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GERENCIA DE PROTECCION RADIOLOGICA Y SEGURIDAD

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APPLICATION OF ICRP RECOMMENDATIONS TO RADIOACTIVE WASTE ISOLATION

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ABSTRACT

Some radioactive waste categories require isolation from the biosphere for extended periods of time. Various mechanisms can be expected in the future leakage of radionuclides; some are the result of "normal", expected processes, while others would be the result of random disruptive events. In the second case, the exposures can only be evaluated on a probabilistic basis. Nevertheless, the three basic principles for protection usually recommended by ICRP still apply: Individual risk limitation, optimization of protection, and justification of practice. In the individual-related assessment, the requirement should be that the overall probability of death from exposure to waste products (considering both the probability of dose and the probability of death, given the dose) should not exceed the probability of death at the dose "upper bound" that national authorities would designate for the practice. In the source-related assessment for optimization of protection, the detriment should be assessed over relevant time periods and be the basis for marginal cost/benefit analysis of the various potential improvements in the combined isolation provided by the engineering and geological features.

INTRODUCTION

The international Commission on Radiological Protection (ICRP) issues basic recommendations on radiation protection . Even though no specific statements have been made on protection requirements for radioactive waste isolation, the general principles are applicable. The authors present their personal views on this application. These views are not necessarily the official views of the ICRP. The matter is under discussion within ICRP Committee 4 and ICRP documents on the subject have not yet been finalized. Valuable ideas have been injected by a number of people, but the authors are particularly grateful to Drs. A.J. González, J.O. Snihs and G.A.M. Webb for original thinking.

GENERAL

Disposal of radioactive waste involves isolation of the radioactive material from the human environment over a sufficient period of time to permit decay in isolation. Any exposure of man that could still occur would be due to mechanisms that may be described as

(1) "Normal" release mechanisms, leading to a predictable exposure pattern in space and time;

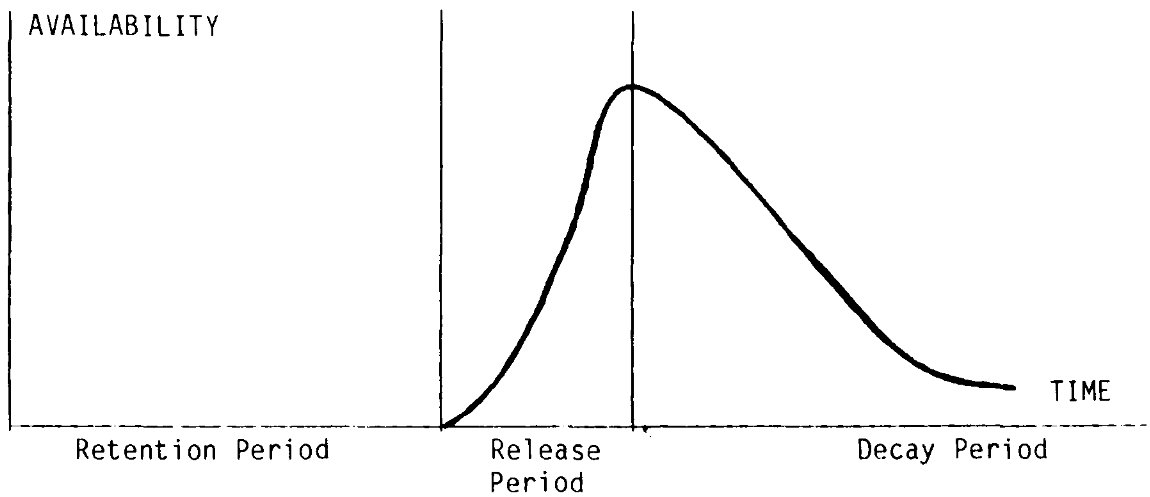
(2) Random disruptive events, for each of which a probability of occurrence and an exposure pattern can be postulated.

The difficulties in direct application of the normal basic radiation protection principle are mainly caused by

(a) The very long time periods involved;

(b) The randomness of type (2) exposures.

In principle, both the normal release and the disruptive events would be expected to give exposure patterns of the general type shown in the following graph:



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.

EXPOSURE PROBABILITIES

Theoretically, there may be an infinite number of possible curves, each representing a more or less probable conceivable retention situation. For each time t, there will therefore be a probability distribution $\sigma(\dot{H})d\dot{H}$ that the dose equivalent rate to individuals in a critical group will fall in the interval $\dot{H}$ to $\dot{H}+d\dot{H}$. At any given time, the probability that any dose rate, including zero, occurs, obviously will be one, i.e.

$$\int_0^\infty \sigma(\dot{H})\, d\dot{H} = 1$$

A similar probability distribution may be imagined for the collective dose rate ($\dot{S}$).

It is not a practicable task to derive these probability distributions by linking dose rates to their possible causes in a fault-tree type analysis. In practice, we shall have to simplify the assessment by defining (1) a "normal" exposure pattern, and (2) a few disruptive events for which analyses of event-tree type can be made. Even this may turn out to be difficult since the time patterns of possible exposure situations after a disruptive event would also differ depending on the time at which the initiating event occurs.

Some compromise will have to be made between the degree of simplification of assumptions and the degree of realism behind the result. However, the principle remains the same.

OBJECTIVES

The immediate objectives in radiation protection is to keep individual exposures below the 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. We are therefore concerned with both individual-related efforts (risk limitation) and source-related efforts (optimization of protection). How can these be applied in the case of waste isolation?

INDIVIDUAL-RELATED ASSESSMENT

It is an interesting policy question whether we wish to protect future individuals at the same level of ambition as we protect present individuals. Some may feel that we have more obligation to the present than to an uncertain future. Others may feel that we have a special obligation to the future when we cause risks for our own benefit. For our present purpose, we merely assume that our ambition is to protect all individuals alike, irrespective of time and location. A different policy would not change the following principles, only the numerical results.

The dose limits recommended by ICRP are intended for the total dose from all sources (excluding natural background and medical exposure of patients). For the contribution from any one particular source, the 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.

Taking into account both present and projected practices involving radiation exposure, it is possible to postulate an upper limit for the annual dose contribution from the practice of radioactive waste isolation in general. However, for the practical application, we are interested in the upper bound

$$H_{UB}^{(k)}$$

for the anual dose, to be applied to one particular depository (k). If ε is the fraction of the ICRP annual dose limit that it is appropriate to use as the upper bound for waste isolation in general, the primary requirement will be that

$$H_{UB}^{(k)} < \varepsilon H_{limit}.$$

However, each depository may also contribute somewhat to the per caput global dose. It must therefore be ascertained that a large number of depositories will not cause an unacceptable total global contamination.

This will be prevented if the upper bound is derived on the basis of the amount of uranium utilized in order to produce the waste in the depository. If this amount is denoted W_k and the total amount of uranium available for nuclear power utilization in the world is W_{tot}, the safe upper bound for a given depository (k) would be

$$H^{(k)} = a_k \frac{W_k}{W_{tot}} \varepsilon H_{limit}$$

if a_k is the ratio of the dose to the critical group to the global <u>per caput</u> dose from depository k. The above value for the upper bound is more restrictive than just $\varepsilon \cdot H_{limit}$ as long as $W_k < W_{tot}/a_k$ and should then be used.

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

$$H^{(k)}_{normal} < H^{(k)}_{UB}$$

where the first term is the annual dose in the critical group from the normal releases from depository k.

This simple requirement is complicated if the possibility of disruptive events cannot be neglected. Probability values must then be assigned to the few disruptive events that are expected to cause significant exposures if they occur. Event-tree assessments will yield composite 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.

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

$$P_{max}(harm) \leqslant \sum_{i=0}^{n} p(H_i) \cdot p(harm/h_i)$$

In this summation, the "normal" release case is also included (i=0). Since the ambition should be that no individual should run a higher probability of severe stochastic harm than he would do at the dose upper bound, the design requirement should then be that

$$P_{max}(harm) < p(harm/H_{UB})$$

This corresponds to the requirement that the mathematical expectation of individual annual dose in critical groups must never exceed the annual dose upper bound. The qualifications implied in a valid concept of mathematical expectation of dose, however, cannot be readily described and it is conceptually more valid to base the requirement directly on the probability of harm.

This reasoning is also valid for doses which could cause non-stochastic effects. In this case, the probability of death, given a dose, is non-linear with dose and the non-linear function must be used for p(harm=death/h) in the previous expression.

So far we have related the maximum probability of harm committed annually to the maximum annual dose H_i. In the case of non-stochastic effects, the dose distribution over time will affect the probability of harm to the exposed individual, i.e. while a dose of 5 Sv over a short time is probably lethal, an annual dose of 0.1 Sv over 50 years is probably not lethal. For this reason, it may be more appropriate to assess actual individual doses for various cohorts of individuals in order to find the highest individual lifetime doses.

If we take as an example that the dose upper bound for a year has been set at 0.1 mSv, i.e. a death probability of $2\ 10^{-6}$, and only one release situation is assumed as possible, the following relations would exist between the maximum annual dose H_i in the critical group (and the corresponding probability of death or severe stochastic harm) and the maximum probability (p_i) which would be considered acceptable for the release situation (Table 1).

Table 1 - Relation between maximum annual dose (and risk) and the highest acceptable release probability

H_i Sv	p(death/H_i)	$p_i$max
0.0001	$2\ 10^{-6}$	1
0.001	$2\ 10^{-6}$	10^{-6}
0.01	$2\ 10^{-6}$	10^{-6}
0.1	$2\ 10^{-6}$	10^{-6}
1	0.02 - 1	10^{-6} - $2\ 10^{-6}$
10	1	$2\ 10^{-6}$
100	1	$2\ 10^{-6}$

If there are ten dominating sequences of events (i), including both the normal situation and those following disruptive events, then on the average their individual probabilities should not exceed 1/10 of the values for $P_i$max in Table 1, since our requirement is that P(harm) = Σp_i should be less than $2\ 10^{-6}$ (in the example we have chosen). This is illustrated by Figure 2:

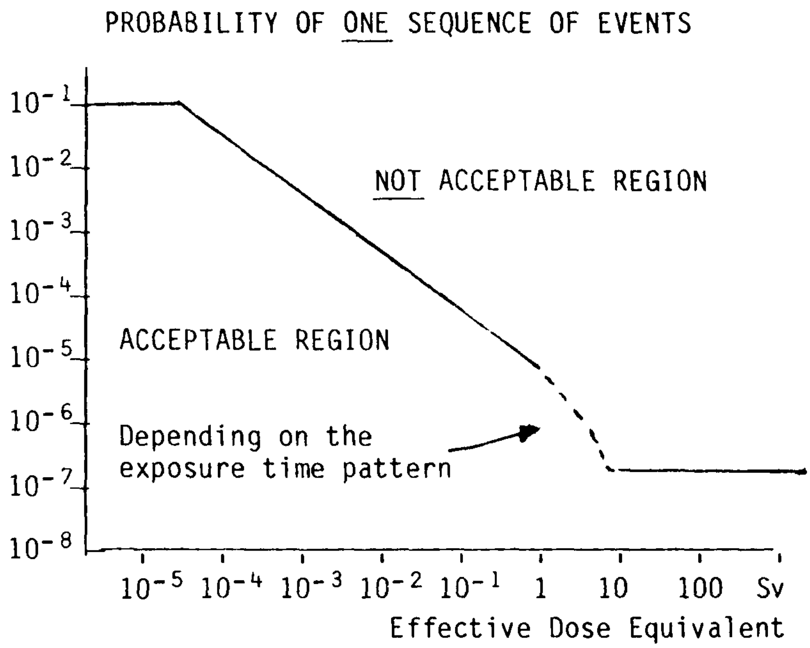


Figure 2: Example of acceptability criterion curve for each sequence of events in the case of an assumed number of 10 sequences and a risk upper bound of 2 10^{-6} per year.

At high doses, the individual consequence is no longer dependent on dose, because a dose of, for example, 10 Sv would be as lethal as a dose of 1000 Sv, and the limit of the probability of the corresponding sequences of events would be the same in the two cases. It should be remembered that we are still discussing the individual-related requirements. Later on, when we deal with the source-related requirements, it will be obvious that a large number of deaths would be worse than a few deaths, but this is not relevant for the present discussion.

Very low probabilities are not easy to assess. Reference to probabilities lower than 10^{-6} are often not well founded. Therefore, the acceptability test in the region of low probability and high dose may have to be limited to the lack of perception of any mechanism that could give doses in excess of, say, 1 Sv.

SOURCE-RELATED ASSESSMENTS

It is conceivable that some sequences of events that would fall in the acceptable region in a diagram like Figure 2, on the basis of individual risk, might still cause a large collective consequence. In the source-related assessments, it is the total consequence that would determine the efforts that authorities would request for improved protection. It will not only be the most exposed cohort of individuals and the critical group that would be at some risk. The overall harm expected from each sequence of events may be assumed to be proportional to the total collective dose, in time and space, that will be expected from that sequence. As long as no weighting is introduced to discriminate against, for example, exposures late in time or at large distances, the assessment of collective doses in easier than the assessment of maximum doses in time and space. Procedures similar to those used by UNSCEAR[2] may be employed.

Optimization of protection may be based on the total collective doses and their probabilities (i.e. the probabilities of the various sequences of events) as long as no high individual doses with non-stochastic effects can occur. In the case of radioactive waste isolation, "optimization of protection" applies to the engineering of the depositories (barriers, containers, fillings, depths underground, etc.) but also to the choice of alternative locations.

It is possible to calculate 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 of events with a low probability (p_i) causes a collective dose S_i, the expectation value is $\overline{S}_i = p_i S_i$. However, the statistical uncertainty of the actual outcome is large, the standard deviation being $S_i/\sqrt{p_i}$. The use of the expectation value in protection optimization may therefore hide the mproblem caused by low probability-high consequence situations.

If also high doses, beyond the region of assumed linearity between dose and response, may occur, more involved assessments are necessary to obtain expectation values for the consequence. These expectation values are even more subject to the above uncertainty, since the event probabilities are most likely extremely small.

A further problem is the long life-time of some of the radionuclides. An assessment of the total collective dose commitment from a disruptive event as well as from the normal release is therefore highly speculative. Fortunately, however, this is not the quantity actually needed. In optimization of protection, we are only concerned with doses actually avoided by changes in the protection. The time period of interest is therefore the period in which the alternative protection levels (engineering solutions) have an influence on the exposure pattern. This time period cannot be longer than the assumed retention period. The retention period may be short enough (10,000 years?) to make collective dose assessments reasonably realistic. No depository is expected to retain the deposited material over geological time periods.

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