Potential Exposures and Lessons Learned from Industrial Radiological Accidents

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Abstract. Ionizing radiation is used in many industrial practices such as industrial radiography, nuclear gauges, petroleum well logging and industrial irradiators. These practices can result in radiation exposures whose intensity can be foreseen with some level of certainty. They are called normal exposures. Nevertheless, in routine practices other type of exposures can also occur. They are called potential exposures. Potential exposure is exposure that, while not certain to occur, can be anticipated and to which a probability of occurrence can be assigned. In industrial radiography, the dose rates near the gamma radiography apparatus or X-ray equipments are high enough to cause, in a few seconds, serious injuries to extremities of the human body, leading to amputation. In industrial irradiators, the radiation sources employed have very high activities, with consequent high potential for causing serious accidents that could lead to severe injuries or even death. One of the most important lessons learned from radiological accidents is the relevance of probabilistic safety assessment (PSA). This can be very useful to elucidate the main human errors or equipment faults. The lessons learned from radiological accidents improve the knowledge and comprehension of the mechanisms and event sequences leading to potential exposure.

KEYWORDS: radiological accidents; industrial radiography; potential exposure

1. Introduction

The use of radiation sources in industry has proven to be an important factor for technological development. Ionizing radiation is broadly used in industrial area in practices such as industrial radiography, nuclear gauges, well logging petroleum and large irradiation units. These technologies bring large number of benefits.

Industrial radiography is a nondestructive test used to evaluate material faults. Nuclear gauges are devices that use ionizing radiation to control quality of processes, materials and products. Oil well logging uses a probe with a radiation source to continuously measure parameters such as the density of the materials in the probe’s vicinity. Large industrial irradiators use a radiation source for sterilization of medical and surgical dischargeable products, and to preserve food and perishable goods.

2. Potential exposures at industrial facilities

The routine practices in industrial applications of ionizing radiation can result in exposures in which radiation intensity can be predicted with some level of certainty. They are called normal exposures. However, in routine practices another kind of situation can occur, leading to overexposures. Potential exposure is exposure that, while not certain to occur, can be anticipated and to which a probability of occurrence can be assigned.

In industrial radiography, the dose rates near the gamma radiography apparatus or X-ray equipments are high enough to cause, in a few seconds, serious injuries to extremities of the human body, leading to amputation. Whole-body overexposures leading to death are not common, but can occur when radiation sources are mishandled or reached and kept by members of the public.

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In developed as well as in developing countries, roughly half of relevant recorded accidents in industrial applications of ionizing radiation are related to industrial radiography [1]. Failure in following operational procedures is the most common primary cause of accidents in industrial radiography practices, particularly the failure in performing radiation survey of the exposure container to guarantee that the source is at the safe shielded position.

Other primary and common causes of accidents related to industrial radiography are: (a) lack of adequate training and capability; (b) lack of regulatory control; (c) poor equipment maintenance; (d) human error; (e) equipment fault; (f) design flaws; and (g) deliberate infraction.

In large industrial irradiation units, the radiation sources employed have very high activities, with consequent high potential for causing serious accidents that could lead to severe injuries or even death. In most of the accidents at large industrial irradiator units the initiating event was linked to some fault of the devices used for material transportation or at the system used for moving up and down the radiation source. Other primary and frequent causes are: (a) poor equipment maintenance or equipment design flaw; (b) interlocking system failure or deliberate bypassing; and (c) human error and inadequate training.

In many accidents in industrial area there is a combination of causes. This indicates the existence of management problems that let the installation operate in the absence of the required safety procedures, such as a quality assurance program.

3. Safety assessment in industrial facilities

One of the main lessons learned from the many accidents that occurred along the history of technological development is the relevance of probabilistic safety assessment (PSA) in industrial practices [2]. The main goal of safety at any industrial installation is to adequately protect the occupationally exposed individuals and members of the public from the risks associated with the use of radiation sources. However, despite of all efforts, these risks cannot be reduced to zero. Even if it was possible to reduce the risks to minimal values, the costs of this reduction could raise exponentially, leading to a waste of human and financial resources.

The start up of nuclear regulatory activities, simultaneously to the development of the nuclear industry itself, is characteristic of the nuclear activity. This feature makes this practice different from other technological activities, because it was developed to avoid potential risks. The concept of safety in nuclear industry is based on a group of principles, among which we can point out defense in depth, redundancy, diversity and physical separation of safety systems, followed by the installation’s responsibility, safety policy and regulatory efficiency.

At the beginning of the use of the probabilistic safety assessment at nuclear industry, the judgment of experts prevailed, combined with deterministic methodologies and also comparisons with other nuclear reference centers. A pyramid of laws developed gradually, leading to regulations and guides of general application, currently followed.

Analysis of accidents at high risk industrial facilities, through the use of probabilistic safety assessment (PSA), requires wide knowledge of the facility in order to obtain a full understanding of the accident and its implications to safety, as well as to draw a relationship between the accident and the risk study performed and to enforce the execution of the necessary changes [3].

At first, it is necessary to select the accidents for which safety assessment will be performed, including a revision of the operational events connected to functions, systems or equipments related to the safety facility. In general, any accident which damages or starts the safety functions of an industrial facility is a candidate for analysis.
4. Lessons learned from accidents in industrial areas

4.1. Accidents in industrial radiography

The following lessons have been learned from the investigation of accidents in industrial radiography.

If the safety procedures had been correctly followed, most of the accidents would have been avoided. Failure in following the safety requirements usually occurs due to commercial and production pressures, such as:

- In most overexposure cases, personnel involved failed to follow procedures and did not carry out area radiation survey;
- Several overexposures occurred because interlocks and other safety systems were intentionally damaged, despite of established procedures;
- In several overexposures just one operator supervised the qualified staff.

Safety is in danger if the regulatory control activities related to licensing and inspections are not applied, i.e. the observation and analysis of the design of the radioactive source, radiological safety procedures and personnel qualification. Whenever these aspects are not taken into account, insecure situations can occur, including radiation exposure of members of the public, such as, for instance:

- Inadequate analysis of the source device design led to disconnection and public exposure;
- At on-site industrial radiography safety procedures were not adequately observed.

Radiation protection officers (RPO) can lose control of the level of knowledge of operators and how they work if systematic audits, capacity evaluation and recycling courses are not carried out. For example:

- In several overexposure cases, the operators did not have enough capacity to operate the gamma radiography equipments and safety devices;
- Frequently, overexposed operators did not use area monitor or misused it;
- In many cases the operators involved in accidents were not bearing a personal dosimeter.

In many cases, poor safety policy resulted in degradation of safety systems and operational procedures. It appears that huge amounts of work and production costs had priority over safety. For instance:

- Operators involved in tasks for recovering a loose source had deliberately not used their personal dosimeters in order to avoid the increase in their recorded doses;
- Some accidents occurred because not enough attention was given to the maintenance of safety systems and instruments;
- It was noticed a high level of tolerance related to personal safety and lack of care with the public;
- Frequently there were not enough qualified operators to adequately respond to unsafe situations.

In most accidents, the operator’s capacity was deficient, including poor initial training in safety and emergency procedures. For example:

- Sources had been recovered without adequate instruments, tools or planning, and in unfavorable environmental conditions;
- Overexposed operators in many instances did not have basic knowledge of the fundamental principles of operation of the equipments;
- In general it seems that there were lack of knowledge of basic principles of safety and radioprotection;
- Operators have not used basic principles of operation, safety and radioprotection, i.e. their knowledge was not deeply ingrained.
4.2. Accidents at large industrial irradiation units

Several lessons have been learned from the investigation of serious accidents at large irradiators. Safety systems with redundancy and diversity could have prevented most of the accidents [5]. For example:

- In all accident cases, operators involved trusted the access barriers, interlocks and had just one signal for indicating the source position;
- In all accident cases, the access barriers with interlocks had not been installed, had been removed or were intentionally bypassed;
- In many accidents, the indicator of radiation source position was displaying a wrong signal due to failure of just a single component, or because it was manipulated to indicate a false signal at the control panel;
- In several accidents, it was possible to bypass the access barriers while the control panel was in operation mode.

Safety is compromised if the facility design is not carefully reviewed to identify critical conditions to safety. This requires considerations of redundancy, single mode failure and human errors. Whenever these factors were not taken into account, it resulted in unsafe conditions. For instance:

- Switching off a critical safety system from the control panel resulted in unsafe conditions while an accelerator was still working, or caused a gamma source to remain outside the pool in a large industrial irradiator unit;
- Disconnecting a critical safety system from the control panel resulted in unsafe conditions when an accelerator was not automatically shut down, or the radiation source was not shielded at the correct position inside the pool in a large industrial irradiator;
- While trying to solve problems, operators were tempted to bypass access barriers, by using ladders, crawling or manipulating switchers.

Managers of industrial irradiators can lose control of operators and employees’ knowledge level and performance if they do not perform systematic audits and do not promote retraining. For example:

- In many accidents, the operators used tricks to bypass safety systems;
- Operators involved in accidents did not carry a radiation survey monitor while entering the radiation room, indicating that it was common not to follow the procedures. It was also observed that most of the operators did not bear their individual dosimeters.

Wrong practices and attitudes performed by managers of industrial irradiators resulted in degradation of safety systems and operating procedures. It seems that in many instances production costs took priority over safety. This was particularly evident when the regulatory authority was absent or inefficient. For example:

- Managers allowed the removal or bypassing of interlocks, which caused several accidents;
- Many accidents occurred after managers had received the manufacturers’ recommendation to install a protection that would prevent accidents, but failed to comply;
- In at least one accident, the manager approved the installation of a switch to bypass an interlock system and removed the only passive detection system that could not be circumvented easily;
- Many accidents occurred during shifts when only one trained operator was working. The employees’ behavior appeared to reflect the management policy of having just one person doing all tasks and having as many responsibilities as possible.

Personnel trained to work with routine tasks did not have enough knowledge to deal with situations such as to switch off the electron beam or put the source back into the safe shielded position. For example:

- Operators involved in accidents frequently failed to monitor the area with an adequate radiation monitor;
• Operators involved in accidents frequently failed to follow instructions to communicate their superiors when the alarm was signaling that the source was not at the secure shielded position;
• Operators involved in accidents had forgotten or had not fully understood the fundamental principles of operation of the equipments with which they used to work.

4.3. Accidents in other industrial facilities

Accidents in industrial installations with nuclear gauges or oil well logging have occurred with smaller frequency and severity when compared to accidents in industrial radiography and large industrial irradiators. The main lessons learned from accidents at those two practices are similar to the ones described before, with emphasis in the following items:
• Inadequate training of operators in the use and safety of equipments;
• Failure of operators in following safety procedures for the use, stock and transport of radiation sources;
• Lack of adequate maintenance of equipments and facilities.

5. Conclusions

Potential exposures can occur as a consequence of accidents. Safety assessment in industrial practices has shown the importance of accident analysis, which is a relevant part of the study of potential exposures. Analysis of accident cases showed the main operators’ errors and equipments faults, with respective lessons learned.

Lessons learned from accidents can lead to a better understanding of the mechanisms and sequence of events that could cause potential exposures. The knowledge gained from these assessments can lead to the implementation of devices and systems; improve safety procedures and safety policies, so as to make better the safety in industrial practices, decreasing the risks of potential exposures.

Acknowledgements

The authors are grateful to all of those who, direct or indirectly, collaborated with this work.

REFERENCES


