WHAT IS ALARA ?

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I - INTRODUCTION

The system of dose limitation recommanded by the International Commission on Radiological Protection /1/ formulates three radiation protection principles :

1) the so-called "justification" principle which states that "no practice shall be adopted unless its introduction produces a positive net benefit" ;

2) the so-called "optimisation" principle which states that "all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account" ;

3) the limitation of individual dose which insures that the dose equivalent to an individual shall not exceed the limits recommanded by the ICRP.

Acknowledging the fact that these requirements are interrelated, the following paper will be devoted to an presentation of the second principle, assuming that the two other ones are satisfied. As defined by ICRP, the optimisation principle is strictly equivalent with the commonly known "ALARA" principle ("As Low As Reasonably Achievable"). ALARA may be considered altogether as a guiding principle for radiological protection management, as well as a procedure allowing the implementation of this principle.

II - THE BASIC ASSUMPTIONS PROVIDING RATIONALE FOR "ALARA"

The most fundamental assumption, and the one whose adoption leads inexorably to the need for some concept comparable to that of ALARA is absence of threshold in the relationship between dose and the probability of induced health effects. This assumption means that any dose may induce a "stochastic" health effect (cancer or genetic damage). Therefore it is no longer possible to accept as a guiding principle for management the "zero-risk" goal, because this would be equivalent to a "zero dose" requirement, which is often impossible, both for economical and technical reasons.

Clearly this fundamental assumption is not of a scientific nature, it is an assumption providing a rationale for the radiological protection management.

It is important to make the distinction between the continuous process of scientific investigation aimed at understanding the interaction of ionizing radiation from the viewpoints of biology or physics and the need for a workable assumption on which to base the daily business of protection.

As a consequence of this basic assumption, is the requirement for quantitative risk estimation in order to assess the magnitude of the risk, as a first step of the management procedure.

However, the shape of the relationship between dose and the probability of induced health effects is submitted to considerable scientific debate. Here again, the need for a workable assumption appears necessary within a decision making framework.

For the latter purpose the "linear" assumption has served well and some argue that it would remain the only practical assumption for protection purposes even if non-linearity became a demonstrated scientific fact for the interaction of radiation with human tissue at the dose rates of interest. Whether or not this is so, it is now becoming evident from several studies that the implications of a choice of a particular relationship raised by the BEIR Committee /2/ are not so great in practical terms, as can be seen in the paper entitled "Dose-response relationships and ALARA" /3/. Nonetheless we must keep in the back of our minds the remembrance that this is an assumption, and hence introduces uncertainties which couple with those of other aspects of the overall system. These include the almost complete indifference to the age or sex of the people being exposed, use of the average dose in an organ or tissue as the measure of the absorbed energy, use of average risk coefficients and use of average values for food and drink intakes, metabolic parameters, etc. Without wishing to imply that these are not sensible assumptions and generalizations, especially when dealing with large populations, they mean that any particular numerical results, even if they appear precise, have inherent uncertainties that are rarely quantified ; the results should therefore be used with this in mind.

Another basic assumption underlying the idea of ALARA is socio-economic. ALARA is a procedure aimed at getting a satisfactory compromise between generally conflicting criteria : health effect reduction and costs involved. Stated in rather broad terms, this is that in making resource allocation decisions for protection, it is proper to carry out some kind of balancing of the resources put into protection and the level of protection obtained against a background of other factors and constraints. It provides an answer to those pushing a zero risk argument who do not realise that having reached a certain protection level further "improvement" works against the better allocation of safety and protection resources and even the protection of certain sub-groups of the population at risk. Given the "linear assumption", optimisation - that is balancing protection costs and residual level of exposures - becomes an attempt to base the problem of protection resource allocation on socially accepted criteria. This broad idea applies in many fields and has therefore been formalised with more or less sophistication as part of economic theory and operations research. As a result a number of decision making aids based on these ideas are available to use in formalizing the ALARA process as will be seen later.

III - ALARA : A DECISION-AIDING PROCEDURE FOR RADIOLOGICAL PROTECTION MANAGEMENT

The implementation of the ALARA principle through the procedure which main features are shown in figure 1 provides a decision-aiding tool for radiological protection management.

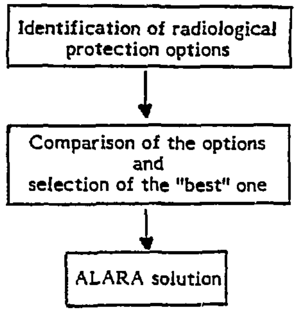


Figure 1 : The main features of the ALARA procedure.

The ALARA procedure is aimed at clarifying the problem under consideration, so that the main alternative radiological protection options are properly identified, as well as their performances in terms of risk reduction.

Notwithstanding the fact that the options which are to be considered here are aimed at reducing the routine exposure to ionizing radiation, (radiological protection) it is important to remind that these options may have consequences on other dimensions of risk : accidental radiation risk, radiation risk on other groups than the one for which the options are originally considered, chemical risk,...

- In such circumstances, the performances of the options should include not only the radiological risk reduction brought by the various options, but also the favorable or unfavorable consequences on the other dimensions of risk. The performances will then be expressed in the general term of "risk reduction".

The correct knowledge of the performances and of the costs associated to the various alternative options allows then the comparison of the options, through the appropriate quantitative technique, in order to select the solution which offers the best balance between protection costs and risk reduction.

It must be kept in mind that the ALARA procedure is only a decision-aiding tool to be introduced into the radiological protection management process and does not necessarily provide the final decision. Depending of the decision level at which ALARA is implemented, other factors of technical nature as well as of psychological and social nature may put a burden in the decision making process. Then a clear-cut distinction should be made between the "technical" status of the solution provided by the ALARA procedure and the more or less "political" status of the solution chosen at the very end by the decision-maker.

However, the lower the decision level will be, the closer the two solutions will tend to be.

IV - VARIOUS LEVELS OF RADIOLOGICAL PROTECTION MANAGEMENT REQUIRE VARIOUS LEVELS OF SOPHISTICATION OF ALARA

Decision-makers responsible for radiological protection can be found at various levels of an organization, ranging from high-level administration officials to field engineers and technicians. The decisions that they are called upon to make range accordingly in level so illustrated below.

- decisions for the choice of socially recognised matters such as a high level waste disposal site,

- decisions for the choice of technical solutions to particular engineering problems such as the choice of the design for a radwaste system for a nuclear power plant,

- operational and management decisions for the day - to - day operation of the system chosen and built such as the choice of a better shielding of an X- ray device, or of specific maintenance procedures.

The ALARA procedure can be implemented at these various levels of decisions. However it is clear that the analytical resources devoted to decision aiding should be apportionated to the magnitude of the choices at stake.

It is then suggested that the ALARA procedure should be implemented keeping in mind the amount of resources involved by the decision to be taken. At higher levels of decision, full implementation of all stages of the procedure, including the use of the appropriate quantitative technique should be carried out. In such cases, engineering experience and judgement may benefit largely from an analytical study. This will be the case, particularly at the design stage of large projects.

At lower levels of decision, the ALARA procedure would certainly be of help, provided that the latter is mainly oriented towards its first stages : analysis of the problem, identification of alternative options, assessment of the costs and of the performances of the various alternative options. For day-to-day operations, the previous process would be generally equivalent to exercising engineering judgement.

It should be recognised that the proper definition of the radiological protection problem, the identification of various options instead of a unique one, the (approximate) knowledge of the reduction of risk associated with the options will appear to be a significant improvement of decision-making processes, which otherwise would often remain quite empirical.

V - THE CONTENT OF THE ALARA PROCEDURE

The different steps of the ALARA procedure will now be considered in more detail.

V.1. The identification of radiological risk situations

This step belongs to risk assessment rather than to the proper risk management procedure. However experience tends to show that one of the main contributions of the ALARA procedure is the incentive for a more systematic research of situations where doses do not appear to be as low as they should be. In other words, the implementation of the ALARA principle provides an excuse to look systematically at situations which otherwise might remain inadequately taken care of. This is true for example for some medical activities involving X- rays or radiological sources.

It is the same for various industrial activities such as gammagraphy. The papers entitled "Optimisation of the design of an industrial radiography facility" /4/, "Optimisation of occupational protection in a diagnostic radiology department" /5/, "Optimisation of protection in gynaecological radiotherapy" /6/ give examples of the potential benefit which can be expected from the introduction of the ALARA procedure outside the framework of the nuclear fuel cycle.

It may be suggested that the ALARA procedure could bring significant results in terms of reduction of doses in sectors of activity which did not benefit in the past from the special attention devoted since a long time to the occupational or public radiological risk related to nuclear power plants.

V.2. The scope of the analytical procedure

As was seen earlier, the radiological protection problem may involve either a rather high level of decision, for which a generic ALARA study will be necessary, or the problem is of a more restricted character, dealing with a given plant, a hospital room etc...

The problem has yet to be properly defined because, often, there is a need to draw the most appropriate bordeline between what should be considered within or outside the framework of the ALARA procedure. This delineation is sometimes not straightforward, due to various interacting factors.

V.2.1. Interaction between different types of risks

As was already noted previously, different types of radiological risks may exist and interact as shown in table I.

- public/worker
- routine operation/incident/accident
- long-term/short-term
- high individual risk/collective risk
- operation doses/maintenance doses
-
-

Table I : The different types of radiological risk and their possible interactions.

The technical protection options available in view of reducing a given radiological risk such as public doses or occupational doses in relation with normal operation may have other consequences, either favorable or unfavorable, on other aspects of radiological risk than the one for which the options are considered.

The options may actually involve trade-offs between public and occupational doses (effluent treatment systems), between routine operation and accidental situations (inspection visits) between short-term risk and long-term (long-lived wastes for example), between operation doses and maintenance doses. The paper entitled "Optimisation of public exposures in PWR's : the trade-off between public and workers" /7/ illustrates one of these trade-offs.

V.2.2. Interaction between radiological protection and production

In some circumstances, radiological protection options cannot be regarded as having a "pure" protection function as it is the case when add-on type of devices are considered (a thicker shield, or an additional effluent treatment plant...). This is particulary true when the ALARA procedure takes place at the design level.

At this stage, it may be observed that there is an almost continuous spectrum of options starting from the specifically add-on type of devices and extending to equipments which belong entirely to the production process, but present, however, a beneficial influence as for as reduction of dose is concerned (eg. robotic components). An example of an automatic device belonging to this category is analysed in the paper entitled "Optimisation of occupational exposure in PWR's" /8/.

V.2.3. Setting boundaries

In order to clarify the extent and the boundaries of the problem, it may be useful to discuss with safety and protection experts as well as decision makers. It is important that types of risk that are deliberaty excluded from study, but which may nonetheless be affected by decisions, are not then entirely neglected.

For example, in examining whether or not to install additional radioactive effluent treatment plant in a nuclear site, the ALARA procedure may be directed to solely address the potential reduction in individual and collective doses to members of the public. However if the plant has implications for occupational doses or exposures in the event of an accident, then these should at least be qualitatively noted.

Consequently some technical factors, acknowledged as relevant ones may be either excluded or included in the ALARA procedure.

However it should be kept in mind that separate considerations of these aspects may lead to inconsistencies in the levels of protection or to an unnecessary increase of protection cost. As far as possible it will be appropriate to consider simultaneously these trade-offs within the framework of ALARA.

V.2.4. Other factors than those incorporated in ALARA : the "remaining" factors

Much is made by those who have to make decisions of the importance of "other factors" in arriving at decisions from ALARA and that these decisions should be based on the outcome of simple quantitative techniques. It is clear that there are other factors which enter into decisions, it is less clear that these other factors can be concisely described or quantitatively enumerated. They certainly include technical factors which are difficult to incorporate in the assessment of costs for radiation protection such as reliability of various options and level of technical development of different options.

There are also non-technical factors such as the reaction of public opinion and workers or the political pressures on those who have to make decisions. It is possible that the development of multiattribute analysis will provide a means to incorporate some of these factors (See VI.2.1).

However, as will be considered later (Section IX) the usefulness of incorporating to the largest extent possible these "remaining" factors into the ALARA procedure is far from being obvious.

V.3. Identification of alternative options

This step is an important one because it provides a strong incentive to consider not only the "straightforward" solutions able to solve the radiological protection problem, but also other alternative solutions.

As for as design is concerned, it should be reminded that the first place for ALARA is right at the start. Even while having the first ideas about a new problem, a designer is more or less consciously evaluating alternatives against general objectives and criteria. Thus it is important to introduce the procedure from the outset, so that features for radiological protection can form part of the original design and can be implemented at little or no extra cost. The simplified example given in Annex, given by Akins /9/, illustrates this idea.

As far as occupational protection options are concerned, the radiological protection objective often consists of reducing the collective occupation dose. But other considerations such as the individual dose distribution may be taken into account simultaneously.

Looking more specifically at the collective dose reduction, it may be useful to remind that the collective dose S is the product of three terms as shown is the following simplified formula :

$$S = d \times t \times N$$

where d is the mean dose rate, t the mean exposure time of N workers.

Hence, various radiological protection options may be identified.

1) Various options are devoted to the reduction of the dose rate such as shielding or reduction of the radioactivity of the sources.

2) Other options lead to a decrease of the stay time of workers and involve thinking in terms of staff management. Solution such as special training before operations implying heavy exposures are already largely used.

3) Other options allow a reduction of the number of people to be exposed to radiation through shifting to automatic or robotic devices instead of staff(x).

V.4. Quantitative or qualitative estimation of the set of factors introduced in ALARA

The set of factors introduced in the analytical procedure will vary, depending of the problem. These factors will generally involve the investment as well as the operating and maintenance costs of the radiological protection options. Often, the collective dose will have to be considered, as well as, sometimes, the individual dose distribution. But as was noted earlier, many other interacting factors may intervene, such as the short-term/long-term consequences (eg. in waste management problems), the possible influence of the protection devices on the safety of the facility, the impact of the options on the production costs and so on.

(x) This is also possible as far as public is concerned : see /10/ about rerouting the transportation of radioactive material.

V.4.1. The estimation of protection costs

The technical aspects of cost calculation will not be considered here because the paper entitled "Financial cost of protection" /11/ deal specifically with this item. It will only be noted here that in some cases better protection may even improve the total productivity. This point has not always received much attention until now but needs thought to integrate it systematically in the relevant cases.

A second point deals with how the protection costs can be clearly disengaged from the production costs. As was seen earlier no clear answers exist in many cases and it is necessary to allocate in a some what arbitrary manner a fraction of the total system costs as the protection costs. Value judgements are often required at that step, and as a consequence, sensitivity analysis should be performed to evaluate the impact of choosing a particular value on the final result.

V.4.2. The assessment of radiation exposures

One of the basic problems with assessment of radiation exposures stems from the fact that direct measurements of the exposure levels of the different groups of population at risk are often not practicable. As the ALARA procedure requires the establishment of a quantitative relation between the source of exposure and the resulting individual and collective doses, even if some measurements are available for existing circumstances, it is necessary to determine the relationship for other alternative options. This can generally only be carried out using modelling techniques. An example of such a modelling will be found in the paper entitled "Optimisation of occupational exposure in an uranium mine" /12/.

The modelling process is thus an important part of the ALARA practice and it is necessary to develop and improve models taking into account the inherent uncertainties. Many models have been developed, especially environmental transport models, for example by UNSCEAR /13/, which allow prediction of population exposure levels corresponding to most situations.

The relation between the source of exposure and the corresponding individual doses is not always easy to determine. For example, individual dosimeters provide the information about the total integrated occupational dose but does not specify the fraction of the dose originated by the source of exposure submitted to the ALARA procedure. Such an example is extensively considered in the paper entitled "Optimisation of occupational protection in a diagnostic radiology department" /5/.

VI - USE OF QUANTITATIVE TECHNIQUES FOR THE SELECTION OF THE MOST "APPROPRIATE" OPTION.

VI.1 - Choice of the technique according to the type of decision

In order to compare the various available options as they are characterized by their cost, detriment and other features, different quantitative techniques are available, which lead to the selection of the most appropriate option. Depending on the decision level, the quantitative technique to be used may vary largely. When the protection options involve large potential modifications of the plant in which they are to be installed, these options may affect many factors such as the productivity of the plant, the level of safety... The choice between the options appears then as a multidimensional problem. In this case, rather sophisticated methods such as multicriteria or decision analysis may be envisaged. They will be briefly described in subsection VI.2.

On the other hand, when the protection options deal with a narrower aspect, such as a specific component of the plant, the determinaion of two factors only, namely the collective dose and the protection cost related to the various options will often be sufficient for comparing these options. In this case, a cost-benefit analysis will be the quantitative technique to be used.

Other considerations, such as the availability and the quality of data required to carry out the quantitative analysis, may influence the choice of the technique. When large uncertainties exist, a method able to handle the uncertainty, such as a multicriteria analysis may be prefered to a simpler one, because the latter would require better quality of data.

However, when the uncertainties are very large, even the multicriteria analysis finds limits in its applicability.

VI.2 - The available techniques

It may be considered that decision aiding techniques can be devided into two broad categories :

- Multicriteria methods in which the various options available are compared in pairs against each of a number of independant criteria.

- Aggregative methods in which the valuation of the various criteria is integrated for each option to provide a single "figure of merit".

VI.2.1. - Multicriteria methods

Multicriteria methods compare options by pairs to determine whether one option is preferable to another. A strength of the technique is that it can be used to compare options which have little difference in a number of criteria but substantial differences in others. To reflect this, an option A is considered better than another option B if the number of weighted criteria for a which A is better than B is sufficiently large, and if, for the remaining criteria, the advantage of B over A is not excessive.

From the whole set of preferences obtained for each pair, it is then possible to determine the best option or options through an appropriate outranking algorithm.

Sometimes for a pair of options there is no preference, the options are either too close to be distinguished or they are too heterogenous to be compared. This method will be considered in detail in the paper entitled "Multicriteria analysis of public protection in PWR's" /14/.

VI.2.2. - Aggregative methods

In these methods, instead of comparing the different options in pairs, the performances of each options for the various criteria are combined to a single value which is used to rank the different options. It is obviously essential in aggregative methods to adequately quantify these performances and bring them into a form in which they can be combined. The most widely used aggregative methods are based on utility functions related to the different criteria. A utility function is a scale expressing the possible value for one criterion by numbers lying between 0 and 1, assigned in such a way that if one outcome is preferable to another, the utility of the first is greater than the second. Utility functions are not in general linear, and the foundation for obtaining them is preference, usually of "the decision maker". Account is taken of the relative importances assigned to the various criteria by giving a weight to each. The best option is then the one that maximizes the total utility.

Under this classification scheme, cost-benefit analysis is a particular form of aggregative procedure in which linear and additive functions are used. These methods will be considered in the paper entitled "Quantitative decision-aiding techniques" /15/.

VII - SENSITIVITY ANALYSIS

The various steps presented above involve a set of data and models, as well as assumptions and value judgments, all of which introduce uncertainties of various types :

1) The unaccuracies related to data collection about the number of exposed individuals, the specifications of the radiological protection options, the estimation of the financial costs when, for example, economies of scale or technological innovation are to be considered.

2) The unaccuracies related to radiation dosimetry (eg. neutrons).

3) The uncertainties resulting from the use of models such as atmospheric diffusion models or dose-effect relationships.

4) The uncertainties attached to parameters reflecting social preferences such as the cost of detriment, discounting rates,...

Taking into account the uncertainties through a sensitivity analysis, lead to the correct evaluation of the stability of the results vis à vis the modification of the parameters and data introduced in the analytical procedure.

The sensitivity analysis allows putting into light the factors which have the heaviest influence on the results. It shows the items for which allocation of resources in terms of research may contribute to fill in the gaps of knowledge which are the most crucial in view of radiological protection management. An example of sensitivity analysis is to be found in the paper entitled "Optimisation of occupational exposure in an uranium mine" /12/.

Sensitivity analysis is part of the analytical procedure and is then carried out by the authors of the ALARA study. The analysis may give them the occasion to appreciate the solution(s) proposed by the ALARA procedure against the remaining factors (such as impact on safety, impact on maintenance....) which were not integrated in the analytical procedure but do nevertheless play a role when coming close to the step of final decision.

VIII - SUMMARY : THE ALARA FLOW CHART

The differents steps of the ALARA procedure may be summarized as follows in the flow chart presented in figure 2.

IX - THE ALARA SOLUTION AND THE FINAL DECISION

The previous steps lead generally to one (or a small group) of solutions which may be regarded as the "technical" solutions brought by the decision aiding procedure. This (these) solution(s) do have a technical status in the sense that they are the result of an analytical procedure which necessarily reduces the range of the numerous factors, more or less relevant, which inevitably interplay in the final judgment of the decision-maker. This will be the more so as the level of decision is high. It may consequently happen that the ALARA solution will not be the one finally chosen by the decision maker. This may be explained by the fact that the importance of the "remaining" relevant factors is not necessarily appreciated the same way by the technical staff carrying out the ALARA study and by the decision maker. Moreover, other factors than the so called relevant ones may sometimes play an implicit but important role in the decision making process.

At least, the decision aiding procedure will have brought to the decision maker's consciousness the main relevant factors, the main implicit or explicit value judgments which lie behind his choice.

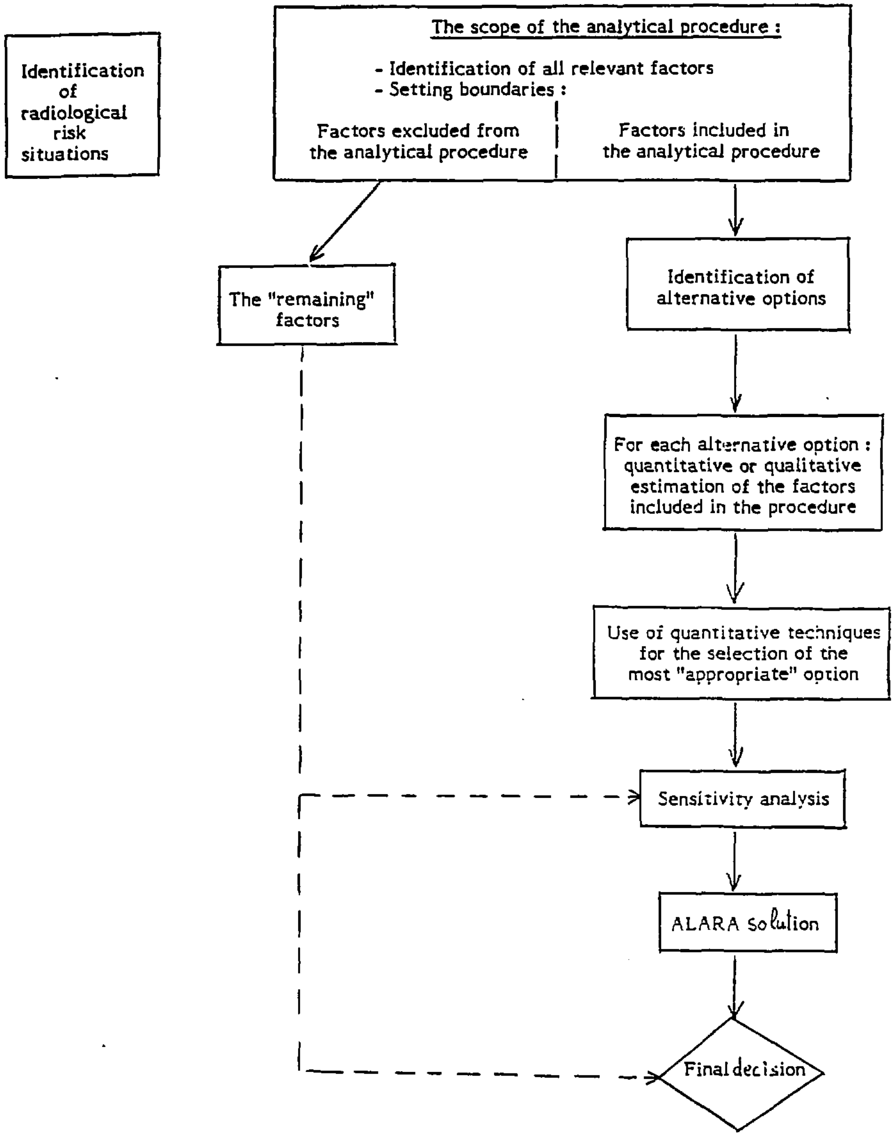


Figure 2 : The different steps of the ALARA procedure.

A word should be said about the integration of psychological and social factors which interfere somewhat with the radiological protection problem. Some authors do favor the integration to the larger extent possible of these dimensions in the analytical ALARA procedure. Other argue that these factors are not easily correlated to the various levels of risk reduction that the options are intended to bring and hence should not be integrated or at least, very roughly.

This question should not be solved "a priori" and a common sense judgment, in front of a given specific problem, will often help to determine to what extent these factors are worth to be integrated in the ALARA procedure. In particular, this may heavily depend of the level of decision. Caution, however, must be put on the temptation to identify the ALARA procedure with the decision making process itself. This would withdraw the decision maker from his main responsability : to take decisions.

ANNEX

The place of ALARA procedure is at the start of the design process.
An example developped by I.F. White, NRPB.

Let us imagine a shielding enclosure containing a valve and a large pump for an active liquid stream. The valve will have to be operated once a day. The pump will need maintenance only once a year.

Figure 1 shows a poor layout for the enclosure. The worker will have to pass by the pump every day to get to the valve, and will be exposed unnecessarily to the radiation from this large contaminated item. Figure 2 shows a better layout ; now the worker can operate the valve without going near the pump, and the door will provide extra shielding while open. This improvement was obtained simply by moving a door on a drawing, at negligible cost. However, the benefits of making the same improvement at a later stage of design would also have to be balanced against the inconvenience and cost of redesign.

The new location for the door in Figure 2 would make annual maintenance of the pump slightly more difficult, so the dose saving may be less than at first sight. The overall annual dose due to daily operation of the valve and annual maintenance of the pump could be readily assessed from existing work study data and information on dose rates. Figure 3 shows a better layout still, with two separate rooms and doors, though this would be significantly more expensive than the first two options. If all the alternatives can be roughly costed and the doses assessed, and the extra cost and dose savings can be compared in a simple cost benefit analysis for example to choose the optimum.

FIG. 1
Poor design

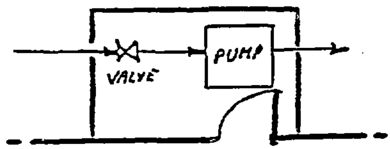


FIG 2
Better protection,
no extra cost

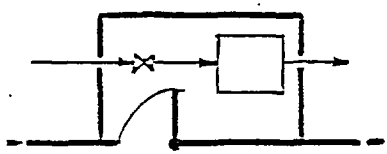
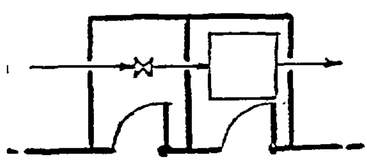


FIG 3
Even better protection,
but extra cost



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