The basic safety standards for radiation protection

by A.J. González*

Publication of the third edition of the Agency's Basic Safety Standards for Radiation Protection in 1982 marked another step in the long march to provide protection against radiological hazards. Scientists had recognized this need since the early years of this century, and by the 1920s proposals were being made to establish standard units and adopt quantitative international radiation protection recommendations. In 1928, with the formation of the International X-ray and Radiation Protection Committee (the present International Commission on Radiological Protection [ICRP]), it became possible to issue quantitative recommendations for limiting doses received by radiation workers. Another quarter-century passed before the ICRP began to recommend limits on the exposure of members of the public.

The role of the ICRP has always been to consider the fundamental principles upon which radiation protection should be based and their practical application; detailed implementation was left to national authorities. When the IAEA was formed, its Statute spelled out the establishment of safety standards for protection of health as one of its basic functions. Then, in 1962, the Agency published the first edition of the Basic Safety Standards for Radiation Protection. The third edition of this document, jointly sponsored by the World Health Organization (WHO), the International Labour Organisation (ILO) and the Nuclear Energy Agency (NEA) of the OECD, was issued in 1982 as IAEA Safety Series No.9.

These Standards take the ICRP recommendations and expand and interpret them in practical terms, giving detailed guidance that will serve not only for the Agency's own operations but as a basis for Member States to develop and implement their own regulations. When the second edition was published in 1967, the Agency's Board of Governors recommended that all Member States should conform their own regulations to the Standards.

The system of dose limitation

A salient feature of the latest revision of the Basic Safety Standards is that they incorporate the currently recommended ICRP system of dose limitation which, with its complementary requirements, may have enormous implications for protection against man-made hazards. This new system sets individual-related requirement, i.e. individual dose limits which are not to be exceeded; such requirements are common to norms for health protection. But the system also introduces source-related requirements, a device rarely used in other protection systems. These requirements imply that, regardless of how low individual doses may be, two conditions must be fulfilled: (a) the introduction of practices involving ionizing radiation must be justified, taking into account the radiological harm they may cause; and (b) further efforts to reduce radiation exposure must be undertaken whenever the benefit – in terms of dose reduction – warrants the efforts to achieve it. This second condition is known as optimization of radiation protection.*

Individual-related requirement – As for the individual-related requirement, the Standards establish primary dose limits in order to identify a forbidden range of individual doses. Secondary limits – related to the primary dose limits – are also specified, e.g., in terms of limits of intake of radioactive material into the body.

Staying below the dose limits keeps the individual radiological risk originating from all controllable sources of ionizing radiation at such a low level that it should be of no concern for the individual. The aim is not to control the overall radiological harm delivered by a source, but to limit the individual risk from exposure to all sources. However, since an individual may be exposed to several sources, the dose limits cannot be used for limiting the individual dose delivered by a single source; rather, it is implicit that "source upper-bounds" should be used for each source in order to ensure that the sum of the doses from all sources can not approach the dose limits (Fig.1(a)). The fraction of the exposure due to natural sources not technologically enhanced is not considered. Individual exposures of medical patients, apart from research, are also excluded since in such cases the individual benefit is assumed to override the risk.

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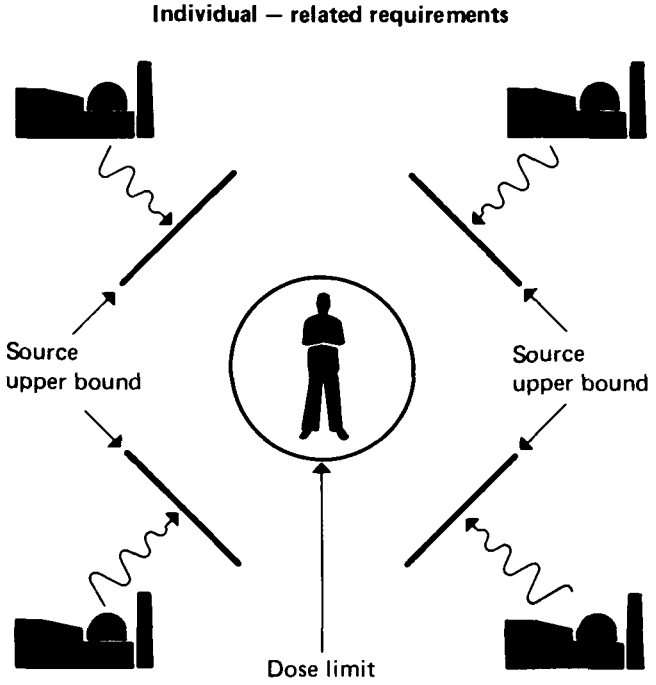
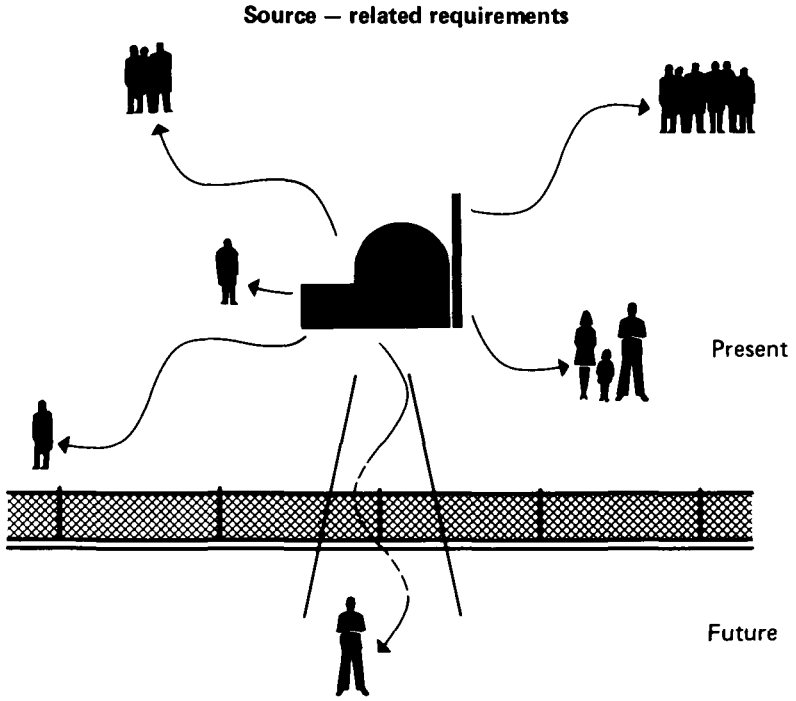
* Optimization of radiation protection is an abbreviated term used to identify the requirement that all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account.



(a) The Basic Safety Standards for Radiation Protection ensure an adequate level of individual protection through an *individual-related requirement* which establishes that no *individual* shall be exposed, as a result of controlled sources and practices, in excess of the *dose limits* set forth by the Standards. The total individual dose excluding natural background and medical exposure of patients must be considered. If exposure from several sources is possible, *source-upper bounds* should be established; these are fractions of the dose limits, assigned to particular sources of exposure;



(b) The Standards provide additional protection through *source-related requirements* which establish the *justification of the practice* – for which the source is needed – and the *optimization of radiation protection* to be applied to the source. These take into account the sum of all doses – however small – delivered by the source regardless of location and time of the exposure.

Figure 1.

Source-related requirements – The requirement of *justification* of a practice establishes that in order to prevent unnecessary exposure, no practice involving exposure to ionizing radiation shall be authorized by the competent authorities unless the introduction of the practice produces a positive net benefit. The requirement of *optimization* of radiation protection establishes that planning, designing, using or operating of sources and practices shall be performed in such a manner that exposures are as low as reasonably achievable, economic and social factors being taken into account (Fig.1(b)).

Although justification appears to be an obvious requirement, regulators may have sometimes authorized the introduction of practices without questioning whether their societal benefit outweighed their detrimental impact. The concept of justification provides a warning for regulators: i.e., before deciding to approve the introduction of a practice involving exposure to ionizing radiations, do not forget to consider the radiological harm to society that the practice may produce.

Optimization applies to all situations where radiation exposures from a source can be controlled by protective measures. A similar requirement could conceptually be used for planning protective actions where a source may get out of control. Optimization requires that the "optimum" level of protection that must be used should be determined from an appropriate balance between protective efforts and benefits derived from such efforts in terms of radiation harm reduced. The Standards introduce cost-benefit analysis techniques as practical guidance for performing optimization of radiation protection.

Basic concepts and quantities, concerns, and problems of implementation

Risk and detriment – To understand and apply the dose-limitation system, it is essential to comprehend the concepts of risk and detriment as used in the Standards.

The *risk* associated with a given radiation dose is defined as the probability that an individual experiences a particular radiation effect from receiving that dose. A number between 0 and 1 represents the probability (i.e. the degree of belief) that a radiation dose will harm the recipient. It follows that the objective of the individual-related requirement is to keep the individual probability of radiological harm below appropriate low levels.

Detriment is defined as the mathematical expectation of harm from a source. For evaluating the detriment, both the probability and the severity of the possible harmful effects are taken into account. The number expressing the detriment can be very large depending on the harm expected from the source. It depends not only on the individual doses received but also on the number of people being exposed by the source. The detriment is used to quantify the source-related requirements of radiation protection. It is an extensive quantity, i.e. it can be divided into components which can be summed.

Collective dose commitment – One relevant component of the detriment is its "health component", or mathematical expectation of effects, which – assuming proportionality between dose* and risk in the range of doses below the dose limits – is proportional to all doses added up from the source, regardless of level, place, and time of exposure. The addition results in a quantity called *collective dose commitment*, which results from two summations (or integrals if differential components are summed), one spatial and one temporal: (i) all individual dose rates produced by a source are summed, in order to obtain the collective dose rate from the source as a function of time; and (ii) all collective dose rates are summed over time to obtain the collective dose commitment.

"De minimis" dose – One conceptual concern as regards the summation of individual dose rates originates from the question as to whether it would be reasonable to truncate the sum when the individual dose rates are very low (e.g. when they are negligible for the individual). This might have been the case if, for example, the individual dose rates were comparable to the natural background fluctuations. Such a dose-rate level was sometimes called the "de minimis" dose and regarded as of no concern to the regulatory authorities. However, although a dose may be trivial for an individual, there may be substantial harm to society resulting from the sum of many trivial cases, a fact that the authorities cannot ignore. On the other hand, if both individual and collective doses are negligible, the "de minimis" concept could conceptually be used for regulatory purposes. In general, therefore, the Standards do not provide any justification for neglecting individual dose rates – however small – in the collective dose-rate assessment. However, the Standards do not prohibit the regulatory authority from ignoring negligible individual doses provided that they result in a negligible collective dose.

Integration over infinity – Another concern is the practicality of integrating collective dose rates over an infinite period of time. In particular, some practices may involve long-lived radionuclides which can cause exposures over thousands or even millions of years. For justification, the full exposure pattern must be known by the regulator, but the great uncertainty of collective dose estimates for very long time periods must also be recognized. In optimization assessments,

* The term *dose* is used to mean *effective dose-equivalent*, a quantity introduced in the Standards to designate the absorbed dose appropriately weighted by taking into account the type of ionizing radiation and the radiosensitivity of organs and tissues.

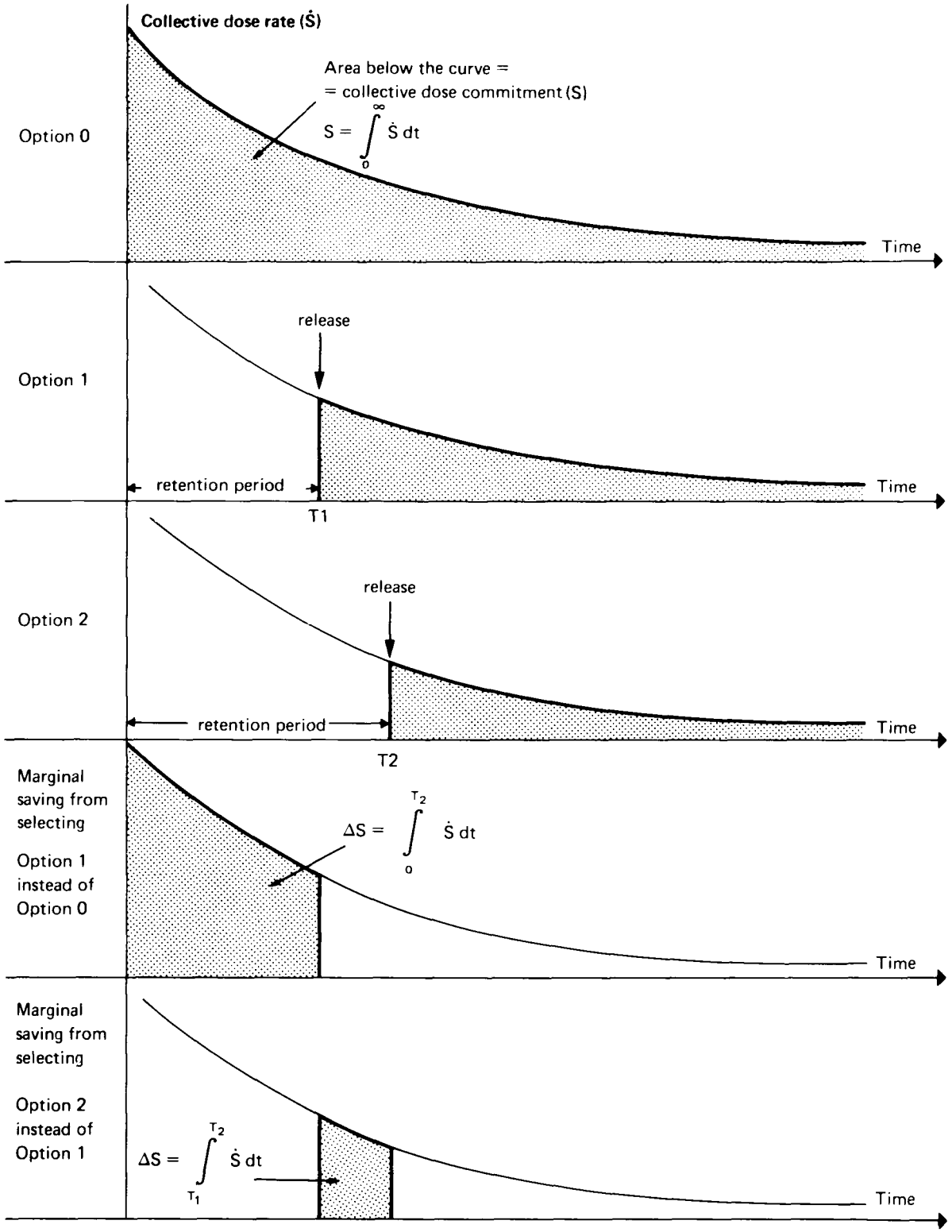


Figure 2. The uncertainties involved in estimating doses to be incurred in the distant future, for assessing the collective dose comitment, are irrelevant in the process of optimizing radiation protection. For example, the figure shows the collective dose rate as a function of time for three options for controlling the release of radioactive material into the environment. The area below the curve is equal to the collective dose comitment from each option. *Option 0* is no control at all; a collective dose rate will be incurred from time zero to infinity. *Option 1* is absolute retention until time T1 after which no control is expected; the collective dose rate will be incurred from T1 to infinity. *Option 2* will perform similarly to Option 1 but until time T2. The choice between option 0 and option 1 will take into account solely the doses incurred between time zero and T1. Similarly, the decision as to whether to select option 1 or 2 will consider solely the doses incurred between T1 and T2. If no other option is available any doses incurred after T2 will be irrelevant to the decision.

however, only the fraction of the dose which is affected by protective measures should be considered and the time periods of concern are those during which the radiation exposure can be controlled. Exposures at later times do not affect the optimization result. Therefore, infinite time integration of collective dose rates are not needed for optimization assessments. They do not use absolute collective dose commitments but differences between commitments from available options. The difference between two integrals over infinity is a finite integral. This may be illustrated by an example: if in a radioactive effluent control system, option (1) would retain the radioactive material for a time T1, option (2) would retain it until a time T2, and option (0) would be no control system at all, then the benefit from selecting (1) instead of (0),or selecting (2) instead of (1), can be measured by the detriment saved, which is an integral over a finite period of time (Fig.2).

Cost-benefit analysis – Cost-benefit analysis for performing quantitative optimization is by no means exclusive. Other approaches – some quantitative, some more qualitative – can also be used for optimizing radiation protection. However, cost-benefit analysis is a simple technique to demonstrate that a balance has been reached between the achieved benefits, in terms of radiation detriment reduction, and the protective efforts. This is the case if the sum of the values assigned to the efforts made for further improvement of the protection and the resulting decrease in the detriment is at a minimum (Fig.3). While protective efforts can easily be quantified in terms of the *cost of protection,* the assignment of a value to the detriment to obtain the so-called *cost of the detriment* is a particularly difficult problem.

Assigning a value to the health detriment – The Basic Safety Standards require that all doses delivered by a source should be included when determining the health detriment, without discrimination as to dose distribution. The Standards recommend use of a constant, "alpha", to be applied to the collective dose commitment for obtaining the value of the health detriment. Since for comparative purposes the cost of the detriment should be presented in the same units as the cost of protection, alpha is usually expressed in monetary units per collective dose unit. This has produced a widespread misunderstanding regarding the philosophical and ethical consequences of such an approach because the intrinsic connotation is that a monetary value would be assigned to a human life. However, the Standards clearly state that they do not place a monetary value on human life and that there is no limit on the cost of the protection needed to keep individual exposures within recommended limits. Optimization requires that, if there is any further reduction of exposure, economic and social factors should be taken into account so as to ensure that there is an optimum use of the resources available in achieving that reduction.

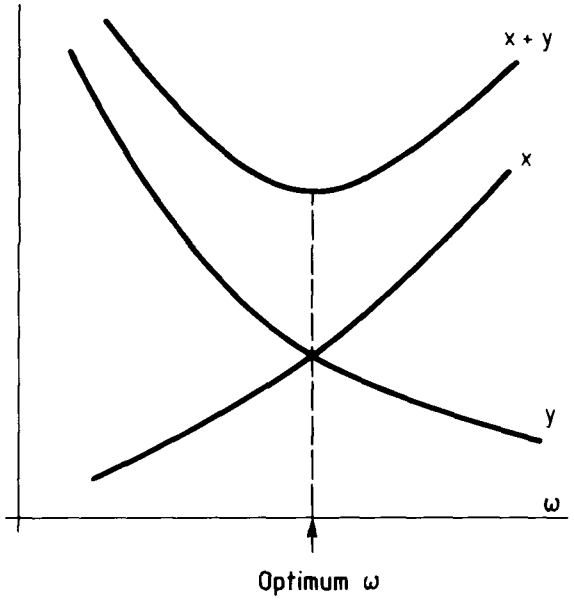


Figure 3. Optimization of radiation protection can be performed through *cost-benefit analysis* techniques. In this case, the aim is to find the protection level at which the sum of the *cost of protection,* X, plus the *cost of detriment,* Y, is at a minimum. In some cases, the minimization process is relatively simple – as shown in the figure – because both the protection and detriment costs are continuous functions of one protection parameter, W. This will be the case if the protection parameter is, for instance, the thickness of shielding or the flow-rate of a ventilation system. In other cases, only alternative protection options – which cannot always be defined by a single parameter – are available; the optimum can only be achieved through an iterative process, by which increasingly higher levels of protection are tested to arrive at the point which satisfies the condition of minimum total cost.

The recent ICRP recommendations on cost-benefit analysis in the optimization of radiation protection suggest that, although cost-benefit analysis techniques require the valuation of the change in life expectancy of unknown individuals, no value is being assigned to identified individuals. In fact, the factor alpha represent the amount allocated by society to avoid a unit of collective dose, and its magnitude determines the attainable level of radiation protection. It has nothing to do with a valuation of human life but is a rational device for conserving lives. It contributes to society's acceptance of a level of radiation protection which is the highest possible that can be attained without conflicting with other legitimate needs and duties of society.

Distributional problems – An interesting question is whether or not detriments occurring at different places or different times should be valued on an equal basis.

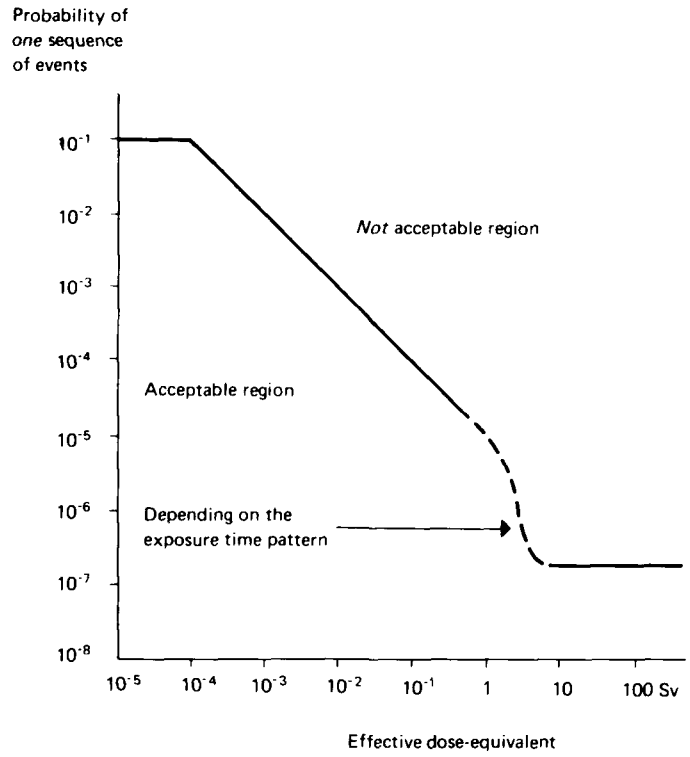


Figure 4. In cases of potential exposure – which can be only evaluated on probabilistic basis – the principle of individual risk limitation, set forth by the Standard's individual related requirement, may still apply. The requirement, in these cases, will be that the mathematical expectation of individual annual dose must never exceed the annual dose upper bound established for the source. This can be formulated as acceptability criterion curves of probability versus dose. The figure shows an acceptability criterion curve for radioactive waste depositories, presented at the IAEA International Conference on Radioactive Waste Management. The curve should be used for each sequence of potential disruptive events in the case of an assumed number of ten sequences and a risk upper bound of $2 \cdot 10^{-6}$ per year.

The basic ethical principle that efforts to improve life expectancy should not be discriminatory regardless of where and when the life is expected to be lived, appears to be the only rational approach. In the Standards there is no discrimination in the assignment of value to different spatial and temporal components of a detriment. However, it has been suggested that the valuing of components from different times might justify applying different weighting factors to the respective costs. Some advocates have suggested use of negative factors for future cost on economic grounds, using the accounting concept of discounting future costs to bring them to present time; others have recommended positive weighting factors, on the ethical grounds that future generations who will experience the detriment cannot participate in establishing the costing procedure.

In this connection, the Agency's Principles for Establishing Limits for the Release of Radioactive Materials into the Environment (IAEA Safety Series No. 45) establish that the assignment of present values to future costs is a matter for careful judgement by regulatory authorities, who must decide whether it is reasonable to attach less weight to doses far in the future than to doses in the near future. A recent draft report of a group of experts convened by the Holy See's Pontifical Academy of Sciences recommends that future doses that can be avoided by protective measures should always be given the same weight as present doses. The controversy may, in the end, prove to have no practical implications since for many optimization assessments only detriments to be incurred in the relatively near future have to be considered.

Trans-boundary aspects Since radiation detriments originating from a source in one country can be incurred by people in another country, it appears obvious that international agreements will be necessary to assign values to the trans-boundary components of such detriments. ICRP suggested that the relevance of this problem could be reduced if some internationally acceptable minimum limit for the value of alpha could be established. In any case, the value applied to other countries should not be lower than the value applied within the source country. In implementing the Standards, the Agency has already started to promote such an international agreement.*

Other components of the detriment – According to the Standards, the collective dose commitment provides the measure of the objective health detriment from a source. Commitment components having higher individual risks are not treated any differently than

* A group of IAEA and WHO consultants has prepared a document, recommending a minimum value of alpha, which will be considered by an advisory group meeting in December this year.

others. This approach is supported by one of the philosophical bases of the dose-limitation system, which is that the dose-limit constraint should keep individual risks at such low levels as to make them meaningless for the individual concerned. Accordingly, values assigned to different components of the collective dose commitment resulting from doses lower than the limits need not be different. The Standards, however, recognize that other subjective factors such as those involved in risk perception may be included as separate components of the radiation detriment. Thus, taking advantage of the extensive property of the detriment, an extra component can be added to the health component of the detriment – without modifying it – to take these factors into account. In the Standards, this component is assumed to be a funtion of average individual doses in the exposed people concerned.

Potential exposures – Although, strictly speaking, the system of dose limitation applies only to sources under control, the same basic principles might also be applied conceptually to sources which have the potential to produce exposures, or, implicitly, to exposures that have a certain probability of occurring, for instance, as a result of accidents in nuclear power plants or in radioactive waste repositories. Before this can be done, however, several questions need to be answered. It appears acceptable to apply the concept of risk in the individual-related assessment. The risk would in this case be proportional to the potential individual dose times its probability of occurrence. Criterion curves have been suggested (Fig.4) to determine whether a potential exposure would be acceptable from the individual viewpoint.

On the other hand, the use of the concept of detriment in the source-related assessment is not as straightforward as in the case of actual exposures. Although, in cases of potential exposures, the mathematical expectation of harm may also be a factor in deciding on the level of protection that is reasonably achievable, this would not necessarily be the sole factor and the total consequences of the actual occurrence of the exposure might well be the relevant parameter to be considered. In fact, although optimization of the protection against potential exposures may be based on the expected collective doses, the statistical uncertainty of the actual outcome can be very large. The standard deviation of the expected collective dose is proportional to the expected value and inversely proportional to the square of the probability of occurrence. For very low probabilities, such as those assumed for some accidents, the deviation can be orders of magnitude larger than the expected value which would make this value meaningless for decision-making purposes. In such cases, a complementary approach might be envisaged for deciding what is the optimum among a set of available protection options. It has been suggested that non-linear utility functions (which would increase the weight assigned to the expectation as long as the potential exposure increases) could be used or, alternatively, another detriment component, which should be directly proportional to the potential exposure, could be added to the expected collective dose component.

Outlook

Some features of the new dose-limitation system have provided a challenge for the radiation protection discipline. The Agency has organized seminars and symposia which have proved the feasibility of the system. Plans are under way to direct Agency efforts in radiation protection to the implementation of the Standards. Some of the practical questions have already been answered. For others, appropriate practical responses have to be developed.

If the conceptual problems for using the radiation protection principles in cases of potential exposure can be solved, the range of applications for the principles of the dose-limitation system will be expanded. Current issues such as nuclear safety goals or criteria for radiation waste repositories could be more rationally treated and eventually solved. The Agency is therefore looking into this problem with particular attention and follows closely scientific developments on the subject.

The system of dose limitation incorporated in the Agency's Standards is based on an extremely sophisticated philosophy which, although primarily evolved from radiation protection, takes into account ethics, social sciences, and other sciences. It has been suggested that a similar approach could be applied to control other toxic and mutagenic agents. The Standards provide a basic framework for implementing the Agency's statutory objectives to accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world, taking appropriately into account the detrimental effects of ionizing radiations. They can also serve as a model for attacking other threats to human life.