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The Optimisation of Radiological Protection

- Broadening the Process -

Report by the
ICRP Committee 4 Task Group on
Optimisation of Protection

The Optimisation of Radiological Protection

Table of Contents

PREFACE

On October 20, 2001 the Main Commission of the International Commission on Radiological Protection (ICRP) approved the formation of a new Task Group, reporting to Committee 4, to develop guidance on the principle and application of the optimisation of radiological protection. As stated in the terms of reference, the objective of the Task Group was to review the principle of optimisation and the requirements for its implementation in relation to the 2005 Recommendations. In this perspective, particular attention had to be given to the role of constraints, the distribution of individual exposures, stakeholder involvement and application in regulation and operation

It was anticipated that the document produced as a result of the Task Group's work would form one of the basic building blocks for the 2005 Recommendations. This report is the outcome of the Task Group's efforts, and it addresses the areas mentioned above. The guidance in this report builds upon the concept of optimisation of protection previously implemented by ICRP.

The membership of the Task Group was as follows:

Wolfgang Weiss (Chairman), Germany
Mary E. Clark, United States
Jean-Francois Lecomte, France
Jacques Lochard, France
Yihua Xia, China

Ted Lazo, France, served as corresponding member.

The Task Group would like to thank those organisations and staff that made facilities and support available for its meetings. These include the Federal Office for Radiation Protection (BfS) in Germany, the French Institute for Radiation Protection and Nuclear Safety (IRSN), and the Nuclear Energy Agency

The report was adopted by the Main Commission at its meeting in (????????), on (?????), 2005.

Abstract

This report describes the role of the optimisation principle in the system of protection in the light of the Commission's 2005 Recommendations. The basic objective of optimisation has been described in previous ICRP recommendations, e.g. *Publications 37, 55, and 60*, as: to maintain the level of exposure resulting from any source within the system of radiological protection as low as reasonably achievable, taking into account social and economical factors. The approaches to quantitative analysis and organisational issues addressed in *Publications 37 and 55* are still valid. However, the 2005 Recommendations increase the emphasis on protection of the individual within the optimisation process; that is, they shift more to an equity-based system that recognises individual rights and a basic level of health protection. The 2005 Recommendations also recognise the increasing role that "stakeholders" can play in the preparation process needed to make decisions that are accepted by all those involved. They also reflect this evolution and aim at the consolidation of the Commission's recommendations since 1990. The basic definition of the optimisation process given in *Publication 60* remains valid, but the 2005 Recommendations stress that conceptually the process is broader. It entails consideration of the avoidance of accidents and other potential exposures, involves the adoption of a safety culture, and incorporates a range of qualitative and quantitative approaches.

This report focuses on the underlying concepts and main characteristics of optimisation in the system of radiological protection, and also addresses the basic requirements for the application of the optimisation principle in operation and regulation. Detailed examples of the practical application of the optimisation principle for protection at the workplace, of the public in planned situations, and in controllable existing situations are given in the Annexes.

The comparison of protection options for the purpose of optimisation involves the consideration of the distribution of doses within all groups of exposed individuals. Groups can be characterised by attributes, such as age, gender, habits, and by exposure characteristics, such as mean, deviation, minimum and maximum individual doses as well as by the number of individuals exposed, the likelihood of their incurring the exposure, the total group dose. Additional aspects to be considered in the comparison of protection options are the social values that enter into the judgement (e.g. equity, intergenerational considerations). In the past the distribution of group exposures was characterised by the use of collective dose. The Commission now recommends the disaggregation of the distribution of individual doses related to a given source. The characteristics of this process are described in the report.

The application of optimisation in operation and regulation requires a clear definition of the roles of the operator and the regulator and a continuous and strong dialogue between the authority and the operator. The success of the optimisation pro-

cess will strongly depend on the quality of this dialogue. The document describes the key requirements of this process.

EXECUTIVE SUMMARY

This foundation document describes the underlying principles of optimisation in the system of radiological protection as well as the basic requirements for its application in operation and regulation. The optimisation of protection has been one of the fundamental principles of the Commission's system of radiological protection since the 1970s (*Publication 26*). The Commission has previously published several reports describing how optimisation is applied in various circumstances and reflecting the increasing role of the precautionary principle, stakeholder involvement, and individual equity in modern societies.

In this report, the principle of optimisation and the requirements for its implementation are presented in light of the Commission's 2005 Recommendations (RP05). The description of optimisation is an evolution and consolidation, but not a fundamental change from the Commission's previous recommendations. The optimisation of protection is addressed for all situations and is relative to single sources - except medical exposure of patients which is dealt with separately by the Commission. Detailed examples for the practical application of the optimisation principle in various fields of radiological protection are given in the Annexes to this document.

In the system of radiological protection, the role of optimisation is an essential complement to the primary requirement that quantitative individual dose restrictions are basic levels of protection. This basic level is achieved through source-related dose constraints, which are upper bounds to the optimisation process. The process of optimisation involves evaluating and, where practical to do so, incorporating measures that tend to lower radiation doses to the public and to workers under the prevailing social and economic circumstances. The definition of the optimisation process given in *Publication 60* remains valid, but the 2005 Recommendations stress that conceptually the process is broader. It entails consideration of the avoidance of accidents and other potential exposures, involves the adoption of a safety culture, and incorporates a range of qualitative and quantitative approaches.

Characteristics of the optimisation process

Optimisation of protection is a process that is at the heart of a successful radiological protection program. It is forward-looking, aimed at preventing unnecessary exposures before they occur. It is ongoing and iterative, taking into account both technical and socio-economic developments, and requires both qualitative and quantitative judgements (*Publications37 and 55*). The involvement of those parties who have interests and concerns about a situation provides an important input to the process. Thus, while quantitative methods provide an input to optimisation, they should never be the sole input given the many qualitative factors involved.

The transparency of the process requires that all relevant information is provided to the involved parties, and that documented traceability is integral to the decision-

making process, aiming for an informed decision. The endpoint of the process is expressed by the Commission as the designation, by the decision maker, of the most appropriate protection option under the prevailing circumstances, duly taking into account the views developed by stakeholders during the decision -framing and -making processes. Depending on the situation, the endpoint could be close to or well below the appropriate constraint. Exclusion or Exemption levels should not, de facto, be considered as relevant endpoints to optimisation.

Optimisation and Exposure Distribution

The comparison of protection options involves the consideration of dose distributions for all groups of exposed individuals. Each group can be distinguished by attributes that include characteristics of the population such as age, gender, habits, by exposure characteristics such as mean, deviation, minimum and maximum individual dose, the number of individuals exposed, the likelihood of incurring the exposure, and the total group dose, among others. Additional attributes that may be considered are the social values that enter into the judgement such as equity and intergenerational issues. For occupational exposure the establishment of the individual dose distribution associated with an exposure situation is relatively easy to achieve. For public exposure, access to individual exposure characteristics is in most cases very limited, and surrogates must be used. A single attribute or exposure characteristic is generally insufficient to compare fully protection options.

The distribution of group exposures has historically been characterised using the *collective dose,* defined as the product of average dose and number of exposed individuals. The value of collective dose is limited, however, particularly in the case of public exposures distributed over extremely long times and vast areas. The Commission now recommends the disaggregation of the distribution of individual doses related to exposures from a given source. This separates the dose distribution into different components, reflecting the attributes and the exposure characteristics of the exposed individuals, and the time and space distributions of exposures relevant for the decision making process.

The disaggregating process results in a set of exposure characteristics and attributes that can be constructed on a case by case basis. To define these elements, the most straightforward approach is, very often, to ask ‘when, where, how and by whom are exposures received’. In some situations, e.g. those having far-future components, the definition of the elements may be driven by ethical and intergenerational issues.

A representative list of useful aspects to be considered is presented in this report. The relative importance of each element can then be individually assessed based on the relevant considerations of those involved in the decision-making process. The transparency of the process, with a clear separation of the various attributes, characteristics and values considered to compare the protection options, is an important aspect for confidence in the final decisions.

The Application of Optimisation in Operation and Regulation

Both operators and the appropriate national authority have responsibilities for optimisation. Operators design, propose and implement optimisation, and then use experience to improve it further. Authorities require and promote optimisation and may verify that it has been implemented effectively. An active safety culture is a key to the successful application of optimisation. This implies that there is a need for national policies, priorities, rules and procedures to ensure that a vibrant safety culture exists at all levels of management and the workforce. The focus of the regulatory authority should be to determine whether there is an effective, appropriately supported and functioning program and safety culture that promotes finding optimum solutions to manage doses effectively for each exposure situation.

Except in cases of regulatory violation, it is not the role of the regulator to focus on specific outcomes for a particular situation, but rather on processes, procedures and judgements. An interactive dialogue must be established between the authority and the operator. The success of the optimisation process will depend strongly on the quality of this dialogue. Depending upon national governmental and regulatory structures and schemes, and upon the nature of the situation requiring a decision, this approach can be implemented differently, as necessitated by different legal systems and approaches.

Optimisation of Radiological Protection

1. Introduction

(1) The optimisation of protection has been one of the fundamental principles of the system of radiological protection since the 1970s (*Publication 26*; ICRP, 1977), stating essentially that all that is reasonably possible should be done to assure public and worker protection. While this concept has remained relatively unchanged over time, its application has evolved considerably. Having begun as a process with its focus on quantitative techniques, mainly cost-benefit comparisons of protection options, the optimisation process is now viewed as a broader judgemental decision-making process. It should be based not only on quantitative, but also on qualitative approaches, for selecting the most appropriate protection solution under the prevailing circumstances.

(2) The Commission has previously published several reports that include recommendations specifically related to the optimisation principle (*Publications 37 and 55*; ICRP, 1983, 1988). These previous publications describe, in more or less detail, how optimisation is applied in various circumstances, mostly focusing on quantitative approaches that can be used to optimise radiological protection. The advice given in these Publications represents the current views of the Commission with regard to the principle of optimisation and its application. In general, information in these previous reports is still relevant, particularly as it applies to quantitative methods for performing analyses, or to specific aspects that should be taken into account for particular situations or under certain circumstances.

(3) Recently, more emphasis has been placed on a consensus-building process based on interactive dialogue. The Commission's current views have evolved since *Publication 60*, and have been presented in a series of publications reflecting the increasing role of the precautionary principle, individual equity in modern societies and stakeholder involvement (*Publications 82 and 91*; ICRP, 1999, 2004).

(4) In this report the principle of optimisation and the requirements for its implementation are presented in light of the Commission's 2005 recommendations. All situations where radiological exposures are amenable to control are addressed except patient exposures, which are dealt with separately by the Commission.

(5) The way in which the optimisation principle is presented in this report is an evolution and a consolidation, but not a fundamental change in the Commission's recommendations concerning optimisation.

(6) Particular attention is given in this report to the treatment of individual dose distributions in the optimisation process, to the respective responsibilities of operational management and competent authorities in the implementation of the optimisation principle, and to opportunities for the involvement of stakeholders in the optimisation process.

(7) Section 2 provides background information on the foundation and evolution of the optimisation principle. Section 3 addresses the role of optimisation in the system of protection. The characteristics of the optimisation process are described in Sections 4. Section 5 addresses the role of exposure distribution in the optimisation process. Finally, Section 6 provides information about the application of optimisation in operation and regulation. The document is complemented with annexes on the application of optimisation in specific types of exposure situations: occupational exposure, public exposure from planned, regulated sources or exposure situations, and radon exposure.

2. The history of the optimisation principle

Foundation of the Principle

(8) The introduction of the concept of optimisation in the ICRP recommendations was a direct consequence of the recognition, during the 1940s, of the so-called stochastic effects, coupled with the impossibility of demonstrating the existence or non-existence of a threshold for this type of irreversible effects. Indeed, as long as the only recognised harmful effects of radiation were the deterministic effects, the limitation of exposure below the known thresholds for the appearance of these effects was considered sufficient to avoid any undesirable consequences of radiation. Because of the uncertainty of the dose-effect relationship for stochastic effects, the use of a limit was no longer a guarantee of the absence of risk. This led the Commission to adopt in 1950 a prudent attitude and to recommend "*that every effort be made to reduce exposures to all types of ionising radiation to the lowest possible level*" (paragraph VI, ICRP, 1955). This position facilitated the Commission's introduction two decades later of the optimisation principle.

(9) The adoption of the "Precautionary Principle" for the management of stochastic effects raised immediately the issue of justification of the exposure. In a context of uncertainty, imposing a risk on a group of individuals is justified only if there is a clear social benefit in return. Moreover, if an activity were to result in such a benefit, a second consideration is how far to reduce the risk and at the same time preserve the viability of the risk-causing activity. These considerations led the Commission to reword its first formulation and to recommend that "*all doses be kept as low as practicable and that any unnecessary exposure be avoided*" (paragraph 45; *Publication 1*; ICRP, 1959). The current understanding of justification by the Commission is: any action involving a deliberate modification in the level of exposure of individuals (either an increase by starting a planned operation or a decrease in an emergency or an existing controllable exposure) should be justified, in advance, so as to ensure a positive net benefit following the action.

Evolution of the concept

(10) The next development in the optimisation principle was the elaboration of criteria for determining the level of exposure that can be considered 'as low as practicable'. Introduced in Publication 9, these were described in a new formulation of the earlier recommendation: "*As any exposure may involve some degree of risk, the Commission recommends that any unnecessary exposure be avoided, and that all doses be kept as low as is readily achievable, economic and social considerations being taken into account*." (paragraph 52; *Publication 9;* ICRP, 1966b). It was also stated in *Publication 9* that risk has two dimensions - individual and societal - and must be balanced with the benefits of the proposed activities. Furthermore, the objective of keeping exposure 'as low as readily achievable' must be balanced with the effort required to achieve this objective.

(11) Another key step in the principle's evolution was *Publication 22* (ICRP, 1973), which was entirely devoted to the clarification of the statement given above from *Publication 9*. In particular, the Commission introduced a cost-benefit model to implement the principle in practice. The key point in *Publication 22* was the statement that: "*It is possible to define the point at which it can be said that a dose is as low as is readily achievable, economic and social considerations being taken into account, by choosing the dose at which the economic and social gains of further reducing the dose are equal to the economic and social costs of achieving that reduction*" (paragraph 11; ICRP, 1973).

(12) Furthermore, the adverb "readily" was replaced by "reasonably" (paragraph 20; *Publication 22*; ICRP, 1973) to describe more accurately the Commission's intent concerning the effort to be devoted in reducing risk. Such an approach was made possible due to the availability of the first estimates of the magnitude of somatic and genetic risks associated with exposure to low doses and low dose rates published by the Commission in 1964 (*Publication 8*, ICRP, 1966a). The derived risk values per unit of exposure allowed the development of the concept of detriment, defined as the mathematical expression of "*the expectation of the harm incurred from a radiation dose*" (paragraph 21; *Publication 22*; ICRP, 1973). This concept constitutes one of the basic elements of the cost-benefit model for deciding whether a reduction in dose is reasonable or not.

(13) A minor change in the formulation was introduced in *Publication 26* (ICRP, 1977), where the term "considerations" was replaced by "factors". The following Table summarises the evolution of the wording for "ALARA" over the past 50 years.

to **reduce** exposures	**to the lowest**	**possible** level		(ICRP, 1954)
To **keep** exposures	**as low as**	**practicable**		(*Publication 1;* ICRP, 1959)
To keep exposures	as low as	**readily achievable**	**economic and social considerations** being taken into account	(*Publication 9;* ICRP, 1966)
To keep exposures	as low as	**reasonably achievable**	economic and social considerations being taken into account	(*Publication 22;* ICRP, 1973)
To keep exposures	as low as	reasonably achievable	economic and social **factors** being taken into account	(*Publication 26;* ICRP, 1977)

(14) For more than a decade, the cost-benefit model presented in *Publication 22* was the underlying concept of all methodological and practical developments for

incorporating optimisation into the concrete management of public and occupational exposures. The next significant step was *Publication 37* (ICRP, 1983), which was devoted to a mathematical presentation of the cost-benefit model as well as its practical use in the design and operation of installations.

(15) It soon became evident to those involved in the practical implementation of optimisation that decision making was driven by more parameters than those embodied in the strict cost-benefit approach. A first attempt to incorporate additional factors was the exploration of less rigid decision-aiding techniques, particularly those based on the scoring and ranking of multiple factors. A second approach was the development of procedures to assist operators with committing to ALARA.

(16) Both of these efforts were reflected in *Publication 55*, adopted by the Commission in 1988. Although this publication continued to apply theoretical developments and mathematical formulations, it also began the evolution towards a broader perspective for the decision-making process related to radiological protection and a more practical approach. For example, it stated that "*The concept of optimisation of protection is practical in nature. Optimisation provides a basic framework of thinking that 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, so as to obtain the best that can be achieved in the circumstances*." (paragraph 8, *Publication 55;* ICRP, 1988).

(17) The further evolution of the concept is present in the 1990 Recommendations adopted only two years later. It is noticeable in this publication that, beyond the strict cost-benefit model, the Commission insists on the importance of informal processes and practical procedures to keep exposure as low as reasonably achievable. Moreover, the emphasis is placed on the issue of equity raised by the uneven distribution of benefits and detriments through society. In this perspective, it is recognised that the "*optimisation of protection may thus introduce a substantial inequity between one individual and another*" (paragraph 121, *Publication 60;* ICRP, 1991). The Commission addresses these considerations by introducing the concept of dose constraint as "*the source-related values of individual dose used to limit the range of options considered in the procedure of optimisation*". (paragraph 144, *Publication 60*; ICRP, 1991).

Recent developments

(18) Several publications since *Publication 60* have introduced new elements concerning optimisation in relation to its application in various contexts. For example, *Publication 63* on the Principles for Intervention for Protection of the Public in a Radiological Emergency (ICRP, 1993) emphasises the key role of optimisation in the design of protection actions for mitigating the consequences of accidents. The optimisation principle is also the major focus of *Publication 75*, devoted to the protection of workers (ICRP, 1998). The developments in this publication stress the importance of managerial arrangements in the practical implementation of optimisation for the protection at work. In *Publication 77* (ICRP, 1997), which addresses

the Radiological Protection Policy for the Disposal of Radioactive Waste, the Commission reiterates the judgmental nature of the optimisation principle. In particular, the Commission recommends going beyond the quantitative approaches developed during the 1970s and 1980s and advocates adopting a broader perspective.

(19) Another important move in this direction is taken by the Commission in *Publication 82* (ICRP, 1999) on the Protection of the Public in Situations of Prolonged Radiation Exposure. In this publication, the Commission reiterates that it provides recommendations on radiological protection on the basis of objective assessments of the health risks associated with exposure levels and relevant attributes of various exposure situations. It also recognises, however, the reality of socio-political and cultural considerations which usually influence the final decision on the level of protection. As a consequence, the Commission anticipates that the decision-making process related to the selection of protection options "*may take into account of attributes other than those directly related to radiological protection*" and "*will include the participation of relevant stakeholders rather than radiological protection specialists only*" (paragraph 4; *Publication 82;* ICRP, 1999).

(20) Following these recommendations, analyses of practical experiences at the national and international levels have allowed a better understanding of the challenges, implications and benefits associated with greater stakeholder involvement in radiation protection decision-making processes. (NEA, 1998, 2001 and 2004). As a result, the Commission now considers in the 2005 Recommendations that "the involvement of stakeholders is an important input of optimisation" because it "reinforces the safety culture and introduces the necessary flexibility in the management of the radiological risk that is needed to achieve more effective and sustainable decisions".

3. The Role of the Optimisation principle in the System of Protection

(21) In the system of radiological protection recommended by the Commission (RP05), optimisation is an essential component of the primary principle that requires quantitative individual dose restrictions as basic levels of protection.

(22) As it is presumed to be some probability of health effects even at small increments of exposure, the dose restrictions are necessary, but not sufficient, for protecting individuals. It is necessary to complement them with the requirement to optimise to enhance the level of protection.

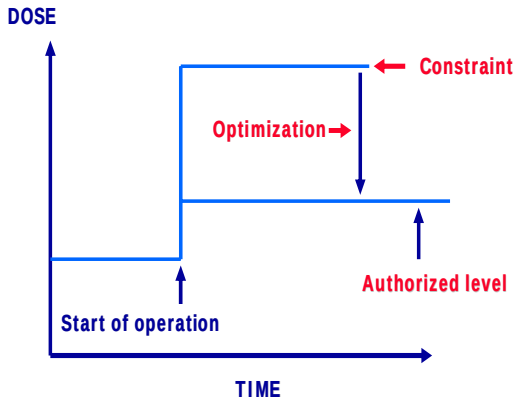
(23) The basic levels of protection are both the dose constraints and the dose limits. Dose constraints are single source-related restrictions on individual dose for all situations within the scope of the recommendations. Dose limits are used only in planned situations and are individual-related restrictions.

(24) For optimisation purposes, a single source is generally taken to be a licensed facility, such as a nuclear power plant, a factory producing radiopharmaceuticals, a hospital. Such facilities have the commonality that they are authorised to operate, the authorisation generally taking the form of some sort of license or permit granted by the relevant radiological protection authorities. In such circumstances, the source for which protection is being optimised is clearly and unambiguously identified. Similarly, an exposure situation is generally taken to be a particular circumstance causing an exposure, for example being exposed to radon in the home, living in a contaminated area, or being exposed to radiation in an accident situation. In these cases, the choice of the relevant dose constraint for protection against exposures will depend largely on whether or not the source or exposure situation is the dominant source to the exposed population under consideration. If more than one source exposes the same individuals, then the regulatory authority will have to decide, perhaps through some sort of stakeholder consultation, what dose constraint should be allocated to each source being considered. Quantified values of constraints are recommended by the Commission, which apply to all situations. They help in deciding which value to choose in a specific situation. The Commission recommends that realistic assumptions should be used to assess individual exposures, such that relevant dose constraints can be selected.

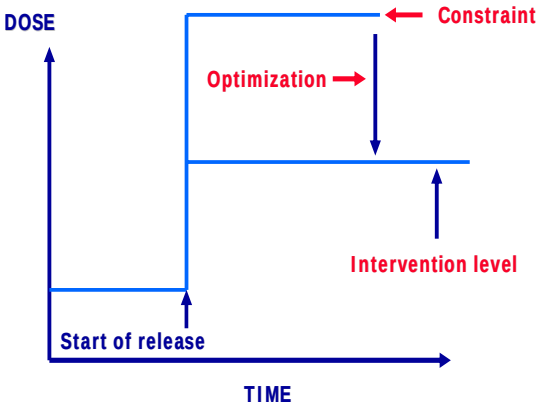
(25) Like dose constraints, optimisation applies in all situations that are addressed by the Commission: planned situations, emergencies, and controllable existing situations. Dose constraints are upper bounds to the optimisation process. The following figure graphically shows how optimisation below dose constraints is applied to all sources and exposure situations.

Figure 1: Application of Constrained Optimisation in All Exposure Situations

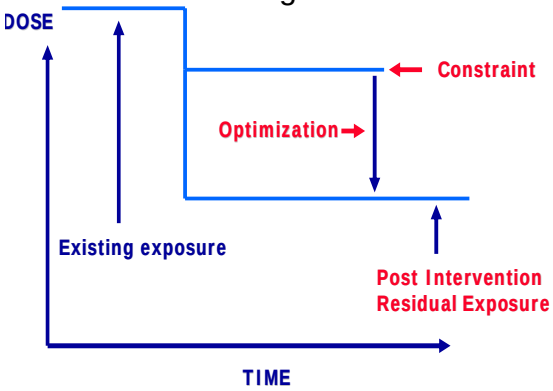
Planned Situations



Emergency Situations



Controllable Existing Situations



(26) The process of optimisation involves evaluating and, where practical to do so, incorporating measures that tend to lower radiation doses to the public and to workers. *Publication 60* defines this procedure as follows: "*In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account*".

(27) This definition remains valid, but conceptually the process is broader. It entails consideration of the avoidance of accidents and other potential exposures; it also involves the adoption of a safety culture and incorporates a range of qualitative and quantitative approaches for achieving an optimised level of protection.

(28) The basic role of the concept of optimisation of protection is to foster a 'safety culture' and thereby to engender a state of thinking in everyone responsible for control of radiation exposures, such that they are continuously asking themselves the question, 'Have I done all that I reasonably can to avoid or reduce these doses?'. Clearly, the answer to this question is a matter of judgement and necessitates co-operation between all parties involved and, as a minimum, the operating management and the regulatory agencies.

4. The Optimisation Process

(29) Optimisation of protection is a process that is at the heart of a successful radiological protection program. This process presents several well-defined characteristics. First, it must be carefully framed to take into account the relevant attributes of the exposure situation. Furthermore, it should include, as appropriate to the exposure situation, the involvement of the relevant stakeholders. These two features, which were introduced in *Publication 82,* ICRP 1999, are now considered by the Commission as important components of the optimisation process.

Framing the process

(30) The objective is to identify clearly and systematically the relevant attributes needed to select the best protection options under the circumstances. In this respect, the characteristics of the exposure distribution (i.e. individual doses, mean dose, number of people exposed) are only part of the attributes to be considered. Such attributes are important for the comprehensive evaluation of the appropriate information related to the exposure situation. The recommendations provided in this report are mainly based on scientific considerations on radiation protection. It is expected that they will serve as an important input to the final (usually wider) decision making process which may include social and political attributes as well as the participation of relevant stakeholders. The Annexes describe characteristic examples of the selection of relevant attributes as well as aspects of the decision making process itself.

(31) To identify the relevant attributes, the most straightforward approach is to ask ‘when, where, how and by whom are exposures received.‘ Responding to these questions will result in a set of attributes expressing the characteristics of exposed populations and their exposures as well as technical, economical, social, environmental and ethical considerations relevant to the situation. Regarding the exposures, particular attention is given by the Commission to the avoidance of accidents or any potential exposure, transfer of exposure between groups, and the distribution of exposures over long time periods and distant populations. For many situations, the participation of stakeholders in the framing process is an effective way to identify attributes comprehensively.

(32) A representative list of useful attributes to be considered to select the best protection option is presented in the following table. This list is not exhaustive, and other aspects may need to be included depending upon the specific context of the exposure situation.

Representative Attributes to select the best protection option
(non-exhaustive list)

Characteristics of the exposed population
- gender
- age
- health status
- sensitive groups (e.g. pregnant women)
- habits

Characteristics of the exposure
- distribution of exposures in time and space
- number of individuals
- minimum individual dose
- maximum individual dose
- mean individual dose
- statistical deviations
- total group dose
- likelihood of occurrence (potential exposures)
- pre-existing radiological conditions (e.g. high natural background, post-accident)

Social considerations and values
- equity
- ability to control (measurements, health surveillance…)
- fairness
- sustainability
- intergenerational consideration
- individual benefit
- social benefit
- level of information / knowledge held by those exposed

Environmental Considerations
- impacts on fauna and flora

Technical and economic considerations for protection options
- feasibility
- costs
- uncertainties

Characteristics of the process

(33) The process of optimisation has been extensively described in several publications from the Commission (*Publications 37, 55, 60;* ICRP, 1983, 1988, 1991) and other international bodies (IAEA 2002, NEA 1997, 2001). In this report, only the key characteristics related to the dynamics of the process are discussed.

(34) The optimisation of protection is a forward-looking iterative process aimed at preventing exposures before they occur. It is continuous, taking into account both technical and socio-economic developments and requires both qualitative and quantitative judgements. This process must be systematic and carefully structured to ensure that all relevant aspects are taken into account. Optimisation is a frame of mind, always questioning whether the best has been done in the prevailing circumstances. It also requires the commitment from all levels of all concerned organisations as well as adequate procedures and resources.

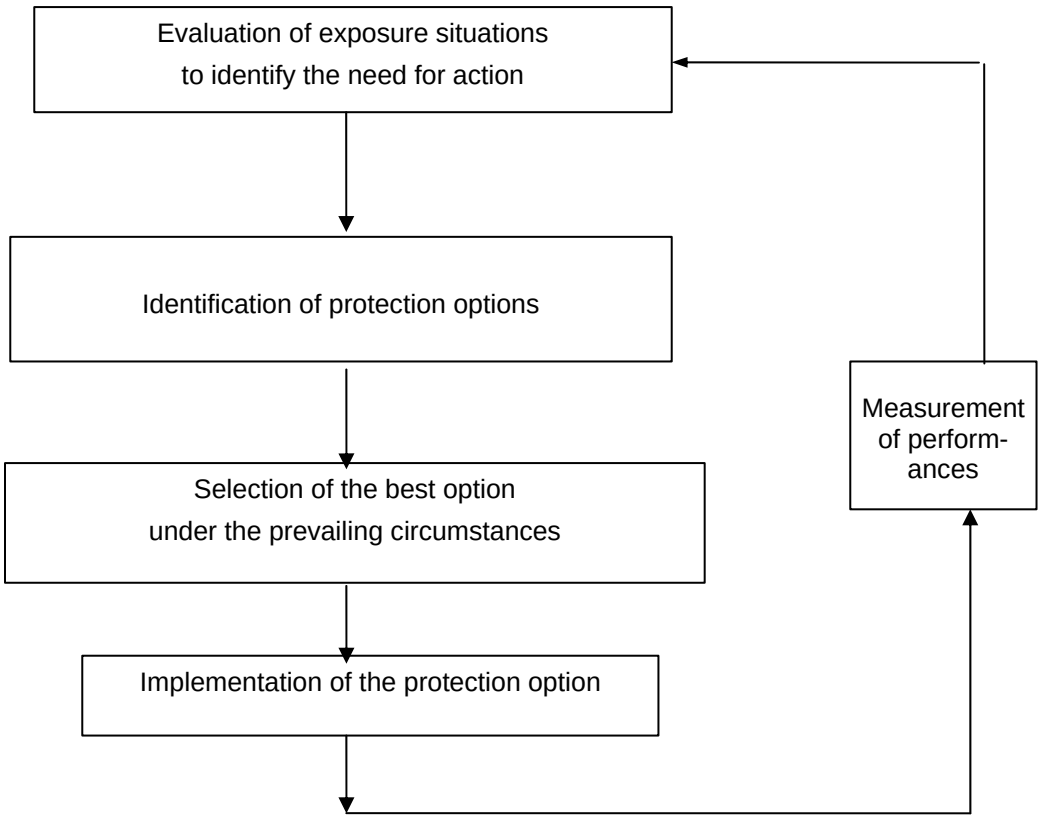
(35) The optimisation of protection is a systematic process. For normal situations, much of the protection is built-in during the design phase of a project for controllable sources, when options are evaluated, often for the selection of engineered controls. The process of optimisation of protection must continue during the operational and termination phases. In emergency situations, optimisation should be used at the planning phase to identify protection strategies and to determine corresponding levels for the selection of protection options, and during any actual emergency, is applied in a flexible manner to allow for the prevailing circumstances. In existing controllable situations, optimisation is used as part of the process to select and implement protective actions. Methods used to judge reasonableness may change with phase and time. Optimisation is a way to introduce improvements into radiological protection, taking into account legal, technical, economic, and social developments.

(36) During an operation, the optimisation of protection is also an ongoing, iterative process that is always questioning whether enough has been done before, during and after the exposure occurs. As shown in Figure 2, the optimisation process is cyclical. It is essential that reviews be planned and implemented at regular time intervals. Past performance, trend analyses of dose (or other data), results of internal audits, peer reviews, incident reports, and lessons learned all feed into this process. When the selected option is implemented, reviews may indicate that the results differ from those expected. In such circumstances a new evaluation cycle may then be needed.

(37) The implementation of the optimisation process aims at the selection of the best protection option under the prevailing circumstances. Because of its judgemental nature, all the data, parameters, assumptions, and values that enter into it must be presented and defined very clearly. There is a strong need for transparency and clarity.

(38) The procedure for assessing protection options, and for judging that no further dose reduction is reasonable, should involve the comparison of a number of feasible protection options to reduce the planned or potential doses to individuals and groups. Measures taken to protect individuals or groups of individuals from a source of radiation can be applied at the source, in the environment between the source and the individual, or to the individual. Where feasible, controls applied at the source are preferable. Such measures are less disruptive, and for any source they apply to all pathways for all individuals. In contrast, controls applied to the environment or to the individuals may not be all-inclusive. Further, at least regarding public exposure, there is less likelihood of unexpected social-economic implications to measures that are source-related.

Figure 2: Schematic View of the Optimisation Process



(39) Options including environmental actions should also be considered. For example, for the control of emissions to the environment the principle of the best available technology, not entailing excessive costs, may be used with due consideration to social and economic factors. Since the Rio Conference (UN 1992), the central organising principle of international environmental policy, Sustainable De-

velopment, has, in the non-radiological sector, moved beyond health-driven emission standards towards BAT techniques, focusing on reducing or where practical eliminating emissions at source. This approach is being increasingly applied to facilities and operations having radiological emissions, focusing the objective of protection on emission reduction rather than on health-effect / probability-of-effect reduction.

(40) At the operational level, an organisational structure should be established to organise dialogue between the many professional disciplines generally involved in an operation, including co-ordinators, working groups, or committees, whether or not the resulting structure is dedicated solely to optimisation. This is particularly useful for both production as well as radiological activities.

(41) Procedures are also necessary to clarify responsibilities, to set rules for operations, and to provide details for implementation of decision-aiding tools.

(42) For any optimisation process, there is a need to make numerous decisions related to radiological protection, taking into account a number of attributes, such as technical feasibility, cost, social factors, potential adverse impacts, long-term effectiveness and public or workers concerns, among others, as well as their relative importance. Such decisions include whether an action is really needed, which option is the most effective and efficient, and what resources are reasonable to complete the undertaking.

(43) The optimisation process incorporates a wide range of qualitative and quantitative methods and tools. Several of them, such as measurements, models, check-lists, real-time software, on-the-job analyses, operational dosimetry systems, radiological performance targets, documentation, databases, decision-aiding tools, reference monetary-value for the Man-Sievert, among others, are commonly used and have been presented in previous *ICRP Publications 37 and 55* (ICRP, 1983, 1988). Quantitative methods may provide valuable input to the decision making process but given the many qualitative factors, they should never be the sole input. Because of uncertainties, approximations, pragmatic concerns, technical and economic restrictions or conflicting societal values, a qualitative judgmental approach is also necessary. In many situations such an approach may usefully complement approaches based on decision-aiding techniques relying on quantitative data. In the decision-aiding process in particular, the involvement of the relevant stakeholder, is becoming increasingly recognised as an effective input.

(44) The optimisation process should be as elaborate as needed to address the given situation. A graded approach is needed to take into account both the level of exposure and the complexity involved. For most exposure situations, decisions can be easily made using sound methods, tools, and professional skills. However, past experience shows that complex and long processes are sometimes needed to arrive at protection decisions related to relatively low levels of exposures when economic, social, and political considerations are dominant.

(45) The transparency of the process assumes that all relevant information is provided to the involved parties, and that the traceability of the decision-making process is properly documented, aiming for an informed decision.

(46) Optimisation is a frame of mind. The effective implementation of the process entails that all stakeholders involved know and agree with the basic assumptions of radiological protection, and adhere to an active safety culture (IAEA, 1991). The acknowledgement that any level of exposure can involve a risk should be the incentive to ensure that all those involved in the optimisation process are accountable for its effective implementation.

(47) Finally, the effective implementation of optimisation requires commitment from all relevant parties, ranging from competent authorities to those exposed. Elements needed to ensure this commitment include:

- putting optimisation into regulation, willingness to enforce it, providing guidelines with proper balance between dialogue and control;

- defining a radiological policy, setting general goals, developing and adhering to procedures, delegating responsibilities, allocating means and resources, maintaining independence of radiological protection professionals from operation; and

- sharing information, maintaining vigilant attitude, training and retraining, and consciousness-raising in radiological protection.

The respective responsibilities in implementing these provisions are presented in more detail in Section 6 (IAEA, 2002).

Stakeholder Involvement

(48) The involvement of stakeholders, a term which has been introduced by the Commission in *Publication 82* to mean those parties who have interests in and concern about a situation, is now seen as an important input to the optimisation process.

(49) While the extent of stakeholder involvement will vary from one situation to another in the decision-making process, it is a proven means to achieve the incorporation of values into decisions, the improvement of the substantive quality of decisions, the resolution of conflicts among competing interests, the building of shared understanding with both workers and the public as well as trust in institutions. Furthermore, involving all parties affected by the decisions reinforces the protection culture and introduces the necessary flexibility in the management of the radiological risk that is needed to achieve more effective and sustainable decisions.

(50) Each stakeholder has a personal or general interest in the outcome. Stakeholder involvement is a way to incorporate these interests in the optimisation and decision-making process. The decision maker (generally the operating management or an administrative authority), the operator, and the radiological protection authority have clearly-defined roles and responsibilities in the process.

(51) Others, beyond these types of involved individuals and groups, are also considered stakeholders. Examples include the exposed individuals (either workers or members of the public) or their representatives (trade unions, local associations), institutional and non-institutional technical support to the decision-making process (approved dosimetric services, qualified experts, formal technical services, public expert organisations, private laboratories), and representatives of the society, either by an elective process (elected representatives) or a participative process (environmental associations).

(52) Depending upon the circumstances, it may not be necessary to involve all stakeholders, or types of stakeholders, in every aspect or phase of the process. Many radiological protection decisions will not be complex or socially contentious, and thus will not need broad stakeholder involvement in the decision making. Plurality of views, however, will generally enhance the quality and effectiveness of the final decision. Stakeholders may be particularly helpful for the identification of the attributes of the exposure situation and their relative importance, as well as for the identification of the protection options within the framing process.

(53) While there is no unique approach for developing stakeholder involvement, experience is increasing. Various methods have been developed in different areas to structure the process of linking stakeholders to the decision-making process. The spectrum covers classical consultation processes at one end and structured consensus building techniques with or without assistance of a third party at the other end (Beierle, 2002; NEA, 2004).

(54) While the qualitative nature of optimisation input implies flexibility of results, this flexibility does not imply that authorities relinquish their responsibility to make the final decision, or their accountability for that decision. There will be a need, for instance, to frame the decision making process to balance national policy needs and local stakeholder needs. The question of final responsibility for decisions, as well as legal constraints, must not be occulted during the shared steps of decision framing, problem identification and process development. While, in general, the responsibility for the “final decision” with respect to the adequacy of public protection solutions lies with the government and/or the regulatory authority, the process of “reaching a decision” can be shared more appropriately among all involved stakeholders.

Endpoint of the Optimisation Process

(55) The endpoint of the optimisation process is expressed by the Commission as the designation, by the decision maker, of the most appropriate protection op-

tion under the prevailing circumstances, duly taking into account the views developed by stakeholders during the decision-framing and -making processes.

(56) The endpoint is always specific to the exposure situation and represents the best level of protection that can be achieved given the circumstances. Therefore it is not relevant to determine, a priori, a dose level below which the optimisation process should stop. Depending on the exposure situation, the endpoint could be close to or well below the appropriate constraint. The exclusion levels, as defined in the 2005 Recommendations, should not be considered as a relevant endpoint to optimisation.

(57) In some cases, the technical, economic, legal, or social contexts may change optimisation solutions that have previously been agreed upon. For example, introduction of new technologies, increasing public concern, or availability of new resources for protection, will be incentive for revisiting the situation, implementing new protection options and possibly setting a new endpoint. Such changes should be addressed on a case by case basis, as has been done in the area of construction codes and building fire protection regulations.

(58) The numerical results of optimisation will demonstrate that the process complements the use of the constraints, and its application has led to a higher level of protection. The residual dose (i.e. the dose added as a result of the activity) will be the primary tool to demonstrate this compliance, and will also most likely be important for the affected groups (workers or population).

(59) In the case of existing situations, including those arising from emergencies or past activities, the optimisation aims at the progressive reduction of individual doses towards the levels that are applicable for normal situations. In such situations, averted dose (i.e., the dose saved through the implementation of a protection action) is a concept that is commonly used in optimisation to evaluate the effectiveness of any protection action. Using only averted dose, however, could lead to residual doses that are not necessarily optimised, and the residual doses could be kept above the constraint.

5. Exposure Distribution

(60) The comparison of protection options involves the consideration of dose distributions for all groups of exposed individuals. Each group can be characterised by different attributes, such as age, gender, and habits, which should be taken into account in the optimisation process. In addition, each group can be characterised by various exposure parameters, such as mean, deviation, minimum and maximum individual doses, the number of individuals exposed, the likelihood of their incurring the exposure, as well as the total group dose, for example. A single exposure characteristic, however, is generally insufficient to compare fully the various protection options.

(61) For occupational exposure situations, information about individual doses to workers is generally accessible, and the assessment of the individual dose distribution is relatively easy.

(62) For public exposure situations, access to individual doses is in most cases extremely limited, and these can be only estimated using surrogates. For example, modelled average individual doses can be estimated for different subgroups exposed to a given source. For such an approach, it is necessary to define for each subgroup of exposed individuals the place inhabited (distance from the source), age and gender distribution and living habits (diet, types of recreation). If needed, it is also possible to estimate for each subgroup the evolution of exposure in time for the current generation and those following. The accuracy of the estimates will decrease with the distance from the source, and with length of time since exposure (particularly into the far future).

(63) Additional aspects to be considered in the comparison of protection options are the social values that enter into the judgement (e.g. equity considerations between groups), and the relative importance given in the optimisation process to each attribute. For example, individual dose distributions associated with alternative protection actions can be compared for a given work activity. These different actions may affect the same group of workers, and they may be characterised by similar average individual doses and total group dose doses. In such a comparison, equity considerations will in most cases lead to the discarding of protection options with the highest individual exposures.

Use of Collective Dose

(64) In the past, there was a tendency to characterise the distribution of exposures within groups using a ‘collective dose’, or summing of applicable doses. This collective dimension of protection emerged from concerns related to the fallout from nuclear weapon tests and radioactive releases into the environment associated with the development of the nuclear power industry. Hence, the use of the collective dose concept represented an effort to take into account the global impact of a given source on the population. It was originally introduced in the 1970s for

two reasons: first, as a basis for restricting the uncontrolled build-up of exposure to long-lived radionuclides in the environment and second, for facilitating optimisation by cost-benefit analysis. A description of the evolution of the concept of collective dose can be found in a report from IPSN (IPSN, 2002).

(65) In Publication 60, the Commission defines the collective effective dose concept for an exposed population subgroup as the product of the arithmetic mean dose and the number of individuals in that subgroup. If several subgroups are involved, the total collective effective dose associated with a source or an event is defined as the summation of the collective effective doses in all subgroups exposed by this source or this event.

(66) In the case of occupational exposure, the concept of collective dose is commonly used as a “performance indicator” to deal with the total exposure for a given task, or for the operation of an installation over a given period of time. For the purpose of comparison of protection options, the collective dose is not always sufficient to characterise the exposure distribution, especially when significant differences exists in the magnitude of individual doses within the exposed group. In such cases, methods to take into account both the magnitude of individual doses and the distribution of exposures in the comparison of occupational protection options have been proposed in various publications (e.g. IAEA, 2002; Lochard et al., 1996). Annex 1 provides further discussion of approaches to usefully characterising such individual occupational doses for optimisation purposes.

(67) For public exposure, the collective dose may be one useful input to the comparison process when the individual dose distributions are relatively homogenous and clearly defined. However, depending on the source, the radiological impacts can be more or less spread geographically (from local impacts to regional and in some circumstances even larger areas) and in time (from short term to mid term or sometimes long term). While in such situations collective doses can be estimated based on pathway assumptions, the value of such collective dose estimations for protection decisions is somewhat limited.

(68) When the exposures occur over large populations, large geographical areas, and over large periods of time, the Commission now considers that the total collective effective dose, as defined above (i.e. the summation of all individual exposures in time and space), is not a useful tool for decision aiding because it may aggregate information excessively and could be misleading for selecting protection actions.

(69) A disadvantage of the collective dose concept applied to an undifferentiated population is that it masks the individual characteristics (e.g. age, gender) and exposure characteristics (e.g. evolution of the magnitude of the individual doses in time and space), as well as the inherent uncertainties attached to the dose assessment. Furthermore, it does not allow for due consideration of important social and other socio-political considerations that may be particularly important for evaluating and comparing options. Annex 2 provides further discussion of ap-

proaches to usefully characterising such public exposures for optimisation purposes.

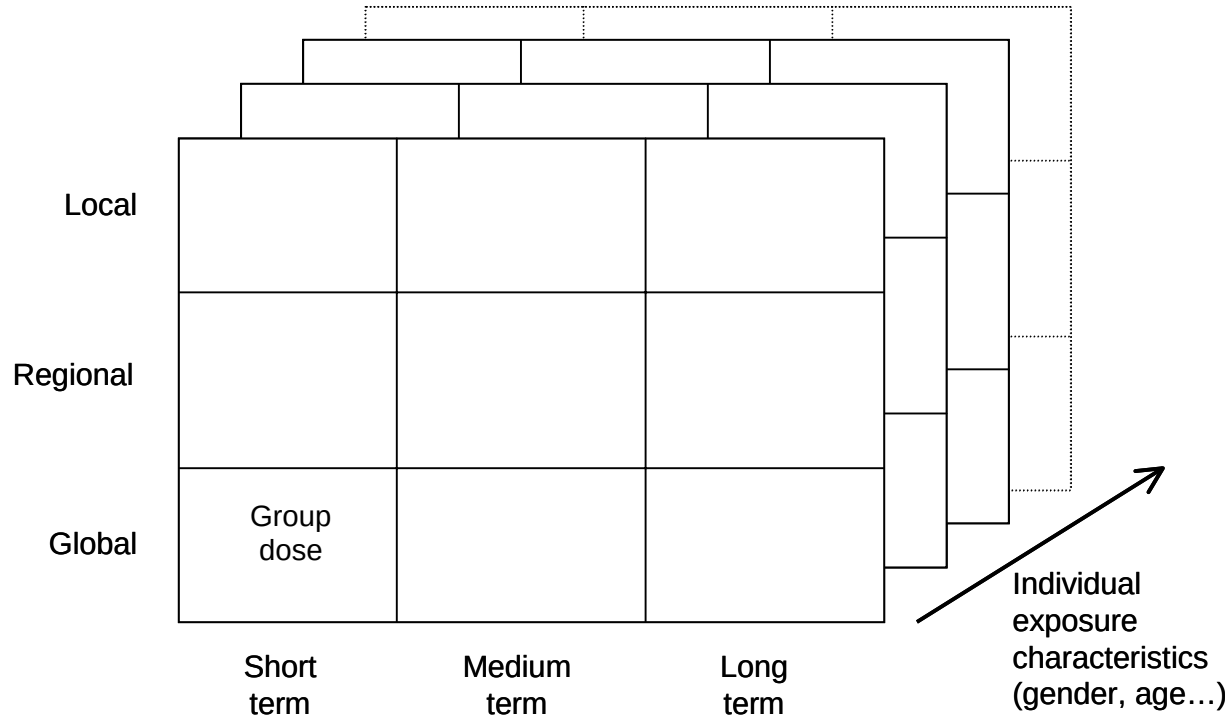
Exposure Distributions in Time and Space

(70) To overcome these limitations associated with collective dose, particularly where the public exposure distribution is applied to large geographical areas and large time periods each relevant exposure situation must be analysed to identify the individual characteristics and exposure parameters (particularly in terms of time and space) that best describe the exposure distribution for the particular circumstance. Such an analysis results in the identification of various population subgroups with homogeneous characteristics to be considered for optimisation. For each subgroup it is then possible to calculate a "group dose" (subcollective dose). The appropriate parameters used for the calculation of the group dose may be defined on a case by case basis.

(71) For a source spreading long-lived radionuclides, for example, it is possible to estimate different exposure parameters for all the individuals living in a given radius around the source, as well as at different points in time and space at the scale of various geographical entities. It is also possible to estimate the collective doses for a particular population subgroup living in a particular area or having specific habits. For example, assuming the data are available, the collective dose can be estimated for a regional population (subgroup) due to the ingestion of contaminated fish (one exposure parameter) coming from a given river or sea (one geographical entity).

(72) The relevant exposure characteristics can be constructed using the same approach as the one used for framing the optimisation process (see Section 4), and includes asking when, where and by whom such exposures are received. As an example, a set of group doses resulting from such questioning can be presented in a three-dimensional matrix such as that shown in Figure 3. Each element of the matrix corresponds to a subgroup of the exposed population within time and space, described by its exposure characteristics (i.e. mean dose, number of individuals involved). Each of the three dimensions of this basic scheme can be more or less detailed depending upon the specific situation.

Figure 3: Basic structure of “dose matrix”



(73) Once the collective dimension of the exposures is disaggregated, the relative importance of each element of the dose matrix can be individually assessed based on environmental, technical, economic and social considerations and values, and the preferences of those involved in the decision-making process. The nature of the considerations may vary significantly from case to case, as will the importance given by the stakeholders to each element. Equity considerations, the degree of uncertainty in the level of exposure, and any other relevant factors may also be considered.

Relative weights, for example, can be assigned to group doses based on the magnitude of the mean individual dose that characterises each group. This may be a way to give more importance to groups of individuals receiving higher doses than to groups of individuals receiving lower doses. Weights can also be assigned according to the time at which the exposure will occur. Examples of approaches that may be used for weighting are given in Annex 2.

6. The Application of Optimisation in Operation and Regulation

(74) Within the system of radiological protection both the operators and the appropriate national authority have responsibilities for optimisation. The optimisation of protection is the responsibility of the operating management, subject to the requirements of the competent national authorities.

(75) This is the case for all sources and exposure situations; planned, emergency and controllable existing. It should be noted, however, that the notions of “operating management” and “competent national authorities” should be interpreted broadly in these three situations, more along the lines of “implementing organisation” and “decision maker”.

(76) An active safety culture is a key to the successful application of optimisation and that both operational management and competent authorities have essential roles in ensuring that an effective safety culture develops and is maintained. In particular, regulatory authorities should encourage the operational managements to develop a ‘safety culture’ within their organisations. Such a safety culture should also exist within the regulatory authority.

(77) In practice, operating management makes decisions regarding the design, organisation, and ongoing implementation of the optimisation process. Appropriate competent authorities promote and may require optimisation as a way to reach the level at which licence to operate, if any, can be granted. They also may verify that optimisation is effectively implemented during operation. The burden of proof of this implementation rests with operational management. The decision to authorise an exposure-causing activity, or the implementation of exposure-reducing measures and their implied residual doses, rests with the appropriate competent authorities. In some cases, work is planned, assigned, performed, and overseen by others who are not under the direct control of the operators. In such circumstances, any sharing of responsibility for optimisation should be clearly documented and fully understood by all parties.

(78) Operational management should develop and provide internal policies, priorities, rules, procedures and quality assurance programmes to ensure the existence of a solid safety culture at all levels of management and those exposed, particularly the workforce. In this context, the objective of managing organisations is to prevent accidents, manage the probability of potential exposures, and keep worker and public exposures as low as reasonably achievable, social and economic factors being taken into account.

(79) All aspects of optimisation cannot be codified; optimisation is more an obligation of means than of results. Except in cases of regulatory violation, it is not the role of the competent authority to focus on specific outcomes for a particular situation, but rather on processes, procedures and judgements. A strong dialogue must be established between the authority and the operating management. The regula-

tion should provide guidelines designed to build such a dialogue. The success of the optimisation process will depend strongly on the quality of this dialogue.

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ANNEXES

A1: The Applications of Optimisation in Occupational Exposure

1. Introduction

Occupational exposure is defined by the Commission as the exposure, from natural and artificial sources, incurred at work and principally as a result of work. Radiation work is defined [91ICRP, 96EU] as work in which the annual effective dose of an exposed worker of age 18 or over from radiation sources at work may exceed the dose limits for members of the public, e.g. 1 mSv per year. The limit of effective dose for exposed workers as recommended by the Commission [91ICRP] is 100 mSv in a consecutive five-year period, subject to a maximum annual effective dose of 50 mSv in a single year.

The individual dose received in the workplace is well known. Individual monitoring is required for category A workers. Category A includes any radiation work in which the annual effective dose is or might be higher than 6 mSv, or the annual equivalent dose of the lens of the eye, the skin or hands and feet is or may be higher than 3/10 of the dose limit stipulated for these tissues or organs. Category B includes all other radiation work. For practical reasons, monitoring of category B workers is often treated similar to category A workers by individual monitoring. In many practical situations where task monitoring is required in environments with the possibility of elevated radiation levels, “active” dosimeters are needed which include immediate warning capabilities, e.g. electronic dosimeters. Many countries have established registers for the recording of individual dose levels from occupational exposure [01FPA].

Optimisation of protection has a long lasting history in the field of radiation protection at the workplace. It relates not only to engineering or physical protection measures, but also to other aspects such as safety organisation and management, safety culture and safety training. As optimisation involves social and economical factors, its objectives have typically been related to local circumstances. In general terms occupational radiation protection over the past few decades has been successful with solid downward trends in many key performance indicators, e.g. the annual average dose, the annual collective dose, the number of workers exposed to high doses and the number of accidents and overexposures. It must be pointed out, that - whereas this is clearly documented for the situation of practices in the nuclear fuel cycle, this is not necessarily the case for exposures in medicine and industry or for exposures to natural sources, for example the mining of ores. Furthermore, there remain problems in both the formulation and the application of standards for the protection of pregnant workers and the embryo and foetus.

2. Implementation of the process

Over many years, the practical application of optimisation in occupational radiation protection has become part of the normal job planning: occupational exposures are optimised below limits by proper planning, preparing, implementing, and reviewing of work. This concept, broadly termed “Work Management”, is a holistic, start-to-finish, multi-disciplinary approach to jobs. The key points of the structure of programmes to optimise working procedures and to keep doses as low as reasonably achievable are common to most countries. The implementation of the process of optimisation should involve stakeholders - including workers, employers, regulators and professionals - in arriving at occupational radiation protection decisions and their implementation in the workplace. If properly applied, "Work Management" can result in the reduction of the number of workers needed to perform a job, the number of person-hours spent in the radiologically controlled zone, the reduction of the amount of rework (due to faulty design, planning, preparation, implementation, or follow-up) and the reduction of occupational exposures. In order to utilise the results of exposure analyses for planning purposes, the dose distribution within a group of workers or a job, the time dependent changes of the dose distribution as well as the specific skills, knowledge and abilities of the workers should be taken into account.

Multi-disciplinary communication is one of the keys to effective work preparation. For example, the work site can be optimised in terms of the placement and availability of support equipment (temporary shielding, ventilation, area decontamination, etc.). Personnel selection and training are also very important. The result of the optimisation process is an essential part of the job description and the working arrangements.

In the international discussion of occupational exposure, distinction is made between the nuclear industry, the medical sector, the general industry, research and education and natural sources. The characteristics of these areas in relation to the implementation of optimisation are briefly described here [ESOREX 2004].

2.1 The nuclear industry

Occupational radiation protection in **nuclear fuel cycle** facilities has received more attention than in any other practice. Consideration is given the appropriate assignment of responsibilities, the creation of and role definition for what is called in many countries an “ALARA Committee”, the creation of and role definition for an “ALARA Engineering Group” to review work procedures, and the establishment of criteria as to when and to what level jobs are sent to such a group to receive “ALARA Reviews”.

Appropriate work selection, e.g. identification of those tasks which are “necessary”, is an efficient way to optimise working procedures. Work which falls into this category includes regulatory requirements, work related to the reliable operation of the plant, and work associated with refuelling. Unfortunately, not all jobs are obviously

“necessary” or “unnecessary”, and it is here that the concept of Work Management must be applied to appropriately select jobs to be performed. The necessity to perform each job should be questioned systematically and should be based on plant condition. Typical questions to be asked are "Is the proposed job necessary to make the plant safer, more reliable, or more efficient?" or "Is the necessity for the job based on overly conservative calculations?"

The most important concept for the work implementation is the control of work and the work environment. One of the key functions of radiation protection personnel is to provide assistance and advice to workers. To facilitate this task, in some countries particular radiation protection personnel are designated to follow particular tasks (work on the steam generator secondary or primary side, work on the reactor coolant pump, work in the dry well, for example). Also, the use of radiation protection “hold points” assures that advice will be sought and given at particularly dose-intensive portions of a task (for example, requiring a radiation protection survey of the steam generator channel head after opening of the manway). Assigning individual worker dose restrictions can also assure that advice is sought and given at important points.

To ensure effective control, work supervisors must spend sufficient time at the work sites to be aware of the radiological status of their work. To resolve any problems encountered, inter-service communications must be quick and efficient. The control of access to and time spent in the controlled zone is also important. The reduction of “transit doses”, e.g. the doses received by workers going to and from, or looking for their place of work), can increase work efficiency. By assuring that workers spend their “dead time” and break time in low dose areas, dose savings can be further augmented. Concern is still warranted over the control of itinerant workers and contractors who are subject to divided responsibility.

The final stage of work is that of assessment and feedback. In terms of work assessment, the indicators used to assess work, and the bench marks against which these indicators are judged, must be multifaceted. For example, collective dose and individual dose distribution must be joined by other indicators such as person-hours, number of workers, work duration, rework required, delays and problems, etc. For such bench marks and indicators, data from pre-job ALARA analysis, historical data and data from other sites is essential.

The general aspects of implementing optimisation in occupational radiation protection describe above are also applicable in the other areas of applications of ionising radiation but their implementation including formal arrangements are less developed in these areas. Standardisation of procedures and inter-comparison of results of optimisation between different operations and operators is less feasible in these areas. The major features in these areas are described below.

2.2 Medical uses

Medical applications of radiation are some of the oldest uses of radiation. Whilst a large fraction of medical radiation work uses well established technology associated with established optimised occupational protection procedures there are new technological developments that bring in new challenges to the optimisation and the occupational exposure control. Exposures of workers in conventional diagnostic radiology and radiotherapy are generally well controlled and the principles of optimisation are part of routine working arrangements. There are, however, new areas of medical practise, especially interventional radiology, in which high exposures are received and where efforts to optimise procedures are warranted. The control and reduction of such exposures requires continuous efforts in post graduate education and in awareness-raising of the medical professionals involved. The participation of health physicists in the implementation of optimisation programmes in interventional radiology is strongly recommended [IAEA 02, EAN 2002].

2.3 Industry and research/education

In the general **industrial** as well as in **research** and **education** many applications of radiation are not standardised. In many cases optimisation of protection is, however, an integral part of the day to day instructions and of work procedures. In many situations, compliance with the radiation protection standards including optimisation is to some degree subject to the personal control of workers over their own working arrangements. This situation makes the inculcation of the awareness of optimisation needs at the individual level very important. Specific types of work, e.g. industrial radiography, very often have to be carried out in difficult environments where safety relies largely on procedures and human performance. These types of work are often characterised by high routine exposures and the occurrence of accidents. The major cause of accidents has been identified as the failure to follow optimised procedures and working arrangements, e.g. to use alarm dosimeters [EAN 2001].

2.4 Natural Radiation

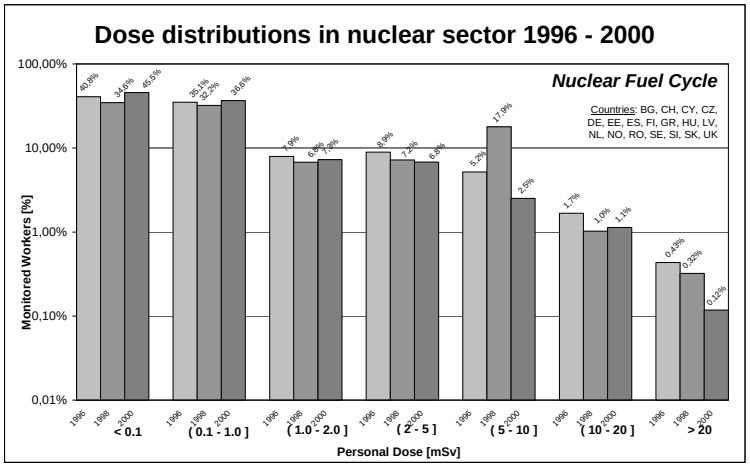
It is recognised, that exposures to **natural radiation**, which are amenable to control by the employer, need to be considered further from a radiation point of view. Workers exposed to natural radiation should be given the same level of optimised protection as those exposed to artificial radiation. As natural radiation is an inescapable feature of life clear guidance is needed to decide which activities should be regulated and how suitable and optimised solutions to protection at the workplace could be applied. There is a need to come up with proposals for optimised solutions at various types of workplaces (cf. Annex 3).

3. Distribution of exposure

In many countries the general features of the distribution of individual occupational exposures are well known. The dose distributions of a given workforce or a group

of workers are confined by zero dose (e.g., the detection limit of the dosimeters or the minimum reporting level) and by the limit of effective dose for exposed workers. Available databases of occupational exposure in the nuclear industry, the medical sector, the general industry and in research and education consistently show similar frequency distributions of the dose (ESOREX 2005): The majority of the occupational dose values are observed below a value of 1 mSv per year. The relative contribution of the doses in this dose range varies between about 75% in the nuclear industry and 95% in research and education. The fraction of workers receiving doses between 10 and 20 mSv per year varies between ≤0.1% (research and education and medical) and 1% (nuclear industry and general industry); the respective figures for dose values above 20 mSv per year vary between 0.01% for research and education and 0.3% for the nuclear industry. During the last 5 to 10 years a distinct decrease has been observed in the numbers of workers receiving doses above 20 mSv per year for workplaces in the nuclear industry and in the general industry. As an example Figure 4 shows the dose distribution in the nuclear industry for the years 1996 to 2000 (ESOREX 2005).

Figure 4: Trends in Nuclear Worker Doses



The distribution of individual occupational exposures resulting from natural sources is significantly different: Less than 50% of the workers receive doses below 1 mSv per year; the fraction of workers receiving doses between 10 and 20 mSv per year and above 20 mSv per year is about 8% and 2% respectively. In recent years, efforts of radiation protection and optimisation of procedures have resulted in a continuous decrease of the numbers of exposed workers in these dose ranges.

Relative Weighting

Continuous exposures near the dose limit would involve risks comparable to those in recognised high-risk occupations. These circumstances justify paying particular attention to avoiding or reducing the number of workers receiving high individual doses near or above dose limits. Optimised protection solutions additionally aim at

lowering both the number of people and their mean dose in the whole dose range with time. It is evident from the dose distribution shown above that consequent application of this principle would lead to a reduction of number of workers in the upper part of the dose distribution with time and to a shift of the spectrum towards lower doses. Figure 5 demonstrates that these features are observed for some areas of occupational exposure.

Figure 5: Trends and changes in occupational exposure distribution 1996 – 2000 (ESOREX 2005)

↔ no ↘ little ↘ moderate ↘ strong	Nuclear sector	Medical sector	General industry	Research education	Natural sources
Countries	16	21	22	17	9
Mean dose	↘	↔	↘	↔	↘
Collective dose	↘	↘	↘	↘	↘
Cases with high doses	↘	↔	↘	↔	↘
Dose distribution shift	←	←	←	←	←

In case of occupational exposure, at the level of an operation, there is no need to built a large list of dose attributes because the collective dose of the concerned workers is already a group dose (called workdose) for which the space is the location of the operation (inside the facility), the time is the duration of the operation and the relevant group of workers is those who are exposed (some segmentation could be done for the different categories of involved workers e.g. by speciality, work station, inside/outside workers…)

However, some dose matrices could be built to be aware of the occupational exposure at the level of a facility, a company, a country and also a sector (nuclear industry, medical installations…), etc. Each level determines the space reference. The time reference is generally one year or the lifetime of a worker. The characteristics of the workers could be the same as for an operation Further aspects to be considered in this context are the age and the gender of the workers.

4. The role of operators and authorities

Within the ICRP system of radiological protection the primary responsibility for the optimisation of protection can be defined in the following way: This complementary requirement of the Optimisation of Protection … is the responsibility of the operating management, subject to the requirements of the competent national authorities. Both the operators and the appropriate competent authority have responsibilities for optimisation."
Competent authorities make decisions regarding the establishment of and the enforcement of compliance with standards, the authorisation of exposure-causing activities and the response to incidents and discovered exposure situations. Except in cases of regulatory violation, it is not the role of the competent authority to focus on specific outcomes for a particular situation, but rather on processes, procedures and judgements. In many countries registries dose operated to monitor both compliance with dose limits and trends in dose distribution and other parameters relevant to optimisation. Regulatory authorities should encourage the operational managements to develop a 'safety culture' within their organisations. Key factors that might improve the situation in the general industry are the targeting of regulatory pressure, the request for more involvement on the part of qualified experts, appropriate and continuous training of operators and feedback of lessons learned from accidents. For natural radiation the competent authority must provide clear guidance to decide which activities should be regulated. So far, regulatory requirements to include the need for an active safety culture in both the authority itself and all regulated operating management are rare, except in the nuclear industry and improvements are warranted.

Operating management has to make decisions regarding the implementation of the optimisation process, and prove to competent authorities, that optimisation has been achieved. This implies that operational management should develop and provide internal policies, priorities, rules and procedures to ensure the existence of a vibrant safety culture at all levels of management and the workforce. The degree of stakeholder involvement strongly depends on the type of work and could, as a minimum consist of a dialogue between the operator and the workforce.

5. Conclusions

The Commission's current recommendations for occupational protection against exposures use the same practical approaches as the Commission's previous recommendations. This optimisation remains a mixture of quantitative and qualitative aspects, now focusing more on case-specific judgements and technical elements to assist decision making. Decisions will be influenced by various technical, societal and policy factors, and will need to balance radiological impacts and risk transfers, for the workers and the environment, against more judgmental assessments of international national, regional and local "costs" and "benefits".
Maintaining and - where appropriate to do so - improving the safety culture in occupational exposure remains an important issue which requires continuous efforts

of all parties involved in the process. In some areas further efforts are needed to avoid accidents which may lead to high individual doses.

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A2: The Application of Optimisation to Public Exposures from Planned, Regulated Sources or Exposure Situations

1. Introduction

The radiological protection of the public from exposures caused by planned, regulated sources or exposure situations must be optimised below the relevant dose constraint. Public exposures can be external, such as can occur beyond the facility boundary or in on-site areas accessible to the public, and/or internal, such as from gaseous or liquid effluents, or from solid materials, any of which may be authorised for release by regulatory authorities. The optimum protection approach against these exposures is determined by considering a mixture of qualitative and quantitative aspects.

Although many of the ICRP's more recent publications have related to public exposures from nuclear facilities (ICRP Publications 51, 56, 67, 69, 71, 72, 74), and to the optimisation of radiological protection of the public (ICRP Publications 37 and 55), ICRP Publication 60 is the most significant of the Commission's previous recommendations on the optimisation of public protection. Paragraph 186 states:

> *In practice, almost all public exposure is controlled by the procedures of constrained optimisation and the use of prescriptive limits. The dose constraint should be applied to the mean dose in the critical group from the source for which the protection is being optimised. If the exposures in any critical group are likely to approach the dose limit for public exposure the constraints applied to each source must be selected to allow for any significant contribution from other sources to the exposure of the critical group.*

The Commission continues to recommend the use of constrained optimisation. However, this approach is now applied to the planning as well the implementation phases of a licensed activity, and the Commission is now providing further discussion of the relevant constraints to be considered, particularly with respect to the identification of a single source or exposure situation against which protection is being optimised.

2. Implementation of the Process

The optimisation of public protection below dose constraints is achieved through both quantitative and qualitative processes.

Quantitatively, optimisation focuses on the assessment of public exposures under various possible protection solutions. Because individual exposures can not be measured directly, it is necessary to use models, supported by environmental monitoring, for this process. The Commission now recommends that a more realistic approach should be used in making assumptions for the modelling of these ex-

posures, and provides detailed guidance in its recommendations on the Characterisation of the Individual (reference XX).

Qualitatively, optimisation focuses on the rationale for judging one option against another, and for judging when enough has been done. Typically, two key optimisation concepts are used in the context of public exposure management: keeping public exposures “As low as reasonably achievable (ALARA)”; and the use of “Best Available Techniques, not entailing excessive costs (BAT)” to control effluent emissions (NEA 2003, NEA 2004a, European Union Integrated Pollution Prevention and Control Directive, EU 1996). These are both judgmental, subjective assessments that are, in general, made on a case by case basis, with input from the relevant bodies and groups involved in the decision. ALARA and BAT complement each other. With a view to the consequences to human health, the control of residual exposures will be driven by the optimisation of estimated radiation doses to individuals using ALARA. With regard to the control of effluent releases, or in situations where humans are not directly affected or not the primary protection target, the optimisation will generally apply BAT to control effluent releases.

Both ALARA and BAT are moving targets, in that what is currently regarded as “reasonably achievable” and “best available” change with developing societal perceptions and advancing technology. Since the Rio Conference (UN 1992), the central organising principle of international environmental policy, Sustainable Development, has, in the non-radiological sector, moved beyond health-driven emission standards towards BAT techniques, focusing on reducing or where practical eliminating emissions at source. This approach is being increasingly applied to facilities and operations having radiological emissions, focusing the objective of protection on emission reduction rather than on health-effect / probability-of-effect reduction.

To identify sustainable decisions, qualitative social considerations are often important to obtain a balanced process. This aspect of decision making in radiological protection situations has been described in a series documents summarising the NEA’s Villigen Workshops (NEA 2004b, NEA 2004c, NEA 2004d, NEA 2001). These workshops have clearly demonstrated the value of and need for stakeholder involvement to achieve accepted decisions in certain situations. Stakeholder involvement can be effective at incorporating public values into decisions, increasing the substantive quality and sustainability of decisions, resolving conflict among competing interests, building trust in institutions, and educating and informing the public.

While qualitative input implies flexibility of results, this flexibility does not imply that authorities relinquish their responsibility to make the final decision, or their accountability for that decision. There will be a need, for instance, to frame the decision making process to balance national policy needs and local stakeholder needs. The question of final responsibility for decisions, as well as legal constraints, must not be occulted during the shared steps of decision framing, problem identification and process development. While, in general, the responsibility for the “final deci-

sion" with respect to the adequacy of public protection solutions lies with the government and/or the regulatory authority, the process of "reaching a decision" can be shared more appropriately among all involved stakeholders.

Selection of Relevant Dose Constraints

In the context of the optimisation of public protection from planned, regulated sources or exposure situations, it is important to correctly and precisely identify the source or exposure situation causing the public exposure so that an appropriate dose constraint can be selected.

In broad terms, a source or exposure situation is generally taken to be a licensed facility, such as a nuclear power plant, a factory producing radio-pharmaceuticals, or a hospital. Such facilities have the commonality that they are authorised to operate, the authorisation generally taking the form of some sort of license or permit granted by the relevant radiological protection authorities. In such circumstances, the source for which protection is being optimised is clearly and unambiguously identified. In these cases, the choice of the relevant dose constraint for protection against exposures from the licensed facility under consideration will depend largely on whether or not this facility is the dominant source to the exposed public under consideration. If the facility is the dominant source, a dose constraint of 1 mSv/a would be the appropriate starting point for optimisation of protection. If more than one licensed facility exposes the same public individuals, then the regulatory authority will have to decide, perhaps through some sort of stakeholder consultation, what dose constraint should be allocated to each of the licensed facilities being considered in order to assure that public exposures remain below the dose limit of 1 mSv/a. Here, the Commission recommends that realistic assumptions should be used to assess individual exposures from each of the identified licensed facility, such that relevant dose constraints can be selected.

Some circumstances, however, may complicate the identification of the source or exposure situation. For example, a licensed facility may include several installations or sub-divisions producing radiation. This would be the case for situations such as a hospital equipped with several radiation-producing devices, or a radiopharmaceuticals factory producing several such products in different buildings/areas within a single facility, or a nuclear power plant site containing multiple reactor units. In these cases, the regulatory authority will again have to decide, perhaps through some sort of stakeholder consultation, what dose constraint should be allocated to each radiation-producing process/device within the licensed facilities being considered in order to assure that public exposures remain below the dose limit of 1 mSv/a. Should more than one licensed facility expose the same public individuals, further consideration of the appropriate dose constraint for each such facility would be necessary. Realistic assumptions should be used to assess individual exposures from each of the identified radiation-producing process/device such that relevant dose constraints can be selected.

Although the philosophy and application of optimisation of protection in emergency situations and in controllable existing situations are similar to those for planned situations, the selection of relevant dose constraints requires a slightly different approach than for planned situations. Because it is not possible, a priori, to guarantee that exposures will be below a specific level, dose limits are not applicable in emergency situations and in controllable existing situations. As such, the choice of a relevant dose constraint will very much depend upon the situation being considered. For example, an accident situation that could lead to exposures approaching or exceeding levels that could cause deterministic effects would call for a dose constraint to avoid these effects, i.e. 100 mSv. However, for situations where exposures would not approach these levels, for example in less severe accidents, at a greater distance from the accident source, or in an existing controllable situation, it would be more appropriate to choose a dose constraint of 20 mSv to more realistically reflect the dose reductions that can be achieved. These situations will be described more completely in future ICRP recommendation documents pertaining specifically to emergency situations and to rehabilitation.

3. Distribution of Exposures

To utilise the quantitative results of exposure analyses for decision making most effectively, the Commission is now recommending that exposures should be expressed in a matrix format as a collection of elements and attributes. For example, using the hypothetical representative individuals selected using the above-referenced Commission recommendations, internal and external exposures to the public resulting from a facility or operation could be characterised by several dimensions, including:

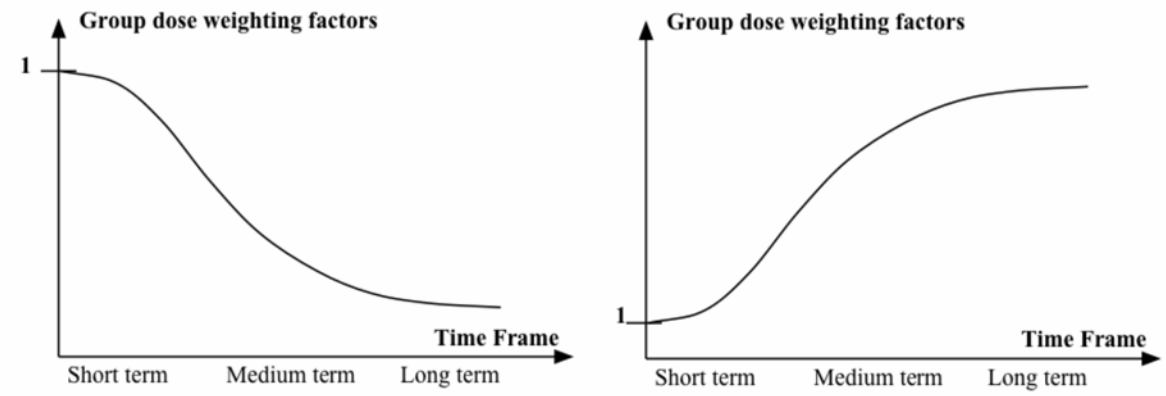
- The distribution of individual doses can be represented, for example, in histograms of the number or fraction of individuals receiving doses within a series of dose ranges.
- The age and gender distribution of the exposed population can be represented, for example, the number or fraction of individuals in a given age range that is applicable to the half-life of the radionuclide under consideration. Individuals exposed to short-lived radionuclides would not significantly change “age group” over the period of exposure, however this would not be the case for long-term exposures.
- The geographic distribution of the exposed population can be represented, for example, at various distances from the source, such as adjacent, local, regional, national, or international
- For exposures that are expected to last over long periods, the above matrix dimensions can also be expressed over a series of generations

For example, assuming the data are available, the collective dose can be estimated for a regional population (subgroup) due to the ingestion of contaminated fish (one exposure parameter) coming from a given river or sea (one geographical entity). The best characterisation of group exposures will vary from case to case. Authorities should work with stakeholders, as appropriate, to identify relevant aspects that can be characterised to best serve decision making.

Relative Weighting

In assessing public exposures from planned, regulated sources or exposure situations, the various characteristics of the exposed groups become visible. As such, it is possible to assign relative weights to these characteristics, for example based on stakeholder considerations. Many approaches are possible. For example, weights can be assigned according to the time at which the exposure is predicted to occur. Progressively less importance could be given to individual exposures received in the far future due to the increasing uncertainty. Conversely, in particular exposure situations, more importance could be given to exposure occurring in the future based on intergenerational equity considerations. Another judgement could be that exposures should be equally weighted in time. Figure 6 provides a simple graphical representation of these examples.

Figure 6: Options for group weighting factors as a function of time



In general, however, both the individual doses and the size of exposure population become increasingly difficult to predict as the time increases. In addition, the current relationship between the dose and detriment may no longer be valid for future populations. As such, the use of exposures for decision-making purposes becomes increasingly problematic as those exposures are predicted to occur farther and farther in the future. The Commission feels that our current state of knowledge, and our ability to model populations and exposure pathways can appropriately contribute to decision-making for exposures predicted to occur over a time period covering a few generations. Beyond such time frames, the Commission recommends that predicted doses should not play a major part in decision-making processes. Figure 4 provides a quantitative example of how future exposures could be taken into account in a decision-making process.

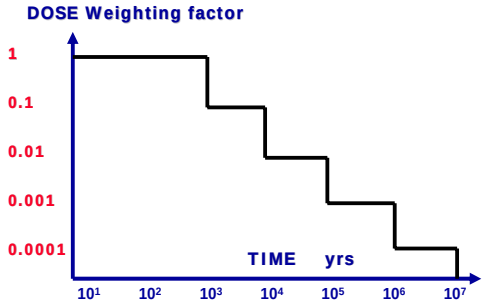


Figure 7: Example of weighting quantification

4. The Role of Operators and Authorities

The radiological protection of the public is achieved through both regulatory authority and operator actions. The regulator, in general, will require that operators optimise radiological protection, and will inspect to judge compliance with regulatory requirements. Operators, in general, are responsible to assess radiological protection options, optimise protection solutions, propose these to the regulatory authorities, and implement the authorised solution. Operators are further required to self-inspect and to follow-up on inspection findings to improve protection.

5. Conclusions

The Commission's current recommendations for public protection against exposures from planned, regulated sources or exposure situations are to use the same practical approaches as the Commission's previous recommendations. This optimisation remains a mixture of quantitative and qualitative aspects, now focusing more on case-specific judgements and technical elements to assist the decision making process. Decisions will be influenced by various technical, societal and policy factors, and will need to balance radiological impacts and risk transfers, for the public, workers and the environment, against more judgmental assessments of international, national, regional and local "costs" and "benefits".

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A3: The Application of Optimisation for Radon Exposure

1) Introduction

Radon is a naturally-occurring radioactive gas, and in the outdoor ambient environment it is not considered a controllable source (usually with concentration on the order of few tens of Becquerels per cubic meters - Bq m^{-3}). However, radon also occurs in dwellings and buildings at generally higher concentrations. These indoor concentrations vary widely, depending on geophysical factors (geology, climate), architectural characteristics of the building, the way in which the building is used (domestic customs) and time periods (season, day or night). Thus, while some generalisations can be made, each building may be considered as a particular case for which optimisation can be applied.

The awareness of radon has existed for several centuries, but it has only been in the past 30 years that its harmful effects have been recognised (EPA, FL). Over the past 20 years many international organisations (WHO 1987) and countries have developed relatively consistent public health policies. While techniques to manage radon are generally well known but, many buildings still have elevated radon concentrations. In addition, while advice on construction methods for new facilities is also available, these methods are not consistently applied nor required in all building codes.

The Commission considers radon-222 at home and at work as a controllable source, principally because the levels indoors are enhanced due to human activities. The previous recommendations for protection against radon-222 issued by the Commission in Publication 65 [1] are generally still valid. In this publication, a broad optimisation approach led to a suggested range of values – 200-600 Bq m^{-3} for radon at home and 1000-1500 Bq m^{-3} for workplaces – within which so-called *Action Levels* were expected to be set. In both cases the corresponding doses were in the range of 3 to 10 mSv/y (taking into account the exposure duration). In this system, it was recommended that protection actions be implemented above the action level and that no action was needed below the action level.

2) Implementation of the process

The Commission now recommends the use of dose constraints for radon exposure instead of action levels. According to the 2005 Recommendations, the upper levels of 600 Bq m^{-3} for homes and 1500 Bq m^{-3} for workplaces from Publication 65 can now be seen as maximum constraints, since the Commission considers these levels as providing the basic level of protection. The corresponding dose level (on the order of 10 mSv/y) is consistent with the maximum constraint recommended in Table 7 of the 2005 Recommendations. This level applies to exposure situations with characteristics, similar to those of radon exposure (20 mSv/y), that are: easy to

control; direct or indirect benefit, information and assessment for the public, training and monitoring for workers.

As with all other controllable sources, it is the responsibility of the appropriate national authorities to establish their own constraints [2]. Such a constraint may be chosen by considering local factors such as the national mean of indoor radon concentration. Separate levels may be set for homes and workplaces due to the different number of hours spent at each. Specific constraints could also be set for new buildings *(ICRP 65, § 77)* or for public exposure to radon in some places open to the public. After setting national constraints, the 2005 Recommendations require optimisation below these constraints.

3) Distribution of Exposures

The purpose of this annex is not to repeat the provisions of Publication 65 but to present the application of optimisation as an on-going process. The following discussion applies to existing buildings, however, some information regarding new construction is also presented. While some generalisations can be made, each building may be considered as a particular case for which optimisation can be applied.

For a given building or group of buildings, this process generally includes the following four steps:

a) Identification of radon-prone areas and selection of dwellings, other buildings and workplaces

Identification of radon-prone areas could be made using measurement campaigns or evaluations of geological factors *(ICRP 65 §62 and 63),* among other methods. In Publication 65, it is suggested that areas with more than 1% of buildings with radon concentrations exceeding 10 times the national average concentration might be designated as radon-prone, but the choice will depend on local conditions. If the measurements are made in dwellings, non-residential areas also have to be taken into account *(ICRP 65, § 84)*. It is important to recognise that some locations with high radon concentrations may occur outside the identified radon-prone areas; furthermore, some locations with low concentrations may occur inside such areas. Concerns of the public and public health organisations should also be used to assist in identifying areas. These stakeholders are also very helpful in increasing the awareness of, and encouraging the testing for, radon in buildings.

Once a radon-prone area has been identified, the selection of candidate buildings should take into consideration places that are open to the public for prolonged periods, such as schools, hospitals or jails.

The selection of workplaces to investigate is more difficult since radon concentration is generally less related to the work activity than to the building or to the location in which the work is conducted. Some workplaces deserve special attention, such as mines and other underground facilities, spas, and activities based on the handling of materials containing naturally-occurring radionuclides.

b) Measurements of concentration levels

Radon measurements should be taken in selected places, buildings or work activities, which are situated in radon-prone areas.

Testing protocols should be established or evaluated by a competent authority. For example, measurements should be made in locations where people live or inhabit (not in cellar or record office, except to identify radon source and pathways inside the building). In locations with several buildings, measurements should be made in each occupied building. The measurement results that are compared to the relevant constraint should be representative of the annual concentration mean and should include relevant information about measurement conditions. The measurement process should include two steps: a screening measurement, followed by, (in particular if constraints are exceeded), complementary investigation measurements. These latter measurements are useful in identifying radon source and pathways inside the building, and if relevant the ratio radon/progeny. Professionals taking the measurements should be properly trained, and the results should be carefully documented

c) Implementation of protection actions

Since radon exposure is a pre-existing situation, for radon concentrations above the constraint protection actions should thus be implemented with the aim of reducing the concentration as low as reasonably achievable below the constraint (resulting in residual doses), taking into account economic and social factors.

When a concentration level is found below the constraint, the decision to undertake an action is more a matter of judgement as well as the availability of resources. The concentration level is one of the criteria to be taken into account: the lower the concentration is below the constraint the less protection action is needed. Time of exposure is another criterion: per year and during the lifetime (some individual dose calculation could help to appreciate the situation, compared to the mean level of exposure to natural radiation). The characteristics of exposed individuals are also of importance. In dwellings, for example, protection actions are more required when the place is occupied by children; if the inhabitants are elderly, protection action can be delayed because of the latent period of the effects resulting from radon exposure. However, the gender of the individuals is not a relevant criterion.

Except in case of a site contaminated with naturally-occurring radionuclides, radon is not controllable by direct actions on the source, but instead by environmental pathways (actions on the building). Proven measures against radon are readily available. Protection actions could be a combination of passive and active means. Options are chosen in order to ensure that the concentration level becomes as low as reasonably achievable below the constraint, taking into account economic factors and the use of the building. Generally, the implementation of protection actions needs only one step to reduce radon concentration below the constraints but it is almost impossible to reduce concentration to zero.

Current mitigation techniques from the building industry (building shields or ventilation) are generally sufficient. There undertaking should not imperil the soundness of the building, and its existing features, such as heating and cooling systems, should be carefully taken into account. The choice of the technical option will finally depend on the use of the building (public or private), the characteristics of the exposed population (children or elderly people) and the available resources of the owner. Actions with immediate effect (aeration) while waiting for remedial work could be useful in case of high concentration.

Preventive actions should also be applied during the design phase of new buildings. Constructions codes and building guides should be set in order to prevent elevated radon concentrations and to provide for easy introduction of further protection actions if the initial construction fails to achieve concentrations below the constraint for existing buildings *(ICRP 65, § 78-79-105)*, generally with good effectiveness and without further cost. Relocation would not be appropriate unless the irreducible concentrations were an order of magnitude or higher than the constraint adopted *(ICRP 65, § 74)*.

Measurements and protection actions could be mandatory, possibly with specified time limits, in workplaces and places open to the public due to the legal responsibility of the employer and the manager. For private dwellings, measurements and protection actions are generally voluntary; however, they could be mandatory for some specific situations such as sale or renting.

d) Follow up of protection actions

Measurements of concentration levels should be recorded. The outcome of preventive and remedial procedures should be closely monitored to ensure that they are reliable and durable *(ICRP 65, § 81)*, by measurements in the same conditions as screening.

Areas of workplaces should be treated as supervised areas in which periodic measurements may be needed to confirm that concentrations have not increased with time *(ICRP 65, § 98)*, and occasionally as controlled areas if the radon concentration is largely due to the operations). It is sufficient to use workplace, rather than individual, monitoring *(ICRP 65, § 99)*.

4) The role of operators, authorities and other concerned parties

The application of optimisation for radon exposure implies the commitment from all concerned organisations and people at all levels. National authorities should define a regulatory framework. Proper information and training should be provided to elected representatives who are often responsible for the concerned places open to the public, civil servants, employers, workers, staff in charge of the health protection of workers, staff in real estate activity and building industry, medical practitioners, teachers as well as tenants and owners of dwellings. For an effective control of radon exposure in dwellings, it is of considerable importance to ensure that

both tenants and owners, are fully aware of the risks of radon and the available protection options *(ICRP 65, § 74)*.

5) Conclusions

Implementation of the Commission's current recommendations for optimisation for radon exposure, whether in residences or at the workplace, will utilise the same practical approaches implied by the Commission's earlier recommendations. This optimisation remains a mixture of quantitative and qualitative aspects, now focusing more on case-specific judgements and technical elements to assist decision making. A clearer recognition of stakeholder views, more information characterising the distribution of exposures and attributes of exposed populations, and a larger significance for residual dose will, however, be needed.

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