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Risk Prevention for Nuclear Materials and Radioactive Sources

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ABSTRACT

The present paper investigates the parameters which may have effects on the safety of nuclear aterials and other radioactive sources used in peaceful applications of atomic energy. The emergency response planning in such situations are also indicated. In synergy with nuclear safety measures, an approach is developed in this study for risk prevention. It takes into consideration the collective implementation of measures of nuclear material accounting and control, physical protection and monitoring of such strategic and dangerous materials in an integrated and coordinated real-time mode at a nuclear or radiation facility and in any time.

Keywords: Nuclear Materials/ Risk Prevention/ Safeguards/ Physical Protection.

INTRODUCTION

The need for energy in the world is basic for survival and sustaining of life. The services of electric energy -in particular- are essential to the quality of life of the people. These services will continue to increase in the next decades as both the populations and the incomes increase. The efficiency improvements, higher quality of management in the demand/supply and the use of "Non-Fossil" fuelled energy systems, such as; Renewable energy sources, Nuclear Fission and Fusion energy sources, ... , etc., would be the available options(1-2).

Controlled self-sustaining fission chain reactions in a nuclear reactor can provide a useful nuclear source of power. Nuclear reactors are designed as research or power reactors. Research reactors are used for a wide range of applications, such as; scientific-research, neutron irradiation processes, radioisotope production, materials testing, .. , etc. Power reactors are used for the generation of electric energy, the production of steam and hot water for town heating or industrial processes, sea-water desalination, power propulsion for marine vessels and satellites, ... ,etc. (3,4).

The nuclear materials [NMs] are the working fuel in the nuclear fission reactors. The processes undergone by NMs in their use as fuel in nuclear reactors constitute the elements of the nuclear fuel cycle [NFC]. The "front end" and the "back end" of the NFC include many processes involving different categories of NMs -mainly- mining, leaching, milling, conversion to uranium hexafluride, enrichment in U-235 isotope and production of uranium oxides. Also, it includes the storage of irradiated fuel [IF] and spent fuel [SF], the reprocessing of SF, the production of uranium oxides and plutonium oxides from reprocessed SF and; the process of radioactive waste treatment (4).

Radiation sources may be constituted from radioactive materials and from radiation or nuclear apparata (e.g., particle accelerators, nuclear reactors). Radioactive materials may be in the form of NMs (e.g., Enriched Uranium, Thorium, Plutonium) or radioactive sources [RSs] (e.g., Cobalt^{60}, Cs^{137}). These materials may be naturally occurring or man-made. Certain types of RSs may be produced by means of nuclear reactors or particle accelerators (eg., electrostatic accelerators, cyclotrons, synchrotrons). Such particle accelerators can produce energetic beams of charged particles (e.g, electrons, protons, alpha particles). Also, they may be used as radiation sources for scientific research and development, as industrial irradiators; and -in particular- for the production of short-lived RSs for medical applications [4-6].

As a matter of fact all types of radioisotopes and all kinds of NMs that are involved in the NFC are "radioactive" materials which would emit Beta, Gamma, or X-radiations and/or protons, neutrons, alpha particles and fission fragments. Such radiations (or emissions) could present potential hazards to the workers, the population at large and the environment [4,7].

The purpose of this work is to investigate the parametrs which may have effects on the safety of nuclear materials and radioactive sources and to describe an approach developed for dealing with risk prevention for such strategic and dangerous materials.

RISK PREVENTION

General

It is worthy to remark that the nuclear energy is characterized by high energy density in the processed nuclear fuel, and correspondingly low quantities of fuel and waste. The occupational risks are mainly related to mining and power production related accidents and; the public risks are relatively small due to routine low-level emissions within the NFC and low probability accidents. It is well known that radiation events and its risks command considerable public attention. However, it is not generally realized that safety regulations in the atomic energy field are much stricter for NMs and RSs than for any other dangerous materials used in industry [5-8].

In reality, "Risk" is a common word that may convey different meanings to different people. Then, for the purpose of making comparisons between different types of risks, the risk associated with a specified event is given the technical definition as the "Consequence of the Event per Unit Time". However, the public acceptability of a given risk depends not only on the size of the risk, but also on the magnitude of the consequences of the event. Also, risk can be defined as the likelihood of damage or loss multiplied by the potential magnitude of the loss [8].

As a matter of principle in any of nuclear (and radiation) facilities the potential risk demands careful and experienced design, manufacturing, installation and operation to avoid harmful radiological exposure and other detriments. It is therefore extremely important to achieve high degree of safety and maintain it during the whole life of the facily. That is to keep to the lowest possible level, and to ensure that accidents are prevented, or at least, accidents with high consequences are Extremely Unlikely. In order to achieve this, the safety philisophy concepts have to be applied, i.e., defence in depth, safety analysis, safety system, redundancy, diversity, independence and fail-safe design [5-8].

Furthermore, safety measures to guard against radiation and criticality hazards when dealing with NMs and other radioactive materials are also required as measures taken against hazards associated with handling such dangerous materials. The national regulatory systems in the concerned State -as a rule- should require operators of nuclear plants (or radiation facilities) to comply with the following elements [9-14]:

1. Plant operational safety.
2. Radiation protection against hazards to health of workers and public.
3. Environmental radiation protection.
4. NMs accountability and control.
5. Physical protection against theft, misuse or malvolent acts against NMs and installations.
6. Monitoring of radiations and radioactive emissions.

Then, reviewing and assessing of the safety features and any other factors -as mentioned above- of a nuclear or radiation facility by the concerned competent authorities would recommend whether additional safety measures should have to be taken [6].

Risk Management

Risk management may take one of several different forms. Good programs of risk management should include a combination of "Risk Financing" [Insurance] and "Risk Control Tools" to treat the risk. The tools would include measures such as; "Avoidance", "Reduction", "Spreading", "Transfer" and "Acceptance" [15-16].

The risk may be defined mathematically as a product of one or more probability factors and one or more consequences. Actual analysis of risk requires the creation of a numeric algorithm that reflects the interaction of the different probability factors. Usually, probability data draws on direct measurements of incidences. The algorithms may take the general form [7];

Risk = Probability of incidence occurrence x Consequence

(1)

APPROACH

In fact, the global security measures for NMs and RSs would necessitate the implementation of measures in synergy with safety features in order to attain their objectives. The approach developed in this work is based on the idea that the design and analysis of all risk elements would be addressed as an integrated system to the concerned facility (including environmental health and safety, property engineering and security risk) This could be achieved through the implementation of measures of the "Accounting and Control" [AC&C], the "Physical Protection" [PP] and the "Monitoring" [MON] of the NMs and other radioactive materials in production, use, transport and storage in "Coordinated Real-time Mode" to be integrated with the safety measures in the facility. Fundamentally, this is a national task which should be implemented through appropriate authorized national regulatory systems. Also, according to certain agreements, "International" and/or "Regional" systems of control may be involved in parallel to national systems for the purpose of global nuclear safety and nuclear security in the world. The major features of the AC&C, PP and MON are given in the following [9-14].

Accounting and Control

The NMs accounting and Control depend on the principle of conservation of matter. Any changes to the inventory of NMs present in a defined area should be equal to the net production or loss of such material within the area plus the inward flow of that material from outside, minus the flow out of the area. Such areas defined in nuclear facilities for the application of the conservation principle are called "Material Balance Areas" [MBAs]. Then an effective verification technique based on this principle requires knowledge of the flow and inventory of the NMs and, the compilation of periodic NM balances [9-12].

An effective accounting and control system should be capable to ascertain Quantitatively "what, where and how much" NM is present in a specific facility; and how much NM may be missing from that facility at any given time. Also, the system should ascertain that the type, category and location of the materials in the concerned facility are conformal to the national nuclear regulations[13].

Physical Protection

The physical protection [PP] of NMs, other radioactive materials and their facilities against misuse, unauthorized operations or forcible seisure, theft, acts of terrorism or other criminal activities whether at such facilities or during transport is an extremely impotant national security task, and the responsibility lies on the concerned State. Then, the necessary organizational and technical measures of PP Systems should be applied under control of a "Competent PP Authority" designated by that State [(14)].

Monitoring

The monitoring of ionizing radiations and radioactive emissions represent a major task for the localization of any radiation incident and hence implementing verifications and control actions for the purpose of environmental amelioration. Radiation monitoring of radioactive emissions - whether inside or outside nuclear and radiation facilities, in the nearby areas or far-away regions in the country as a whole**-** should be implemented on specific regimes in air, waters, earth, ... , etc. [(4, 12)].

Radiation monitoring systems would establish a general radioactivity background data base in the country. Then, in the case of occurrence of unusual radioactivity conditions in certain areas, radiation monitoring would give "Early Warning Signals" so that the regulatory authorities would take the necessary verifications and actions for the control of the situation and the application of the remedial processes accordingly [(12)].

Risk Consideration

On the one hand, the risk elements associated with measures of safety, radiation protection and environmental radiation protection may be represented as [(6-8,17)] **;**

$$R(s) = P(s) \times \mathbf{C}(s) \qquad (2)$$

Where:

P(s) is the risk probability associated with the above indicated measures.
C(s) is the consequence.

On the other hand, by considering the risk elements associated with the measures of the AC&C and MON to be included with those for PP purposes, their collective risk R(c) may be represented as [(15-7):]

$$R(c) = P(A) \times [1-P(I)] \times \mathbf{C}(c) \qquad (3)$$

Where:

P(A) is the probability of an adversary attack (or malevolent act) during a period of time (value from 0 to 1).
P(I) is the probability that the defined adversary act will be interrupted by the facility response measures (value from 0 to 1)**.**
C(c) is the normalizing consequence (value from 0 to 1) that relates to the severity of occurrence of the event.

The risk elements in Equations (2) and (3) may be treated as independent elements although some of them could be inter-related in practical cases. Then, the total risk may be estimated by substituting Eqns. (2) and (3) in eqn. (1). Representation of risks associated with the coordinated and integrated measures of the present approach for risk prevention is given in Figure (1).

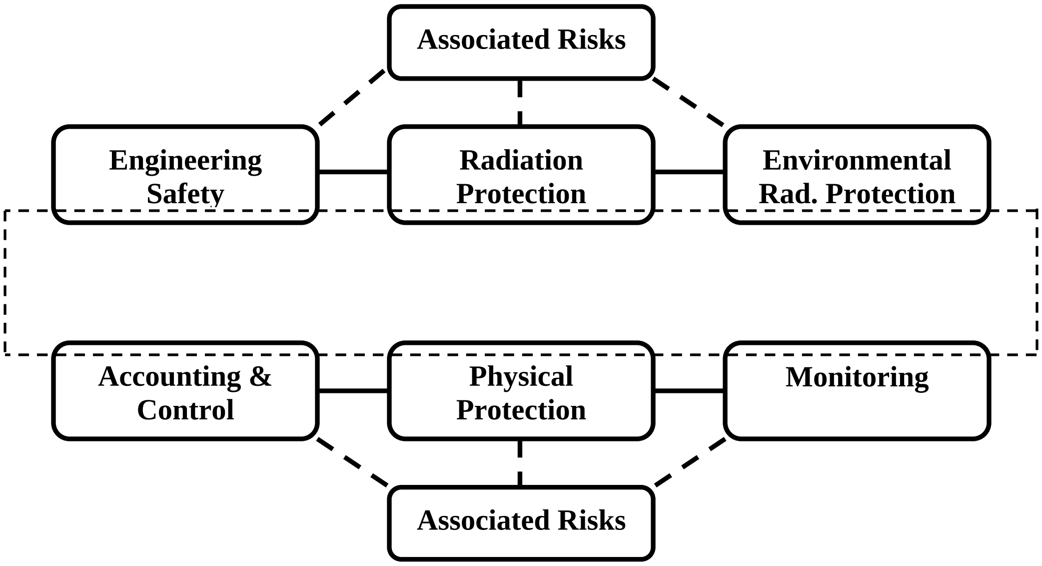

Figure (1). Representation of risks associated with the coordinated and integrated measures of risk prevention

EMERGENCY RESPONSE PLANNING

Overview

The goal of the "Emergency Response Planning" in a concerned State is to establish a powerful well organized system capable of immediate responding to any radiological emergency in a coordinated manner authorized by that State. Such a planning would describe in detail -as necessary- the capabilities of the concerned "National Organizations" and how to integrate their activities to attain the ultimate goal of protecting the workers, the people and the environment against the radiological risks. The specific responsibilities and authorities assigned to those national organizations by the Emergency Response Planning System [ERPS] would not change their original normal authorities and responsibilities (18-22).

In fact, the concerned State should assign a certain national organization for carrying out the "Technical Organization" duties related to the ERPS and the responsibility of coordination and technical support for the other cooperating concerned organizations. Such responsibility starts with the declaration of the "State of Emergency" and ends with the end of the response activities exercised by all of the concerned national organizations. The basic activities are summarized very briefly in the following (8-22).

Planning

- Identifying radiological hazards and threats
- Hazard mitigation
- Develop emergency plans and procedures
- Identify necessary personnel and resources

Preparedness

- Acquire and maintain resources
- Training
- Drills and exercises

Response

- Apply resources to stabilize the situation
- To mitigate consequences to workers, public, systems, and environment

Recovery

- Follow-up actions to prepare for re-entry and continued operation
- Initial characterization
- Minor shielding or decontamination

Radiological and medical considerations

- Radiation and contamination
- Determination of types of radiation, radioactive decay and half life
- Dosimetry
- Psycological aspects and Medical treatment

Then, the above indicated safety capabilities and activities should operate with the NMs AC&C measures, the PPS measures for the NMs and the nuclear facility itself and the measures of monitoring -all of them- integrated and in close coordination in Real-time Mode [13, 18-22].

CONCLUSION

The present investigation has shown the great importance of the parameters affecting the safety of NMs and other radioactive sources in production, use, storage, operation or in transport; and the probable risk or accident occurrence. The methodology of risk prevention approach developed in this work is based on the implementation of measures of the" Accounting and Control", the "Physical Protection" and the "Monitoring" at the different stages for handling of NMs and RSs in an integrated and coordinated "Real-time Mode" with the safety measures in the nuclear or radiation facility.

Also, this study could underline the importance of using this methodology in calculating and/or assessing the risk for the purposes of emergency response planning needed for accident situations and how to mitigate the consequences of the accident at its source.

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NOMENCLA TURE*

lAEA	International Atomic Energy Agency [UNO]
NMs	Nuclear Materials
SM	Source Material
SFM	Special Fissionable Material
RSs	Radioactive Sources
NFC	Nuclear Fuel Cycle
SSAC	State's System of Accounting For and Control of NMs
SG	NM Safeguards

PP(S)	Physical Protection (System)
*	[Ref. 3, 5, 7]

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