MANAGEMENT OF CONTAMINATED AGRICULTURAL ENVIRONMENTS FOLLOWING A MAJOR NUCLEAR ACCIDENT. AN OVERVIEW ON POSSIBLE SHORT-TERM AND LONG-TERM COUNTERMEASURES

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INTRODUCTION

Accidental release of radioelements from nuclear facilities may give rise to severe consequences for the agricultural environment. The deleterious effects will, in addition to the nuclides released and their deposition density, depend on the sensitivity of the agricultural land with respect to climate and soil types and hence the type of agriculture practiced. Another crucial point for the consequences, at least during the first year after the accident, is the point of time in the year when the fallout occurs. In the winter period the deposition mainly will take place on the bare or snow-covered ground surface, while a fallout during the vegetation period to a varying extent will be intercepted and retained by growing crops. Depending on the stage of development of the crop and the translocation rate of the single nuclides food and feed can be highly contaminated (the concept of "seasonality", *1*).

CRITICAL NUCLIDES AND EXPOSURE PATHWAYS. DOSE CALCULATION MODEL

With respect to the volatility of nuclides of biological importance, which can be released at a large reactor accident, their abundance will decrease in the following order: iodine isotopes > caesium isotopes > strontium isotopes > transuranic elements. While the radioiodine isotopes ^{132}I and ^{131}I in practice have decayed after one and eight weeks respectively, the effects of radiocaesium (^{134}Cs and ^{137}Cs) and of ^{90}Sr will last for years or decades. Radioiodine and radiocaesium exert both external and internal exposure, while ^{90}Sr (and the relatively short-lived ^{89}Sr) and transuranic elements mainly will be of importance for the internal exposure.

Fallout nuclides in the agricultural environment thus will give rise to external exposure of farmers and others living in the contaminated area and to internal exposure of people eating food with origin from the area. The following general dose calculation model may be used for assessment of the dose contribution from a certain exposure pathway *(2)*:

$$H = C * U * D * P$$

where H means the dose rate to a certain organ or individual, C means the deposition density of a certain nuclide (in *Bq per* m^2) or the concentration of this nuclide in a certain crop product or food stuff (in *Bq per kg*) and U is the utilization rate of this food item or, in the case of external exposure the time of sojourn in a certain environment. D is the dose conversion factor for the nuclide in question (*Sv per Bq*) and P is a dose reduction factor taking into account that the external radiation partly is shielded by soil material, building structures vehicles etc. (as compared with the deposition on a smooth ground surface). In the case of internal exposure P may be considered as a dose reduction factor due to various mitigating actions, which can be undertaken in order to reduce the transfer of the nuclide to a certain crop product or food stuff (as compared with the case where no counter measures have been taken). For calculation of the total dose commitment the contributions have to be summarized for various organs in the body and for all nuclides and exposure pathways integrated over the time and taking a number of natural dose-reducing processes into consideration.

Immediately after a release from a nuclear accident external and internal exposure from the passing plume, and external exposure from nuclides deposited on the ground surface, buildings, vegetation etc. potentially will give doses high enough to cause deterministic effects. After some days decay of the short-lived nuclides the exposure will give rise to stochastic effects only. The external exposure from the deposited nuclides (mainly ^{131}I and $^{134+137}Cs$) will be a dominating exposure pathway, independent of the season when the deposition occurs.

Direct contamination of growing crops will give rise to a number of internal exposure pathways as the nuclides are transferred through the food chains to man. Such a critical exposure pathway is the transfer of radioiodine, radiocaesium and radiostrontium through the chain: pasture grass - grazing cows - milk - man. The effects of a direct contamination will last as long as the crop products are available for feed and food, usually up to one year after the deposition, unless the crop products are condemned.

During the following years the internal exposure will be due to the soil-plant transfer of the long-lived nuclides (indirect contamination). This pathway will usually give much lower nuclide concentrations than after a direct contamination of the crops.

BASES AND STRATEGIES FOR DECISIONS ON COUNTERMEASURES

A number of dispersion models have been calculated for possible reactor accidents, taking various source terms and weather parameters etc. into consideration. The Chernobyl accident in 1986 showed, however, that the dispersion pattern of a radioactive plume can be much more complicated, with respect to variation in deposition density and range of the plume, than can be foreseen in more idealistic models. This fact, in addition to the variation in the radioecological sensitivity with respect to soils and crops, also means that the need for countermeasures in the agricultural environment will vary considerably even between adjacent single farms.

Preparedness planning for the agricultural sector in the case of large reactor accidents includes a number of steps. Besides the basic dose criteria, knowledge of the agricultural environment with respect to soils and crops, population and livestock density etc. will be of importance for predictions of the consequences. Transfer factors for the various nuclides and steps in the food chain, obtained in experimental or environmental studies, will also be a necessary tool. Early warning systems, locally for the environment around single nuclear facilities and on a national or international basis, will be valuable in order to prevent exposure leading to deterministic health effects, but also in such a way that countermeasures can be taken in advance before the passage of the plume. A well established organization for monitoring, sampling and nuclide specific activity measurements will be of utmost importance as a basis for fast decisions on suitable countermeasures. Open and continuing information from the authorities to farmers and others living in the contaminated area will also be important, as any for psychological reasons.

As soon as data on deposition density and nuclide concentrations are available these should be used in prediction models for calculation of the expected nuclide concentrations in crop products, milk, meat etc., as to estimate whether these will be acceptable for human consumption or should be discarded. A continuos following up of the monitoring will be necessary during the vegetation period. All countermeasures should be based on the dose criteria given by ICRP and the cost of an action should be reasonable in relation to the value of the saved dose commitment (*3*).

COUNTERMEASURES FOR THE AGRICULTURAL ENVIRONMENT

A number of possible countermeasures for various situations after an accidental release are discussed and evaluated below. The fallout is assumed to take place just before the first harvest of grass for hay or silage.

A. The acute situation (the first week after the accident).

If the early warning time permits and the trajectory of the plume can be foreseen *evacuation* of persons not involved in the livestock management should be undertaken to prevent exposure from the passing plume and deposited activity. Grazing cows should be installed. Harvest of uncontaminated forage, e.g. by using modern techniques for enwrapped silage, would be an effective countermeasure in such a situation. For persons staying on the farm *sheltering* or *indoor sojourn* during and after the passage of the plume should be recommended as far as possible. *Intake of stable iodine* before or up to 30 min. after the passage of the plume would be an effective mean as to reduce the thyroid dose. After the passage of the plume all field operations should be postponed and the use of food and feed should be restricted until the fallout has been monitored with respect to external exposure and nuclide contents in the crops. (*3, 4*).

B. The intermediate situation (from one week up to one year after the accident)

The restrictions for field operations and for use of crop products should remain until the external exposure has become acceptable and the deposition density and the nuclide concentrations in animal and crop products can be estimated. If the concentrations of critical nuclides in the crop products will not be judged as acceptable as food or feed, *removal and discarding of growing crops* may be a way to reduce the deposition density of the land. A dense crop may initially intercept up to 50% or more of a deposition, why fairly concentrated wastes are obtained. After removal of such a highly con - taminated grass crop the new growth, however, may be acceptable with respect to the nuclide concentration (compare C below). *Removal of contaminated soil* etc. around the farm buildings may be effective for reduction of the external exposure.

C. The long-term situation (one to ten years after the accident)

During this period of time the internal exposure mainly will be due to the soil- plant transfer of radiocaesium and ^{90}Sr. The transfer factors for ^{90}Sr have been shown to be up to one order of magnitude higher than for radiocaesium and for both elements the transfer usually will decrease in the order peat soils > sandy soils > clay soils. The possible strategies for reducing the long-term effects refer to the following categories (*4*): *a. removal of the contaminated soil surface layer; b. deep placement of the contaminated layer; c. application of agrochemicals to the soil* (or application of feed additives) and *d. changing the line of production* (*4* and refs. cited here)

Scraping of the contaminated surface soil for removal and deposition can be a rather efficient method for decontaminating agricultural land, although the costs will be high. For handling the large amounts of soil (350-600 tons per ha) special equipment is needed and the work has to be carried out under ideal conditions. Therefore this method will hardly be realistic for large scale operations. On grassland the use of flail-type forage choppers with equipment for removal of the crop may be a method for the removal of a contaminated crop and the upper part of the contaminated sod

By ploughing the contaminated land the fallout nuclides will be distributed in a 20-30 cm deep soil layer and thus be less available to the crops as compared with a distribution in the uppermost few cm. Ploughing up contaminated grassland, wherever this will be possible, followed by the establishment of a new grassland will almost always reduce the nuclide transfer to a factor 5-10 or even more. By deep ploughing or by use of specially designed double layer ploughs a deeper placement of the contaminants can be obtained than after conventional ploughing. However, such ploughs are rare and have a low capacity. All ploughing should be performed under ideal conditions as to be a successful mitigating action.

Application of potassium fertilizers usually will depress the transfer of radiocaesium (by a factor of 2-3 or more at annual applications of 100-200 kg K per ha) and liming acid soils will reduce the transfer of ^{90}Sr and often also of radiocaesium. Generally a well-balanced fertilization, aiming at a positive potassium balance and an optimal pH of the soil, will give a sustainable low transfer of most radioelements.

By changing the line of production of the farm, e.g. from growing crops where vegetative parts are utilized (grassland crops) to cereal or seed crops, a reduced nuclide transfer into the food chain will be obtained. Usually a combination of the various measures will be necessary for the best outcome of the problems.

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