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<**Review**>

ALARA for Nuclear Power Plant Operation

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1. Introduction

The concept of maintaining exposures as low as reasonably achievable has a laudable ring to it. Unfortunately the concept is general and diffuse. Like a misty mountain top in the distance, it is inspiring to look at but the path to the top is not clear. Some may be disuaded from making the trip.

In this short talk I hope to bring a measure of clarity to the discussion in two ways; first, by reviewng the basis for this important concept and second, by presenting a specific example of ALARA action.

2. ICRP Recommendations

Let us first review portions of the latest recommendations of the Internationl Commission on Radiological Protection[1], (ICRP), to provide a perspective on where the concept of as low as reasonably achievable, (ALARA), fits into the exposure control picture.

The main features of the ICRP system of dose limitations are:

a) no practice shall be adopted unless its introduction produces a net positive benefit.
b) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account, and
c) the dose equivalent to individuals shall not exceed the limits recommended by the Commission.

The first of these requirements, (that there must be a net benefit), is generally applied at the policy making level. For example. the question of whether the benefits of nuclear power exceed all its negative aspects is answered in the form of national policy when the nation chooses to accept or reject this option. The outcome of such cost benefit analyses is not the subject of our discussion today. We are dealing with those activities for which it has already been concluded that the benefit out weighs the cost.

Likewise, we are not concerned with exceeding recommended dose equivalents. The Health Physics profession has shown itself more than equal to this task. we shall soon see, however, why consistant exposure at the recommended dose equivalents leads to an unacceptable level of hazard for radiation work as compared with other safe industries.

The present state of knowledge provides a basis for deviding radiation induced detrement into stochastic and non-stochastic effects. Stochastic effects are those for which

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the probability of occurrence, rather than severity, is a function of dose without threshold. Non-stochastic effects have the opposite attributes.

With a few exceptions, which need not be discussed here, exposure control based on stochastic effects will assure adaquate control of non-stochastic effects as well.

Among the stochastic effects, carcinogenesis is considered to be the chief somatic risk of irradiation at low doses and, therefore, the main problem in radiation protection. Genetic effects make a significant, but somewhat smaller contribution to the detriment from stochastic effects.

A basic assumption which underlies the Commission's recommendations is that, within the range of exposure conditions usually encountered in radiation protection work, there is a linear relationship without threshold between the dose and the probability of a stochastic effect.

Given this information and this assumption, it is immediately clear that, when the probability of the effect and its increase with dose are significant, it is not practical to think only in terms of some maximum permissible dose. Any increment of dose will bring with it an increased probability of detriment and, accordingly, all unnecessary or unjustified exposure is to be avoided.

Furthermore, since increased dose brings increased probability of harm and since total outcome is the product of probability times the number of individuals effected by that probability, collective dose equivalent, expressed in man-Sv or man-Rem, becomes a meaningful way to measure harm.

Once one fully recognizes that each increment of dose increases the probability of the occurrence, the recommended dose equivalent limits are seen in a different light.

Such limits are not statements of what is safe and what is dangerous. They are not statements of what dose equivalent is acceptable. Rather, they serve only as benchmarks against which to measure success in exposure control, as limitations on the amount of harm to an individual, as specific criteria for design and regulation and as part of a mechanism for controlling and reducing exposures.

Any organization of activity for the accomplishment of a goal requires such "tools" as the recommended dose equivalent. But the use of such "tools" always carrys with it the possibility that they will be used improperly. For example, the dose equivalent limits may be erroneously considered to be the goal rather than a means to achieve that goal.

When this error is made, the concept of ALARA is not recognized to be of the first importance but is rather thought of as a further "fine adjustment" of an already satisfactory situation. Let us consider the ICRP system of dose limitation further to see why this is a false view.

Among the principles underlying the Commission's recommendations is the belief that the calculated rate at which fatal malignancies might be induced by occupational radiation exposure should not exceed the occupational fatality rate for industries recognized as having high standards of safety. Such industries are genenally considered to be those in which the annual average mortality due to occupational hazards does not exceed 10^{-4}, one in ten thousand per year.

In ICRP publication 26, the Commission reviews the total stochastic risk from uniform whole body irradiation and concludes that the mortality risk factor for radiation induced cancers is about 10^{-2} Sv^{-1}(10^{-4} rem^{-1}) as an average for both sexes and all ages. The additional average risk for hereditary effects, as expressed in the first two generations, is substantially lower and the Commission estimates it to be 4×10^{-3} Sv^{-1}.

In the same publication it is noted that in circumstances where the Commission's recommendations, including the annual dose-equivalent limit of 50 mSv, have been applied, the distributions of annual dose equivalents in large occupational groups have been shown to fit a log normal function with an arithmetic mean of about 5 mSv (500 mrem) with very few values approaching the limit. The Commission points out that under these conditions the average risk in these radiation occupations is comperable with the average risk in other safe industries.

If, on the other hand, the distrubition of annual dose equivalents in an occupational group was around a mean near the recommended limit of 50 mSv. the predicted annual average mortalty rate would exceed 10^{-4}. In this case, although the recommended dose equivalent was not exceeded, the level of safety would have passed into an unacceptable range.

In the past, radiation has been used under conditions that have made it possible to keep average exposures to a relatively small fraction of recmmended limits but with time and particularly with the advent of the large scale use of nuclear power, this picture has changed. The very high costs of nuclear power plant construction and the large cost of down time have put great pressure on exposure control and the result is seen in an increase in the average annual exposure to radiation workers. In response to this challenge the Health Physics profession must develop new skills and techniques.

How can we establish what is as low as is reasonably achievabls? Again the ICRP provides some useful guidance by emphsizing the concept of differential benefit[2]. The Commission notes the key guestion is whether a particular activity is being carried out at a sufficiently low level of exposure, and thus detriment, so that any further reduction would not be considered to justify the incremental cost required to produce it.

The net benefit of a product or operation may be thought of as the gross value minus production cost minus all the costs of achieving a selected level of safety minus the total detriment represented by the production use and disposal of the product.

When making an ALARA determination it is already assumed that the net benefit is positive and that the gross benefit and production cost are fixed. The maximum permissible radiation detriment is also set by the recommended dose epuivalent. The problem is then to reduce to a minimum the combination of the remaining two terms, the detriment and the cost of safety. When this is done the maximum net benefit will result.

Initally the reduction in detriment will be large enough to more than offset the safety cost required to produce the reduction. Thus the combined term will be reduced. However, at some point the cost of safety will begin to exceed the value of detriment reduction and the combined term will stop decreasing and begin to grow. It is at this point that the exposure is considered to be as low as reasonably achievable.

3. ALARA in Practice

3-1. Responsibilities

Now we come to a real problem. At the

present time we lack information which is essential for minimizing the combined term. We are only beginning to accumulate data on typical man-rem expenditures for a few selected activities[3,4]. We have less information on the costs involved in achieving these values. There is little information on alternate methods and even less on the costs and man-rem expenditures associated with these alternate methods. Preoccupation with these difficulties has served to deflect attempts to apply the ALARA concept in many cases.

However, there are positive steps which can be taken. The application of careful study and professional judgement identify measures whose contribution to detriment reduction so clearly exceeds their costs that lack of precision in quantification is of secondary importance. It is here that the serious Health Physicist must make substantial contributions. In the interactron of conflicting responsibilities that characterizes all organized activity only the Health Physicist can work consistantly toward this goal. If he does not achieve it, clearly, there is no one else who will.

In order for the Health Physicist to carry out this important work it is essential that the necessary work environment be provided. I want to describe some specific steps which are being taken in the United States to establish the framework within which effective ALARA judgements are being made.

As part of its regulatory program, the United States Nuclear Regulatory Commission, (NRC), publishes a series of documents referred to as Regulatory Guides. These guides are designed to make clear the criteria against which the NRC reviews license applications. These licenses authorize such things as radioactive material use and the operation of nuclear reactors. The Regulatory Guide provides license applicants with an example of an acceptable method of meeting a regulatory requirement. Further, if the applicant agrees to use the methods described in the applicable Regulatory Guides, he is assured of obtaining a license.

Over the last few years the NRC has issued several Regulatory Guides which deal with ALARA matters. These documents have provided guidance on such aspects as information, goals and objectives for planning, designing, constructing, operating, and decommissioning nuclear power stations,[5] operating philosophy,[6] methods to be applied at medical institutions[7] and design stage man-rem estimates[8].

A large part of the material in these documents consists of statements of good practice which are familiar to the practicing Health Physicist. However, they also contain much worthwhile new material.

One of the major aspects emphsized is a definition of the responsibilities of management. It is corporate managment that must provide the environment within which the Professional Health physicist carries out his ALARA duties. This environment is produced by action in five main areas; 1) provision of a written policy and commitment to the ALARA concept, 2) establishment of a well qualified, well supervised radiation protection capability, 3) delegation of adequate authority and provision of adequate support to the radiation protection organization 4) periodic audit of ALARA activities, and 5) provision of appropriate worker training.

Corporate management must develop a policy for, and a commitment to, ensuring that the exposure of personnel is ALARA. The policy must be reflected in written statements, procedures and instructions which apply both to employees and to the designers, constructors and vendors who supply facilities and equipment.

Corporate management must assure that a well qualified radiation protection capability exists, that it is well supervised and that its responsibilities are clearly defined. In addition, management must support this organization by delegating sufficient authority to permit it to carry out its responsibilities, and by supporting its decisions. Management must provide adequate funding to attract and hold fully qualified personnel to man this organization.

Corporate management must periodically perform audits through reviewing procedures inspecting the plant and consulting with the radiation protection staff and outside consultants to determine where ALARA action isrequired and what action has been taken.

Corporate management must see that radiation workers receive sufficient training to understand how radiation protection applies to them, what the management commitment to ALARA means, why it is important and how it can be applied their jobs. This training should be repeated annually and the workers should be tested on their understanding each year.

The Regulatory Guides also deal with the responsibilities of the plant manager and of the radiation protection manager.

The plant manager who is responsible for all aspects of plant operation, meets his ALARA responsibilities by participating in the selection of specific goals and objectives. and by supporting the actions of the plant radiation protection manager.

Among the many activities of the radiation protection manager there are a group which define his ALARA program.

These include:

a. participating in design reviews for facilities and equipment that can affect potential radiation exposures,
b. identifying locations, operating and conditions that have the potential for causing significant exposures to radiation,
c. initiating and implementing an exposure control program,
d. developing plans, procedures, and methods for keeping radiation exposures of station personnel ALARA,
e. reviewing, commenting on, and recommending changes in job procedures to maintain exposures ALARA,
f. participating in the development and approval of training programs related to work in radiation areas or involving radioactive materials,
g. supervising the radiation surveillance program maintain data on exposures of and doses to station personnel, by specific job functions and type of work,
h. supervising the collection, analysis, and evaluation of data and information obtained from radiological surveys and monitoring activities,
i. supervising, training, and qualifying the radiation protection staff of the station; and
j. ensuring that adequate radiation protection coverage is provided for station personnel during all working hours.

3-2. Example of ALARA Steps

Let me be even more specific and move further from generalities to the specifics encountered in daily activities at operating plants.

Work which requires ALARA consideration can be classified into either relatively routine activities or special jobs. Both types of work make substantial man-rem contributions, an example, let us consider a special job, such as steam generator surveillance or the repair of some major component. Such a job would be characterized by difficult and relatively unfamiliar activities carried out in a high radiation hazard environment.

ALARA controls would be excercised prior to initiating the work, during the job and after the job is completed. The following is a brief outline of the steps which would constitute a sound ALARA program.

Several weeks before the job the radiation protection manager would appoint a single individual from the radiation protection staff to be responsible for the following ALARA actions;

a. survey radiological and related conditions,
b. estimate a man-rem goal and a projected rate of man-rem accumulations (to be used as management control tools only), the estimated values should be based on the survey and experience at similar operations both at the plant and in similar plants,
c. provide for adequate personnel, equipment and supplies,
d. review the experience and training of supervisors and workers to identify necessary additional training,
e. assure that radiation safety aspects are included in written procedures covering the work to be performed, make necessary changes and additions,
f. discuss the proposed work with operating or maintenance supervisors who have responsibility, for perfoming the work, assure they understand the ALARA goals and obtain their recommendations for work changes and procedures that will contribute to significant exposure reduction,
g. determine whether a mock-up will be necessary to significantly reduce man-rem accumulations,
h. provide necessary training, including emphasis on management commitment to ALARA, general indoctrination in necessary concepts and specific step-by-step implementation of the actual procedures, conduct practice runs using these procedures, the responsible individual and the radiation protection technicians who will cover the job should observe this training to gain familiarity and to detect problems and necessary changes to the procedure, and;
i. establlish a system which will report the total man-rem accumulated on the job each day and require action when accumulations deviate signicantly from projected values.

During the conduct of the job the following actions are necessary.

a. a radiation protection supervisor must be present to observe the initiation of the job, anticipated problems should be identified and promptly resolved through procedure changes, provision of necessary epuipment, further training or other means,
b. excercise radiological control throughout the job by means of appropriate work permits and the presence of health physics technicians as needed,
c. the individual responsible must examine the man-rem accumulated each day and compare it with the projected values, when a significant deviation from expected values occurs, an immediate review should be undertaken to effect appropriate corrective action, such action might involve any number of alternatives ranging from a revision

of goals, (it determined appropriate) to cessation of activities, typical actions might include, reduction of numbers of personnel present, retraining, provision of special equipment, additional shielding, or changes in procedures, and;

d. the radiation protection supervisor must revisit the job at unannounced intervals to remain current on conditions and control.

After completion of the work the following additional ALARA steps should be taken:

a. summarize accumulated man-rem, radiation survey results and other pertinent information in a form that can be used at subsequent jobs, and;
b. prepare and submit to management specific recommendations for significant man-rem reduction the next time the job isdone.

4. Summary

Comparison of the risk of death due to radiation exposure with the same risk due to occupational hazards in other safe industries underlines the importance of the ALARA principle. The outlined responsibilities and listed examples presented here can serve as a basis for expanding and developing the concepts necessary for its successful application.

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