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THE OPTIMISATION OF OCCUPATIONAL POTENTIAL EXPOSURES
Preliminary considerations

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ABSTRACT

One of the major innovation brought about by the ICRP 60 recommendations and emphasised by the ICRP 64 publication, is the introduction of the concept of potential exposures into the system of radiological protection. Potential exposures are characterised by "probability of occurrence lesser than unity" and "radiological risks exceeding normal levels" where normal must be interpreted as not exceeding the planned routine exposures. It is then necessary to develop consensual methods to look for and choose the optimum scenarios (i.e. those for which probability of events and possible consequences have been reduced as low as reasonably achievable). Moreover, the boundaries for the unacceptable levels of risks for workers should be defined, as well as reasonable risk indicators.

The aim of this paper is to discuss the actual changes in the field of occupational radiological protection, induced by the potential exposure concept with particular emphasise on the optimisation of protection.

INTRODUCTION

One of the major advancements brought about by the ICRP 60 recommendations [1] and emphasised by the ICRP 64 publication [2], is the introduction of the concept of potential exposures into the system of radiological protection. Much of the discussion that has followed, focused on the impact and appropriateness for public protection and nuclear safety approaches, especially relating to the prevention of accidental situations and the mitigation of their consequences. This concept has needlessly thrown people involved in nuclear safety and in radiological protection into a real confusion, essentially centering on the usefulness or appropriateness of such a concept in their respective domains. One may hope that ICRP 64 or the future INSAG publication on potential exposures will definitively close the discussions.

The aim of this paper is to discuss the actual changes in the field of occupational radiological protection, induced by the potential exposure concept. The potential exposure concept most certainly calls for new methods in the practical application of occupational radiological protection, in particular for the optimisation of protection.

BASIC CONCEPTS

Potential Exposures

From the ICRP point of view, a potential exposure *is an exposure that, while not certain to occur, can be anticipated as a result of introducing or modifying a practice ("human activities that increase the overall existing radiation risk"), and to which a probability of occurrence can be assigned. Such exposures involve considerations of risk which fall outside the general boundaries considered for normal exposures, being recognised that, if these exposures effectively occur, they may lead to interventions ("human activities intended to decrease the already existing radiation risk").* The potential exposures are then characterised by "probability of occurrence lesser than unity" and "radiological risks exceeding normal levels" where normal levels have to be interpreted as planned routine exposures.

Risk

The word "risk" has been debated for a long time because of its different definitions and interpretations. In a common way, risk is understood as the "possibility of a harmful effect". Probability is the most common indicator to express this possibility. However, the methodology of "effect" and "probability" assessment have to be adapted case by case depending on the size of the problem considered: the risk appraisal of the practice itself, an operation inside a given practice, or specific tasks included in a given operation that will not lead to investigations in the same ranges of probabilities and consequences. Even if the general objective of any risk assessment is a matter of establishing a quantified framework to help decision-makers in their final choices, it is clear that one specific model of risk assessment ("mathematical expectancy of fatal cancers", for example) could be well-adapted to one situation and totally unsuitable to another due to its possible multidimensionality.

THE MANAGEMENT OF POTENTIAL EXPOSURES

The Optimisation Of Uncertain Risk

The optimisation of radiological protection allows to consider the best use of resources in reducing the radiation risks to individuals. The ICRP 60 recommendations expressed that its broad aim should be to ensure that *the magnitude of the individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received, are all kept as low as reasonably achievable, economic and social factors being taken into account.*

The likelihood that a person will suffer a given detrimental effect is quantitatively expressed by:

$$P = P_s . P_e(D_s)$$

where P_s is the scenario probability (where scenario has to be understood as an unique combination of events, sequences, processes and procedures), and P_e is the probability of severe radiological effect related to the individual dose D_s arising from the given scenario and defined by the dose-response relationship model.

In the case of doses staying below deterministic thresholds, risk may be expressed by

$$R = P_s . c_R . D_s$$

where:

- $P_s = \left(1 - e^{-T.\frac{dp}{dt}}\right)$ is the likelihood of the event knowing that the value of P_s is not far from the probability rate $\frac{dp}{dt}$ (per year) only for practice whose duration T is in the order of one year.

- c_R is the nominal probability coefficient for dose ranges leading to only stochastic effects (fatal cancer or fatal cancer equivalent).

But, it must be underlined that in the case of doses which may lead both to stochastic and deterministic effects, the proportionality between risk (expected fatal effects) and doses is no longer an acceptable estimate. The definition of the harm indicator is no longer straightforward and the problem of the summation of probabilities of health effects of different nature must be added. Moreover, trade-offs between potential and actual exposures should be addressed.

Even if these problems are solved, optimisation aims to demonstrate that everything possible has been done to reduce as low as reasonably achievable (ALARA) both probability of events leading to potential exposures, as well as the individual (and collective) doses themselves, economic and social factors being taken into account. Thus, the main goal of optimisation is not to respect a tolerable level of risk but clearly to ensure that an acceptable residual risk level has been reached by reducing both the probability, P_s (action of prevention), and exposures, D_s (action of mitigation), independently or simultaneously.

The problem lies in the fact that it will be generally difficult to balance prevention vs mitigation (see Figure 1), especially when situations do not directly implicate installation safety (for which prevention is a priority). The optimisation techniques will have to be adapted to take into account this bi-dimensionality, emphasizes the cases where mitigation would be more cost-effective, or more useful, than prevention and vice versa. In other terms, optimisation should permit the most satisfactory allocation of resources and protection efforts towards reduction of potential consequences or towards reduction of the probability of events.

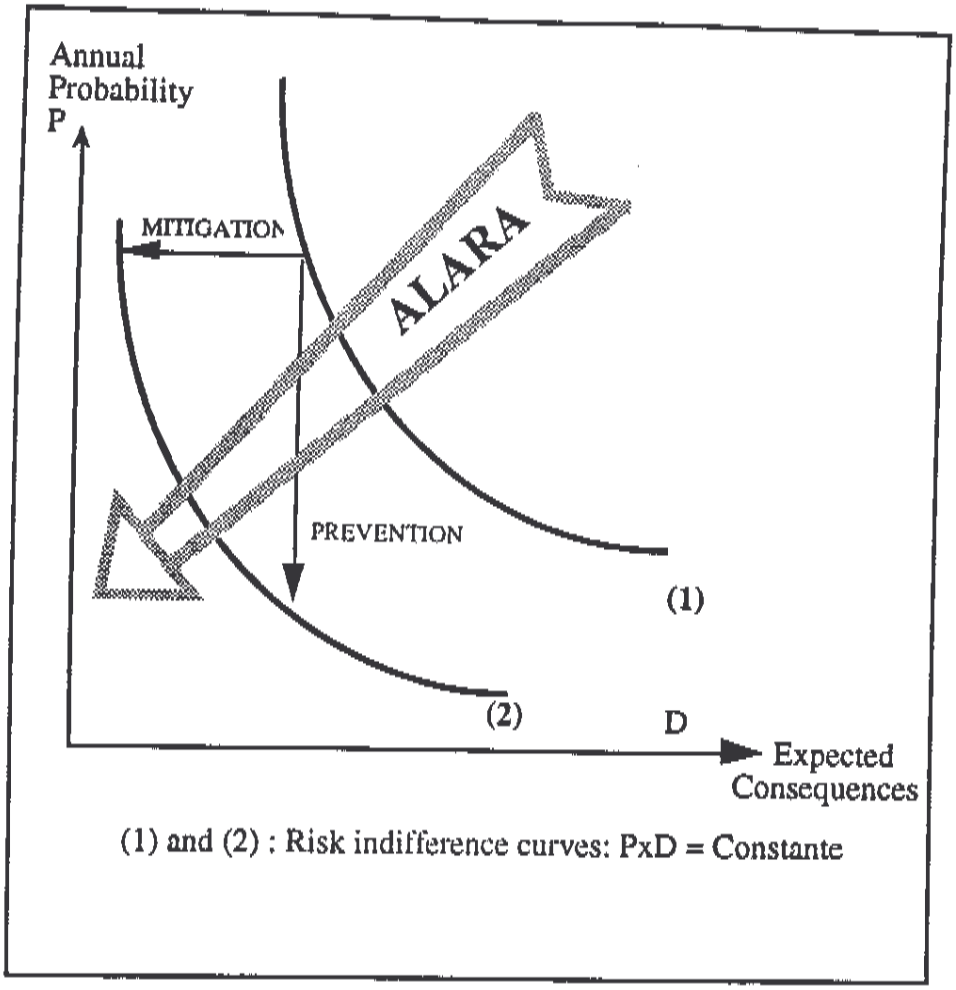

Figure 1. Reduction of potential occupational exposures ALARA

Risk Aversion

The acceptable level of risk for a given practice (i.e. the ALARA level of risk) depends, in fact, not only on the estimated level of the maximum individual and collective levels of risk but also on social, economic and other factors conveying with the individual perception of risks and reflecting the collective attitudes towards potential consequences at a given time. This last aspect is probably the most important point in the assessment of the acceptable risk and can be formalized by:

$$R_{acceptable} = f(R, A(D_s, P_s))$$

where A, is a risk-acceptability function defining the individual aversion, according not only to the potential level of exposures but also, the probability of the event giving the dose. It will lead to considerations for aversion to high potential exposures or expected exposures dispersion, which are sometimes taken into account in cost-benefit analysis. But, it will also lead to considerations for aversion to allocate resources to the reduction of probabilities of potential events, with clearly uncertain results. This last point is probably a very novel aspect which could shed light on the decision making process.

In the case of aversion to exposures in a given group of individuals or between different groups, methods of optimisation should reveal preferences in the distribution of potential doses, especially since doses in the deterministic range are possible. Account must also be taken for the dispersion of potential individual doses and the possible risk transfers (for example, from workers to other workers, workers to public or, even the present to future).

A next step is to introduce methods to assess aversion for making decisions under uncertain conditions and to include monetary and non-monetary attributes. Techniques (based on maximisation of expected utility, stochastic dominance...) already developed by financial risk theorists [3] could be adapted in order to help decision-makers in their choices and judgments on the acceptability of practices or scenarios with occupational potential exposures.

In the case of the optimisation of occupational practices or operations (i.e. large operations for example, steam generator replacement, installations dismantling..., involving many workers, and smaller more specific and repetitive tasks involving smaller staff of specialists during shorter periods) the acceptability of the individual levels of risk is certainly easier to check, because it is dealing with better known and well-followed populations and with time- and space-limited potential consequences (i.e. with more limited risk systems of reference).

However, special considerations like aversion towards possible high exposures, risk dispersion in the worker population (considering their other possible tasks), possible risk transfers between them still exist. These aspects, which are not yet really taken into account for the normal exposure management, will have to be more carefully assessed or weighted in the case of potential exposures.

The Tolerability of Risks

As the individual dose limits restrict the field of the optimisation for normal exposures, risk constraints could be used to ensure that the level of potential exposures of a given practice is effectively under a tolerable level (i.e. to ensure that the practice is "safe enough"). In this context, it is necessary to define bounds above which the level of risk becomes unacceptable. Symetrically, it can be noted that lower bounds below which the risk level may be considered as negligible regarding both probability and exposures will be also useful to decision makers.

Tolerable upper risk bounds for accident consequences have already been proposed [4] to define probabilistic safety objectives.
Analogously, ICRP Publication 64 defined a range of annual probabilities vs individual whole body exposures, whereby constraints for potential individual whole body exposures could be selected (see Figure 2). The proposed ranges are large enough to fit with the case of public risks as well as the workers case. It shows that potential occupational exposures with annual probabilities greater than 10^{-2} should be considered as normal and constrained by the actual limits for normal occupational exposures.

More debatable is the fact that the system should *a priori* authorize potential exposures leading to possible deterministic effects in the range of annual probability from 10^{-6} to 10^{-5}. Anyway, the tolerable risk boundary scheme to be applied for incidental and accidental occupational situations, should take into account greater probabilities of events leading to higher potential exposures (i.e. above regulatory occupational limits). The reason to define the occupational risk boundaries is to verify *a priori* the tolerability of a given practice or scenario, even if it does not entail very important societal or collective consequences, but because it may lead to important individual harm to workers.

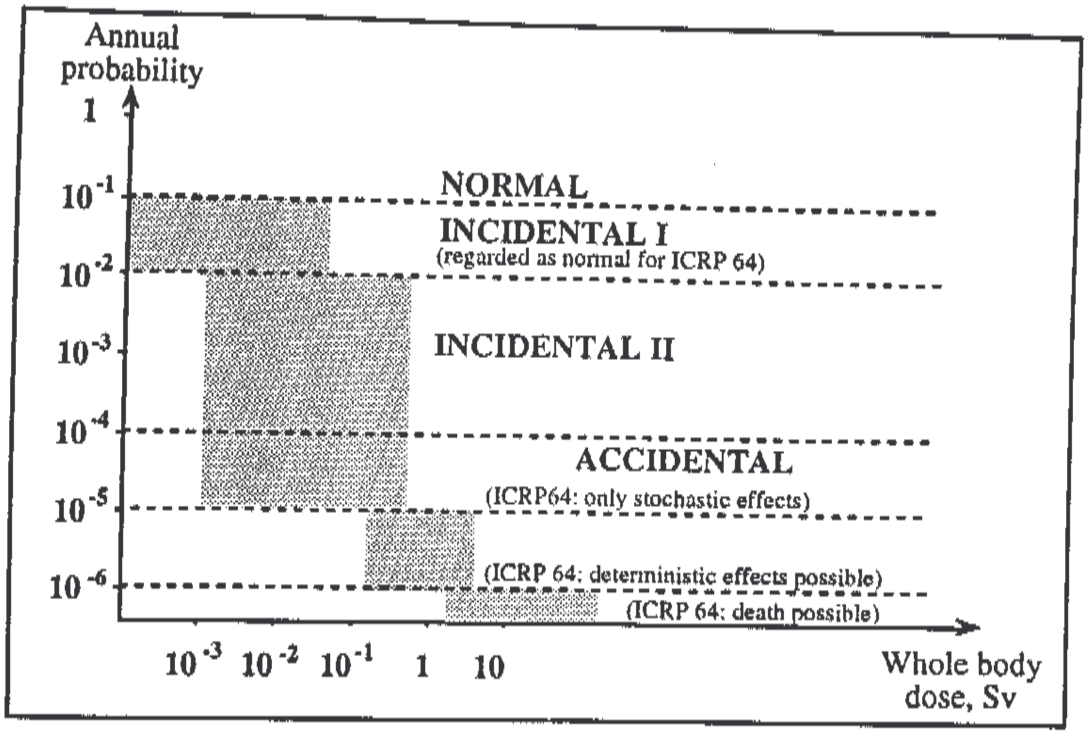

Figure 2. ICRP 64 domain of risk constraints for whole body potential exposures (workers and public)

In conclusion, the definition of what could be the boundaries for tolerable occupational risk of exposure is an important step in the potential management of exposures . But, they must be discussed and chosen taking into account different points of view of employers, authorities and regulators.

PRACTICAL CONSEQUENCES

Despite the difficulties related to the definition of acceptable and tolerable risks of exposures, the structuring and dissemination of potential exposure assessment through the radiation protection framework could effectively enhance the protection of workers. Some practical results and consequences from this assessment could then be included at the operational level.

Analysis of Occupational Incidents and Mishaps

In many countries, the control of occupational exposure and the statutory recording of occupational doses are based mainly upon the results provided by dosimeters. But, the increasing emphasis on optimisation of protection (ALARA) will gradually constitute adequate dosimetric data banks to relate the potential exposures of individuals to specific tasks. More specifically, the systematic recording of incidents and dosimetric mishaps during specific tasks would form a sound basis of feedback experience to identify where efforts must be given in priority. In most cases, better work management (organisation, training, motivation...) will provide high improvements [5], but sometimes and especially for well-managed scenarios, it could illustrate that radiological mishaps may be better prevented (by improvements in the reliability of system and materials) or mitigated (by improvements in the protection). Having such an approach for the detection of the most probable incidental causes of workers exposures and generalising it at the national -even international- level leads to the reduction of the collective and individual doses. Up to eighty percent of the doses during NPPs French outages are due to unplanned events [6], more often brought about technical mishaps and/or human errors; these mishaps must be well known, understood and quantified and therefore can be early prevented and mitigated.

Probabilistic Occupational Radiation Assessment

Techniques of identification of potential scenarios leading to unplanned exposures have to be developed. These techniques are well known in the safety field, but essentially focus on the reduction of risk related to accidents with off-site consequences or incidents with high consequences for the installation safety. They could probably be adapted to the radiological protection framework by defining dominant sequences of incidents and dose-event trees.
Resulting from deterministic ("postulation of initiating events" like human error or material failures) or from a probabilistic approach ("Probabilistic Occupational Radiation Assessment"), the methodologies should predict with high confidence the practices or scenarios which are leading to clearly untolerable radiological occupational risk. To perform such studies at the design stage of nuclear cycle installations, will obviously reduce the possibilities of incidental scenarios (prevention), as well as potential doses in case of their occurrence (mitigation).

CONCLUSION

The need to take into account potential exposures into the radiological occupational protection framework is not to demonstrate. Nevertheless, it will be necessary to develop consensual methods to look for and choose the optimum scenarios (i.e. those for which probability of events and possible consequences have been reduced as low as reasonably achievable). Moreover, the boundaries for the unacceptable levels of risks for workers must be defined, as well as reasonable risk indicators. This approach will turn radiological protection into actual risk management by controlling and limiting the scale of the exposures presented by the nuclear practices, and reducing the probability of incidents that might occur. At last, it must be keep in mind that even if it will lead to new occupational arrangements, the final aim of that process is to enhance both radiological protection and safety of workers.

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