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A RISK SYSTEM FOR SETTING RADIATION DOSE LIMITS

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FOREWORD

The following presentation reflects the author's personal views. Although it gives his interpretation of the current ICRP recommendation it is not given on behalf of the Commission and may not be the only appropriate reading of the original texts.

INTRODUCTION

Before the 1950's, the main objective of radiation protection was to avoid biological harm that would inevitably follow high doses of ionizing radiation. Such harm, e.g. skin erythema or malfunctioning of the bloodforming organs, is now referred to by ICRP as non-stochastic effects. The threshold dose for such effects is so high that, short of accidents, they will no longer occur if current radiation protection standards are respected.

From the mid-1950's, therefore, the interest has been focussed on effects like cancer and hereditary harm, for which no threshold doses have been established and the occurrence within an exposed population, although related to the individual doses, seems to be randomly distributed at equal doses. These effects are referred to as stochastic effects.

DOSE-EFFECT AND DOSE-RESPONSE RELATIONS

Not only do the nonstochastic effects show a dose threshold in their dose-response relationship (probability of effect as a function of dose), their dose-effect relationship (severity of effect vs. dose) is characterized by dose-dependent severity of effect. The stochastic effects, on the other hand, show no dose threshold in their dose-response relationship and the severity of the effect (e.g. cancer) is not dependent of the dose.

Since it is assumed that the stochastic effects may be caused by any small radiation dose, no radiation dose can be called absolutely "safe": it is always the matter of degree of safety.
THE OBJECTIVES OF RADIATION PROTECTION

On the previous basis, the aim of radiation protection is to prevent non-stochastic harmful effects and to reduce the probability of the stochastic effects as far as "reasonably achievable". This means that one should stop dose reduction at the point where further risk reduction (considering both the probability and the severity of effect) is not worth the price, because better protection results might be bought elsewhere for the same money.

THE CONCEPT OF RISK

"Risk" has many different meanings in English, as in many other languages. For example, Webster's Third New International Dictionary (1976) lists the following meanings of the word:

1: the possibility of loss, injury, disadvantage, or destruction;
2: someone or something that creates or suggests a hazard or adverse chance: a dangerous element or factor - often used with qualifiers to indicate the degree or kind of hazard;
3a (1): The chance of loss or the perils to the subject matter of insurance covered by an contract; (2): the degree of probability of such loss;
3b: amount at risk;
3c: a person or thing judged as a hazard to an insurer;
3d: an insurance hazard from a (specified) cause or source;
4: the product of the amount that may be lost and the probability of losing it - compare expectation.

No wonder that the use of the word without further specification causes confusion; the author has seen it used with three of the above meanings in one and the same sentence. It is therefore desirable to use some better defined quantities, such as

- the probability that a given individual will be subject to a specified harmful effect;
- the type of harmful effect;
- the degree or severity of the harmful effect;
- the total consequence (e.g. one death in cancer) if the harmful effect occurs;
- the probability of an action that will cause harmful effects;
- the mathematical expectation of consequence, i.e. the product of probability and consequence.
THE DETRIMENT

For the following presentation it is useful to consider the particular case when the cause of harmful effects is a radiation exposure and the harmful stochastic effects are cancer or severe hereditary harm in the first two generations of offspring of the exposed individual. The following quantities will be used:

\[ \begin{align*}
    P_{ik} &= \text{the probability of harm of type } (i) \text{ (cancer or hereditary harm) after exposure of a given individual } (k); \\\n    C_{ik} &= \text{the consequence of harm of type } (i) \text{ occurring to individual } (k); \text{ and} \\\n    G_{ik} &= C_{ik} = \text{the expectation of consequence of type } (i) \text{ to individual } (k).
\end{align*} \]

The further definition of consequence causes some conceptual difficulties. There is a primary consequence to the exposed individual, which can be described by the fact that cancer occurs and by the severity of the particular type of cancer. There is also the secondary consequence to other individuals and to the community in that any case of cancer causes concern and care, some of which is quantifiable (e.g. hospitalization costs) while other is intangible. A particular case of secondary consequence is the concern related to the perception of dose rather than to the occurrence of consequence. For example, the public or national authorities may consider radiation doses near or above authorized limits undesirable to an extent which does not correspond to the expectation of primary consequence.

ICRP has only considered the primary consequence and has assumed that any secondary consequence may be assessed on the basis of this. In the following the presentation will deal with the primary consequence.

The total expectation of consequence to all individuals from all types of cancer and hereditary (two generation) harm due to a certain radiation source (A) will be

\[ G(A) = \sum_i \sum_k P_{ik} C_{ik} \]

If the consequence \( C_{ik} \) includes weighting for the severity (\( g_{ik} \)) of the effect, \( G(A) \) may be called the detriment of source A, in line with ICRP Publication 26.

**IMPLICATIONS OF THE PROPORTIONALITY ASSUMPTION**

For the purpose of radiation protection assessments, ICRP has postulated proportionality between "dose" and probability of stochastic effects over the dose range of interest. For "dose" ICRP uses the dose equivalent, thereby making a formalistic weighting for different biological efficiency for different qualities of radiation.
A further simplifying assumption is that harm of type (i) is uniquely related to the mean dose equivalent in an organ or tissue (T=ι), i.e. cancer of the thyroid is caused mainly by exposure of the thyroid, cancer of the breast mainly by exposure of the breast, etc. With the postulated proportionality between dose and probability, it then follows that

\[ P_{ik} = a_{ik} H_{ik} \]

where \( a_{ik} \) is the probability proportionality factor. The quantities \( P_{ik} \) and \( H_{ik} \) should be read as incremental quantities: what we are interested in is an added cancer probability after a small dose equivalent in addition to that already received or expected to be received from other sources such as natural background radiation or medical practices. In radiation protection, we are never faced with a small dose increment above zero dose, so the actual slope of the dose-response curve at zero dose or at extremely small life-time doses is of no practical interest. Natural background alone gives us a life-time whole body dose equivalent near 100 mSv (10 rem).

The individual consequence if the harmful effect occurs is cancer in the exposed individual or severe hereditary harm in his immediate descendents. Each such consequence could be considered a unit consequence, but with the weighting for severity with a factor \( g_{ik} \) the expression for consequence may be written

\[ C_{ik} = 1 \cdot g_{ik} = g_{ik} \text{ (in units of severity-weighted cases of harm)} \]

The individual detriment may therefore be written

\[ G_k = \sum_i P_{ik} C_{ik} = \sum_i g_{ik} a_{ik} H_{ik} \]

The product of the probability proportionality factor and the severity factor may be called the risk factor, as by ICRP. If it is denoted \( r_{ik} \) we obtain

\[ G_k = \sum_i r_{ik} H_{ik} \]

The incremental detriment to the individual may therefore be assessed from the dose increments caused by the particular practice which is under consideration, irrespective of other exposures, as long as proportionality between dose and response is postulated.

In order fully to describe the exposure situation, one would have to assess all organ doses \( H_i \). Alternatively, the exposure may be characterized by one single quantity, the effective dose equivalent, defined by ICRP.
EFFECTIVE DOSE EQUIVALENT

The effective dose equivalent \( (H_e) \) was introduced by ICRP in line with a proposal by Jacobi in order to have a quantity to which the detriment would be proportional irrespective of the distribution of dose within the body. It should therefore satisfy the condition

\[
G_k = r \cdot H_{ek}
\]

where \( r \) is the total risk factor. It follows from the previous expression for \( G_k \) that this will be the case if \( H_e \) is defined as

\[
H_e = \sum_i \left( \frac{r_{ik}}{r} \right) \cdot H_{ik} = \sum_i w_i \cdot H_{ik}
\]

where \( w_i = w_T \) are the organ weighting factors listed by ICRP.

VALIDITY OF THE PROPORTIONALITY ASSUMPTION

Although the validity of the assumption of proportionality between dose and response for the stochastic effects may quite appropriately be challenged, it cannot yet (and probably not for a long time) be proven incorrect. Particularly for cancer from high-LET radiation and hereditary effects from all types of radiation there is at present little evidence against the proportionality assumption.

It should also be remembered that in radiation protection we are usually interested in small dose increments above contributions which we have already received or expect to receive from natural background radiation or from medical exposures. It is less likely to find non-linearity over a limited dose range than over the full range from zero dose to the high doses where we have most of the epidemiological observations.

If the true dose-response relation were found to be grossly non-linear, each new dose increment would carry entirely different significance depending upon the individual’s overall risk situation. A release of radioactive materials into the environment might cause little consequence if it is the only release but great consequence if it comes in addition to many other releases.

In such a situation, national authorities would face a situation of such complexity that it is very likely that they would chose to work on the basis of averages and on a shared responsibility for the ultimate sum of all dose contributions, rather than try to deal with each contributions on an individual basis. They would act in exactly the same manner as if proportionality had been postulated.

The advantage of the proportionality assumption is that it is probably cautious but not prohibitively so, it is easy to apply and it is easy to defend. It is an assumption which, for these reasons, is attractive to national authorities, but it is not chosen on its scientific merits.
SOURCE-RELATED DETRIMENT

From the previous presentation it follows that the detriment caused by a particular practice or source (A) is

\[ G(A) = \sum_i \sum_k P_{ik} C_{ik} = \]

\[ = \sum_k C_k(A) = r \sum_k H_{Ek}(A) = r \cdot N \cdot H_{E}(A) \]

where \( N \) is the number of individuals and \( H_{E} \) their average effective dose equivalent.

The product \( N \cdot H_{E} = S_{E} \) is the collective effective dose equivalent. It therefore follows that

\[ G(A) = r \cdot S_{E}(A) \]

The total detriment of source A may be assessed as the product of the risk factor and the collective effective dose equivalent expected to be caused by the source.

In the case of \( N=1 \), i.e. a single individual (k), the detriment is

\[ G(A) = r \cdot N \cdot H_{E} = r \cdot 1 \cdot H_{Ek} = r \cdot H_{Ek} \]

i.e. the same expression as before, although, strictly, the risk factor should have the dimension severity-weighted cases of harm over collective dose equivalent. It should therefore, strictly, be expressed per manSv rather than per sievert.

THE MAGNITUDE OF THE RISK FACTOR

As has already been shown, the organ weighting factors \( w_{T} (T=i) \) given by ICRP are derived as

\[ w_{i} = r_{i}/r \]

\[ \sum_i w_{i} = 1 \]

With the assumptions stated in ICRP Publication 26, it follows that

\[ w_{i}/r_{i} = 1/r = 60 \text{ manSv} \]

60 manSv is then the collective effective dose equivalent which, on the average, would cause one case of severe stochastic effect if the postulated assumptions are valid. It also follows that

\[ r = 1.65 \times 10^{-2} \text{ manSv}^{-1} \]
It should be recalled that the risk factor is the product of the harm probability factor $a_i$ and the severity factor $g_i$. The values used by ICRP are derived on the basis of assumptions regarding both of these factors.

ICRP has postulated that

\[
\begin{align*}
g_i &= 1 \text{ for death in cancer} \\
g_i &= 0 \text{ for curable cancer}
\end{align*}
\]

The omission of the harm caused by curable cancer has been criticized. It can be shown, however, using cancer statistics and reasonable biological assumptions that the omission is not serious. To put a value on $g_i$ is a value judgement: how many cases of curable cancer should be considered to constitute a detriment equal to that of one death of cancer?

Some indication of the relative magnitude of the problem may be obtained on the basis of the quite arbitrary and completely nonbiological but not unreasonable assumption that the severity of a curable cancer is proportional to the mortality rate for that type of cancer. This would give

\[
\begin{align*}
g_i &= 1 \text{ for death in cancer} \\
g_i &= \frac{P_{\text{mort}}}{P} \text{ for curable cancer}
\end{align*}
\]

Hence

\[
\begin{align*}
\hat{r}_i &= P_{\text{mort}} \cdot 1 + (P - P_{\text{mort}}) \cdot \frac{P_{\text{mort}}}{P} \\
&= P_{\text{mort}} \left(2 - \frac{P_{\text{mort}}}{P}\right) \approx 2P_{\text{mort}} \quad \text{for } P_{\text{mort}} \ll 1
\end{align*}
\]

On this basis the detriment would be twice as high as assumed by ICRP for cancer types such as cancer of the skin or the thyroid, for which the mortality rate and assumed severity is low.

The ICRP risk factor, however, will simply be

\[
\hat{r}_i = P_{\text{mort}} \cdot 1 + (P - P_{\text{mort}}) \cdot 0 = P_{\text{mort}}
\]

It is therefore the expectation of cancer death per unit of collective dose equivalent in organ or tissue (i). The values used by ICRP are averages over age and sex and would apply to a group of individuals of both sexes and a wide age distribution. In ICRP Publication 27 it is shown that this probably overestimates the detriment for the average individual but may give an underestimate for young women. The relative values of the weighting factors $w_i$ would, strictly, be different at different ages and therefore different also for workers and members of the public. The differences, however, have not been considered large enough to justify the complexity of a more differentiated weighting system.
The risk factors chosen by ICRP for derivation of the organ weighting factors are essentially the same that can be derived from the 1977 UNSCEAR report.

**WHAT TO CONTROL OR LIMIT**

ICRP emphasizes three basic protection principles:

- The practice causing radiation exposures should be *justified*, *i.e.* its introduction should cause a higher net benefit than any alternative choice;
- Radiation protection should be *optimized* in order to keep all doses as low as reasonably achievable; and
- Individual *dose limitation* should be used as a means to prevent non-stochastic effects and assure that the individual detriment from stochastic effects is not too high.

In order to follow these principles, we should make use of the following dose quantities:

**Justification:**

The total detriment from a practice may be assessed from the collective effective dose equivalent commitment: \( G = r \cdot S_E^c \).

**Optimization:**

The cost of the radiation detriment to be compared with the cost of protection may be assessed from the collective effective dose equivalent commitment: \( Y = \alpha \cdot S_E^c \).

**Dose limitation:**

Non-stochastic effects are prevented if all organ dose equivalents \( H_{ik} \) are kept within dose limits. The individual detriment with stochastic effects will be controlled by controlling the individual effective dose equivalent \( H_{E_k} \).

In the assessment of the justification of a practice, the collective effective dose equivalent expected from the practice provides a possibility of assessing the total detriment; in this case it is the collective dose commitment that should be assessed. This information, however, must be qualified by the uncertainty of the validity of the biological assumptions.

For optimization of protection it is usually less important if the assumptions cannot be validated, since one important objective is to obtain consistency in attitude and to find a strategy for deciding how much it is reasonable to pay for improvement of protection below the ICRP dose limits in particular cases. Such consistency would be achieved if it is decided to pay a given sum, but not more, per manSv eliminated, *e.g.* a sum of the order of 10,000 - 20,000 U.S. dollar (100 - 200 dollar per manrem).
Irrespective of whether the biological assumption is correct or not and provided that it does not change drastically the overall effort put into radiation protection, this strategy leads to a consistent approach. Even if we cannot be sure of the biological effect of each small increment of dose, we can choose to attach a "nuisance cost" to it, such that the accumulated cost would correspond to the total cost society may be willing to pay to avoid the ultimate situation if the dose increments had not been eliminated.

On the other hand, if the assumption of proportionality is valid and if the risk factor is truly $1.65 \times 10^{-2}$ death-equivalent effects per manSv, as ICRP assumes, this strategy implies a willingness of society to pay $(10,000 - 20,000)/1.65 \times 10^{-2}$, i.e. $0.6 - 1.2 \text{ M$ per radiation-induced cancer death or severe hereditary injury (in the first two generations) randomly avoided.}$

If protection can be achieved at this cost, it may be considered "reasonably achievable", but perhaps not if the cost is higher. Optimization is achieved when protection is arranged to give the minimum value of the sum of the cost of protection and the "cost" attributed to the unit collective effective dose equivalent (in, for example, dollar per manSv if the cost of protection is measured in dollar).

It should perhaps be added that "optimization of protection" is synonymous with "keeping all doses as low as reasonably achievable". The principle is sometimes referred to as the "ALARA" principle, from the initial letters of "as low as...". Unfortunately, the term "ALARA" has also been used with quite different meanings, not implying optimization of protection in the ICRP sense. ICRP is therefore hesitant to use the acronym since this is known to cause confusion.

Dose limitation calls for two things: both an organ dose limit in order to prevent non-stochastic effects, and a "whole-body" dose limit to assure that the total probability of severe stochastic harm to the individual will not be so high that it is likely to be objectionable in comparison with other risks. For these purposes, the mean organ dose equivalent $H_{ik}$ and the effective dose equivalent $H_{eq}$, respectively, seem to be the appropriate quantities for limitation.

THE MAGNITUDE OF THE DOSE LIMIT

For the purpose of preventing non-stochastic effects, even after life-long exposures, ICRP recommends an organ dose equivalent limit of 500 mSv (50 rem) in any one year for workers and one tenth of this value for members of the public. There is an exception for the lens of the eye, for which the annual dose limit for workers is 150 mSv (15 rem).

It should be noted that this does not allow 1700 mSv (170 rem) per year in the thyroid, as some critics have claimed.
For the purpose of limiting the individual detriment from stochastic effects, ICRP recommends an effective dose equivalent limit of 50 mSv in any one year for workers and 5 mSv in any one year for individual members of the public. For the latter it is also recommended that the average over a lifetime of the annual effective dose equivalent should not exceed 1 mSv, provided that the doses are realistically assessed.

It would have seemed natural to have recommended a lifetime limit also for the occupational dose. There is a practical difficulty, however. The individual member of the public is not subject to individual monitoring and operational control. His exposure is entirely controlled by source control and there is no further restrictions on his own behavior (e.g. it is not requested that he should restrict his eating habits, his use of his environment or his purchase of consumer products). It is therefore administratively necessary to control his lifetime dose or the average annual dose by controlling the sources (e.g. by restricting releases of radioactive substances into the environment or by restricting the types and properties of consumer products permitted on the market).

The radiation worker, on the other hand, may not always be protected by source control. His own operational behavior will influence his exposure and he is subject to individual monitoring and operational control. If, in addition to a dose limit for any single year, there would also be a dose limit for the average year, the operational control would have to take account of previous and expected exposures. This would lead to a rather complicated dose record bureaucracy where the numbers probably would have little relation to reality, considering that an individual dose meter only very crudely reflects the actual effective dose equivalent. The ICRP recommendation that it will suffice to use dose meter readings instead of a more involved assessment of the actual effective dose equivalent is based on the assumption that the dose meter usually gives an over-estimate of the effective dose equivalent.

WHY HAS NOT ICRP LOWERED ITS RECOMMENDED DOSE LIMITS?

The dose limits recommended in ICRP Publication 26 have been criticized as being too high and various authors have suggested lower values. Why has ICRP retained the old values? The probability of severe stochastic effects at the occupational dose limit seems rather high. I shall try to give some answers to this criticism.

The meaning of the dose limit has been changed

The present dose limits, although numerically the same, have an entirely different meaning than the old limits and should therefore not be directly compared with these. This change in meaning is far more important than any suggested reduction of the old limits.
The previous dose limits were seen as the upper boundaries of safe levels (the threshold thinking dominated) and were recommended as target points "for purposes of planning and design". It was perfectly acceptable to work up to the dose limits and there was no encouragement further to reduce doses which were already below the dose limits.

The present dose limits are rather the lower boundaries of totally unacceptable levels. To be below the dose limits is not an sufficient condition for acceptability. The main recommendation is to keep all doses as low as reasonably achievable. For most workers this leads to a much safer situation than the introduction of lower dose limits without any incitement not to stay at the dose limit.

**Authorized limits for particular operations should generally be lower than the dose limits**

The principle of optimization of protection, although useful for designers and in operational practice, is primarily recommended for the use of competent national authorities, which should use it as one basis for deriving authorized limits or intervention levels for particular practices and operations. These limits and levels are normally expected to be lower than the ICRP basic dose limits or derived operational limits based on these.

This aim is usually not appreciated by the critics, who are afraid that optimization of protection will be left entirely at the discretion of the management of each operation. This is not what ICRP recommends. This may be illustrated by the following quotations:

"Because of the different conditions that apply in various countries, detailed guidance on the application of its recommendations, either in regulations or in codes of practice, should be elaborated by the various international and national bodies that are familiar with what is best for their needs."

*(ICRP Publication 26, para. 5)*

"The national regulatory authorities are, however, expected to establish the necessary standards and control procedures and to expand detailed technical requirements."

*(ICRP Publication 15, para. 3)*

"Limits laid down by a competent authority or by the management of an institution are called authorized limits. These should, in general, be below derived limits though, exceptionally, they may be equal to them. The process of optimization may be used in the establishment of authorized limits and they apply only in limited circumstances. It is important that such limitations should be clearly laid down. Where an authorized limit exists it will always take precedence over a derived limit."

*(ICRP Publication 26, para. 148)*
In the cases where the ICRP dose limits seem unreasonably high and workers need a guarantee of a higher degree of safety, it is therefore quite in line with ICRP Publication 26 for the competent national authority to establish an authorized limit for the particular practice.

The total ICRP system of dose limitation is found to produce a situation where the average probability of death in radiation work is not higher than in occupations which are usually considered safe.

For the average worker, the existence of the dose limits and the optimization requirement, etc. results in annual doses which are only about 1/10 of the dose limits. This produces a risk situation which is comparable with that in occupations which are usually considered safe.

It is important to make the comparison on the basis of death risk to death risk, morbidity risk to morbidity risk, average risk to average risk and maximum risk to maximum risk. Also in so-called safe occupations there are some workers who have a risk which is much higher than average.

Work at the dose limits must not have to be considered entirely safe.

It must be remembered that exposure at the dose limits is not the aim of radiation protection: the dose limits indicate the beginning of an unacceptable situation. It follows that work at the dose limit is not desirable and only acceptable if the risk cannot be reduced by any reasonable means.

When protection is not reasonably achievable, society accepts work at considerably higher than normal risk levels (fishing, construction work, diving, etc.). This work is not labelled "safe" but recognized to carry a higher than normal risk.

The same would be the case with radiation work near the dose limit:

"Exposures consistently near the limits would be comparable with a situation where a higher-than-average risk has been identified for certain individuals in non-radiation industries."

(ICRP Publication 26, para. 101)

"Long-continued exposure of a considerable proportion of the workers at or near the dose-equivalent limits would only be acceptable if a careful cost-benefit analysis had shown that the higher resultant risk would be justified."

(ICRP Publication 26, para. 102)
If the work can reasonably be carried out at lower levels, however, the *optimization* principle requires that this *must* be done. National authorities should determine the mechanism to assure that it is done; setting authorized limits lower than the dose limit is one available method.

If one wishes to have a system that would guarantee all workers the same degree of protection as that which is possible by reasonably achievable results, of course the present basic dose limits could be lowered substantially. This, however, would mean a much higher protection ambition than in any other area since it would rule out entirely any work where reasonable efforts would not suffice to keep the dose within the lower limit. The alternatives would be either to obtain sufficient protection at higher cost than required in other areas or to make an exemption from the lower limit. The latter action, however, would be equivalent to keeping the present limits and the lower limits would only be an illusion.

The degree of protection at the present limits may still be discussed and questioned, if only all the implications are appreciated.

The annual probability of dying in cancer at a certain dose level as indicated by the ICRP risk factor is a risk *committed* annually at the time of exposure but *expressed* first some decades later.

The cancer death *commitment* per unit effective dose equivalent at the time of exposure should not be compared with the total probability of death over the period of time when the exposure occurs. It is the future change in the age specific death rate which is relevant. A very crude assessment based on the age related harm commitments shown in ICRP Publication 27 gives the following values:

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<th>Annual effective dose equivalent</th>
<th>Annually committed prob. of death</th>
<th>Max. increase of future mortality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mSv (5 rem)</td>
<td>$10^{-3}$</td>
<td>5-10 %</td>
</tr>
<tr>
<td>1 mSv (0.1 rem)</td>
<td>$2 \times 10^{-5}$</td>
<td>0.5-1 %</td>
</tr>
</tbody>
</table>

If the annually committed probability of death had been compared (as is usually done) with the age specific mortality rate at the time of exposure, it would have been found to be 200% of the latter for young women. The delay in expression of harm, makes it relatively if not absolutely less important.
INDIVIDUAL-RELATED AND SOURCE-RELATED CONTROL

Individual dose limits are only part of the ICRP full system of dose limitation. It is not enough to provide a low risk to each individual if the total detriment from some sources is out of proportion to the benefit from the same sources or if detriment reduction can be achieved at a cost that justifies the reduction.

Individual dose limitation: individual-related protection

Since for most radiation practices benefit and detriment are not equally distributed over the population, it is not certain that justification of practice and optimization of protection will give a result that is acceptable to all individuals. For this reason, individual-related protection by dose limits is necessary to guarantee that no individual is subject to an intolerable risk.

It should be noted that the ICRP dose limits apply to the sum of all dose contributions, irrespective of source (although natural radiation and medical exposure of patients are not subject to dose limits even though the justification and optimization principles are valid also for these sources).

Justification of practice and optimization of protection: source-related protection

In addition to the individual-related protection which is conventional and easy to understand, ICRP recommends the source-related actions of justification of the practice and optimization of protection. For these purposes the total detriment from the source should be assessed without regard to its distribution over individuals, subject only to the boundary condition of the individual dose limits.

A further source-related control may be necessary if it is expected that a certain category of sources may increase in number or intensity in the future. It may then be evident that each source may have to be more stringently controlled than if it had been the only source of its kind, in order to keep the future individual annual doses within the dose limits. A tool for this purpose is the incomplete dose commitment assessed over a time period equal to the expected duration of the practice. If this is subject to a limit related to a unit of practice, the future situation may be controlled from the very beginning.

CONCLUSION

The ICRP system of dose limitation, of which individual dose limits are only one constituent, is based on a number of assumptions, the validity of which cannot be proven with certainty but is postulated for the purposes of radiation protection. It is the author's belief that this system combines prudent caution, ease of application and an inherent consistency which makes it easy to defend. However, it is an integrated system and its logic will fail if it is only partially applied.
REFERENCES


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