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NON-OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

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Abstract

An overview of non-occupational exposure is presented. The special problems in connection with assessments of collective doses (time, geographical extension, cut-off, uncertainties) are discussed. Examples of methods and principles for monitoring and dose assessments used for various sources of radiation are given and data on public exposure are presented and discussed.

Keywords (chosen by the author)

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NON-OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

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INTRODUCTION

Non-occupational exposure comprises all the dose equivalents and intakes of radioactive nuclides incurred by people but not associated with their work. It includes natural radiation, medical exposure of patients, radiation from fallout caused by nuclear weapon tests, releases from nuclear power installations etc. The levels of exposure vary in time and place. Some part of non-occupational exposure is not controllable, e.g. cosmic radiation, radiation from the ground etc.; some is controllable, e.g. medical exposure and releases from nuclear power. Enhanced natural radiation exposure is partly controllable, e.g. enhanced radiation in houses.

The non-occupational exposure is dominated by the contribution from natural and medical exposure. Normally there is no special benefit to balance the natural radiation, it is only a detrimental factor for people and society. Medical exposure, on the other hand, is expected to be balanced by the benefit of the medical examination. A minor source of public exposure is the releases from nuclear power. The corresponding detrimental effect is expected to be balanced by the benefit of the electrical energy produced by the nuclear installation.

The levels of and possible problems with public exposure and how they are managed and regulated are discussed below.

CONCEPTS AND QUANTITIES

The same concepts, quantities and units are used in connection with public exposure as for occupational exposure. Any supplementary concepts etc will be explained when they are introduced in the following text.

ICRP SYSTEM OF DOSE LIMITATION

Justification and optimization

For the purpose of justification and optimization the collective dose equivalent commitment (here called collective dose) is estimated. Justification and optimization are source-related requirements and need consideration of both the occupational and public exposure. Their application for the protection of the public implies some practical and conceptual problems such as uncertainties, time distribution, small individual doses etc. They are discussed below.

The uncertainties in the assessment of the resultant collective dose should be minimized by using models and dose calculations which are as realistic as possible. This is important in the optimization procedure in order to avoid biased solutions rather than the truly optimized option. In the final judgement of the result of the optimization, the significance of the uncertainties should be taken into consideration.

In case of very long-lived nuclides released to the environment now and after a very long time, as for example from geological repositories for high level waste, there will be a very long term exposure.

The uncertainties of the dose assessment increase as the time of interest increases. In a time period of 10^3 - 10^4 years the uncertainties increase mainly because of insufficient knowledge of people's diets and habits during these time periods. The dose-effect relationship is also uncertain in these long-term perspectives because of possible greatly improved medical treatment of radiation-induced diseases. However, these thoughts can never be more than speculative and do not justify less concern for future doses than doses occurring today. For time periods of more than 10^4 years environmental changes will also occur, new ice-ages, changed climate, geographical dislocations because of ground and seabottom movements etc. This will make the dose assessments even more uncertain.

In geological repositories the radioactive nuclides may be isolated for more than 10^4 years and after that appear in the biosphere during various lengths of time. If that time period is short in geological terms the environmental distributions may be assumed to be the same as now. However, if the release time to the biosphere from the repository is long in geological terms there are fundamental difficulties. It might be argued that all the uncertainties associated with future doses particularly those occurring after say 10^4 years should be reflected in the consideration of these doses in the discussion of various options and levels of radiation protection. Is it reasonable to use the same monetary effort to optimize the protection when the collective doses under discussion occur in the distant future as when they occur during the time for which the dose assessments are much more reliable?

There does not exist any rationale for selecting any special monetary value of a collective dose differing from the present value. Discounting techniques have been proposed for allocating future doses lower monetary values then present collective doses. This is, however, much debated.

The collective dose should include all doses irrespective of where they occur. In many cases releases to the environment of long-lived nuclides will give a much higher collective dose caused by global exposure than that caused by local exposure. Therefore, it would be quite inappropriate for the optimization and justification procedure to consider only the local contribution. If differential cost benefit technique is used the monetary value of the global collective dose (α-value) should be the same as that used for the local components and should not be lower than an internationally agreed value.

There are proposals to use cut-off for small doses, i.e. doses less than the cut-off are not considered in the calculation of collective doses. This could result in a substantial decrease in the magnitude of the assessed collective dose and thus the efforts to improve the radiation protection to the optimum could no longer be justified. The argument for cut-off may be that small doses correspond to such small risks that neither the individual nor society should take an interest and pay special attention to them. This argument would possibly apply if there were only one source in the world and if the judgement (made by the one country having the source) of the insignificance of small doses occuring in other countries is also accepted by these countries. Because neither of these assumptions is true, the argument is not applicable . The only relevant argument would be that small doses may have no biological effect. Because the natural background is of the order of 1 mSv a^{-1} the "small" doses considered must be of that order of magnitude. The doses are always added to the natural "background" dose and the biological effect is depending on the sum.

Limits

ICRP´s recommended effective dose equivalent limit for members of the public is 5 mSv in a year. It applies to the mean dose equivalent in a so-called critical group. A critical group should be representative for those individuals in the population expected to receive the highest dose equivalent. The dose limit is based on considcrations of other risks in the society that are regularly accepted. On this basis a risk in the range of 10^{-6} to 10^{-5} per year would probably be acceptable for any individual member of the public. With an assumed risk factor of about 10^{-2} Sv^{-1}, this acceptable risk would imply restriction of the lifetime dose to members of the public to 1 mSv per year of life-long exposure. *)

This limit should not be used for the purpose of planning the design and operation of a facility from the point of view of radiation protection. It is a constraint for the optimization and in practice the doses to the public are much smaller than the limit.

The limits suggested above refer to the stochastic effects. In order to prevent the induction of non-stochastic effects on individual organs an overriding annual dose equivalent limit of 50 mSv should apply.

The limits are individual-related and should include the contributions from all administratively controlled sources. That implies proper distribution of permissible contributions from the various sources. A practical approach is the use of "upper bounds" as constraints for the optimization of each source. The upper bound value for a given category of sources should be an appropriate apportionment of the individual dose limit, taking into account the expected contribution from other sources. The accumulation of doses caused by the release of long-lived nuclides should be considered. This is made by assessment of the dose commitment. If the dose commitment from one year of practice does not exceed the upper bound expressed as an annual dose limit for a particular source, the annual doses in the future caused by continued use of this source will never exceed the upper bound.

This method of limiting future individual doses is straightforward if the number of sources is constant. If this is not the case, the expected maximum future number of sources of the category of interest must be foreseen. If this number is correlated to the number of people using or getting benefit from the source the maximum future individual annual dose can be controlled by maximizing the resulting collective dose equivalent commitment per unit of practice. For nuclear power, in some countries, this is made by setting a limit on the collective dose equivalent commitment per installed electric power and year, i.e. in manSv $(MW \cdot a)^{-1}$.

Because a time-unlimited use of a source is usually unrealistic,

*) Recently (1985) ICRP has recommended that the principal limit is 1 mSv in a year even though it is permissible to use a subsidiary dose limit of 5 mSv in a year for some years provided the average annual effective dose equivalent over a lifetime is 1 mSv in a year.

for example because of limited resources, the collective dose in this case and for this purpose is assessed by integration over the time during which the source is assumed to be used. For nuclear power a time period of 100-500 years has been used. It must be stressed that this limited integration is made only to meet the purpose of this particular calculation, which is limitation of future individual doses. It does not imply an undervaluation or neglect of future doses. The upper bound for individual dose is set on the basis of apportionment and acceptability of risk. This is a matter of national responsibility but also assumes an international understanding of the global dispersion and consequences of certain releases of radioactive nuclides in air and water. Otherwise, national efforts to keep individual doses below established upper bounds and even below ICRP's recommended primary dose limits would be seriously jeopardized by contributions from foreign countries.

In radiation protection in general, when some doses are received with certainty, doses are compared with dose limits or upper bounds. The dose limits represent the beginning of an unacceptable probability of stochastic effects.

In the case when doses are not received with certainty, but with some small probability (p), the individual would be protected at the same level as in the previous case, if the total probability of stochastic harm does not exceed the probability (po) related to the dose limit (D_o). The total probability would be the product of the probability (p) of a given dose and the probability (s) of stochastic harm, given that dose. This probability (ps) will not exceed the probability at the dose limit, if the product of the dose (D) and its probability does not exceed the dose limit (i.e. $pD \leq D_o$). It should be understood however, that this product, which is formally the mathematical expectation of dose, represents a dose which may never occur and that the expectation value has a standard deviation which, at low probabilities is $1/\sqrt{p}$ times its own value. The whole argument is therefore based on a comparison of probabilities and not on an assessment of the expectation value. All doses that might occur must also be less than, say, 100 mSv in order not to introduce any non-linear relations which would invalidate the assumptions.

It is sometimes argued that the solution to a problem would not necessarily need to be good in the long-time perspective but it is left for future generations to solve the long-term problems. That would be their share of the bill for the inherited welfare. There are at least two objections to that. Firstly, there is no guarantee that the resources available in the future will be sufficient to solve the problems which arise. Secondly, the application of such a principle to all long-term problems would make the future burden of unsolved problems unacceptable, reducing the future margins for expenses and efforts of the future generations to solve their own problems and increase their own prosperity.

Therefore, the major effort should be directed to obtaining reasonable assurances today that the individual doses and corresponding quantity for level of protection in the future do not exceed acceptable values. The acceptable dose level should not exceed those accepted today.

As for occupational exposures, there are secondary and derived limits for the public. The secondary limit ALI need special comments. The values of ALI recommended in ICRP publ. 30 are for workers based on a Reference Man and there are many factors by which they would differ from those appropriate for members of the public. The relative values for infants of the committed dose equivalent in a number of tissues per unit of intake of several nuclides are more than 1 up to 1000 times greater than those for adult workers. The resulting ALI will accordingly be similarly less.

DOSE LIMITATION SYSTEM FOR NATURAL RADIATION

The dose limits recommended by ICRP do not apply to contributions from "normal" natural radiation. However, there are levels of natural radiation that should be controlled in the same way as for artificial sources. ICRP has recently published recommendations applicable to natural sources of radiation, publ. 39.

ICRP makes a distinction between existing and future sources. If the radiation from an existing source is considered to be too high, remedial action should be taken. The competent authority should specify action levels specific to the initiation of the remedial action being considered. ICRP does not consider it appropriate to recommend any general action level but recommends, for the specific case of radon in houses if the remedial action is fairly simple, an action level for equilibrium equivalent radon concentration in the region of 200 Bqm^{-3} (corresponding to an annual effective dose equivalent of 20 mSv).

Future sources can be subject to limitation and control during the planning and decision stages and their introduction should be justified and the protection optimized. However, ICRP´s recommended dose limits should not be applied. Instead, it is recommended that competent authorities set an upper bound of individual dose in the optimization assessments.

MEDICAL EXPOSURE

With the exception of the natural exposure, medical exposure represents the greatest contribution to the exposure of the public. Increased economical and social wellfare in a society increases the medical exposures because of the increased number of medical examinations. But it would also simultaneously or eventually decrease the exposure per examination because of improved radiation protection practice.

ICRP´s system of dose limitation is also applicable to medical exposure except for the limits. Limits are set where benefits and detriments are not received by the same members of the population. In the case of medical examinations they are normally the same persons and ICRP´s limits are therefore not applicable. However, the examinations should be justified and the radiation protection should be optimized. The decision as to whether an examination is justified is the responsibility of the physician.

Some types of examinations require special attention since they may need special protection and dose limitation. Examples are periodic health checks where the justifications depends on the probability of achieving important information and the benefit of that information for the patient. The justification of mass screening and dose limitation should be based on consideration of the benefit to the individual and the whole population and the costs in terms of detriment, equipment and manpower. Another example is medical research which is not always beneficial to the exposed patient. The question of voluntariness and knowledge of the risks is essential and imperative. In these cases authorized limits might be set.

MONITORING AND DOSE ASSESSMENT

Exposure of the public is controlled by monitoring and modelling. Monitoring normally concerns the source but occasionally also the environment. Modelling is needed to assess the doses from contaminated water, air or food but sometimes also to assess doses caused by external radiation from contaminated ground or surfaces.

The objectives of regulative monitoring are one or several of the following:

- to assess doses to the critical group
- to demonstrate compliance with authorized limits
- to check the condition of the source
- to warn in case of unforeseen conditions
- to initiate special actions or countermeasures
- to provide data for information of the public
- to provide data for verification and improvements of models etc.

Besides the regulative monitoring, specific monitoring might occur for special investigations and research. The doses due to public exposure are assessed on the basis of monitoring and/or modelling.

Some examples are given below of methods for assessing the exposure of the public caused by various sources of radiation.

a) Releases from nuclear power reactors:

Releases are measured at the source, doses are assessed by use of environmental models for the dispersion in air and water and uptake in plants, vegetables and animals and by use of metabolic models and models of human behaviour in the environment, shielding effects etc. Some environmental monitoring and sampling are made to improve the assessment. Sometimes stationary monitoring equipment is used in the near environment to measure continuously the external doses and the concentration of airborne radionuclides released from the plant. The measurements are made with respect to the critical group. The collective doses are based only on source monitoring and modelling, even though the models themselves were originally based on measurements in the environment. The doses are assessed as (collective) effective dose equivalent commitment per year of practice or as annual effective dose equivalent.

b) Repositories for high level waste:

The releases are predicted and the resulting doses are assessed exclusively by the use of modelling.

c) Radon in houses:

Long-term measurements are made either by sampling in representative houses or by random grab sampling or using both methods. Factors influencing radon levels in houses such as the ventilation, building material, age of the building, radon releases from ground etc. are measured and analyzed for various houses to get quantitative relationships and the doses are assessed on the basis of statistical treatment of these results and on metabolic models for the correlation between radon daughter levels in air and radiation dose in the lung.

d) Consumer products.

The exposure of the public is estimated on the basis of primary measurements on the product, assumptions on its use, and possible misuse, its disposal as waste and metabolic models.

e) Fallout

Measurements are made on the external radiation from deposited radionuclides on the ground, on the concentration of radionuclides in air and food and by whole-body measurements on people. The results of the measurements are extrapolated to the whole population by knowledge of the representativity of the grab sampling and measurements, and by metabolic modelling.

The examples given show that most of the dose assessments are based on modelling even though monitoring is also continuously performed to support and improve the models. The reliability of the assessed doses varies with the source and the exposure. The most reliable assessments are those of doses such as those due to external radiation from the cosmos and from the ground, internal radiation from ^{40}K, ^{3}H and noble gases and ^{137}Cs from fallout. Examples of less reliable assessments are those of doses from releases into rivers, actinides on the ground and radon in houses. Nevertheless, there are extensive data on the exposure of the public around the world and they are regularly reported by UNSCEAR.

AVAILABLE DATA ON PUBLIC EXPOSURE AND THEIR USE FOR EPIDEMIOLOGICAL STUDIES

The public exposure varies depending on the time, the place and the standard of living. Data are reported from all parts of the world and by weighting them with the number of people in various countries, weighted averages are obtained for the global mean annual dose. The collective doses are less dependent on the variations. A summary is given in Table 1 and it refers to the years around 1980.

Table 1. Annual average, individual doses and collective doses caused by exposure of the public.

Source	Average annual effective dose equivalent mSv	Annual global collective dose equivalent manSv
"Normal" natural sources	2	$8 \cdot 10^{6}$
Coal power plants	$0.5 \cdot 10^{-3}$	2 000
Commercial aviation	-	2 000
Luminous timepieces	-	2 000
Smoke detectors	-	10
Fallout	10^{-2}	$3 \cdot 10^{7}$ commitment
Nuclear power	10^{-4}	500
Medical	(0.4)	$2 \cdot 10^{6}$

Some comments on the table.

a) "Normal" natural sources. About half of the dose is caused by inhalation of radon daughters in indoor air. There are great variations in the radon daughter levels in houses depending on different ventilation rates, radium concentrations in building materials, radon emanation from the ground etc. In some countries the radon daughters in houses cause a great public health problem. For instance in Sweden the inhalation of radon daughters might cause 10-50 per cent of the lung cancers. Some of the houses have had very high radon daughter concentrations corresponding to an annual effective dose equivalent of the order of 1 Sv. The various country-average values of radon daughter concentration are generally higher in the temperate latitudes than in the tropical latitudes (by a factor of 4) due to the rate of ventilation and type of dwelling. The other components of the natural radiation are cosmic radiation, radiation from ground and buildings and internal radiation from incorporated radionuclides in the body, each of these components giving about 0.3 mSv per year.

b) Coal power plants. Coal contains small amounts of natural radionuclides and to some extent they are dispersed in the air when coal is burnt. The pathways of exposure of the population are inhalation during passage of the plume, external exposure and inhalation and ingestion of radionuclides deposited on the ground.

c) Commercial aviation. The cosmic radiation increases with the altitude. From 4 to 12 kilometers altitude the dose rate increases by a factor of 20. During occasional intense solar flares the dose rate may increase even more. In Table 1 the average dose is not given because the individual doses are from zero (those who do not fly) to the order of 1 mSv per year for aircraft personnel. Supersonic aircraft fly at higher altitudes (<20 km) than standard jet aircraft (<12 km) and the dose equivalent rate is therefore higher. But because the speed is higher, the flying time for a given trip is shorter and the total dose equivalent for a flight will be about the same.

d) Luminous timepieces. ^{226}Ra, ^{3}H and ^{147}Pm are the radionuclides used for the illumination of clock and watch dails. The content in watches varies but if the international standards are followed the annual effective dose equivalent from watches with ^{226}Ra is about 40 μSv, with ^{3}H about 0.3 μSv and with ^{147}Pm about 2 μSv. The doses are caused by external radiation, inhalation of tritium and external radiation respectively.

e) Smoke detectors. The ones refferred to are so-called ionization chamber smoke detectors. Most of them contain about 1 TBq ^{241}Am and the exposure of the public is mainly caused by the external radiation from the detector. The annual collective dose equivalent given in the table is an extrapolation from the value given for the United States (1-2 manSv per year).

f) Fallout. The most intensive nuclear explosions in the atmosphere occurred in the years 1954 to 1958 and 1961 to 1962. But testing in the atmosphere still occurs occasionally. The resulting fallout exposes people for a very long time although at low dose rates. It has been estimated that all the nuclear tests conducted up to 1980 have committed the world population to an additional exposure as large as that corresponding to about four years of natural radiation. The major part of the exposure from fallout is caused by 4 radionuclides, ^{14}C, ^{137}Cs, ^{95}Zr and ^{90}Sr.

g) Nuclear power. Because of the very small releases from nuclear power production the resultant radiation doses have to be assessed merely on the basis of modelling. Furthermore, it is not practicable to assess doses caused by all individual sites but to assume hypothetical sites with characteristics representative of each stage of the fuel cycle namely, mining and milling, fuel fabrication, reactor operation, reprocessing and waste management, storage and disposal. Also, the environment has to be hypothetical with the characteristics of existing site environments. Most of the releases consist of relatively short-lived radionuclides and therefore they are only of local concern. Some radionuclides are long-lived and can contribute to a global irradiation of man. The average dose equivalent given in the table is estimated as an global average and in practice the individual doses fluctuate around that value depending on the distance from the nuclear installation. The annual dose equivalent rate for the most exposed individuals is generally less than 0.1 mSv a^{-1}.

The doses given in Table 1 refer to an annual projected nuclear production of 80 GW(e)·a. This number is expected to increase in the future and consequently also the individual and collective doses. A way to predict the future doses is to assess the collective dose equivalent per GW(e)·a of electrical energy produced and multiply by the expected magnitude of nuclear power production in the future. That has been done by UNSCEAR in its 1982 report and with the assumption that there are no technical improvements and that current levels of discharge per GW(e)·a continue for 500 years, the expected doses at the year 2500 are calculated. The results are an annual collective effective dose equivalent of 250 000 manSv from 10 000 GW(e)·a per year to 10^{10} people with an annual per caput dose of 25 μSva^{-1}.

h) Medical exposures. The medical exposure is the largest component to man-made irradiation of man. The frequency of diagnostic x-ray examinations vary between 300 and 900 examinations per thousand inhabitants per year in industrialized countries excluding mass surveys and dental examinations. Absorbed doses to various organs vary between 0.01 and 50 mGy per examination. The annual collective effective dose equivalent caused by diagnostic radiology in developed countries is of the order of 1 000 manSv per million population. In developing countries the corresponding number would be one order of magnitude less and a weighted value for the whole world population would be about 400 manSv per million population per year. Nuclear medicine examinations contribute insignificantly to the doses caused by x-ray diagnostic procedures, although its relative contribution may vary in different countries.

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