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THE DOSE LIMITATION SYSTEM IN THE NUCLEAR FUEL CYCLE AND IN RADIATION PROTECTION

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LIMITATION OF FUTURE RADIATION EXPOSURES FROM THE PRESENT OPERATION OF NUCLEAR FUEL CYCLE INSTALLATIONS

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Abstract

LIMITATION OF FUTURE RADIATION EXPOSURES FROM THE PRESENT OPERATION OF NUCLEAR FUEL CYCLE INSTALLATIONS.

This paper reviews the bases and the formulation for limiting the doses in the future from the combined contribution of present and future practices causing radiation exposures. Local, regional and global contributions to the exposure of given population groups are discussed, and the use of the collective dose commitments for predicting future exposures from continuing practice is presented. The paper discusses the limitation of the dose commitment and of the collective dose commitment per unit practice as procedures for controlling future exposures. It also presents the bases used to assign upperbounds of exposure, which are fractions of the relevant dose limits, to exposures caused by a given source or practice. These considerations have been introduced in the regulatory requirements used in Argentina, and the paper examines the bases of the relevant provisions.

1. INTRODUCTION

1. A practice involving exposures usually gives rise to a distribution of doses, and thus of detriment, and to a distribution of benefits. In general these two distributions are quite different and, therefore, the distribution of benefits can be used to justify the distribution of detriments only if the detriment to each individual is small, not exceeding levels which could be regarded as acceptable. The dose limits recommended by the ICRP are intended to ensure this protection even for the most highly exposed individual.

2. The dose limits, however, are not intended to be values used for design installations, or for planning operations, but are rather the lower boundary of a region of unacceptable values in normal circumstances. Values above the limits are specifically not permitted, but values below the limits are not automatically permitted. In this sense, the limits are only constraints for the optimization of protection [1].

3. The use of the dose limits as constraints for optimization presents some conceptual difficulties, specially in the case of general exposures of members of the public. The dose limit is an individual-related requirement, while optimization is a source-related requirement. Because the dose limit applies to the combined exposure from many practices, it can not be used to limit a given single practice even when optimization would allow it. In fact, exposures at the limit from one single practice would leave no margin for other practices which would expose the same critical group.

4. The problem of overlap of exposures from different practices is not restricted to any given instant of time. Each year of operation of a continuing practice can cause exposures which would be delivered in the future and which would add to the contributions of other years of operation of the practice. The dose rate resulting from the combined effect of all such annual discharges will increase reaching eventually a steady state, or a maximum if the practice is discontinued in the future. The maximum value of the annual doses from continuing practices could occur far in the future, and also be maintained over considerable periods of time.

5. For the purpose of constraining optimization of the protection of specific practices, it seems therefore reasonable that national authorities select "dose upper bounds" which are small fractions of the dose limit, allowing for the exposure overlap from continuing practices and reserving also some margin for unforeseen requirements in the future which otherwise would be precluded.

2. CONTRIBUTIONS TO THE EXPOSURE OF CRITICAL GROUPS

6. Critical groups are defined for given sources of radiation exposure. The annual limit for the effective dose equivalent in individual members of the public, recommended by the ICRP, applies to the average effective dose equivalent in the "critical group", namely the group representing the most exposed individuals [1], from the sources under consideration. Critical groups, however, can be exposed also by other sources contributing regional or global exposures. All these contributions have to be considered at the time in the future when they are expected to be maximum, if the practices are of continuing nature.

2.1 Maximum future exposures from continued practices

7. A continued practice at a constant rate may be regarded as a series of events, each generating in a given critical group

a *per caput* effective dose equivalent rate which is a function of the time elapsed since the event. The combined effective dose equivalent rate will increase, reaching eventually a steady state value. This value, $\dot{H}_m$, can be calculated by integrating the contributions to an arbitrary time T after steady state has been reached [2]:

$$\dot{H}_m = \int_{-\infty}^{T} \dot{R}\,\dot{H}_1\,(T-t)\,dt = \dot{R}\int_0^{\infty} \dot{H}_1(t)dt = \dot{R}\,H_1^c$$

where $\dot{R}$ is the practice rate (units of practice per unit time), $\dot{H}_1(t)$ is the effective dose equivalent rate in the critical group, per unit practice, as a function of the time elapsed since that unit of practice, and H_1^c is the effective dose equivalent commitment per unit practice, in the critical group under consideration.

8. In an actual situation the practice rate may not remain constant, and in any case the practice may not be long enough for the dose rate to reach a steady state value. In these cases it is still possible to obtain an approximate value of the maximum future dose rate using the expression described above, if the "incomplete" dose commitment is used, integrated over a time equal to the duration of the practice [2].

2.2 Maximum future exposures from a wide distribution of sources of exposure

9. Contributions from far away similar sources may also expose the critical group under consideration. The total maximum future dose rate contribution from sources present in a region can be assessed by integrating the contributions from all present and foreseen sources in the region. A rough approximation of the future maximum dose rate can be obtained using the collective dose commitment per unit practice.

10. The collective effective dose equivalent rate, $\dot{S}$, in a population is defined by the expression [2,3]

$$\dot{S} = \int_0^{\infty} \dot{H}\,N(\dot{H})\,d\dot{H}$$

where $N(\dot{H})$ is the population spectrum in effective dose equivalent rate, $N(\dot{H})d\dot{H}$ being the number of individuals receiving an effective dose equivalent rate in the range $\dot{H}$ to $\dot{H} + d\dot{H}$. The collective effective dose equivalent rate from a source is obtained by including in the population under consideration all individuals receiving a dose from the source.

11. The collective effective dose equivalent commitment, S_1^c, due to a unit of practice is defined as the infinite time-integral of the collective effective dose equivalent rate, $\dot{S}_1(t)$, caused by that unit of practice:

$$S_1^c = \int_0^\infty \dot{S}_1(t)\, dt$$

Assuming for simplicity that on the average and over long periods of time exposures are independent of direction and only a given function of distance from the source, the collective dose commitment per unit practice would be given by

$$S_1^c = \int_0^\infty \int_0^\infty \dot{H}_1(x,t)\ \delta\ 2\pi\ x\ dx\ dt$$

where $\dot{H}_1(x,t)$ is the dose rate caused by a unit of practice, at a distance x and at a time t after that unit of practice, and δ is the population density which can in the general case be a function of both x and t.

12. A simple case of the use of the collective dose commitment per unit practice to assess the combined contribution of sources in a wide region to the maximum future dose rates in a given critical group, is the ideal situation of a uniform distribution of sources in that wide region. In this case, the future steady state dose rate $\dot{H}_m$ from the combined exposure to all sources, at an arbitrary time T, would be

$$\dot{H}_m = \int_{-\infty}^{T} \int_0^\infty \dot{H}_1(x,T-t)\ \dot{A}\ 2\pi\ x\ dx\ dt$$

where $\dot{A}$ is the practice density rate (number of units of practice per unit time and per unit area), and the other symbols have the same meaning as previously.

13. If the population density can be assumed to remain approximately constant, during the period of time and over the space contributing to the integrals of the above expression, then it follows from the two previous paragraphs that

$$\dot{H}_m \simeq \frac{\dot{A}}{\delta} S_1^c$$

As in the case of the use of the incomplete dose commitment [2], if the region contributing to the exposure is not very wide, the appropriate space integration would also be incomplete, up to the relevant distances.

14. Obviously the assumption of uniform distribution of sources and of population is not very realistic, and the maximum future dose rate resulting from all the sources will vary from place to

place. In assessing the contribution from sources in the region and from those world-wide distributed, it can be assumed as a rough approximation that the exposure in the critical group is equal to the *per caput* exposure in the region or world-wide, respectively [3, 4,5]. These *per caput* contributions can be assessed using the expression presented in the previous paragraph, introducing the appropriate averaging for the region (R) and the global (G)

$$\bar{\dot{H}}_{m,R} = \overline{\left(\frac{\dot{A}}{\delta}\right)_R} \, S^c_{1,R}$$

$$\bar{\dot{H}}_{m,G} = \overline{\left(\frac{\dot{A}}{\delta}\right)_G} \, S^c_{1,G}$$

and using the values $S^c_{1,R}$ and $S^c_{1,G}$ which are respectively the regional and global collective dose commitment per unit practice.

15. The average value of $(\frac{\dot{A}}{\delta})$ in an area of interest can be obtained from the ratio of the practice rate and the number of people in that area. This ratio, namely the number of units of practice per unit time $\dot{R}$ divided by the number of people N, can be called the "practice intensity", I:

$$I = \frac{\dot{R}}{N} = \overline{\left(\frac{\dot{A}}{\delta}\right)}$$

16. In the assessment of future maximum *per caput* dose rates ($\bar{\dot{H}}_m = I\, S^c_1$) it is necessary to take into account the expansions of present practices by increasing I appropriately. This parameter is the *per caput* practice rate and predictions of its evolution should be consistent with other parameters of the models used to describe development.

3. SELECTION OF "UPPER BOUNDS" FOR SPECIFIC PRACTICES

17. The selection of a "dose upper bound" for the direct exposure of the critical group by a practice which is likely to continue in the future should take account of the projected maximum dose rate from far away sources, leaving also a margin for future unforeseen practices. On the other hand, it seems also advisable to restrict the contribution that the practice under consideration will make to the exposure of other critical groups, regionally or globally. This is a responsible attitude which, if carried out by all concerned, would prevent the eventual occurrance of undesirable situations of the type prevailing for some non-radioactive pollutants.

18. For achieving the two aims indicated in the previous paragraph it is necessary to limit by upper bounds both the annual dose in the critical group and the collective dose commitment per unit practice. The two upper bounds are interrelated, and their selection should be consistent.

19. The requirement of complying in the future with the individual dose limitation can be formulated as

$$\sum_i \dot{H}_{m,i} \leq f\,L$$

where $\dot{H}_{m,i}$ is the maximum future dose rate (really annual dose) from practice i, L is the dose limit of members of the public, and f is a factor smaller than 1 to allow for future exposures of unforeseen justified sources. As the situations considered involve exposures which would be maintained over considerable periods of time, the appropriate dose limit L can be taken to be 1 mSv in a year [1].

20. If the value of the factor f is chosen to cover all future practices except those relating to the nuclear fuel cycle for electrical energy generation, the dose limitation in the vicinity of a given installation k could be formulated [4] as:

$$U_k + I_R\,S_R^* + I_G\,S_G^* \leq f\,L$$

where U_k is the upper bound for the annual dose in the critical group due to the operation of installation k, I_R is the regional practice intensity, I_G is the global practice intensity, S_R^* is the upper bound for the regional collective dose commitment per unit electrical energy generated, and S_G^* is the upper bound for the global collective dose commitment per unit electrical energy generated.

21. The coherent selection of values for U_k, S_R^* and S_G^* would be very dependent on decisions made by the national authority regarding factor f, and on the projections of the practice rate (installed nuclear capacity per person), both regionally and globally. The example presented below reviews the bases and the formulation of the regulating requirement used in Argentina to limit the doses from nuclear energy generation.

4. EXAMPLE OF LIMITATION OF EXPOSURES FROM THE NUCLEAR FUEL CYCLE

22. In Argentina there is a strong commitment to the use of nuclear power and to a complete implementation of the associated

nuclear fuel cycle operations. In addition, reactors presently used, constructed or planned are heavy water moderated, and due to their carbon-14 production they could produce substantial collective dose commitments unless specific retention of this nuclide is provided.

23. For these reasons the dose limitation approach outlined in previous paragraphs was used to establish the regulations concerning radioactive effluent discharges from installations of the fuel cycle. The first basic decision was to reserve 50 % of the individual dose limiting value (1 mSv per year) for all other exposures except those relating to the nuclear fuel cycle. It was also assumed that in the future the nuclear installed capacity in the region would eventually reach about 5 kW per person, a value which in any case is projected for Argentina after a few decades.

24. The "practice intensity" for the world as a whole is very difficult to project, but as the duration of the practice (electrical generation by fission) could proceed for several centuries, it was assumed that it could eventually reach similar values as the assumed regional future level. With the assumptions mentioned above, the following condition should apply:

$$U_k + 5 \frac{\text{kW}}{\text{man}} S^* \leq 0.5 \frac{\text{mSv}}{\text{a}}$$

where U_k is the upper bound for annual dose in the critical group due to a nuclear power plant or another installation of the fuel cycle, and S^* is the upper bound for the collective dose commitment per unit electrical energy generated. This commitment is the incomplete quantity, integrated over the period of the practice, assumed to be several centuries (500 years).

25. The above relation should be satisfied taking into account, among other factors, what is technologically feasible. The regulatory authority in Argentina decided to use the pair of values U_k = 0.3 mSv/a and S^* = 40 man·Sv/GW·a for the two upper bounds. It should be noted that the value for S^* applies to the entire fuel cycle. Of this total, a value of 15 man·Sv/GW a was assigned to the nuclear power plant.

26. The upper bounds of 0.3 mSv/a and 15 man·Sv/GWa have been incorporated by the Comisión Nacional de Energía Atómica in the regulatory requirements for nuclear power plants, in particular in the safety standard CALIN 3.1.2 [6]. This standard requires that the two upper bounds are respected, in addition to requiring that the control of the release of effluents is optimized. It

is interesting to mention that a result of the standard CALIN 3.1.2 has been a design requirement for the third nuclear power plant in Argentina regarding the retention of carbon-14 from the effluents [7].

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DISCUSSION

H.T. DAW: If sources are optimized and doses to individuals do not exceed 0.3 mSv/a, as indicated in your paper, why do you enforce an upper bound for collective dose per GW(e)?

D. BENINSON: The upper bound for collective dose commitment per unit practice indirectly controls the contribution made to the exposures of other critical groups, regionally or globally. If this method is followed by all concerned, it would prevent possible undesirable situations in the future caused by the multiplication of sources, even if the protection of each is optimized.

A.B. FLEISHMAN: What was the rationale for assigning 50% of the dose limit to the nuclear fuel cycle in Argentina instead of, say, 10 or 20%? Do you not think there is a danger that judgements on apportioning dose limits will impose essentially arbitrary constraints on optimization procedures?

D. BENINSON: The decision was to reserve 50% of the limit for all other exposures except those relating to the nuclear fuel cycle. It should be remembered that the maximum annual doses from continuing practices could occur far in the future and be maintained over considerable periods of time. Therefore it seems reasonable to reserve a value similar to that reserved for the most important source for the foreseeable future (nuclear fuel cycle) so as to leave a margin for an unforeseen important practice which might occur in the distant future. Of course, the decision is a matter of judgement, but this decision must be consistent with the decisions regarding upper bounds for individual dose in the critical group and for the collective dose commitment.

H. BONKA: I don't think I can really agree with your simplistic treatment of the regional dose contribution. To my mind it is too idealistic and you end up with a number which is too low in reality. It would surely be best to consider different nuclear facilities on the basis of a forecast of the nuclear industry planned for the future. Since nuclear facilities are built on riversides, the dose rate via the water pathway is proportional to the number of facilities, assuming that the emission rates are the same and that the radionuclides are dispersed in the whole water volume. In the case of the air pathway, enhancement of the maximum dose rate in the vicinity of a nuclear plant from other emittants is very low. At a distance greater than 10 km, the contribution of the second emittant of the same order is only a few per cent. One large emittant, let us say a reprocessing plant, will increase the maximum dose rate in the vicinity of a small emittant, for example a nuclear power plant. None of these details can be taken into account in your simple model.

D. BENINSON: Yes, the procedure of using the collective dose commitment to assess the future maximum per caput annual dose is, of course, a simplification. However, the seemingly more realistic procedure you suggest would be useful only for predicting exposures in the near future. As the maximum per caput dose rates from effluent emissions from continued practices can occur far in the future (and be maintained over considerable periods of time), the actual distribution of future sources would have to be known for your calculation procedure to be used. However, the future distribution cannot be predicted over several centuries, a period of time over which the production of electrical energy by fission can proceed, whereas it is possible, to a greater degree, to project the energy consumption rate per caput in the future, and it is this quantity which is used in the procedure in my paper.

As regards your comment on the small contribution by facilities situated more than 10 km away, it is true if there is one such facility. However, multiplication of sources in the future can make a significant combined contribution by the addition of many small contributions. The purpose of the procedure presented in my paper is to limit such combined exposure, and therefore all contributions are considered. The use of such a procedure would prevent the future occurrence of undesirable situations now prevailing in the case of some non-radioactive pollutants caused by many releases, each of which was considered small.