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RADIOLOGICAL PROTECTION CRITERIA FOR RADIOACTIVE WASTE REPOSITORIES

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(*) Not shown in INIS Thesaurus 1985.

RADIOLOGICAL PROTECTION CRITERIA
FOR RADIOACTIVE WASTE REPOSITORIES

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INTRODUCTION

This paper explores the possibility of extending the use of the "system of dose limitation" to the design and safety evaluation of repositories for high level radioactive waste. Individual dose - limitation and optimization of protection cannot be directly used for judging the safety level of systems intended either to prevent or to limit potential future exposures. Nevertheless, it appears that the basic principles can conceptually be extended to the limitation of such uncertain exposures.

The third component of the system of dose limitation, the justification of the practice, relates to the larger matter of energy production by nuclear means. The net possitive benefit must be associated with that practice "in toto" and not with an unavoidable part of it, such as the disposal of the wastes.

Disposal of radioactive waste involves isolation of the radioactive material from the human environment over a sufficient period of time. Exposures of man that could still occur would be due to mechanisms that may be described as either (1) "Normal" release mechanisms, leading to a predictable exposure pattern in space and time, or (2) Random disruptive event, for each of which a probability of occurrence and an exposure pattern can be postulated. The main difference is that the normal release is expected to occur first after a retention period which is long enough to permit the activity to decay to clearly acceptable values, while disruptive events may cause releases before there is sufficient decay to make the exposures acceptable.

The main objectives in radiation protection are to keep individual exposures below recommended limits and to reduce them further as far as it is reasonably achievable. The purpose of the individual dose limits is to limit each individual's probability of severe harm at an acceptable level. The extent to which doses are as low as reasonably achievable is determined by optimization of protective efforts related to a given radiation source or practice. Radiation protection is therefore concerned with both individual-related efforts (risk limitation) and source-related efforts (optimization of protection).

INDIVIDUAL RELATED REQUIREMENTS

The dose limits recommended by ICRP are intended for the total dose from all sources (excluding natural background and medical exposures of patients). For the contribution from any one particular source, competent authorities are expected to set an upper bound which should only be some fraction of the ICRP dose limit if exposure from other sources is possible (1)(2).

The use of the concepts of limit and upper bound in the case of high-level waste repositories involves three main conceptual difficulties (3): a) the question of the level of ambition for protecting individuals in the far future; b) the global contribution of each repository to the "per caput" dose; and c) the problem of potential exposures of probabilistic nature.

The first is a policy question which obviously can have several answers. The crucial question is whether we wish to protect future individuals at the same level of ambition as we protect present individuals. Some feel that we have more obligation to the present than to an uncertain future. Others feel that we have a special obligation to the future when we cause risks for our own benefit. Others, again, would state that present benefits are indirectly prerequisites for future benefits and well being. In this paper it is assumed that the ambition is to protect all individuals alike, irrespective of time and location. A different policy would not change the following principles, only the quantitative results.

The second conceptual problem relates to the selection of an upper bound. It is possible to postulate a generic upper bound for the annual dose contribution from the practice of radioactive waste isolation, which would limit the dose to any critical group resulting from all repositories. Such generic upper bound would be of little use in practice. What is required is an upper bound for the annual dose due to a given repository. In this case, however, it is necessary to take account of the "per caput" global contribution of all the repositories which would add to the local dose contribution of the repository under consideration.

The "normal" release situation and its resulting exposure pattern, by definition, have a probability which may be considered equal to one. The design requirement would therefore be that at all times

$$H_{L,k} + \Sigma_i \; H_{g,i} \leq f \; H_{lim}$$

where $H_{L,k}$ is the annual dose contributed locally to its critical group by repository k, $H_{g,i}$ is the global "per caput" annual dose contribution of repository i (the summation being carried over all repositories), f is the fraction of the ICRP dose limit considered appropriate for waste isolation in general, and H_{lim} is the dose limit.

The establishment of "upper bound" conditions, therefore, must take account of the interplay of the local dose contribution and the "per caput" global dose contribution. This is a particular case of a problem that was discussed in another paper related to limitation of releases of radioactive materials to the environment (4).

The relation presented above could also be expressed as

$$H_{L,k} + \sum_i r_i H_{L,i} < f H_{lim}$$

where r_i is the ratio of the "per caput" dose to the local critical group dose (both due to repository i), $H_{L,i}$ is the local critical group annual dose, and the other symbols have been defined previously.

It seems reasonable to postulate that the "per caput" contribution of a repository is proportional to the amount of uranium utilized to produce the waste in the repository (3). This implies that

$$\frac{r_i H_{L,i}}{\sum_i r_i H_{L,i}} = \frac{W_i}{W_t}$$

where W_i is the amount of uranium originating the waste in repository i and W_t is the total amount of uranium which is predicted to be used for nuclear power generation.

The limiting equation for doses in the critical group for repository k can therefore be written as

$$H_{L,k} \left(1 + r_k \frac{W_t}{W_k} \right) < f H_{lim} ,$$

and the upper bound, U_k, for the annual dose in the critical group is given by

$$U_k = \frac{f H_{lim}}{1 + r_k \frac{W_t}{W_k}}$$

It must be indicated that the upper bound will differ significantly from the simple value f H_{lim} only in the cases where $r_k(W_t/W_k)$ is not small. For planning purposes, and similar to the case of upper bounds used at present for some nuclear installations, the value of f H_{lim} can be taken to be in the order of 10^{-1} mSv in a year.

The third conceptual problem in applying individual dose limitation to radioactive waste repositories relates to the potential exposures resulting from probabilistic disruptive events.

It should be recognized that even in "normal" release conditions, the occurrence of detrimental biological effects is probabilistic. For radiation protection purposes, the probability of stochastic effects, namely fatal cancer and serious genetic effects, is taken to be approximately 2 10^{-2} per sievert of effective dose equivalent(1). The probability of non-stochastic effects, above the threshold increases from cero to one over a usually small range of doses. For example, for mortality due to the accute radiation syndrome resulting from whole-body irradiation, the probability at less than 2 gray is practically cero, while it is nearly one above 6 gray.

In the case of random disruptive events one deals with the probability of the event and with the resulting doses in the group of individuals receiving the highest doses. Regarding radiation effects one deals, therefore, with effects of second order stochasticity. For example, the probability of dying (risk) of a member of the public due to a given potential disruptive event can be expressed as $R = P_1 P_2$, where R is the "risk", P_1 is the probability of occurrence of the event which would result in a dose H to the member of the public under consideration, and P_2 is the conditional probability of death given dose H.

If several potential situations are taken to be possible, the risk R defined in the previous paragraph becomes

$$R \simeq \sum_i P_{1i} P_{2i}$$

It should be realized that P_2 is proportional to dose at the lower doses (where only stochastic effects are possible), but increases steeply with whole-body dose at values above 2 Gy due to acute non-stochastic effects.

Probability values must be assigned to the few disruptive events that are expected to cause significant exposures if they occur. Event-tree assessments will yield probability values p_i for a number of exposure situations (i) due to various sequences of events. In each exposure situation a maximum annual dose (H_i) in time and space may be identified. The simplest approach would be to assess these maximum doses as if they occurred simultaneously in one and the same critical group. This will overestimate the probability of harm to any given person but will grossly simplify the assessment(3).

On the assumption that the maximum probability of harm committed in a year, given an exposure situation (i), is a function of the maximum annual dose that would occur in that situation (H_i), the maximum value of the total probability of harm, R_{max}, that is committed for one year can never exceed the direct summation of the maximum values for each exposure situation:

$$R_{max} < \sum_{i=0} p(H_i)\ p(\text{harm} \quad h_i)$$

It is proposed that the basic objective is to ensure that the maximum individual risk of a member of the public due to potential disruptive events in a repository does not exceed the risk due to "normal" radioactive releases. The order of magnitude of the upper bound suggested in previous paragraphs (0.1 mSv in a year) corresponds to a risk of lethality of the order of 10^{-6} in a year. Therefore, the proposed objective can be stated as

$$R_{max} \leqslant 10^{-6}$$

where R_{max} is the maximum value of the probability of lethality committed for one year.

If several disruptive event sequences are considered (the order of magnitude of the number being ten), then on the average their individual risk contribution should not exceed a value $R_i = 10^{-7}$ in a year. The "acceptable" probability of occurrence of a sequence giving dose H_i would be $\left(\leqslant 10^{-7}/10^{-2} Sv^{-1} \cdot H_i\right)$ in the region of doses H_i where only stochastic effects can occur.

At higher dose values the "acceptable" probability of occurrence would be $\leqslant 10^{-7}/f(H_i)$, where $f(H_i)$ is a non-linear function of dose which becomes 1 at high doses. The annual probability of disruptive sequences yielding non-stochastic lethal doses should not exceed therefore the order of 10^{-7}.

The procedure described above for applying individual dose limitation to probabilistic disruptive events has been expressed in a "criterion curve"(3), similar to curves used in the probabilistic nuclear safety philosophy(5).

SOURCE-RELATED REQUIREMENT

A source of both "normal" and potential exposures corresponding to only low individual risks might still cause a substantial collective consequence. A source-related requirement is therefore to optimize the level of protection to be applied to the source in order to keep the consequence as low as reasonably achievable.

ICRP Publication 37(6) presents the basic principles of optimization, explains its use as a decision tool, discusses the criteria involved in the requirement and describes the conceptual basis and the techniques of cost-benefit procedures for optimization.

The application of such techniques of optimization to the engineering of repositories (barriers, containers, backfillings, etc.) involves conceptual problems, again related to the time scale and to the possibility of disruptive events.

Optimization of protection may be based on the total collective doses and on the probabilities of the various events, as long as no high individual doses causing non-stochatic effects are deemed to be possible. It is possible to calculated the expectation value of the total collective dose in addition to the collective dose that can be assessed from the "normal" exposure situation. If a possible sequence with a probability p_i causes a collective dose

S_i, the expectation value is $S_i = p_i S_i$. However, the inherent uncertainty of the expectation is large, the standard deviation being S_i/P_i. The use of the expectation value in protection optimization may therefore be invalid in the case of contribution of low probability-high consequence situations(7). It would be even more so if high doses, beyond the range of stochastic linearity, are possible.

A further problem is the time scale involved. Due to the presence of very-long life nuclides, an assessment of the complete collective dose commitment is highly speculative. In optimization, however, one deals with differences of collective doses between different protection options. The time period of interest is therefore the period in which the alternative protection levels (engineering solutions) have an influence on the exposure pattern, because the longer exposure tails would cancel when substracting collective doses of different options. The period of interest for the assessment of the relevant incomplete collective dose commitments (a few thousand years) would make such assessments more reasonable that it would appear from the half lifes of the nuclides involved. For these assessments, procedures similar to those used by UNSCEAR(8) can be applied.

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