendations could be taken to reduce the chance of radiation accidents from occurred [42]. The first one is all radiation sources and their applications should be registered. A procedure should be developed and the compliance of the procedures must be followed wisely. After the procedures had been developed, the regulations should be implemented, monitored and enforced as soon as possible. Another lessons identified is that a basic and advanced level education and regular training should be provided as a basis of regulatory in an institutional framework for both undergraduate and postgraduate educational centres. This educational programmes should also be implemented for staff that works in medical field especially radiography and radiotherapy.

Actions that need to be done that subjected to severe violations mentioned above is immediate notification of authorization permit holder by the RSO, next, when failed to report cases, a written notice must be sent to authorized permit holder for evidence. If there is any external shipment occurred a suspension of radioisotope ordering or receipt privileges must be done until corrective actions are implemented to the satisfaction of Radiation Safety Committee [43]. The preparation of public health authority, medical institutions and the staff managements of radiation accidents also important. The preparations are including presence of medical aid to persons that has irradiated or contaminated from radiation.

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