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Current radioecological questions concerning radiation protection

Summary and evaluation of the results of the closed meeting of the Commission on Radiological Protection on 12/13 October 1995

Statement by the German Commission on Radiological Protection

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In the event of any doubts about the meaning, the German original as published shall prevail.

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1 Introduction

Radioecology is the specialist field of radiation protection, a field which is concerned with investigating the presence, transport and location of radionuclides, and quantifying the resulting radiation exposure for humans, plants and animals. For this purpose, the field of radioecology develops and deploys experimental measuring procedures and calculation methods for the retrospective and prospective quantification of transport and radiation exposure. In this connection, what is observed are radionuclides which occur naturally and the changes which their composition in individual environmental areas undergoes as a result of human actions, and radionuclides which emanate from technical sources.

Radioecological investigations can be conducted for a wide variety of reasons, e.g.:

– Basic research on the presence of stabile or radioactive substances

– Research on transports in the atmosphere, bodies of water, the pedosphere or the biosphere

– radiation hygiene evaluations within the framework of approval procedures for nuclear plants

– bases for decisions following the fairly large-scale, accident-induced release of radionuclides

– radiation hygiene evaluations of natural radiation exposure, or radiation exposure which is modified by human actions.

2 Natural environmental radioactivity

On the basis of both the current state of knowledge concerning natural radiation exposure in Germany and its possible contribution towards the frequency of cancer among the population at large and the greater consideration which is afforded to natural radioactivity in the field of radiation protection, the Commission on Radiological Protection submits the following summary and evaluation:

2.1 Natural radiation exposure and its possible contribution towards the cancer risk to which the population at large is exposed

a) According to Jacobi, the average annual level of natural radiation to which the population of the Federal Republic of Germany is exposed – derived from the new dose coefficients of the ICRP/ICRU and the ICRP dose convention for radon decomposition products – totals approximately 2 mSv. Of this, around 40 % is attributable to external radiation (cosmic and terrestrial radiation), 40 % to the inhalation of radon and thoron together with their perishable decomposition products, and the remaining 20 % to the ingestion of natural radionuclides contained in food.

b) The variation range of the individual values of radiation exposure can be considerable and is determined in particular by the large fluctuation range of the concentration of radon in apartments, different levels of Pb-210 intake via food and cigarette-smoking, and local differences in terrestrial gamma radiation.

c) Knowledge of the risk of lung cancer due to the presence of radon in houses is predicated on epidemiological studies of miners exposed to radon involving elements of uncertainty with regard to the transfer of radon to the domestic environment. Case monitoring studies which have been conducted to date on the domestic population have failed to produce any unequivocal results with regard to the scale of the risk which small concentrations of radon involve. However, there is a clear indication that – disregarding smoking – the presence of greatly increased concentrations of radon in houses is the key risk factor in lung cancer.

d) On the basis of UNSCEAR risk factors and disregarding the risk of lung cancer due to the inhalation of radon in houses, natural radiation accounts for between 1 and 3 percent of the total number of deaths. Solid tumours account for between 20 % and 25 % of the total number of deaths. It is unlikely that natural radiation accounts for more than 10 % of the total number of deaths even in areas with a greatly increased level of radiation. Therefore, it is not to be expected that comparative geographical studies will be able to produce any statistically significant evidence of the influence of externally natural radiation exposure on regional cancer mortality rates.

e) According to Jacobi, in the case of children and adolescents of between five and fifteen years of age, it is possible to calculate the contribution of radiation exposure towards the leukaemia risk at between 20 % and 34 % (depending upon the model which is selected). Epidemiological data on leukaemia in children and adolescents in relation to their natural exposure to radiation could contribute towards the examination of this hypothesis.

2.2 Consideration of natural radioactivity in radiation protection regulations

a) It is practically impossible to influence radiation exposure due to K-40 in the human body, cosmic radiation at ground level and above-ground exposure due to radionuclides in the untouched earth's crust, for which reason they are excluded from radiation protection regulations. Those natural sources of radiation which are utilized on account of their radioactivity or fissile and breeding characteristics have always been subject to radiation protection regulations.

b) The recommendations of the Commission on Radiological Protection with regard to the restriction of the level of radiation to which the population at large is exposed by both radon and the legacies of uranium ore mining are predicated upon the principle of fixing guide values using figures from the upper range of values occurring under natural conditions (e.g. radon concentration, specific ground activity, etc.). No radiation protection measures are recommended for radiation exposure due to concentration or activity values below these guide values.

c) The Commission on Radiological Protection considers it desirable to afford consideration to both this principle and the overall complex of natural radiation exposure during the discussion on the more rigorous inclusion of natural sources of radiation in the radiation protection regulations.

2.3 Radon in drinking water

a) The median of radon-222 concentration in the supplies of drinking water which were examined in the Federal Republic of Germany is approximately 5 Bq/l; around 10 % of values exceed 50 Bq/l, around 3 % (thirty-two sampling locations) exceed 300 Bq/l. Radon in drinking water can lead to radiation exposure by way of "ingestion" and – following its release into the air – "inhalation".

b) In respect of the median value of Rn-222 concentrations in drinking water of approximately 5 Bq/l, the calculations of the ingestion dose produce an ingestion dose of 0.0025 mSv/a for adults and 0.0075 mSv/a for children (age group five to fifteen years). These doses are small in comparison with the values of radiation exposure from other sources. Very rare concentrations in the region of 500 Bq/l produce annual dose values for children of approximately 0.75 mSv.

c) Assuming certain factors with regard to the transition of radon from drinking water to the indoor air (e.g. while taking a shower or using the washing machine), it is possible to estimate exposure via inhalation. Given a drinking water concentration of, for example, 5 Bq/l, an average additional concentration of radon in the indoor air of a maximum of 0.5 Bq/m^3 can be expected. If these values are compared with the concentrations of radon in residential areas, values which in the Federal Republic of Germany lie within a wide range of up to a few 1000 Bq/m^3 (on average at 50 Bq/m^3), this additional concentration of radon and the associated radiation exposure is very small.

d) In continuation of the discussion at the conference, in December 1995 the Commission on Radiological Protection adopted a report on this subject which essentially reaches the following conclusion:

"*The radon content of drinking water in the Federal Republic of Germany does not constitute a major radiation protection problem for the population at large.*

Nevertheless, the question as to whether and how in the case of waterworks involving high levels of radon concentration a reduction can be achieved in the radon content on grounds of radiation prevention at a reasonable cost should be examined. To this end, the Commission on Radiological Protection proposes initiating some pilot projects in waterworks deploying different water preparation methods. For these projects, only waterworks should be selected at which the radon concentration of the drinking water channelled into the supply network is greater on average than 300 Bq/l.

The Commission on Radiological Protection intends addressing the question of the radiological evaluation of the radon content in drinking water as soon as the results of such pilot projects are available."

3 Radionuclides in the atmosphere

At the Commission on Radiological Protection closed meeting in 1995, calculation models were discussed which are designed to describe the transport of air-borne radionuclides following a hazardous nuclear incident or a nuclear accident. At present, Gauss plume models, which utilize rough estimates, are deployed within the framework of nuclear reactor remote monitoring systems. These models are unable to use flow models as series models and do not facilitate forecasts of future dispersion conditions. In May 1994, the 42nd environment minister conference requested the Federal Minister for the Environment, Nature Conservation and Nuclear Safety to provide a standard computer program for utilization in nuclear reactor remote monitoring systems and to coordinate the contents and function of a standard, computer-aided, integrated auxiliary decision-making system with the federal government and the federal states. The Commission on Radiological Protection had previously addressed the entire range of topics involved, including forecasting and utilizing the possibilities provided by the German Meteorological Service. The Commission on Radiological Protection's report (no. 5), which was also included in the discussion which was held at this conference, reaches the following conclusions:

a) For the purpose of forecasts, a model chain consisting of the German Meteorological Service's numerical weather forecasting models, a small-scale, non-hydrostatic flow model and a dispersion model should be developed. In the longer term, a Lagrange particle model is recommended as a dispersion model. All the necessary input data can be provided by a non-hydrostatic flow model. In order to obtain such a model, it is necessary to render one of the existing non-hydrostatic flow models fit for operational deployment.

b) Possible dispersion models for diagnosis purposes are Gauss-Puff or Lagrange particle models (GPMs and LPMs). Comparative calculations have revealed that both model types can run in real time on modern nuclear reactor remote monitoring system computers. Although LPMs are, in principle, superior to GPMs, input data or series models which are not currently available are required in order to achieve their superiority. The Franco-German Commission recommends a GPM as a common dispersion model, a GPM is deployed in the European auxiliary decision-making system RODOS/RESY, and GPM models can be deployed if it s necessary to reconstruct a source term which has not been measured from environmental measurements.

c) On the basis of an overall consideration and in an attempt to achieve harmonization, it is recommended that in the short term, a Gauss-Puff model fitted with the parametrization of the "Franco-German model" should be rendered suitable for deployment in nuclear reactor remote monitoring systems, the auxiliary decision-making system RODOS/RESY and the source term determination process. The necessary preprocessors are currently under development. Mass-consistent wind field models are already available as series models for Gauss-Puff models.

d) The Commission on Radiological Protection recommends that in the medium term, the foundations for the deployment of Lagrange particle models should be created for the operations stated above.

4 Radionuclides in bodies of water

4.1 Radionuclides in suspended particles and sediments in inland waters

a) The behaviour of radionuclides in aquatic systems can be described with the aid of radioecological models. In this connection, the accumulation and transport of radionuclides in the water/suspended particle/sediment or water/biota systems are determined, preponderantly on the basis of their chemical (particularly speciation) and physical (e.g. particle size, phase ratio). The General Administrative Regulations (AVV) in respect of §45 of the Radiation Protection Ordinance (StrlSchV) contains a model for calculating the dispersion of radionuclides in bodies of flowing water. The results of such a calculation can be compared with readings on the content of radioactive substances in flowing water as a result of discharges from a nuclear power station. Using the Moselle and the Cattenom nuclear power station as an example, it was established that the General Administrative Regulations model overestimates the actual specific activities in the suspended particles and the sediment. The General Administrative Regulations model only affords consideration to the distribution balance between the solid and liquid phases. Although vis-à-vis the actual values, the results of the sorption model for the accumulation of radionuclides in suspended particles and sediments developed at the Federal Institute for Hydrology (BfG) show higher accumulation levels, they are closer to the actual conditions than the results according to General Administrative Regulations. The Commission on Radiological Protection will examine this finding.

b) In the long-distance range, the values for Co-60 in suspended particles obtained using the General Administrative Regulations model are as much as one order of magnitude higher than the readings of the Federal Institute for Hydrology. Along the flowing body of water considerable "dilution" of the contaminated suspended particles apparently occurs. The Commission on Radiological Protection will also examine this finding.

c) The highest specific activities of the sediments are observed in slack water areas in which the contaminated suspended substances are deposited. Within the purport of the Radiation Protection Ordinance, these areas can be regarded as "extremely unfavourable impact areas". In the estimation of the Commission on Radiological Protection, these areas should therefore be considered during the extraction of sediment samples within the framework of the environmental monitoring of nuclear installations, particularly if excavation and subsequent disposal on irrigation fields.

4.2 Radionuclides in fish and food chains

a) The accumulation of radionuclides in aquatic organisms and their food chains is heavily contingent upon the physical and chemical composition of the water. In inland lakes a stable thermal coat develops in summer by means of which the vertical exchange of water and particles is severely restricted. The consequence of this is that possibly contaminated particles (plankton) are not transported to deeper strata of water until the disintegration of the thermal boundary surface in the spring, meaning that the discharged radionuclides are belatedly conveyed to the organisms in the deeper-lying strata (the profundal). This is not the case in the bank zone (the litoral). The Commission on Radiological Protection will examine whether or not models for calculating the consequences of a short-term, greatly increased atmospheric emission should be developed.

b) In flowing bodies of water, both in the water and in organisms the concentration of discharged radionuclides is contingent upon the flow rate, flow and watershed area of a river. In the case of gradual discharges from nuclear installations the equilibrium concentrations in organisms are not generally achieved. The calculation of radiation exposure in consequence of the consumption of fish in accordance with General Administrative Regulations in respect of §45 of the Radiation Protection Ordinance dispenses with a temporal component of activity absorption and discharge. The state of equilibrium of fish in relation to their medium of water is observed, in which connection a single-compartment model containing the biological half-life period is utilized. For this reason, the calculation of radiation exposure in accordance with the General Administrative Regulations model produces conservative results. This is intentional, and the Commission on Radiological Protection currently sees no need for action in this regard.

c) Predatory fish generally contain greater accumulations of radionuclides than non-predatory fish, in which connection the maximum concentration in the case of predatory fish is not attained until a later point in time and fish age. Insofar as the bioconcentration factors for a mixture of predatory and non-predatory fish have been established, the question of whether or not this method is sufficiently conservative should be examined, particularly in the case of short-term, greatly increased radionuclide emissions.

d) In the case of transuranic elements, no accumulation as a result of global fallout was observed in organisms with an ascending food chain. Thus, for example, in Lake Michigan, for Pu there was a reduction of accumulation in each of the various tropism levels by a factor of 10.

e) In spite of large quantities of data, particularly on Cs-137, there are still no quantitative forecasting models to describe the radiological effects of radionuclide emissions in bodies of water and the subsequent contamination of water organisms. The Commission on Radiological Protection recommends that appropriate evaluation and generalization endeavours in respect of short-term, greatly increased radionuclide emissions should be supported.

4.3 Radionuclides in the ocean

a) Waste water from the nuclear fuel cycle industry is discharged into numerous marine areas. The discharges from the reprocessing plants at Sellafield and La Hague were used for the purpose of measuring the transport of water masses by ocean currents over hundreds and thousands of kilometres. The study of such discharges has also enhanced our comprehension of the geochemical behaviour of numerous radionuclides in sea water and sediment. As a tool for studying advective and diffuse processes in sediment and for determining sedimentation rates, artificial and natural radionuclides are indispensable.

b) Current contamination levels in the North Sea are only slightly higher than those which were discharged in the wake of the atmospheric bomb fall out during the 1960s and which are still present. In the German Bight, current values which are measured in respect of Cs-137 and Sr-90 lie between 5 and 10 Bq/m^3. The level of Cs-137 contamination in the sediment are also correspondingly low (up to 20 Bq/kg). In 1980, the concentration levels in the water in the centre of the North Sea exceeded 300 Bq/m^3. This situation was occasioned by the high levels of discharge from the Sellafield plant during the middle of the 1970s, levels which peaked at 5200 TBq in 1975. These discharge levels currently lie between 10 and 20 TBq/a. The discharges from the plant at La Hague were always considerably lower than those from Sellafield.

c) Circumstances are somewhat different in the Baltic Sea, which experienced a high level of deposition, particularly in the northern region, as a result of the Chernobyl reactor accident. The transport of heavily contaminated water masses from these areas to the southern and western areas of the Baltic Sea issue in barely any reduction in concentration levels, with the result that the Cs-137 concentration currently lies between 40 and 70 Bq/m^3. In consequence of the severely limited exchange of water with the north-eastern Atlantic – a water renewal period of between twenty-five and thirty years is assumed for the Baltic Sea –, the contamination levels will only recede to the typical "fallout values" of previous years over a period of decades.

d) The former Soviet Union deposited large quantities of radioactive material in the Barents Sea and the Kara Sea. Inter alia, this includes seventeen submarine and one icebreaker reactors, of which seven still contain nuclear fuel. Contamination of the sediments is only evident in the direct vicinity of the waste deposits; hitherto, no large-scale contamination of these marine areas as a result of these waste deposits has been detected. Therefore, there is no indication that the corrosion of these seven reactors has occasioned the release of any radioactive substances. The circulation of the water masses through the European shelf seas results in the transport of the soluble radionuclides discharged from the Sellafield and La Hague plants to the arctic Barents Sea, Kara Sea and Greenland Sea. Transport from, for example, the Irish Sea to these seas takes between five and nine years. In line with the steep decline in the levels of discharge from Sellafield, the concentration levels are also undergoing a marked decrease in these areas.

   The extent to which the enormous quantities of waste deposits in the Arctic's two shelf seas, namely, the Barents Sea and the Kara Sea, will lead to a significant degree of exposure to radiation in future generations via the consumption of seafood is one of the questions which needs answering on an international basis.

e) Radioecological examination of Pu isotopes in the ocean have revealed that the presence of plutonium in the ocean only constitutes a minor hazard potential. Plutonium is largely sediment-bound and only enters the food chain in negligible quantities.

5 Radionuclides in natural ecosystems

Over the last few decades, studies in the field of radioecology largely focused on research into the transfer of radionuclides in agricultural areas and in the human food chain. Following the Chernobyl reactor accident, the results of these analyses and the models which have been developed from these results facilitated forecasts on the contamination of vegetable and animal foodstuffs. Currently, no comparable models exist for the conduct of radionuclides in natural ecosystems. As a result of the – in comparison with agricultural ecosystems, high transfer rates to natural ecosystems – the Chernobyl reactor accident and its consequences necessitated the more precise study of the temporal conduct of radionuclides, particularly Cs-137. An overview of the current state of knowledge of the conduct of Cs-137 and Sr-90 in forest ecosystems was presented at the Commission on Radiological Protection conference in October 1995. In this connection, as a result of the deficits in this area mentioned above, this overview is presented in some detail.

a) During the passage of air masses, the very effective filter effect of the tree tops results in high levels of deposits of air-borne radionuclides. In view of the fact that most deciduous trees in Central and Northern Europe were devoid of foliage at the time of the Chernobyl accident, the highest deposit levels were found in coniferous trees.

b) In 1986, efflorescence occasioned a marked reduction in the contamination of the tree tops and a relocation of radionuclides to the forest soil. In addition to a horizontal uneven distribution of radionuclides, induced by, for example, trunk discharge, the very different chemical, physical and biological characteristics of the various forest soil horizons have also resulted in a vertical uneven distribution of radionuclides.

c) The organic horizons of forest soils in particular are important for the conduct and plant availability of radionuclides. Whereas in the deeper-lying mineral horizons Cs-173 is immobilized by means of fixation to clay minerals, various studies indicate a largely biological "fixation" of radiocaesium in the organic horizons. This explains its comparatively slow physical and chemical migration (eight years after the Chernobyl reactor accident, most of the Cs-137 was still located in the organic horizons. A model has been developed for estimating the residence time of radiocaesium in various soil horizons. Even after decades, most Sr-90 is still located in the organic soil horizons.

d) Studies conducted at various locations have revealed that the accumulation rate of Cs-137 mushrooms existing symbiotically alongside plant roots is ten times higher than that of parasitic or saprophytic species. In order to establish species-specific transfer factors, it is necessary to determine the mushroom spawn depth of the relevant species. Since 1987, the corresponding transfer factors have remained largely constant. With the aid of the soil model mentioned above and the transfer factors determined in relation to the dry mass (in the region of 0.1 to 40), it would appear possible to forecast the specific caesium activity in the case of fourteen species of mushroom.

e) No species-dependent accumulation factors in the case of mushrooms have been observed for Sr-90. The transfer factors which have determined (in relation to humidity mass) lie between 0.002 and 0.01.

f) The Cs-137 activities in fourteen species of foliage plants at two locations were compared with the corresponding caesium activities in the soil. Whereas there was practically no difference between the average levels of Cs-137 concentrations in the two soils, compared with corresponding plants from the other location, some individual species from the one location revealed a significant higher level of activities. The transfer factors of the species from both locations (in relation to humidity mass) lie between 0.01 and 3.2. In view of the fact that the ratio of Cs-137 to K-40 in various plant sections with different concentrations of potassium is largely constant, it can be assumed that Cs-137 activity is regulated by the potassium metabolism.

g) Sr-90 activity in foliage plants is apparently regulated by potassium content. As with Cs-137, there were fairly high levels of Sr-90 activities in leaves and fairly low levels in fruits. The transfer factors for Sr-90 (in relation to humidity mass) lay between 0.1 and 0.6.

h) Studies of pines and beech leaves indicate that even a few years after the deposition of radionuclides root-based absorption is the main contamination route.

i) Studies of Cs-137 activity in the muscular flesh of deer during the period 1987 to 1993 established that in each case, the highest average monthly value occurred in October. This is explained by an increased consumption of mushrooms with higher levels of contamination in that month. In February, the consumption of winter feed with lower levels of contamination reduced the specific activity in muscular flesh by an average factor of 7. Following the end of winter feeding, the specific activity in the muscular flesh increased again. For two areas, average transfer factors (Bq/kg deer meat to Bq/m^2 soil occupation) of 0.036 and $0.047 m^2/kg$ were established. Comparisons with other species of animals revealed that, for example, there is a far higher level of specific activities in the muscular flesh of wild boars than in that of deer from the same environment. The lower level of contamination in the muscular flesh of red deer can be attributed to the higher proportion of grass with a low level of contamination in their diet.

j) The studies which were conducted after the Chernobyl reactor accident have resulted in a deeper understanding of the behaviour of radionuclides in the forest ecosystem. For the development of a universally deployable model, the individual components of radiologically relevant natural ecosystems will need to be studied in greater detail.

6 Radioecological models and their validation

For the purpose of calculating potential human exposure to radiation during orderly operations and in the event of a hazardous incident, radioecological models are deployed for planning and approving nuclear installations. These are intended to describe – as realistically as possible – the dispersion of radionuclides in the biosphere via aquatic and terrestrial food chains to humans. During the past few years, a number of radioecological models have been developed which describe the processes in the biosphere on a more or less simplified basis. Understandably, there is some interest in examining the quality of the results which are obtained using such a model qualitatively and quantitatively. At the Commission on Radiological Protection conference, the results of two major international studies (BIOMOVS and VAMP) for the validation of calculation models were presented. In addition, reports were presented on post-Chernobyl experiences with the GSF model ECOSYS, particularly in southern Germany:

a) Generally speaking, there was a high level of correspondence between forecast and measured contamination levels in foodstuffs.

b) It became evident that the location-specific conditions can have a major bearing on results; the utilization of generic parameters mainly resulted in misestimations.

c) Models should be examined by means of as many interim steps via comparison with readings in order to facilitate the recognition of self-compensating errors in the submodels for the food chains.

d) In general, all forecasts tended towards an overestimation rather than an underestimation of the actual resulting ingestion doses. This was largely attributable to the absence of data on the behavioural and nutritional habits of the population at large and the substitute utilization of parameters and model assumptions which produced overestimations.

e) The intended purpose of a model should be borne in mind during utilization.

f) At present, no radioecological model exists which is validated for all situations.

g) Care should be taken to safeguard the quality of the readings during the validation of models.

Following these observations, the Commission on Radiological Protection reaches the conclusion that the internationally performed comparative calculations have produced some important information on the evaluation of radioecological models and their results. The Commission on Radiological Protection recommends that the range of application of radioecological models should be expanded and the development of the necessary data records suitable for such models on arable landscapes, natural ecosystems and urban environments should be forced apace. The Commission on Radiological Protection also recommends that the learning ability of such forecast models should be so developed that current measuring data can be utilized for the purpose of enhancing the quality of forecasts.

7 Computer-aided information and decision-making auxiliary systems for evaluating radioecological consequences of hazardous incidents and accidents

The objective of radiation protection in the event of nuclear accidents is to ensure that their effects on humans and the environment are as low as possible by means of initiating suitable measures. Sources of information for the purpose of determining the situation are the operators of an affected installation, various measuring devices, the measuring services of the federal government and the federal states and the personnel of the catastrophe and radiation prevention services. The systems which are deployed for the purpose of determining and assessing the situation can be categorized in four classes. Class 0 systems facilitate the acquisition, transfer and evaluation or radiological and meteorological readings. Class 1 systems additionally facilitate the diagnostic and prognostic determination of meteorological fields (see 3), releases of activity, dispersion conditions and dose and contamination fields (see 6). Class 2 systems also facilitate the simulation of protective measures and countermeasures and the quantification of the associated radiological and material consequences. Finally, Class 3 systems produce a league table of alternative strategies which is determined by means of the comparative assessment of the advantages and disadvantages of measures.

The nuclear reactor remote monitoring systems of the federal states (KFÜ-systems) and the IMIS encompass Class 0, Class 1 and, to a limited degree, Class 2 modules. The RESY and RODOS decision-making auxiliary systems additionally encompass Class 2 and Class 3 modules. In view of, inter alia, the interests of the federal states, the Commission on Radiological Protection supports the initiative of the Federal Minister for the Environment, Nature Conservation and Nuclear Safety to create the RODOS/RESY program system for assisting the decision-making process in the case of nuclear emergencies, and considers the establishment of this system at a central location advisable. The plans for establishing such a central system are not yet finalized.