Methods for Determining the Release of Radioactive Material into the Environment

by Louis Farges and Hussein Talaat Daw

The current policy on the discharge of radioactive effluents calls for the containment of radioactive wastes in most instances. The resulting doses to individuals and populations have been shown by many surveys to be very small (UNSCEAR Report, 1972). Nevertheless, small amounts of radioactive releases are made to the environment during normal operation of nuclear facilities. Whenever discharge of radioactive effluents to the environment is permitted, careful consideration is made of all the relevant factors which might lead to exposure of man. However, with the expansion of nuclear power programmes, more sophistication is required in setting discharge limits to the environment, taking into consideration future sources as well as present sources.

The IAEA's recommendations conform to the dose limitation system set out by the International Commission on Radiological Protection (ICRP). The system implies that the individual dose limits should never be exceeded. Furthermore, the ICRP guidelines require that doses be kept as low as reasonably possible, taking social and economic considerations into account. This second objective, usually called optimization, implies the use of differential cost-benefit analysis.

At present, decisions are still made by other procedures, for example, by applying safety factors to release limits derived only from the dose limits. However, the ICRP system of dose limitation, including optimization, appears to be a more rational approach to the establishment of release limits. Thus, it is necessary to provide basic material on concepts which are intended for use and decision making by national authorities, and the Agency plans to publish a series of complementary documents on the application of these concepts to various specific cases.

GENERAL CONCEPTS

It is worth stressing again that, except for a minor fraction, all of the radioactive wastes from the nuclear industry are contained and not released to the environment. Any releases that are made should comply with the relevant national or local requirements in radiation safety.

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Previously, it was considered sufficient to limit the release of radioactive material to the environment by limiting the concentrations of the various radionuclides in air and water effluents, the limit usually being a fraction of the maximum permissible concentration recommended by ICRP in 1959. Obviously, such a procedure in itself does not prevent substantial amounts of radioactive material reaching the environment if the effluent rates are high. Nor does it assure that ecological processes might not cause high concentrations in certain environmental materials and result in unexpectedly high doses to members of the public. In many cases, these eventualities were taken into account either explicitly or by introducing safety factors in the concentration limits or sometimes in the amounts allowed to be released.

OBJECTIVES OF RADIATION PROTECTION

The basic objectives of radiation protection are to prevent the occurrence of acute effects and to limit the probabilities of occurrence of late somatic and genetic effects. The first of these objectives is easily met since acute effects occur only with exposure to large doses of radioactive material and at high dose rates. The second objective is more difficult, mainly because of the absence of data on the effects on humans at the low levels of risk that are involved. It has been the normal practice in radiation protection to make a conservative assumption, namely that a non-threshold linear relationship exists between the dose and the probability of late effects such as the induction of malignancies and deleterious genetic changes. Furthermore, it is assumed that the risk per unit dose deduced from observations of the effects of high doses and dose rates apply to low doses and low dose rates.

Thus, for small dose increments above natural background, it may be assumed as a first approximation that the increment of risk is proportional to the increment of dose.

This conservative approach, however, may not necessarily form the most appropriate basis for the estimation of the actual risk associated with low dose since the linear extrapolation of risk to the low dose range may over-estimate the risk (ICRP Publication 22).

The basic principles of radiation protection are found in recommendations issued by the ICRP, which are the basis for most of the international and national basic safety standards. With respect to releases of radioactivity to the environment, the following radiation protection conditions apply:

1. The total dose* from all sources, excluding natural background and medical exposure to patients, to individual members of the public shall not exceed the dose limits recommended by ICRP. By respecting these dose limits, or any more restrictive limits set by national regulations, the **individual** risks are kept within acceptable bounds.

2. The total radiation detriment from any practice or operation shall not be unjustifiable in relation to the benefit that would not have been obtained otherwise from that practice or operation. As the distribution of benefits and detriment over the population are not the

* The term dose as used here means dose equivalent, for which the unit is the rem unless qualified otherwise.

same, the benefit can be used to justify the detriment **only** if all detriments to **individuals** are sufficiently low to be acceptable. This condition is ensured if all doses to individuals are below the recommended dose limits.

3. All radiation doses from justifiable exposures should be kept below the recommended dose limits and as low as is reasonably achievable, taking into account social and economical considerations.

DOSE LIMITS

The dose limits given by ICRP are expressed in dose equivalents for which the unit is the rem. These dose limits relate to individuals, with the exception of genetic effects where the dose limit relates to the whole population. They are intended for conditions where the source of exposure is subject to control. They provide standards that make it unlikely that individuals or populations will receive more than a specified dose from all sources (other than to natural sources and medical procedures). The exclusion of the two latter sources of exposure is legitimate because the implied assumption of a linear relationship between risk and accumulated dose also implies that any dose increment carries a risk which is independent of previous doses.

Checking whether exposure of the public complies with the recommended ICRP limits is done not by monitoring all individuals but by assessment through sampling procedures in the environment and by checking the assumptions in the exposure model linking the discharges and the doses. The actual doses received by individuals will vary depending on several factors and it is difficult to determine the maximum dose that might be received individually. In practice it is possible to ensure that this variability does not cause an under-estimate of the risk by selecting appropriate "critical groups" within the population. Such a group should be representative of those individuals in the population expected to receive the highest dose, and the ICRP states that it is reasonable to apply the appropriate dose limits to the mean dose of this group.

In addition to recommending individual dose limits, ICRP has recommended that the genetic dose to whole populations should be kept low, and suggested the dose should not approach 5 rems in a generation (30 years) in addition to the dose from natural sources and from medical exposure of patients.

COLLECTIVE DOSES AND DETRIMENT

Some radiation protection measures require the assessment of collective doses to a given organ or whole body. The collective dose to a population consisting of N individuals is defined as $S = \overline{H}.N$, where $\overline{H}$ is the average per caput organ dose equivalent received by the individuals in the population concerned. The unit of collective dose is the product of a dose unit (rad or rem) and a number unit of individuals (man); the resulting units are man rad or man rem.

The "detriment" to a population as defined by ICRP is the expectation of harm incurred from a radiation source, taking into account not only the probabilities of each type of deleterious effects but the severity of the effects as well.

In a conceptual analysis, the net benefit, B, to be expected from a decision or operation may be expressed by the following equation:

$$B = V - (P + X + Y)$$

where V is the added value from introducing the operation,
P is the production cost,
X is the cost of protection, and
Y is the cost of detriment.

The source of exposure would be justifiable if there is a net gain in benefit.

OPTIMIZATION OF RADIATION PROTECTION

In order to determine whether a given level of radiation protection is as low as is reasonably achievable, it is necessary to consider the benefits to society from further reductions in the radiation detriment and the additional cost to society of achieving these reductions.
The optimal level of protection is reached when the additional cost of achieving further reductions in the collective dose outweighs the cost to society of the detriments arising from this dose. It is achieved when the cost of protection plus the cost of detriment is at a minimum.

ENVIRONMENTAL MODELS

The movement of radioactivity from the source to members of the population can be described by environmental models. Such models are of varying complexity and often compartment models are used in which the rates of transfer of radioactivity between compartments are specified by constants or by time functions. This modelling is similar to that used in many engineering activities and is called "systems analysis". The use of compartment models, even very complex ones, normally implies considerable simplifications of the real transfer processes. This, however, does not impair their usefulness provided the functions specifying the rates of transfer are properly chosen.

By using systems analysis it is possible to predict levels in the environment and, given sufficient information about population characteristics, dose rates in members of the population as a function of time for single, protracted, and continuous releases of radioactive materials.

DERIVED LIMITS

The basic requirement that the individual dose limits should not be exceeded (i.e. that the average dose in the critical group does not exceed the dose limits) is implemented by application of **derived limits.** The derived limit for release into the environment is defined as the annual input of radioactivity of specified composition which will result in a dose commitment in the critical group equal to the recommended annual dose limit.

Derived limits for environmental contamination, in an analogous way, are defined as the annual average contamination level which, under steady state conditions, gives an annual average dose to the critical group equal to the recommended annual dose limit.

In practice, release limits are usually set at levels which will only correspond to small fractions of the relevant environmental derived limit. When setting actual release limits, the following requirements have to be met:

1. Dose limits for individual members of the public (i.e. the critical group) must be met. Therefore, the annual discharge must not be greater than the derived limits for release.

2. Doses must be kept "as low as reasonably achievable". This implies an optimization of protection, and the value of the annual discharge that meets this requirement is obtained by differential cost-benefit analysis. A necessary condition is that discharge is at most equal to the derived limit; usually it is much smaller, which implies that the dose in the critical group is smaller than the dose limit.

3. In establishing optimized collective dose values and the corresponding discharge limits, regard must be given as well to future installations. Two conditions will have to be considered: (a) In a local sector of the environment, the total of the "optimized" annual releases from a given source must be smaller than the derived limit for annual discharge because the other sources must also be taken into account, (b) The average dose resulting from a practice would have to be controlled.

The methods described above are designed to protect man from the dangers of radioactivity. Similar techniques might well be applied to non-radioactive pollutants in order to minimize the harm they cause.