German Commission on
Radiological Protection
(Strahlenschutzkommission)

Office:
Geschäftsstelle der
Strahlenschutzkommission
Postfach 12 06 29
D-53048 Bonn
Germany
http://www.ssk.de

Comparability of natural radiation exposure with radiation exposure due to nuclear facilities

Comment of the German Commission on Radiological Protection

The German original of this English translation was published in 1977 by the Federal Ministry of the Interior under the title:

Vergleichbarkeit der natürlichen Strahlenexposition mit der Strahlenexposition durch kerntechnische Anlagen

in Bundesanzeiger No. 137 of 27 July 1977 and in Vol. 1, Publications of the Commission on Radiological Protection.

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

Adopted at the 11th session of the Commission on Radiological Protection,
16/17 December 1976

Contents

In 1975 the Federal Minister of the Interior requested the Commission on Radiological Protection (Strahlenschutzkommission), which advices him on all questions relating to protection against the hazards of ionizing radiation, to comment on the problem of the comparability of natural radiation exposure and exposure to radiation from nuclear facilities. The Commission on Radiological Protection has discussed this problem in detail and issued the present comment on 16th December 1976.

Introduction

Within the context of the discussion on the peaceful use of nuclear energy it is claimed that a comparison of natural radiation exposure with radiation exposure caused by nuclear facilities is not possible with regard to their biological effects (1). The Commission on Radiological Protection has therefore taken critical stock of the current state of knowledge on both kinds of radiation exposure in order to clarify whether doubts on the reliability of the equivalent dose as the generally applied measure of comparison between radiations from differing sources are justified from the biophysical and radiobiological point of view.

In the reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2), considerable space was given to balancing natural radiation exposure and its range of variation. More recently a comprehensive inventory of natural radiation exposure has been carried out in the Federal Republic of Germany (3) and the United States (4). The Federal Ministry of the Interior initiated a measuring program to determine the actual breadth of fluctuation of terrestrial radiation in the Federal Republic of Germany (5).

The exposure to radiation of the population in the environs of nuclear facilities is determined by the measured discharge rates of radioactive substances and their distribution in the environment. Comprehensive investigations into this question were carried out in the Federal Republic of Germany (6, 7) and in other countries (8, 9).

Comparison of primary events in the effects of radiation

Regardless of the nature of their origin, all ionizing rays cause the same type of primary biophysical processes such as ionization and stimulation of atoms and molecules. Biological effects may proceed from these. The nuclear transformation of radioactive substances and the changes in atomic charge which may be connected with this (inter alia the Auger effect) or changes in the chemical properties (see “Transmutation”), can also lead to biological effects.

With the same energy dose, there may be differences between the various types of radiation and exposure conditions in the relative temporal and spatial distribution of the primary biophysical processes on the absorption of radiation energy, which may exert same influence on the effectiveness of the radiation. If, however, the relative temporal and spatial distribution of the primary biophysical processes are uniform in the same object at the same energy dose, then their biological effectiveness is also the same.

When a body organ is subjected to a certain mean radiation dose, differences in the relative temporal and spatial distribution of the primary events occur

a) due to differing types of radiation or radiation energy,
b) due to differing distribution of radioactive substances in an organ or tissue.

These differences between various radiation exposures at the same energy dose are taken into account in the calculation of the equivalent dose by assessment factors which are uniformly fixed international with the necessary precision for the low doses and dose rates concerned for radiation protection (10). The assessment of current exposure to radiation of the population from nuclear facilities is based on the conviction, that the equivalent dose thus determined is a reliable measure which can also be applied for the comparison of radiation exposure from natural sources and from nuclear facilities.

For this reason it was examined in detail whether relevant peculiarities of the relative spatial and temporal distribution of the primary events regarding the radiation exposure actually possible due to nuclear facilities are known, which would allow a comparison with the natural expoure to radiation on the basis of the equivalent dose to appear unjustified.

For both types of exposure we differentiate between external and internal radiation exposure. External radiation exposure is caused by energy bearing particles and photons which penetrates into the organism from the exterior. Internal radiation exposure is caused by radioactive substances being absorbed into the organism with food intake and air breathed. These substances are distributed in the organs according to their physical and chemical properties and emit rays during their nuclear transmutation.

The types of rays emitted by naturally radioactive substances and the radioactive substances occurring in the discharges of nuclear facilities are the same in principle. They are γ-rays, β-rays, X- rays (after K-capture) and – primarily among naturally radioactive substances – α-rays.

1 External radiation exposure

The causes of natural external radiation exposure of man are the primary cosmic rays and the natural radioactive substances in our environment.

A whole spectrum of secondary ionizing rays occurs on the basis of the interaction of high energy cosmic rays and the earth's atmosphere. Due to the differing absorption strength in the atmosphere, the effective equivalent dose rate depends on the elevation above sea level. In the Federal Republic of Germany the rate is approx. 28 mrem per annum at sea level, 40 mrem per annum at 1,000 m above sea level and 80 mrem per annum at 3,000 m above sea level. The energy dose rate at sea level is due to 90 % to light elementary particles such as e. g. electrons, the effectiveness of which is very similar to that of secondary released by terrestrial γ-rays.

The earth's surface and thus all construction materials and all activated material contains natural radionuclides such as uranium and thorium with their consequential products, potassium-40, etc. These radionuclides also emit γ- rays and thus contribute substantially to external radiation exposure of man. In the Federal Republic of Germany comprehensive measurements in thousands of households and in the open showed clear fluctuations in this radiation exposure. The mean, maximum and minimum values for the individual Federal Lands are shown in Table 1. In the whole of the Federal Republic the terrestrial radiation exposure (reproductive gland dose) lies in the range of 4 mrem per annum (5). The energies of the γ- rays of natural external radiation exposure range up to about 3 MeV. Additional external γ- radiation is caused by radioactive discharges from nuclear facilities. It is due primarily to the radioactive gases in the exhaust air. The energies of these γ- rays lie between 80 keV and 2 MeV. The dose rate calculated assuming the least favourable conditions on the basis of discharges approved to date at the most unfavourable area of influence in the direct environs of nuclear power plants is less than 30 mrem per annum.

In addition to this the body surface is subject to similar exposure due to β- rays from natural and cultivated sources.

The γ- and β-rays from natural sources in the earth and from the cosmos as well as from the discharges from nuclear facilities are comparable as regards their energies and the dose rate for both is exceptionally low. Accordingly the effects per dose unit released by this external radiation exposure are necessarily practically the same.

2 Internal radiation exposure

The natural and artificially generated radionuclides in the environment penetrate into man with the food taken in and the air breathed and cause internal exposure to radiation of the body. The equivalent doses resulting from the radioactive substances absorbed depend on the concentration of radionuclides in the relevant organs and the type and energy of the radiation emitted.

The absorption and distribution of the various radionuclides in the body depend on the chemical behaviour of the compounds in which they are incorporated when they are absorbed in the body. The influences of the chemical bond of the most important radioactive substances occurring naturally and in the discharges from nuclear power plants on the distribution of the radionuclides in the various organs of the body are known from research findings. The radiation doses thus caused have been determined with sufficient accuracy (11, 12).

The exposure of man to radiation due to natural radioactive substances absorbed into the body is due primarily to radionuclides (such as tritium, carbon-14 and potassium-40), which do not prefer to concentrate in any particular organ or tissue and which emit only β-rays or β-and γ-rays. In addition to this further radiation exposure due to radionuclides is caused by the natural decay series which are accumulated in the individual organs and become primarily effective via their α-rays.

When the radioactive substances occurring in the discharges of nuclear facilities are absorbed into the body, they lead almost exclusively to internal radiation exposure with β and γ-rays. In the discharges of German nuclear power plants, above all radioisotopes of antimony, barium, cesium, cerium, chromium, iron, iodine, cobalt, carbon, lanthanum, manganese, niobium, silver, strontium, hydrogen and zinc were measured. Of these radionuclides, all of which emit β-rays or β- and γ-rays, iodine concentrates particulary in the thyroid gland and strontium in the bones.

An uneven distribution of the radionuclides in microscopic areas within individual organs only causes a corresponding unevenness of the spatial distribution of the radiation dose if the range of the rays emitted is small, (i. e. α-rays and low energy β-rays).

The uneven dose distribution within an organ may be more effective than the uniform distribution of the same mean radiation dose if certain selective organ structures or cells essential for life, such as e. g. bone forming cells, the parent cells of blood or the reproductive organs are affected. A relatively high radiation exposure of cells or structures which are not responsible for the occurrence of relevant damage is not significant. The problem of inhomogeneous dose distribution occurs in the following cases:

2.1 α-rays

Various natural and artificial radioactive substances emit α-rays during their transmutation. Some natural radioactive substances lead with their α-rays to an internal radiation exposure of bones, liver and bronchial tubes which is in same cases more than twice as high as the mean internal radiation dose for the whole body. Slight traces of radioactive substances emitting α-rays have also been detected in the discharge of nuclear facilities.

The short range of α-rays leads to relatively high radiation doses in the direct environs of their source of generation. The uneven distribution of these radionuclides therefore causes considerable dose fluctuations from one part of the organ to another or from individual cells to others. That is why precise knowledge of their spatial distribution within the various organs and organ segments, even in microscopic areas, is important for the assessment of the radiation hazard of the various radionuclides emitting α-rays.

This problem is important for the evaluation of the hazard of “hot particles“ emitting α-rays, on which the Commission on Radiological Protection commented on 19.2.1976. It came to the following conclusion:

“The present findings of investigations with animal subjects do not provide any indication of increased lung cancer hazard due to the inhalation of hot particles in comparison to a homogeneous irradiation of the lung. On the contrary, these investigations indicate that with the same mean lung dose, the radiation hazard due to a strongly inhomogeneous dose distribution in the lung is less than in the case of a homogeneous dose distribution.“

In its publication 11 and 19 (14), the International Commission on Radiation Protection (ICRP) discussed the microdistribution of various radionuclides which emit α-rays, which are embedded in the bones, and their influence on the radiation exposure of critical cells in the bone and the resulting radiation hazard. It came to the conclusion that e.g. the relative microdistribution of the dose in the bone due to absorbed radium-224 or thorium is similar to that due to absorbed plutonium or americium. No systematic difference between natural and artificial radioactive radioisotopes emitting α-rays as regards the microdistribution of the radiation dose emitted was established.

There are no systematic differences between the synthetic radioactive substances which may be unintentionally discharged from nuclear facilities and the natural radioactive substances which occur everywhere with regard to the energy of the α-rays emitted, their distribution and their metabolism in the organism or their distribution in microscopic area in the relevant critical organs.

2.2 Low energy β-radiation of tritium

Tritium from natural or cultivated sources is generally present as a component of water molecules. In this form, therefore, tritium is practically uniformly distributed in the soft organs of the body. After absorption of water containing tritium, however, a few percent of the radionuclide penetrates the organic substance of the body and can thus stay in the body longer than water. Despite this the distribution remains almost uniform. This is also the case for tritium which is absorbed e.g. with solid foods. The radiation exposure of organs and cells is correspondingly uniform, regardless of wether tritium originates from natural or cultivated exposure.

Biologically relevant uneven distribution of the incorporated tritium and thus of the radiation dose can practically only occur if tritium is incorporated into the genetic material of the body after an injection of special chemical compounds (in particular tritium-thymidine in high specific activity). This has no significance in the context of the theme under discussion.

2.3 Transmutation

By transmutation we understand the change in the chemical nature of a radionuclide when it is transformed into another element. The changes in atomic charqe connected with the transmutation and the recoils of the atomic nuclei caused by emitting ionizing rays can cause biological effects. Biologically effective transmutation effects have been investigated for both naturally present radionuclides tritium and carbon-14 as well as phosphorus-32, and for these substances generated in nuclear facilities, insofar as they are incorporated in genetic material. These effects are qualitatively similar in the living cell to those of the resulting ionizing radiation, but are quantitatively negligible (15).

2.4 Auger effect

The transformation of certain radionuclides involves the emission not only of low energy γ-rays but also of several electrons from the atom shell (Auger effect). These electrons have a short range and thus generate a high local dose in a very small area. Due to the sudden loss of serval electrons (from the atom shell, an atomic charqe deficit also occurs which in turn can release additional biological effects, depending an the molecular combination of the decaying nuclide.

The Auger effect occurs with both same natural and some synthetic radionuclides, (e.g. potassium-40, cobal-58, iodine-125). To date there are no indications as to the preferred incorporation of such radionuclides in certain critical molecules, cells or structures, in particular the genetic materials (DNS), damage to which can trigger off diseases. According to the present state of knowledge, a biological effect of the Auger effect occurs only after incorporation of a chemical compound (iodine-125-desoxyuridine), which practically does not occur naturally, in the genetic material of the cell (16).

The Auger effect is, therefore not significant in this connection.

Conclusion and evaluation

The biologicä1 effect of the various types of radiation from natural and synthetic radiation sources rests on the same biophysical mechanisms. With an equivalent dose, i. e. taking into consideration the type and energy of the radiation, dose rate and where applicable the rnicroscopic dose distribution and the spatially, determined energy dose, an external or internal radiation from synthetic sources has practically the same effect as radiation from natural sources. A detailed analysis showed that with regard to these factors, there are no relevant differences between natural external radiation exposure and external radiation due to synthetic radioactive substances which occur in the discharges from nuclear power plants. In addition to this when the radionuclides concerned are absorbed into the body, there are no differences on these points between synthetic radioactive substances from the discharges of nuclear facilities and the comparable natural radioactive substances.

The Commission on Radiological Protection finds that the equivalent dose for radiation protection is a reliable, sufficiently accurate measure of comparison for different exposures to radiation. The equivalent doses generated by the natural exposure to radiation of man and their local and temporal fluctuations form a suitable reference system for assessing and evaluating radiation exposure due to nuclear facilities.

Table 1: Reproductive gland dose due to external terrestrial radiation exposure in the Lands *of the Federal Republic of Germany (mrem/annum)*

Land	Values in the open air			Values in homes *)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Baden-Württemberg	45	165	11	57	134	11
Bavaria	50	291	14	61	243	14
Berlin	42	133	22	50	129	17
Bremen	30	45	20	38	65	18
Hamburg	40	86	22	40	77	21
Hessen	43	108	7	65	144	24
Lower Saxony	34	80	7	47	122	12
North Rhine-Westfalia	42	118	4	55	154	14
Rhineland-Platinate	49	90	22	74	180	23
Saarland	57	114	22	87	158	28
Schleswig-Holstein	37	57	13	43	124	19
Total	43	291	4	57	243	11

*) Household mean values from all rooms of the home

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