CONCEPTS FOR THE CALCULATION OF RADIATION EXPOSURE IN THE ENVIRONMENT OF NUCLEAR PLANTS FOR PLANNING AND SURVEILLANCE PURPOSES

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1. INTRODUCTION

In connection with the release of radioactive substances from nuclear plants, the following requirements are to be met in respect of the assessment of radiation exposure of persons in the environment of the plant:

- For the purpose of planning and licencing of nuclear plants, the release rates of radioactive substances are to be limited to such a degree that the dose limit values specified in radiation protection regulations are not exceeded on any site. In doing so, account must be taken of pre-exposure and migration of radionuclides in the environment. This requirement involves the calculation of environmental maximum annual doses (EMAD) for individuals.
- During the operation of nuclear plants it is necessary to calculate the radiation exposure resulting from the annual releases measured for the year of reference. This application requires the calculation of environmental dose commitments (EDC) on the basis of annual releases for persons living in the vicinity of the plant.
- In connection with the long-term prediction of the environmental impact caused by the entire nuclear industry, problems will also arise in conjunction with the local and regional development of the nuclear power industry.

2. CALCULATION OF RADIATION EXPOSURE USING THE EXAMPLE OF INGESTION

2.1 Description of the Transfer of Nuclides in Food Chains by Means of Multi-Compartment Models

The calculation of the ingestion dose involved in the consumption of contaminated terrestrial food is based on the compartment model shown in fig. 1.

Sources /comp. 7/ of the environmental contamination under consideration are fallout and washout in connection with releases of waste air or sprinkler irrigation in connection with the discharge of activity into bodies of water. This may result in a radiation exposure of man by the transfer of nuclides into the food chain.
This transfer is divided into two main pathways. The first one begins with the direct deposition on soil vegetation /1/ and reaches man either directly via vegetables etc. or indirectly via animal products such as milk, meat, etc. /2/. The other pathway essentially involves the transfer from the ground surface /4/ into the soil /5/ and from there through the uptake by

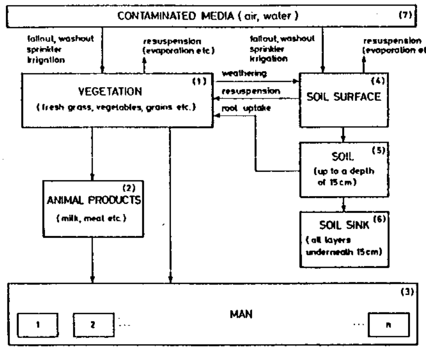

Fig. 1

Radiation exposure model by ingestion of radioactively contaminated food

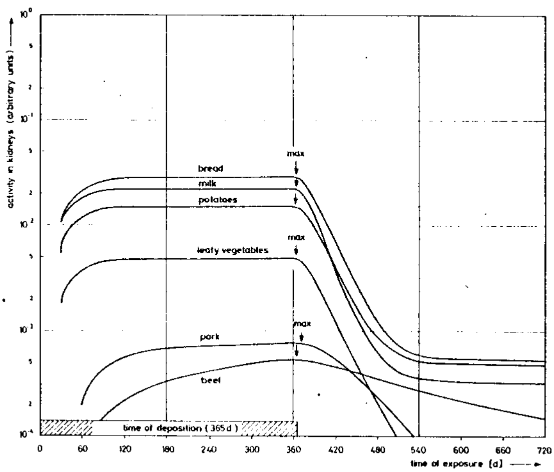

Fig. 2

Sr 90 activity of the kidneys due to ingestion of contaminated food as a function of exposure time for a contamination period of 12 months (The biological half-life of Sr in the kidneys is 16 days)

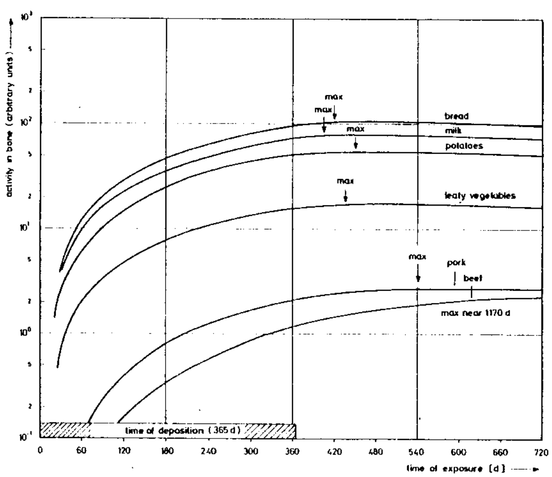

Fig. 3

Sr 90 activity in the bone due to ingestion of contaminated food as a function of exposure time for a contamination period of 12 months (The biological half-life of Sr in bone is 1.8×10^4 days) roots into plants /1/, from where the nuclides may likewise get into the food chain. Since part of the radionuclides involved (e.g. Sr 90, Cs 137) stay in the upper soil layer /5/ for rather long periods of time, there will be an accumulation in this layer, leading to a long-term contamination of the food chain, which may be effective far beyond the lifetime of individual installations.

For describing the activity transfer in the environment according to fig.1, the first approximation is based on a system of linear differential equations of first order (1), (2).

The solution of this system of equations is illustrated in fig. 2 and 3, where the time-dependent activity courses of Sr 90 in the kidneys and the bone due to ingestion via various kinds of food pathways are plotted, assuming constant deposition on the upper soil layer and on vegetation for a period of twelve months.

The basic difference between fig. 2 and fig. 3 is the different residence time of Sr 90 in the organ affected. Due to the rapid removal in the kidneys, the activity inventory chiefly follows the contamination by direct deposition. It is superimposed by the activity supply through the roots. As a rule, the curves reach their maximum at the end of the contamination period.

The activity course in the bone gives a quite different picture. Due to the long biological half-life of Sr 90 in the bone, the organ activity for all food pathways follows the environmental contamination with considerably greater delay. None of the maximum values is reached before the end of the deposition period.

The activity inventory then remains almost constant because the removal from the organ takes place at an extremely slow rate.

2.2 Caculation of Doses

2.2.1 Correlation between Dose Commitment and Maximum Annual Dose

The individual organ doses can be calculated with the aid of the time-dependent activity courses in the organs affected.

Investigations have shown that the identity of the dose commitment and the maximum annual dose, as stated by LINDELL (3), is also applicable in the present case of ingestion of radionuclides with due regard to possible accumulation effects in the soil. Consequently, this identity does not only apply to the transfer of nuclides in the human organism (resulting in internal doses), but is also applicable when including nuclide migration in the environment on the assumption that the transfer of nuclides is independent of the level of activity and that all effects of second order are negligible. This means: EMAD = EDC. In all other respects, the conditions according to (3) are applicable.

2.2.2 Dose Conversion Factors

As explained in more detail in another context (1), (2), it is of advantage for practical application to define the ingestion dose in the following form

$$D = g \cdot N \cdot S \cdot Q$$

g   ingestion dose conversion factor in rem/Ci

N   ingestion utilization factor in m^2

S   sedimentation factor, e.g. fallout factor in m^{-2}

Q   annual amount of release in Ci

The individual factors can be calculated according to (1) and (2), where the values in question are already listed for a number of nuclides, organs and types of food pathways.

The ingestion dose conversion factor (g) in rem per orally ingested amount of activity in Ci exclusively describes the transfer and distribution in the human organism, whereas the ingestion utilization factor (N) represents a measure for the transfer of nuclides in the biosphere from contaminated soil up to the oral activity ingestion with food. For illustration purposes, this factor may be interpreted as the effective area, which is the origin of the volume of activity ingested with food and is essentially dependent on the transfer data of the respective food pathway. Furthermore, the two factors g and N also depend on the age of the person exposed, on the duration of exposure or utilization and on the release time of the installation. The product $S \cdot Q$ specifies the annual mean of surface contamination in Ci/m^2.

3. CONCLUSIONS

Owing to the identity of environmental dose commitment (EDC) and environmental maximum annual dose (EMAD), both problems (licensing of new installations or routine inspection of a plant already in operation) can be handled according to the same computer model for calculating radiation exposure, i.e. it is of no consequence whether the concept of maximum annual dose or the concept of dose commitment is applied. The values specified in (1) and (2) have been determined for the calculation of environmental dose commitment.

Prediction calculations to determine the radiation exposure of individual persons caused by the entire nuclear industry must be based on maximum annual doses.

On the assumption of a certain status of expansion in nuclear industry being frozen during the prediction period for the time of average human life expectancy, it will be possible to calculate a person's radiation exposure at the end of his life using the maximum annual dose. This offers a criterion for assessing whether or not the momentary status of nuclear industry will still be acceptable for individual persons at the end of their lives.

For practical calculation purposes this means: Even in this case, the calculation of dose commitments may be based on dose conversion factors in the same way as in connection with the two problems discussed before.

The doses calculated in this manner are sufficiently conservative.

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