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PAST AND PRESENT OF RISK ASSESSMENT FOR RA-226 RELEASES*†

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RESUMO. Alguns dos conceitos novos introduzidos pelo ICRP26 parecem de difícil aplicação para o caso de doses limites no que concerne às liberações de ^{226}Ra proveniente das fases iniciais do ciclo de combustível nuclear. Assim sendo, a maioria das legislações nacionais ainda não foram permeadas pelas doses limites para ^{226}Ra baseadas em tais conceitos. Este trabalho chama a atenção para o fato de que, por um lado, o conceito mal definido de risco aceitável está implícito no sistema de limitação de dose para ^{226}Ra quando tal sistema é baseado em cálculos de dose como uma fração do $(MPC)_w$ introduzido no ICRP2. Por outro lado, também chama a atenção para o fato de que o ALI recomendado presentemente pelo ICRP30 deve ser usado apenas dentro da infraestrutura de recomendações publicada no ICRP26, que adota um conceito de risco melhor definido.

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Abstract:

Some of the new concepts introduced by ICRP 26 seem to be difficult to apply to the case of dose limits concerning the ^{226}Ra releases from the front end of the nuclear fuel cycle. Accordingly most national legislations have not been permeated yet by the ^{226}Ra dose limits based on such concepts. This work calls the attention on the one hand that a loose concept of acceptable risk is implicitly used in a dose limitation system for ^{226}Ra when such system is based on calculating the dose as a fraction of the $(MPC)_w$ introduced earlier by the ICRP 2, and on the other hand that the ALI currently recommended by the ICRP 30 should be used only in the framework of the recommendations published in the ICRP 26, which adopts a better defined concept of risk.

1. INTRODUCTION

The subject of risk assessment has been part of an intense debate which followed the publication in 1977 of the new recommendations (1) made by the International Commission on Radiological Protection (ICRP). Concepts associated with risk, however, had been used for many years in ICRP recommendations. In particular, the ICRP 9 explicates that any exposure to radiation[1] may carry risks of somatic and genetic effects (2).

On the one hand the dose limitation system based on a fraction of the Maxima Permissible Concentrations (MPC) introduced by the ICRP 2 (3) can be interpreted as having embedded the concept of acceptable risk to the individual and to society pondered by the benefits which may be derived from activities involving exposure to radiation. Paragraph 34 of ICRP 9 (2) explains that a degree of risk, considered to be acceptable, must limit the radiation dose to a certain level. This level of radiation dose is known as the permissible dose and the ICRP suggests that such dose might be called an acceptable dose with the same meaning (2). Paragraph 74 of ICRP 9 points out that at very low levels of risks, as implied by the dose limits for members of the public, chances are that only minor consequences to the health of such members of the public (or to their progeny) may occur if the dose limits are exceeded.

On the other hand paragraph 129 of ICRP 26 reviews critically the recommendation of the former genetic dose limit of 5 rem (50 mSv) in 30 years from all sources of radiation additional to the dose from natural radiation background and from medical procedures. The current ICRP position is based on the assumption that "continuance of the former genetic dose limit could be regarded as suggesting the acceptability of a higher population exposure than is either necessary or probable, and a higher risk than is justified by any present or easily envisaged future development."

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[1]the word radiation, as used in the ICRP 9 and in the context of this work, refers only to *ionizing* radiation.

Furthermore the ICRP recognized that for purposes of regulation and monitoring the quantity called radiation dose is difficult to be determined directly, and suggested accordingly simplified models to establish interrelationships for radiation doses, environmental quantities and parameters, and planned releases of radionuclides into the environment (4). The ICRP recommended also derived and secondary dose limits whose calculations are explained in detail in ICRP 30, Part 1 (5). The metabolic data and models used in the ICRP 30 are essentially those of an adult person with anatomical and physiological characteristics of the Reference Man (6).

The system of risk assessment devised in the ICRP 26 are to be used within a framework of risks versus benefit and cost-effectiveness. This framework is the basis of the cost-benefit analysis to be applied to the field of radiological protection to conform dose reductions according to the established in paragraph 12 of ICRP 26. Here one must bear in mind that paragraphs 47 and 52 of ICRP 9 have essentially the same features as those established in paragraph 12 of ICRP 26.

The present work aims to address some aspects of the problem of risk assessment for ^{226}Ra releases from uranium mining and milling from the past and present ICRP recommendations.

2. PAST ICRP RECOMMENDATIONS

2.1. Historical reasons.

Reviews made by MORGAN (7) and TAYLOR (8) present the historical reasons behind the inchoative ICRP recommendations until 1974. More recently SOWBY (9) published a brief overview of the ICRP activities from inception until 1981.

2.2. Concepts and recommendations.

The changes in concepts and definitions which are used to describe the operational quantities involved in radiation protection may be considered as a result of the evolution of the field. Although there is not any intention to make a review of such concepts and definitions, a description of the information relevant to risk assessment for ^{226}Ra releases will be presented here.

The concept of dose equivalent has been introduced in the field of radiation protection to improve the correlation between potentially deleterious effects of exposure to radiation and the absorbed dose. The latter is essentially the amount of energy deposited by radiation in total or any part of the human body. When considering the concept of internal absorbed dose, it depends on the decay scheme of the radionuclide, its distribution throughout the body or organ, and the time integral of the radioactive concentration at a time, which takes into account the residence time of the radionuclide in the human body. The conceptual basis for the determination of dose equivalent is discussed in the ICRU Report 25 (10), and the adopted definitions for the radiation quantities and units can be found in the ICRU Report 33 (11).

The concept of maximum permissible dose (MPD) was introduced to quantify a degree of risk associated with a limit of radiation dose at which the assumed risk could be considered acceptable to the individual and to society vis-a-vis the benefit derived from activities involving exposure to radiation. These earlier concepts associated with risk are somewhat related to the United Nations Scientific Committee on the Effects of the Atomic Radiation (UNSCEAR) Reports (12, 13) and to ICRP Publications 2 (3), 8 (14) and 9 (2).

The MPD concept gave rise to the maxima permissible concentrations in air $(MPC)_a$ and in water $(MPC)_w$. Both the (MPC)a and the $(MPC)_w$ can be derived based on the power function or the exponential model and the $(MPC)_w$ values are shown in TABLE I. ICRP 2 (3) adopted $(MPC)_w$ values derived from the exponential model based on 1.1ℓ of water consumed in average in a 8 hr work day period, corresponding to one half the water consumed in 24 hr. The biological, physical and chemical information available at the time the $(MPC)_w$ values were adopted can be found in summarized form in ICRP 2 (3).

TABLE I. $(MPC)_w$ for ^{226}Ra calculated by the power function method and exponential model, for occupational exposure. Data from ICRP 2 (3).

Method		^{226}Ra $(MPC)_w$ μCi/cm³		^{226}Ra $(MPC)_w$ Bq/ℓ
Power function		1×10^{-6}		37
Exponential model	a	4×10^{-7}	Maximum permissible burden to bone, $0.1\mu Ci\,^{226}Ra$	15
	b	10^{-7}		3.7
	a	6×10^{-6}	Maximum permissible body burden, $0.2\mu Ci\,^{226}Ra$	222
	b	2×10^{-7}		7.4
	a	10^{-3}	Gastro-intestinal tract (lower level intestine)	3.7×10^{4}
	b	5×10^{-4}		1.9×10^{4}

a. 40 hr/week, 50 weeks/year for a continuous work period of 50 years.
b. 50 years of continuous exposure (i.e., 168 hr/week).

One can interpret that the dose limits recommended by ICRP 2 (3) are based on the assumption that a M.P. burden to bone (the critical organ for ^{226}Ra) of $0.1\mu Ci\,^{226}Ra$ (3.7×10^3 $Bq\,^{226}Ra$) carries "no effect" as far as bone tumors are concerned. A built in risk factor, however, is implicit in recommendations made on the basis of comparisons with radium body burden. Risk factors are concealed in the adopted $(MPC)_w$ values listed in TABLE I, since such values are derived from body burdens based on MPD values associated with a degree of risk assumed to be acceptable.

ICRP 8 (14) moved closer to UNSCEAR position (12, 13) by considering useful to estimate risks for radiation protection purposes. Three types of risks are considered in ICRP 8 (14): somatic risks to the exposed generation, genetic risks to the first generation offspring of exposed persons, and genetic risks to later generations.

Absolute risks were expressed as "the number of disabilities expected per unit dose of radiation in the lifetimes of a million members of a population or as the number of disabilities per year in such a population". Orders of risk were also used in such a way that a risk of death or injury would be defined as a fifth order risk if in a total population of 10^6 persons, 10 to 100 deaths (or injuries) would be expected. Relative risks were considered when the risk associated with an effect supposedly caused by 1 rad could be compared with the risk of a similar effect caused by natural reasons (14).

Tentative estimates of genetic risks proved to contain too high uncertainties to be taken quantitatively into account. The genetic risks which might be associated with low level ^{226}Ra releases from the front end of the nuclear fuel cycle, for example, cannot be estimated with any degree of certainty based on the concepts of risk used in the ICRP 8.

ICRP 9 (2) established that the MPD for occupational exposure should be regarded as upper limits and the annual dose limits for members of the public should be one-tenth of the corresponding MPD.

A specific recommendation concerning risks is included in paragraph 47 of ICRP 9 to state that the risks to the members of the public from controllable sources of radiation should be less or equal the risks from other human activities, and should be justifiable in terms of unequivocal benefits (2). However, neither the risks from low level ^{226}Ra releases above a varying natural radiation background nor the benefits from uranium mining and milling could ever be quantitatively established. One of the main limitations regarding the applicability of the risk-benefit recommendation included in the ICRP 9 is the fact that the members of the public at risk are not necessarily the same members of the public receiving the benefits. In the case of uranium mining and milling for example it is conceivable that the risks may be borne by members of the public of a developing region or country, while the benefits may be received somewhere else, but almost certainly by members of the public which are part of an industrialized region or country. To the best of my knowledge, the ICRP 9 recommendation on risk-benefit never interfered either with the extraction of uranium from an economically feasible deposit or with the market price of U_3O_8.

The lack of precision in the definition of members of the public made such concept unfeasible for dosimetric purposes anyhow, because it would depend on factors such as differences in age, size, metabolism, customs, an environmental variations.

ICRP 9 used also the concept of critical group to avoid some of the uncertainties associated with the definition of members of the public. The critical group is assumed to be "small enough to be homogeneous with respect to age, diet and those aspects of behaviour that affect the dose received" (2). ICRP 7 (15) pointed out that the population distribution and habits of the critical group should be among the factors which would affect the design of a routine survey for radioactivity outside the boundaries of a nuclear installation.

As a consequence of the ICRP recommendations, previous to the ICRP 26, one could have interpreted that pre-operational environmental impact analyses for uranium mining and milling operations should be carried out taking into account hypothetical critical groups whose members would receive the highest doses from ^{226}Ra and other radionuclides released from such operations. In doing so, one should account also for changes likely to occur, during at least the operational time of the installation, in population distribution and habits (including agricultural practices) of hypothetical critical groups. Pre-operational environment impact analyses for uranium mining and milling are not easily found in the literature. Partial reports from Australia (16) and Brazil (17) can be considered, however, as examples of tentative baseline studies.

3. PRESENT ICRP RECOMMENDATIONS

Risk assessment as proposed in 1977 by ICRP 26 (1) is in essence the outcome of an evolution in concepts. The early concern of the ICRP with the prevention of occurrence of health effects is reflected in the recommendations stated in ICRP Publications 2 (3) and 9 (2). Later ICRP 22 (18) tentatively explained the basic principles of dose limitations as recommended in paragraphs 47 and 52 of ICRP 9 (2). Accordingly the word risk used more or less freely in ICRP 9, and thus far in this work, was substituted in the ICRP 22 by the term detriment[2] meaning essentially

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[2]Detriment is defined (18) as $G = P \sum_i p_i g_i$ where P is the number of persons in the group exposed to radiation, p_i is the probability of suffering the effect i, and g_i expresses the severity of the effects as a weighting

the mathematical expectation of occurring a harm to a given individual due to a radiation dose, taking into account the probabilities of occurrence of each type of deleterious effect and the severity of such effects. The term risk[3] started then to be used as the probability that a given individual would undergo a deleterious effect as a result of a radiation dose (18).

The use of cost-benefit analysis techniques for radiological protection was first suggested in ICRP 22 (18). However, only in ICRP 26 (1), which superseded the latter, these techniques were seriously taken into consideration as the basis for a new system of dose limitation. Accordingly, ICRP 26 (1) introduced the concept of collective dose assessment to provide quantitative information for radiation protection of populations.

Here one must bear in mind that the techniques of cost-benefit analysis were introduced in radiological protection to conform dose reductions as recommended in paragraphs 47 and 52 of ICRP 9 (2) and paragraph 12 of ICRP 26 (1), that means, the ALARA principle. Thus the association of such techniques with decision making processes constitutes an effort to compare the tangible with intangible, as the ICRP is recommending that one should compare economical factors with the relative importance of human exposure to radiation. This is to be done under the assumption that radiological protection depends not only on chemical, physical and biological data but also on value judgement. The latter means essentially that a degree of risk is assumed to be always associated with exposure to radiation, no matter how low is the level of such exposure, and that society implicitly or explicitly have to put money values to decrease a risk as compared to other risks.

Assuming that the risks regularly accepted in everyday life could be considered as a basis for the level of acceptability for fatal risks to the general public, and taking into account that the latter are one order of magnitude lower than for occupational risks, ICRP 26 (1) considered that fatal risks "in the range of 10^{-6} to 10^{-5} per year would be likely to be acceptable to any individual member of the public". Taking into account this range for fatal risks and assuming that there would be few practices exposing the public and little exposure outside the critical group, an annual dose equivalent of less than 5 mSv (0.5 rem) to individual members of the public would result in average dose equivalent of less than 0.5 mSv (0.05 rem). These dose limitations for individual members of the public are based on the weighted mean annual whole body dose equivalent limit[4].

Secondary limits called Annual Limits of Intake ALI[5] were recommended by ICRP 30 (5) to meet the basic requirements for limiting occupational exposure. The ALI for ^{226}Ra is 7×10^4Bq (1.9μCi) based on metabolic data taken from ICRP 20 (19), and assuming oral intake by

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[3]Risk is defined (1,18) as $R = 1 - \pi_i\,(1-p_i)$ where p_i has the same meaning as in footnote[2]. This expression can be reduced to $R = \Sigma p_i$ when the effects i are mutually exclusive and/or $p_i \ll 1$.

[4]The recommended annual whole body dose equivalent limit $H_{wb,L}$ is 50 mSv (5 rem) for individual workers, and assumes that the risk should be equal whether the whole body is uniformly or non-uniformly irradiated.

[5]The ALI of a radionuclide is the greatest value of the annual intake I which satisfies the following inequalities:

$$I \sum_T w_T \,(H_{50,T} \text{ per unit intake}) \leq 0.05 \text{ Sv; and}$$

$$I(H_{50,T} \text{ per unit intake}) \leq 0.5 \text{ Sv}$$

where I (in Bq) is the annual intake of the specified radionuclide either by ingestion or inhalation, w_T is the working factor for tissue T, and $H_{50,T}$ per unit intake (in Sv Bq^{-1}) is the committed dose equivalent in tissue T from intake of unit activity of the radionuclide by the specified route for 50 years after intake.

ingestion of food and drinking water. The ALI and H_{50} per unit intake are theoretical maximum values to be used in the control of occupational exposure, and are not supposed to be reached. However, the ICRP 30 (5) recommends that when there is the possibility that an individual has exceeded the ALI, his age and biological parameters should be taken into account, as far as practicable, to estimate the resulting committed dose equivalent.

The present concepts introduced by ICRP 26 seem to be difficult to apply to the case of ^{226}Ra dose limits for populations outside the boundary of uranium mining and milling installations. The difficulties of applying such concepts to the front end of the nuclear fuel cycle were discussed recently by PASCHOA et al. (20). Paragraph 219 of ICRP 26 (1) had in fact anticipated difficulties in applying the new concept of collective dose equivalent for cases involving large populations and low dose levels.

4. PAST VERSUS PRESENT

Risk assessment for ^{226}Ra releases from uranium mining and milling can be considered as a test case for the uncertainties mentioned in paragraph 219 of ICRP Publication 26. The site of occurrence of a uranium deposit economically feasible to be mined depends on geological factors which are unbound to any of the usual criteria adopted for selecting sites for other nuclear installations. Milling facilities are usually located in the same geographical area of uranium mines. As a consequence, collective dose assessment models for uranium mining and milling may have to be used on site specific environmental models associated with the natural occurrence of uranium. The uncertainties associated with these models make it difficult to apply the cost-benefit analysis to the front end of the nuclear fuel cycle.

As a matter of fact, most national legislations for ^{226}Ra releases still reflect the past ICRP recommendations which include the $(MPC)_w$ concept. So, an implicit acceptable risk is embodied in these national legislations for ^{226}Ra, though the correct term should be now acceptable detriment.

The International Atomic Energy Agency (IAEA) states in Safety Series No. 45 (21) the objetives of radiation protection for environmental releases of radioactivity based on the current ICRP recommendations, and is about to publish generic models and parameters for assessing the environmental transfer of radionuclides from routine releases to be used at a pre-operational stage of a nuclear installation (22). These IAEA publications may help national authorities to comply with the dose limitation system currently recommended by the ICRP.

Although, for the specific case of ^{226}Ra releases the past and present risk assessments seem to be almost equivalent because of the uncertainties involved in both cases, the past $0.1 \mu Ci\,^{226}Ra$ ($3.7 \times 10^3 Bq\,^{226}Ra$) maximum permissible burden to bone should not be directly compared with the present ALI of $7 \times 10^4 Bq\,^{226}Ra$ ($1.9 \mu Ci\,^{226}Ra$). The Official Journal of the European Communities suggests that Member States may adopt within 30 months from 3 June 1980 an ALI by ingestion of $0.19 \mu Ci\,^{226}Ra$ ($7 \times 10^3 Bq\,^{226}Ra$) for members of the public (23). National legislations regulating ^{226}Ra releases can be based either on the past or present dose limit system, however, care should be exercised to maintain consistency with the framework of the corresponding ICRP recommendations.

5. CONCLUDING REMARKS

In conclusion some remarks are offered for further discussion. They are as follows:

(i) Most national legislations still use the $(MPC)_w$ for ^{226}Ra as the basis for regulating ^{226}Ra releases to the environment.

(ii) The $(MPC)_w$ values listed in ICRP 2 are mostly based on the assumption that a maximum permissible burden to bone of 0.1μCi ^{226}Ra (3.7×10^3 Bq ^{226}Ra) carries "no effect" as far as bone tumors are concerned.

(iii) It can be interpreted that the $(MPC)_w$ values have concealed risk (or detriment) factors.

(iv) Current ICRP concepts are not easily applicable to ^{226}Ra releases bacause there are many uncertainties in parameters which have to be used for pathway models.

(v) Further discussion, maybe a future symposium, on the application of the current ICRP concepts to the front end of the nuclear fuel cycle may help national authorities facing regulatory problems for ^{226}Ra releases.

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