RADIATION RISK MINIMIZATION

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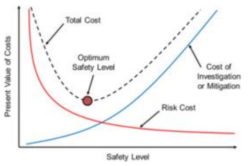

ABSTRACT

Risks are often approached intuitively with the main objective of minimizing their consequences, but without knowing the mechanisms to achieve it. Although the actions to reach the objective seem as being apparently simple, in this study some relevant complexities are analyzed. As an initial premise, it must be remembered that all human activities – including the life itself - carry some type and level of implicit risk. Consequently, risk is also an ever-present issue in the fields of radiation and nuclear applications. On one side, exposed workers perceive the risk according to the types and activities of radiation sources existing in their workplaces, as well as the operations they must carry out. On the other hand, the public can only estimate the level of risk from the information provided by official channels. However, the different modalities of radiological risk necessarily imply a given radiation dose. A systematic approach involves characterizing the exposure scenarios in order to quantify the related risks. The subsequent analysis will eventually allow a protective methodology in order to manage and minimize risks through technical solutions. Furthermore, given the cross-cutting nature of its objectives and principles, this study proposes to apply similar methods in the fields of Nuclear Safety, Radiation Protection and Sources Security, with the aim of unifying concepts, criteria and solutions.

1. INTRODUCTION

People are globally exposed to many kinds of risks, some naturally originated and other anthropogenic. In general, individuals tolerate certain levels of risk until an intuitive threshold according to their purposes and lifestyle. This study addresses the risks posed by the technological development of mankind, particularly those associated with exposure to ionizing radiation. Given the lack of risk factors, frequently the minimization criteria are applied intuitively.

In the technological field, risks are usually associated with accidental situations; however, they are always present even during normal operation. Safety areas such as Nuclear Safety, Radiation Protection and Sources Security have as their main objective the control of specific risks, in order to:

a) Avoid undue radiation doses to workers, public and environment.
b) Prevent accidents and eventually mitigate the effects of those occurring.

Conceptually, from an engineering point of view the overall risk of a given activity, related to its mathematical expectation, can be defined as:

$$\boldsymbol{R = \sum_i P_i \,.\, D_i}$$

where *R** is the sum of the consequences of the potential damage D_i caused by adverse events, weighted by their respective probabilities of occurrence P_i.

A systematic breakdown of the pairs [P_i D_i] may allow establishing actions to be taken over one or both parameters in order to reduce the risk.

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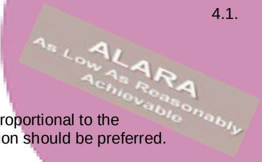
* Risk can also be defined as $R = \Sigma_i f_i P_i D_i$, limiting the associated time period to the frequency (f) of the initiating event.

2. DETERMINISTIC APPROACH

Targeting on the radiological risk, the potential harm results in a given radiation dose, which can be minimized by characterizing the exposure scenarios for normal operation.

The source of the risk is clearly the key factor in order to control its potential effects. Consequently, the processes must be controlled considering the type of source, the radiation field it generates, as well as the consequent exposure of people and/or the environment, through control measures of the source and/or the variables of the process or, finally, by installing protective barriers.

2.1. Control of potential dose from radioactive sources



The minimization process should consider the following parameters:

2.1.1. Activity

The intensity of the radiation field generated by a given radionuclide is directly proportional to the current activity (A). Therefore, the minimum activity compatible with the application should be preferred. In addition, lower rate specific emission radionuclides should be preferred.

2.1.2. Physical form

The dispersion capability of the source is a function of its physical state, i.e. increasing from the compact (or sealed) to particulate solid phases, down to the liquid and gaseous phases, including aerosols. As far as possible, sources of low dispersibility should be used.

2.1.3. Chemical form

The chemical reactivity of some process compounds can generate both particle projections and phase transformations. Consequently, a containment capacity should be designed conservatively.

2.1.4. Process variables

Variables such as temperature (T) and pressure (p) should be controlled within the established ranges in order to maintain the chemical and physical stability of the process.

2.1.5. Exposure time

The individual dose is a linear function of the exposure time (t); accordingly, it should be reduced to the minimum achievable.

2.1.6. Distance from the source

The individual dose rate is an inverse quadratic function of the distance (d) from the source. Therefore, the distance should be increased as much as possible, including tele-grippers or even remote manipulation.

2.2. Control of potential dose from X-ray emitters

The device output, including its potential dose, are characterized by several factors, i.e.:

2.2.1. Accelerating voltage

The dose rate of the emerging beam potentially varies with the voltage applied between the tube electrodes, a condition that implies reducing the voltage to the minimum compatible with the technique.

2.2.2. Electric current

The device output is a linear function of the current applied to the tube filament; therefore this should be the minimum acceptable for the process.

2.2.3. Beam output angle

A small solid angle concentrates the radiation beam in a small area for a given focusing distance. Consequently, the smallest possible area will be defined.

2.2.4. Exposure time

The dose of exposed individuals linearly increases with exposure time. Therefore, appropriate measures must be taken in order to minimize the exposure time.

2.2.5. Target to source distance

The dose rate of a divergent beam will decrease depending on the square of the target to source distance. Accordingly, this factor should be maximized by means of appropriate devices.

2.3. Technological safeguards

Both time reduction as well as distance increasing depend on some process conditioned limitations. As appropriate, exposure time limiting devices will be required or the use of appropriate technological safeguards such as shielding barriers or containment, static or dynamic.

2.4. Emergency situations

Although emergency states escape from conventional standards, it is possible to apply a similar methodology than previously described in order to reduce potential doses, considering greater amplitude in the variation ranges of the specific parameters.

3. PROBABILISTIC APPROACH

The initiating events probability of occurrence can be assessed - and in some cases controlled - considering two different origins as well as the related technological barriers.

3.1. Natural events

By their origin, natural events are essentially uncontrollable; however it is possible to assess them. Some of them are dependent on the geographical location or weather conditions. Consequently, the evaluation of the site is a major importance issue. E.g., nuclear reactors are usually sited far from geological risks and are also protected from thunderstorms.

3.2. Anthropogenic events

Internal operational incidents and consequences of external events can be predicted and corrected by appropriate training and support systems limiting the process parameters.

3.3. Reliability of technological safeguards

A nuclear accident is commonly associated with the failure of a safety system or, more precisely, with a sequence of concatenated system failures.

For both types of initiating events, naturally generated or human made, engineered barriers to reduce and prevent its effects has been developed, e.g. containment buildings, shielding, etc.

The probability of failure P_f of a technological safeguard, considered as a system, is a function of individual failure rates λ_f of its components. Exemplifying with a barrier of a single component, the probability of failure of the system at time *t* will be:

$$\boldsymbol{P_f = 1 - e^{-\lambda_f . t}}$$

Thus, the risk controlled by that barrier results in:

$$\boldsymbol{R_f = D_f\,(1 - e^{-\lambda_i . t})}$$

Complex multicomponent systems can be assessed through the development of event trees and its related fault trees in order to identify the critical elements. In turn, a systematic extrapolation should indicate the need of critical systems redundancy, diversifying or independence.

4. TOWARDS UNIFICATION

As mentioned above, it would be convenient to unify the nomenclature used by the specialized disciplines Nuclear Safety, Radiological Protection and Sources Security in their various specific matters and processes, both operational and regulatory.

In this regard, the relevant definitions are as follows.

4.1. The International Atomic Energy Agency (IAEA) defines *risk* as:
  a) A multiattribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with exposures or potential exposures. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.
  b) The mathematical mean (expectation value) of an appropriate measure of a specified (usually unwelcome) consequence.
  c) The probability of a specified health effect occurring in a person or group as a result of exposure to radiation.

4.2. Also the IAEA defines *radiation detriment* as: The total harm that would eventually be incurred by a group that is subject to exposure and by its descendants as a result of the group's exposure to radiation from a source.

4.3. On the other hand the International Commission on Radiological Protection (ICRP) states that:
  a) Risk relates to the probability or chance that an outcome (e.g. lung cancer) will occur during a given length of time. Terms relating to risk are listed below:
  b) Absolute risk: the probability that a particular adverse event (e.g. the incidence of a particular disease or death) will occur in a specific period.

4.4. Clearly those definitions state that risk is made up of multiple factors; however, it is defined in a cyclical way, associated with danger and some confusion between possibility and probability is created. Regarding the detriment, the definition expresses an absolutely deterministic character.

4.5. From the beginning of its development, the Nuclear Safety area, i.e. the safety measures applied to nuclear reactors, adopted the engineering meaning of risk (R).

4.6. Taking into account:
  a) the common goals of Nuclear Safety, Radiation Protection and Sources Security areas, in order to reduce the related risks,
  b) the convenience of having common and consistent concepts, and
  c) the broad scope of the engineering definition of risk,

it is suggested to adopt this last definition, i. e. risk (R) stands for the sum of the potential damages (D) of the adverse events, weighted by their corresponding probabilities of occurrence (P).

5. CONCLUSIONS

5.1. Since it is impossible to override the radiological risk, the best way to reduce it involves an analysis of the initiating events, including its potential effects and probabilities of occurrence.

5.2. A systematic evaluation allows acting on those greater weighted factors, in order to achieve an effective control.

5.3. A common definition of risk should be adopted.

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