Alara and Internal Exposure:
Some Lessons Learned from External Exposure Management

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Introduction

In its Publication 60, the International Commission on Radiation Protection (ICRP), re-emphasised, for justified practices, the optimization principle, (or ALARA principle) as the core of the radiation protection system. Since a couple of decades, the requirement of keeping exposure 'As low as reasonably achievable, economic and social factors being taken into account' has been demonstrated successfully at many nuclear installations,… but only as far as external exposure is concerned. However, the ICRP also clearly states that " Any exposure at work should be included in the occupational exposure " (ICRP 60). Therefore the optimisation of radiological protection should be implemented for both external and internal exposures of workers. This presents a number of difficulties and experience of implementing ALARA for internal exposures is considerably less prevalent. In order to set the scene for the Workshop the first part of this paper will briefly recall the role of ALARA in radiological risk management. The second part will then address questions concerning the present situation and some issues for the future.

1. From a prudent and responsible attitude to the ALARA practice

1.1 An answer to uncertainty, a prudent and responsible attitude

The protection of individuals against deterministic effects of ionising radiation is straightforward. Since there are thresholds for this type of effect, it is possible to avoid them by introducing adequate individual dose limits.

As far as stochastic effects are concerned the situation is far more complex. The knowledge of the risk of the low doses is still incomplete, though very intensive research has been carried out since the war. Epidemiology, however, has clearly demonstrated that the predominant risk of low doses is an increase in the probability of cancer (stochastic effects); in the sixties this had been demonstrated for populations that had received an instantaneous dose above 1 sievert. Nowadays there is a consensus among the existence of possible radio-induced cancer above 0,2 sievert, some publication even demonstrated it above 0,05 sievert. However the major uncertainty remains the shape of the relationship between cancer probability and dose, as well as the existence of a threshold. Faced with these uncertainties, the ICRP has adopted a cautious approach, setting the hypothesis that there is no dose threshold below which the risk disappears, and with respect to risk quantification, retaining the cautious and practical assumption of a proportional relationship between the degree of exposure and the probability of the development of radio-induced cancer [1].. The linear relationship has been " divided " for low doses or dose rates by a correction factor of two (DDREF[2]).

Broadly speaking, the assumptions retained on the basis of the extrapolation towards low doses of known data for instantaneous doses of over 0.2 sievert have led the ICRP to estimate that there is a whole life 4 % probability of a worker dying from radio-induced cancer if he has received an accumulated dose of 1 sievert during his working lifetime. Under these hypothesis a worker who receives annually during his working life (35 years) 20 mSv, reaches 700 mSv, that corresponds to a 2,8% risk of dying prematurely (15 years sooner on average) from a radio-induced cancer.

[1] To significantly demonstrate the existence of an excess of radioinduced cancer it is necessary, from an epidemiological point of view, to follow up during several decades: 1000 individuals when the dose is around 1 Sievert per person, several tenth of thousand of individuals for 1/10 Sievert, 10 millions of individuals for 1/100 Sievert. It is therefore obvious that for very low doses, epidemiology will never (for technical and economical reasons) provide a proof of the existence, or absence of excess of radiological induced cancer.

[2] Dose and Dose Rate Effectiveness Factor

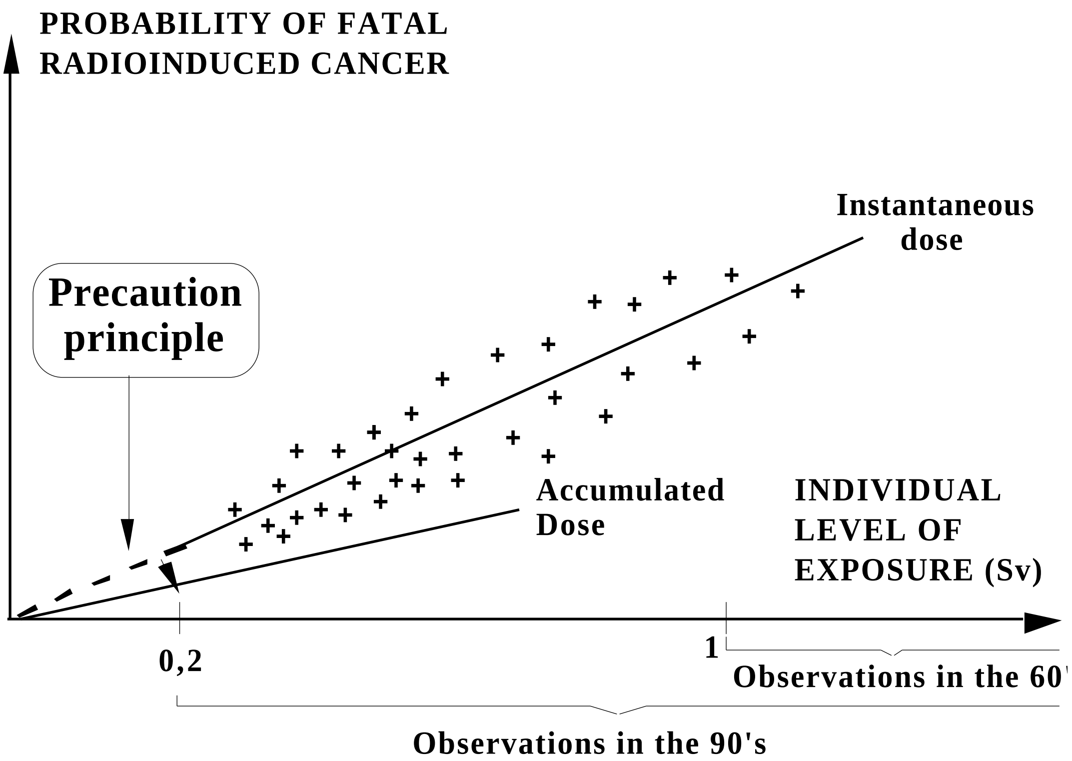

Figure 1: The Dose effect Relationship for low doses.

Since it has been cautiously assumed that the probability of cancer developing is proportional to the level of the individual dose without any threshold, it is legitimate to add up these individual doses in order to estimate the excess number of cancer cases in an exposed population of workers[3]. This sum, conventionally called collective dose (a notion that is obviously not rooted in biology, but solely on epidemiological and statistical concepts), and expressed in man-sievert, is a very useful and powerful tool for a pragmatic management of exposures and as a performance indicator for protective actions.

As soon as a human activity involving the use of ionising radiation has been deemed to be socially "justified" in the terms of ICRP (in other words as soon as the benefit the society expects from it are greater than the risks it involves), a risk mitigation policy must be adopted along with the no threshold hypothesis in order to implement safely that activity. The reduction of all exposures to the lowest level appears to be proper policy for the protection of individuals. However, the reduction of exposures by all possible means and at any price is not acceptable for both economic and ethical reasons.

Because of the law of diminishing returns, resources which are deployed to reduce exposures become less and less effective, and there is a point beyond which the cost of further improvement is out of line with the resulting reduction. Any step to implement additional protection leads to a waste of resources from society's point of view. Furthermore, experience shows that beyond a certain level in the reduction of the risk for a given group, part of the risk is generally transferred to other groups. A typical example is the increase in protection of the public against releases of the radioactive substances from installations. This creates a transfer of risk to the workers inside the installation involved in the management of wastes produced by the radwaste treatment systems.

These considerations have led the International Commission on Radiological Protection to abandon the 'low-est possible level' objective initially recommended and to promote the optimisation principle as a means to keep doses 'As Low As Reasonably Achievable (ALARA), economic and social factors being taken into account'.

1.2 Acceptability of residual risk and equity

In its Publication 60, the International Commission on Radiological Protection (ICRP) specifies the relative functions of the concepts of limit and optimization using the model known as risk tolerability. While the

[3] In its 1999 September meeting the Main Commission of ICRP has unanimously stated that : " the concept of collective dose remains valid and useful in many circumstances, while it has often been misused and within contexts where it was non sense "

concept of dose limit used for deterministic effects is associated with the notion of threshold, for management of stochastic effects, the limit is based on considerations relating to the acceptability of the residual risk. Respecting a limit guarantees that an individual will not only suffer none of the pathologies known to be caused by high doses, but, in addition, that the probability of his eventually developing radio-induced cancer is not socially unacceptable. However compliance with the only limit will not necessary lead to satisfactory situations as long as it is possible to further reduce “ reasonably ” the exposures. It is only when all what is reasonable has been done that the situation may be considered as socially acceptable i.e. ALARA .

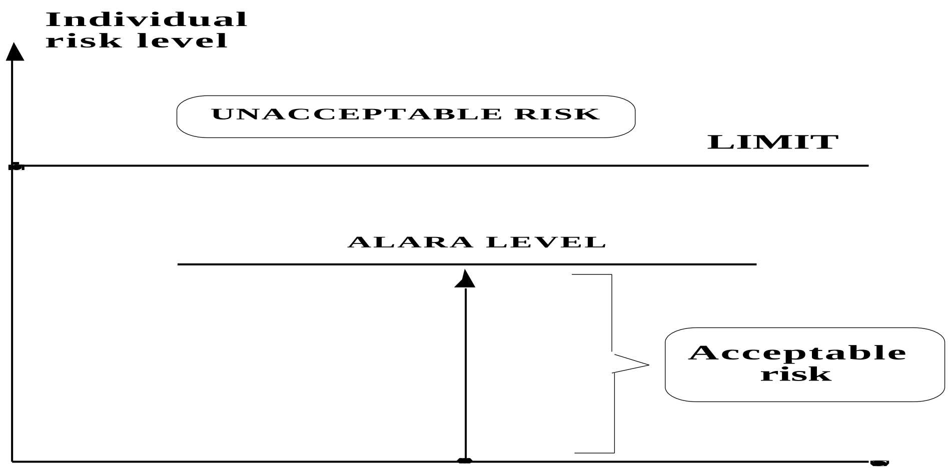

Figure 2. The ICRP 60 risk model

In its most recent recommendations, the ICRP placed particular stress in its formulation of the optimisation principle on the will to limit inequality in the distribution of individual doses. It is clearly stated that the situations in which people are exposed and also the protective steps, can cause inequalities in individual doses which are deemed large enough to require reduction. This could be represented by the fact that the aim of optimisation is not only to reduce collective exposure to as low as reasonably achievable under prevailing social and economics constraints, but also to strive to reduce exposure of persons with the highest individual doses as a matter of priority, since the assumption retained is that the risk increases proportionally with the dose.

Finally one may stress that within the Radiation Protection System recommended by ICRP, the first principle i.e. the political and social “ justification ” of a human practice ensures that a specific use of ionising radiation is deemed socially acceptable. Whenever one activity has thereby been socially justified, it involves an increased risk and the heart of the protection against that risk is the pursuance of ALARA in respect of collective and individual exposures, verifying that no individual exposure exceeds the dose limit.

1.3 The ALARA practice: a way of thinking, a predictive behaviour

The effective implementation of the ALARA principle implies that all the persons concerned by radiation protection are aware of, and accept the assumptions upon which the principle of radiation protection optimization is based (see I.1 above). This acceptance of the notion of residual risk is at the very foundation of each person’s awareness of his responsibility and motivation in seeking the reduction of individual and collective risks. Therefore the ALARA approach corresponds essentially to a state of mind.

From a practical point of view, applying radiation protection optimization should lead to a reduction in risk via the implementation of the most cost effective protection measures. This means implementing an approach that is both predictive and evolutionary.

The approach is predictive, since, in order to “ manage the risk ”, the doses associated with the planned work programme (nuclear or industrial operations …) have to be predicted, and possible protection measures have to be devised. The measures that are selected have to be compatible with available resources as well as equitable. For the first time in 1996 the European BSS Directive has clearly introduced in its wordings the predictive characteristic of the optimization of radiological protection : “ operational protection of workers shall be based…on … prior evaluation to identify the nature and magnitude of the radiological risk to exposed workers and implementation of the optimization of radiation protection in all working conditions ” (Directive 96/27 Euratom article 17)

It is an evolutionary approach because it has to be flexible enough to adapt to changes in techniques, resources, and social context : therefore what is ALARA today may be different from what will be ALARA in the future.

Figure 3 presents schematically how the ALARA approach can interact with the successive phases of an operation.

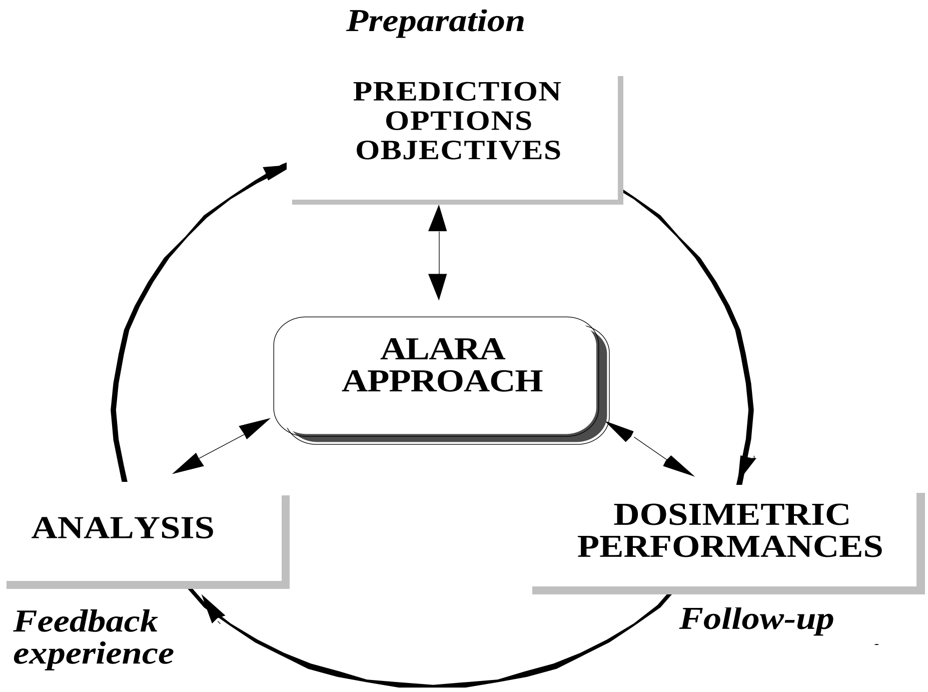

Figure 3.: The ALARA approach

The preparation phase permits the implementation of dosimetric objectives after selection of cost-effective protection actions. During operation, the follow-up of individual and collective doses allows for the identification of potential gaps between the objectives and the actual performances. Finally, the feedback phase allows for the evaluation of the adequacy of the initial choices, and possibly establishment of new protection actions and objectives in the light of past experience.

As a conclusion of the first part of the paper it must be stressed that ALARA implementation relies both on a widespread culture of the residual risk and on the capacity of those in charge of radiological protection to select reasonable and efficient protections options. Therefore there is a need to be able to accurately assess collective and individual exposures, to precisely know what are the tasks giving rise to the highest collective and individual doses and what would be the efficiency of possible protection options.

2. ALARA and internal exposure

2.1 Internal exposure should be part of the ALARA process, as is external exposure

"Any exposure at work should be included in the occupational exposure " (ICRP 60), therefore the optimisation of radiological protection should be implemented for both external and internal exposures of workers. However as far as internal exposure is concerned it is obvious that any significant contamination with some radionuclides of high specific activity such as Plutonium, Americium… may induce unacceptably very high doses and any internal component of the occupational exposure in such situations should be avoided whatever the cost of the protective measures. The internal component of occupational exposure due to many other radionuclides, such as tritium, natural uranium, thorium…during normal operation is mainly generated through inhalation and gives rise to doses in the range of low or very low doses. That component has then to be added to the external one within the optimisation process.

However up to now, much of the thought devoted to ALARA has tended to focus on occupational external exposure and ALARA is currently mostly applied in that domain, mainly in the nuclear sector. When, some decades ago, the process of implementing ALARA for external exposure was just starting, the use of film badge dosimeters, or even TLDs, in most cases could not provide answers to the questions: when, where and how were the doses received? Without this information it is difficult to answer the question "What could be done reasonably to reduce individual and collective exposures?" Since then, much has been done in order to assess and follow up as realistically as possible the doses per job, task, category of workers etc. Several generations of electronic dosimeters have been developed, feed back experience computerised data bases have been set up, ALARA programmes have been elaborated and implemented… Feedback experience from these programmes has showed that three major components are necessary to ensure that the implementation of ALARA would be efficient :

- The commitment of all individuals involved through a common ALARA culture
- The existence of adapted structures to make ALARA decisions
- The use of appropriate tools

There is also now considerable evidence that applying the ALARA principle to external occupational exposure means that a 'global work management approach' must be adopted, considering all the factors contributing to radiation dose as a whole (dose rates, duration of exposure and number of workers involved in the work).

2.2 Some preliminary questions

Unlike in external exposure, it is often quite difficult to predict the levels of intake and hence the doses in internal exposure, because many variables come into play. The problem is compounded by the difficulties encountered in accurately measuring the actual intakes of many isotopes. Over the years, research has improved our understanding and ability to model physical and biological characteristics of internal exposure, i.e. pulmonary, digestive, biokinetic and irradiation models. Many strategies have been proposed for the assessment and the follow-up of occupational internal doses, but these strategies have, in most cases, essentially dealt with the respect of dose limits.

Some questions we have now to answer to are the following :

- Have we adapted tools and strategies to provide answers to the “ when, where, how and what ” questions ?
- How can we take care of the frequently “ incidental ” aspects of internal exposure ?
- How can we define management strategies adapted to situations as different as the operation of nuclear facilities, the dismantling of nuclear and industrial installations, or the processing of Naturally Occurring Radioactive Materials (NORMs) ?

Some case studies have demonstrated the feasibility of the implementation of the ALARA approach for internal exposure, and it will be very important, during that Workshop, to analyse the lessons learned from these cases.

2.3 Needed characteristics of the measurements methods

As in the case of the external component of exposure, the optimisation of protection implies, as an “ necessary even if not sufficient condition ” a realistic, sensitive and analytical assessment of the internal component of individual and collective exposures. That condition has many consequences on the requested characteristics of the measurement methods.

To be realistic any measurement method must minimise all types of biases and uncertainties ; to provide an analytical capacity the measurement method must give the opportunity to point out - the main sources of exposure, - the tasks giving rise to the highest collective and individual doses, - the most exposed workers ; to be sensitive enough, the measurement method must allow, at a reasonable cost, the assessment of doses much lower than the annual limit for a time interval between two measurements and small enough to allow the analysis of tasks contributions.

For a specific task “ x ”, performed by “ y ” individuals in “ h ” hours it will be necessary to take care of all the factors contributing to radiation dose . The dose to the individual will therefore be calculated as:

$$\mathbf{E_{y,x} = (E_{external.y,x} + E_{int.ernaly,x}) = (d_x \,.\, t_{y,x}) + ((V_y \,.\, C_{y,x} \,.\, t'_{y,x}).\, F)}$$

with

- $\mathbf{d_x}$= dose rate (mSv/h)
- $\mathbf{t_{y,x}}$= duration of external exposure (h)
- $\mathbf{V_y}$= respiration rate (m3/h)
- $\mathbf{C_{y,x}}$= concentration of air inhaled (Bq/m3)
- $\mathbf{t'_{y,x}}$= duration of inhalation (h)
- $\mathbf{F}$ = effective dose coefficient (mSv/Bq)

and the collective dose for the task will be:

$$E_x = \sum_{y=1}^{h} E_{yx}$$

Having that equation in mind it is possible to check in a generic manner to what extent the measuring methods may be realistic, analytical and sensitive.

2.4 Measurements methods, realism and sensitivity

For the **collective air sampling systems**, the uncertainty is essentially associated with the representativeness of the air in the workplace compared with the air inhaled, as well as with the quality of the estimation of the respiration rate and the time spent by workers at the different workstations. For the **individual air sampling systems** the uncertainty mainly results from the possible discrepancy between the concentrations inhaled and measured as well as the rate of respiration. This uncertainty is much smaller than in the case of the collective systems if the sampling point is close enough to the respiratory tract entrance and the air sampling rate is high enough to allow for representative sampling. For the **urinary excreta measurements**, over and above the problem of the representativeness of urine samples, the main uncertainty lies in the individual variation of the urinary excreta function and in determining a realistic time-related exposure profile. For the **measurements of pulmonary activity,** the uncertainty mainly lies in a realistic time-related exposure profile. Furthermore, and as in the case of urinary excreta measurements, high measuring frequency as well as allowance for the radioactivity inhaled during the previous measuring intervals (for the least soluble compounds), may make the estimation more realistic. Finally, for every measurement method, some degree of uncertainty will also be associated with the more or less good characterisation of the inhaled compound (solubility, granulometry,…) and the variation among the individuals of the biological parameters taken into account in the dosimetric models.

The sensitivity of air sampling methods, both individuals and collective, will mainly depend upon the air sampling rates and the frequency of measurements. On the one hand, any increase of the air sampling rate will increase the sensitivity as the detectable dose will vary as a direct inverse function of the sampling rate. On the other hand, for a given air sampling rate, any increase of the frequency of the measurement will reduce the sensitivity.

For the bioassays, any increase of the frequency of the measurements will allow to increase the sensitivity for it will ensure that the measured excretum or retention cannot be associated with an intake older than the previous measurement .

2.5 Measurements methods and analytical ability

The **collective air sampling systems** have a level of sensitivity (for some radio isotopes) which make daily measurement possible and may be sufficient to identify the main sources of contamination and the most exposed workstations. Their main disadvantage is that they cannot be used to realistically estimate the exposure of operators. The **individual air sampling systems** can provide a realistic estimate of the exposure of operators, as well as identify the tasks representing the highest risks, by conducting operational studies which assign a sampling device for each task. However, some radio isotopes such as natural uranium will require devices with high sampling rates to make sensitive and realistic estimations for periods shorter than a week. The measurements of **urinary excreta** can provide realistic estimates of the exposure of operators, provided that the urine samples are representative, the measuring frequency is sufficient, and the sensitivity for the considered compounds is high enough. As any bioassay, they cannot allow any analysis of the sources of exposure These measurements can however help to validate dosimetric estimations made with air sampling systems. The measurements of **pulmonary activity** make it possible to estimate operator exposure more realistically than with the urinary excreta. However, their low sensitivity for some radio isotopes and the fact that they are difficult to implement means that they are unsuitable for optimising radiological protection.

All these topics will be illustrated during the sessions of the Workshop.

Conclusion

Although the principle of optimization clearly applies to all forms of exposure, it is often found in practice that internal exposure is treated in a very different manner to that of external exposure, with an approach tending to minimization. The previous discussion has pointed out some needed characteristics of the measurement methods. It has only briefly discussed the point that the accuracy of dosimetric estimations depends on how realistic the exposure model and the various dosimetric sub-exposure models are. Here an important point is the sensitivity of the pulmonary sub-models to solubility characteristics and compounds granulometry. Some presentations during the Workshop will address that point and the recent improvements in that area.

An important task for our Workshop will be to share the recent improvements in monitoring and management of internal doses through case studies and practical experiences of ALARA implementation. It will also be important to identify what is still needed to provide realistic, analytical and sensitive assessments of internal exposure in order to maintain doses ALARA . It is hoped that the results of the Workshop will identify for the European Union areas of research and possible strategies for the optimisation of occupational internal doses.