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**RADIONUCLIDE DEPOSITION AND EXPOSURE IN THE
FEDERAL REPUBLIC OF GERMANY AFTER THE CHERNOBYL ACCIDENT**

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1. Introduction

Chernobyl is located about 1500 km east of the Federal Republic of Germany. The accident at Chernobyl nuclear power station unit four occurred on April 26, 1986, and led to the release of a substantial amount of radioactive material into the atmosphere.

Atmospheric composition and deposition data for material emitted during the Chernobyl accident, when combined with data taken by other agencies in Asia and in the European community, are a unique record of long-range radionuclide transport. When combined with measurements of radionuclide concentration in foodstuffs, parameters for modeling elemental uptake and movement within the food chain may be determined. Finally, these data will be useful in long-term studies of the radiological consequences of radiation exposure.

Initial reports were received from Scandinavian countries, where the total exposure rate increased dramatically in certain areas to up to 5 $\mu\text{Sv/h}$ by April 28, 1986 (1). A change of the weather situation caused the "radioactive cloud" which contained additionally released radioactive material to be transported directly towards central Europe. The arrival of the contaminated air from Chernobyl over central Austria and the southeastern part of the Federal Republic of Germany on April 30, 1986, together with short but intensive rainfalls on that day, led to wet deposition of radionuclides. The highest soil contamination was therefore reported from these areas. The radioactive cloud then went on towards the west and northwest. After it had passed the northern parts of France and Germany, it reached Great Britain on May 2, 1986.

2. Radionuclides in air

The Munich Federal Health Office began measuring particulates, aerosol-bound and elemental gaseous as well as organically-bound

iodine in air, on April 29, 1986. As an example, the results of gamma spectrometric measurements for the time period from April 29 to May 1, 1986, are listed in Table 1. The data show that in early May the largest fraction of total activity in air was due to ^{132}Te and ^{132}I . The maximum activity of 210 Bq/m^3 in air (including iodine isotopes) was measured in the afternoon of April 30. Due to the rainfall at that time, the activity of airborne aerosol-bound radionuclides and iodine isotopes in air was reduced, except for organically-bound iodine which was not essentially influenced by rainfall. A marked decrease of organically-bound iodine activity was seen after May 2. After the washout of aerosol-bound radionuclides, including elemental gaseous iodine on April 30, an increase in activity in air was again observed on May 1. The activity did not reach the intensity of April 30. During the evening May 1, a steady decrease in air activity was noted. There was no more precipitation in the Munich area until May 3. At the time of the highest air activity, the fraction of aerosol-bound ^{131}I of the total ^{131}I activity was approximately 40%, while an additional 35% was due to elemental gaseous ^{131}I , and about 25% was due to organically-bound ^{131}I . The correlation between aerosol-bound ^{131}I and elemental gaseous ^{131}I remained constant during the entire period ($\sim 1:1$). In the following period the decrease of organically-bound ^{131}I activity was less intensive than that of aerosol-bound or elemental gaseous ^{131}I , respectively. Therefore, the fraction of organically-bound ^{131}I in air became more dominant. About two weeks later, the total radionuclide activity in air had decreased to about 0.03 Bq/m^3 . At this time only very low activities of ^{131}I , ^{106}Ru , and ^{137}Cs were measured in air, and the activity concentration of individual nuclides in air had fallen below 10^{-4} Bq/m^3 . The activity concentration of cesium and ruthenium isotopes in air in the Munich area from April 30 to May 8, 1986, is given in Figures 1 and 2. The activity concentration of the different forms of radioiodine is shown in Figure 3.

Table 1. Activity concentration of radionuclide in air
Site: Federal Health Office, Institute for Radiation Hygiene, Neuherberg (near Munich)

Sampling period	Activity concentration (Bq/m ³) ^{a,b}					
	4/29/1:45 pm 4/30/10:00 am	4/30/10:30 am - 2:30 pm	4/30/3:00 pm - 6:15 pm	4/30/6:40 pm - 5/1/11:45 am	5/1/11:40 am - 6:00 pm	5/1/6:00 pm - 8:10 pm
Particulates						
Nb-95	--	0.07 (0.03) ^a	0.03	0.06	0.08	0.09
Mo-99	--	4.5 (2.1)	1.5	1.2	1.7	1.0
Tc-99m	0.20	4.4 (2.1)	2.1	1.7	2.2	1.7
Ru-103	0.39	9.9 (4.7)	5.0	4.0	5.5	4.6
Ru-106	--	2.1 (1.0)	0.91	1.0	1.2	1.3
Ag-110m	--	0.13 (0.06)	0.04	0.06	0.13	--
Sb-125	--	0.14 (0.07)	0.08	0.14	0.21	0.08
Sb-127	--	1.3 (0.6)	0.58	0.38	0.74	0.47
Te-129m	--	11 (5.2)	4.4	4.3	8.6	6.9
Te-129	--	5.9 (2.8)	3.1	3.0	4.3	2.4
I-131	1.1	21 (9.9)	9.3	6.5	13	14
Te-132	2.9	55 (26)	26	21	32	23
I-132	1.8	25 (12)	18	11	14	16
I-133	0.07	1.5 (0.7)	0.56	0.17	0.23	0.20
Cs-134	0.26	4.0 (1.9)	1.7	1.8	4.1	2.4
Cs-136	0.10	1.3 (0.6)	0.48	0.60	1.3	0.76
Cs-137	0.59	9.2 (4.3)	3.7	3.5	7.5	4.5
Ba-140	0.30	4.6 (2.2)	1.8	1.7	3.7	2.5
La-140	0.23	3.6 (1.7)	1.2	1.5	3.5	2.1
Ce-141	--	0.10 (0.05)	0.04	0.06	0.09	0.10
Ce-144	--	--	--	0.03	--	--
Molecular sieve (I₂, elemental gaseous iodine)						
I-131	0.70	18 (8.5)	8.3	8.3	15	9.2
I-132	0.37	13 (6.1)	2.3	3.3	13	2.8
Te-132	0.07	--	0.34	0.12	0.25	0.81
I-133	0.08	1.0 (0.5)	0.40	0.27	0.51	0.14
Charcoal (organically-bound iodine)						
I-131	1.3	13 (6.1)	16	15	20	15
I-132	0.05	1.1 (0.5)	0.75	0.32	2.2	0.98
Te-132	0.03	0.2 (0.09)	0.42	--	0.44	0.49
I-133	0.07	0.8 (0.04)	0.79	0.57	0.48	0.50
Total	11	210	110	90	155	110

^aNuclide composition in percent is given in brackets.

^bUncertainty of data in the range of 10-15%.

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Fig. 1. Activity concentration of cesium isotopes in air for the period from April 29 to May 8, 1986.

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Fig. 2. Activity concentration of ruthenium isotopes in air for the period from April 29 to May 8, 1986.

Fig. 3. Activity concentration of aerosol-bound, elemental gaseous, and organically-bound ¹³¹I in air.

Measurements in other parts of Germany have shown that the ratio of radionuclide concentrations in air was nearly constant. The activity concentration in the air did not exceed the values measured in south Germany. For example, in Berlin a maximum activity concentration of particulates of 30 Bq/m^3 was observed (2).

The second arrival of the radioactive cloud after it circled the globe was observed in southwest Germany on May 25, 1986. This cloud had an activity concentration that was to be expected due to the radioactive decay of the individual radionuclides and the atmospheric retention time of particulates in air. By the end of May 1986, the activity concentration of ^{137}Cs was of the order of a few mBq/m^3 and the concentration dropped to some $10 \mu\text{Bq/m}^3$ by the end of July. The values were similar to those prior to the Chernobyl accident by the end of the year 1986 (3).

Results from the first strontium analysis were available as early as May 5, 1986, with the maximum activity concentration for ^{90}Sr in air being 0.09 Bq/m^3 . The corresponding value for ^{89}Sr of 1.0 Bq/m^3 was about a factor of 10 higher. The contribution of ^{90}Sr of less than 0.1% to the total activity in air was relatively small. After May 3, neither ^{89}Sr nor ^{90}Sr activities above the detection limit of about 0.05 Bq/m^3 and 0.02 Bq/m^3 , respectively, could be found on the particulate filters. The $^{137}\text{Cs}/^{90}\text{Sr}$ ratio came out to be about 100:1.

Measurements of particle size distribution of radionuclides on aerosols revealed that 80% of the activity was accumulated on particles with an aerodynamic diameter between $0.2 \mu\text{m}$ and $2 \mu\text{m}$, except for ^{90}Sr . The distribution of individual nuclide activity is lognormal with a mean value of about $0.6 \mu\text{m}$. The geometric standard deviation ranged from 3 to 4 for ^{131}I and from 2 to 2.5 for the other radionuclides mentioned. About 90% of the activity of ^{90}Sr was attached to particles with an aerodynamic diameter between $1.0 \mu\text{m}$ and

10 μm . The corresponding mean particle diameter value for this radionuclide lies between 2 and 3 μm .

The highest activity concentration of ^{238}Pu or $^{239}\text{Pu}/^{240}\text{Pu}$ in air measured by the Federal Health Office was found to be 130 $\mu\text{Bq}/\text{m}^3$ and 200 $\mu\text{Bq}/\text{m}^3$, respectively, on May 1, 1986. For the time period from April 30 to May 2 and April 30 to May 4, respectively, a mean activity concentration of ^{242}Cm in air of 100 $\mu\text{Bq}/\text{m}^3$ and 60 $\mu\text{Bq}/\text{m}^3$ respectively, could be determined.

A significant increase of the activity concentration of ^{14}C (as carbon dioxide) in the air could not be observed. For tritium (as H^3HO) a doubling of the activity in rainwater could be determined for the time period from April 28 up to May 5, 1986 (4).

Measurements of noble gas activity in air were performed by a few institutes only. Of the radioactive noble gases released, ^{85}Kr and ^{133}Xe could be observed. The Federal Health Office in Munich used an in situ gamma ray spectrometer for the determination of the activity concentration of ^{133}Xe in air. The results of these measurements are summarized in Table 2.

Table 2. Activity concentration of ^{133}Xe in air at the Munich area, measured with an in situ gamma ray spectrometer

Date (1986)	Activity concentration (Bq/m^3) ^a
April 30 (12:00 p.m.)	140
May 1 (09:30 a.m.)	120
May 1 (12:30 p.m.)	80
May 1 (01:30 p.m.)	50
May 1 (05:00 p.m.)	60
May 2	≤ 40

^aUncertainty of data about 25%.

The highest activity concentration of ^{133}Xe in air measured at the Munich area was about 160 Bq/m³ on April 30, 1986. At that time the activity concentration of particulates including iodine was 210 Bq/m³. The activity concentration of ^{85}Kr at the same site was determined by the Institute for Radiohydrometry of the Association for Radiation and Environmental Research, Munich, to be 2 Bq/m³ (previous value 1 Bq/m³, sampling period from April 30 to May 3, 1986) (5).

The Federal Bureau for Public Protection in Freiburg^b also performed measurements of noble gas activity. According to their results, ^{85}Kr activity had doubled in early May from 1 to 2 Bq/m³ over a short period of time. The activity concentration of ^{133}Xe reached a maximum of about 100 Bq/m³ on May 1, 1986 (6).

3. Soil contamination

Measurements of the soil contamination with an in situ gamma ray spectrometer were started at the site of the Institute for Radiation Hygiene in the morning of April 30, 1986. At that time only dry deposition of radionuclides was relevant. The intensive rainfall in the afternoon of that day caused a strong increase of soil contamination. Results of these measurements until August 1986 are summarized in Table 3. On May 1, 1986, the total soil contamination amounted to about 400 kBq/m². During the first days, $^{132}\text{Te}/^{132}\text{I}$ and ^{131}I contributed the major part of the soil contamination rendering activities with about 100 kBq/m² (25% each) and 70 kBq/m² (17%), respectively. The deposition of ^{137}Cs was measured to be 18 kBq/m² for that site. This value is about four times as much than the ^{137}Cs soil contamination due to the nuclear weapon testing. The portion

^bFreiburg is located about 280 km west of Munich. The radioactive cloud passed this area with a considerably lower air activity approximately one day after it had passed Munich.

Table 3. Soil contamination measured with an in situ gamma ray spectrometer sited at the Institute for Radiation Hygiene near Munich

Date	Soil contamination (kBq/m ²) ^a							
	04/30/86 ^b before rainfall	05/01/86 after rainfall	05/15/86	05/19/86	06/01/86	07/03/86	07/15/86	08/07/86
Nuclide								
Zr-95	--	--	0.31	--	0.30	0.18	0.12	0.13
Nb-95	--	0.62	0.51	0.39	0.58	0.45	0.34	0.31
Mo-99	--	7.3	--	--	--	--	--	--
Tc-99m	0.3	6.6	--	--	--	--	--	--
Ru-103	0.75	18	17	15	11	6.4	5.0	3.5
Ru-106	--	4.2	4.2	4.2	4.2	4.0	4.1	3.8
Ag-110m	--	--	0.32	0.34	0.24	0.23	0.26	--
Sb-125	--	--	--	--	0.40	0.50	0.41	0.44
Sb-127	--	1.5	--	--	--	--	--	--
Te-129m	--	18	20	16	12	5.6	4.2	--
Te-129	--	12	12	9.4	7.8	3.7	3.4	0.73
I-131	4.0	68	26	16	5.0	0.29	0.12	--
Te-132	3.5	100	6.3	1.9	0.1	--	--	--
I-132	4.5	110	6.6	2.0	0.1	--	--	--
I-133	--	1.7	--	--	--	--	--	--
Cs-134	0.33	9.4	11	9.7	8.9	8.8	8.5	8.8
Cs-136	--	3.3	1.6	0.8	0.6	--	--	--
Cs-137	0.66	18	19	17	16	17	16	17
Ba-140	0.40	11	5.3	3.8	1.7	0.31	--	--
La-140	0.31	8.8	6.3	4.5	2.2	0.39	0.16	--
Ce-141	--	--	--	0.42	0.35	0.20	0.08	--
Ce-144	--	--	--	--	0.46	--	--	--
Total	-15	-400	-140	-100	-70	-50	-40	-40

^aCalculation based on a relaxation depth of $1/\alpha = 1$ cm for a model of exponential decrease of the activity with increasing depth.

^bPortion of the measured air activity taken into account (semi-infinite cloud).

due to radionuclides like $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$, ^{103}Ru , ^{129}Te , and $^{129\text{m}}\text{Te}$ as well as ^{134}Cs , ^{136}Cs , ^{137}Cs , and $^{140}\text{Ba}/^{140}\text{La}$ amounted to about 1-5% each of the total soil contamination during the first days in May. Figure 4 shows the activity of some radionuclides deposited at the Munich area as a function of time. The distinct rise of the soil activity due to the rainfall can be clearly perceived. With the beginning of May, no further substantial contamination of the soil could be observed.

The deposition of ^{86}Sr and ^{90}Sr was determined to be 2 kBq/m^2 (on May 5, 1986) and 180 Bq/m^2 , respectively. The ^{90}Sr value was much lower than that originating from atmospheric nuclear weapon testing. In Figure 5, values for ^{137}Cs and ^{90}Sr soil contamination from atmospheric nuclear weapon tests are compared to those from the Chernobyl reactor accident at the Munich area.

The nuclide specific measurements of soil contamination with an in situ gamma ray spectrometer were extended during summer and autumn 1986 to cover the entire territory of the Federal Republic of Germany, supplemented by measurements of soil samples. The ^{137}Cs deposition as well as the total amount of precipitation for the period from April 30 to May 5, 1986, are given in Figures 6 and 7. The maps are based on data collected and evaluated by the Institute for Radiation Hygiene and the Institute for Water, Soil, and Air Hygiene of the Federal Health Office, supplemented by data from the State Institute for Environmental Protection in Baden-Württemberg (southwest Germany). The precipitation data were given by the German Meteorological Service. All data have been compiled by the Institute for Water, Soil, and Air Hygiene of the Federal Health Office. Figure 8 shows the ground-level external exposure rate due to ^{134}Cs and ^{137}Cs based on in situ gamma spectrometry measurements.

As can be clearly seen from these figures, a marked decrease exists in the soil contamination towards the north of Germany, from the

Fig. 4. Activity of radionuclides deposited at the site of the Institute for Radiation Hygiene near Munich.

Fig. 5. Deposition of ⁹⁰Sr and ¹³⁷Cs due to atmospheric weapon tests (7) and the Chernobyl reactor accident at the site of the Institute for Radiation Hygiene near Munich.

Fig. 6. Precipitation from April 30 to May 5, 1986, in the Federal Republic of Germany.

Fig. 7. ^{137}Cs deposition in the Federal Republic of Germany.

Fig. 8. Exposure rates (nSv/h) due to ^{134}Cs and ^{137}Cs measured on Sept. 1, 1987. Results were obtained with an in-situ gamma ray spectrometer. Contour values indicate an exposure rate of <20 at Frankfurt; 20-40 at Stuttgart; 60-80 at München, and a maximum value of 140-160 in the southeast corner of the country.

results of air activity measurements. The values of soil contamination due to ^{137}Cs range from as low as 1.6 kBq/m^2 in the north to a maximum of 44 kBq/m^2 in the southeast. Generally the river Danube marks a distinct boundary, separating the higher contaminated areas in the south from the areas of relatively low soil contamination in the north.

In order to evaluate the soil contamination from the measured spectra, knowledge of the distribution of the radionuclides in the soil is essential. Some soil samples gave evidence that the distribution of the artificial radionuclides could be described as an exponential decrease with increasing depth. During the first months after deposition the relaxation depth for ^{137}Cs as evaluated from all soil samples measured was found to be about 1 cm, i.e., more than 80% of the ^{137}Cs activity could be found in a soil layer down to 2.0 cm. At present this important parameter for the evaluation of soil contamination from the in situ spectra varies between 1.5 and 2 cm.

A strong increase in the exposure rate to nearly $1 \text{ } \mu\text{Sv/h}$ in the evening hours of April 30 was clearly evident when radionuclides were rapidly washed out from the atmosphere. By mid-May the exposure rate had already declined to about $0.30 \text{ } \mu\text{Sv/h}$ and in June 1986 it had decreased to a value where the influence of the variation of natural radioactive substances on the exposure rate could again be observed. The long term exposure rate at the site of the Federal Health Office in Munich increased from $0.03 \text{ } \mu\text{Sv/h}$ to $0.11 \text{ } \mu\text{Sv/h}$ due to the deposited ^{137}Cs . For the sites where soil contamination measurements with an in situ gamma ray spectrometer were performed, the resulting exposure rate due to deposition of both cesium isotopes was calculated. The calculation is based on a uniformly chosen relaxation depth of 2 cm and a soil density of 1.3 g/cm^3 with the exposure rate conversion factors taken from (8). For comparison, Figure 9 shows the exposure rate due to the natural terrestrial radiation in the Federal Republic of Germany. In Figure 10 both the

Fig. 9. Exposure rates (nSv/h) due to natural terrestrial radiation in the Federal Republic of Germany (9). Contour values indicate an exposure rate of 20-40 at Hannover; 40-60 at Frankfurt; and a maximum value of 140-160 in the border regions located east of Nurnberg.

Fig. 10. Exposure rates (nSv/h) due to natural terrestrial radiation and to ^{134}Cs and ^{137}Cs measured on Sept. 1, 1987. Results were obtained with an in-situ gamma ray spectrometer. Contour values indicate a minimum exposure rate of <20 to the north of Hannover; 40-60 at Hannover; 80-100 at Nurnberg and Munchen, and a maximum value of >220 in the southeast corner of the country.

natural terrestrial and supplementary artificial radiation due to ^{134}Cs and ^{137}Cs on September 1, 1987, are given. The effect of radioactive isotopes of cesium on the exposure rate due to terrestrial radiation becomes significant in the southeast of the Federal Republic of Germany. The previously mentioned distinct boundary along the river Danube is even more obvious if exposure rates due to the cesium isotopes are evaluated.

4. Radionuclides in foodstuffs

In addition to radioactivity measurements of air and other media during the first days of May 1986, the analysis of radionuclides in foodstuffs was also of great importance. The major attention was first drawn to milk and milk products and vegetables, mainly spinach and lettuce. From the middle of May onwards, the measuring program was intensified and extended to other foodstuffs. These measurements, according to the German Radiation Protection Committee (3), lead to a total of much more than 10^5 measurements in the Federal Republic of Germany.

^{131}I was regarded as the radionuclide of most importance in foodstuffs during May 1986, and after that period the major attention then shifted towards cesium isotopes. In southern Bavaria, maximum values of up to 10^3 Bq/l of ^{131}I in cow and goat milk and of more than 10^4 Bq/l in sheep milk were measured. On May 2 activity concentrations of ^{131}I in cow milk were well below 200 Bq/l. On May 3 and 4 the mean activity rose to 200-300 Bq/l and reached maximum values on May 5 and May 6, when about 30% of the measured samples contained ^{131}I between 500 and 10^3 Bq/l. Figure 11 shows the development of the activity in milk of one single producer for the period from April 30 to June 2, 1986, with the maximum activity between May 3 and May 6. The activity then declined distinctively, which can be explained by the physical half-life of ^{131}I and by plant

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Fig. 11. Activity concentration of ^{131}I and ^{137}Cs in milk after the Chernobyl accident as a function of time. The herd had been grazing on a pasture north of Munich.

growth. ^{137}Cs activities also reached maximum values at the beginning of May. Yet the activities decreased more slowly, since the physical half-life of cesium is of hardly any consequence for this short period and the cesium metabolism is much slower than that of iodine. At the beginning of June, the values generally were below 10 Bq/l of ^{131}I and 100 Bq/l of ^{137}Cs . In August ^{131}I concentrations in milk were below the detection limits, while the ^{134}Cs and ^{137}Cs activities ranged between 10 and 20 Bq/l.

^{90}Sr activities in milk ranged between 1 and 2 Bq/l with the corresponding ^{90}Sr activities between 14 and 34 Bq/l. As expected, the values for whey concentrate and whole milk powder were higher than those for milk. The ^{90}Sr activities were lower than the ^{137}Cs activities by a factor of about 100, as could be observed in the results of the air activity measurements.

For milk and milk products about 3×10^4 measurements were made in different regions of the Federal Republic of Germany (3). The results show that the highest activity concentrations of ^{137}Cs in milk of about 130 Bq/l as a weekly average were found in southern Bavaria by the end of May 1986. The activity concentration then dropped down to weekly averages of about 10-20 Bq/l until September and October 1986. Due to the feeding of cattle with contaminated hay and silage from November 1986, the activity concentration in milk reached a second maximum of about 60-100 Bq/l in late November 1986. Following that date, the values are decreasing again to the present ^{137}Cs concentration of 5-10 Bq/l. These two maxima could be observed at about the same time in all regions of the Federal Republic of Germany, but the intensities being a significant order of magnitude lower in the north. For comparison, the activity concentration of ^{137}Cs in milk in northern Bavaria did not exceed 500 Bq/l (weekly averages) during the first maximum. In the northern part of Germany the weekly averages were even less than 20 Bq/l for that period.

However, this result of decreasing activity concentration of ^{137}Cs in milk towards the north was to be expected in principle from the radioactivity measurements of air and soil samples. During the heavy rainfalls in southern Bavaria at the end of April and beginning of May 1986, radionuclides were deposited on plants. Consequently, measurements of outdoor vegetables rendered relatively high specific activities. Leafy vegetables with specific activities of more than 20,000 Bq ^{131}I and 3,000 Bq ^{137}Cs per kg were not uncommon. Around Munich even the ^{131}I values for lettuce and spinach under foil cover or in greenhouses were above the level of 250 Bq/kg recommended by the German Radiation Protection Committee (Strahlen-Schutz-Kommission, abbreviated SSK). This surprising result may be due to the presence of ^{131}I in ventilation air or to the use of rainwater for irrigation. Other radioactivity measurements of foodstuffs included berries, fish, beef, and fruits.

Finally, it should be noted that drinking water was also included in the measuring programs. However, the activity concentration was insignificant as compared to other media and hence did not contribute to the resulting radiation exposure.

5. Dose assessment

The dose equivalent resulting from the contamination of air, soil, and food after the reactor accident has been estimated for the time between May 1 and August 31, 1986, taking into account the exposure pathways of inhalation, ingestion, submersion, and soil radiation. The dose factors for inhalation and ingestion were calculated at the Institute for Radiation Hygiene according to ICRP 30 (10, 11). If there was more than one retention class the most conservative value for the dose factor was chosen. The dose factors for the external irradiation were taken from (12).

For the exposure pathways inhalation and ingestion, the effective dose and the thyroid dose were calculated for adults and infants (age: 1 year). The activity concentration in air was assumed to be constant during the individual sampling periods.

The values for the breathing rate were taken from (13). It was assumed that there is no reduction of the air activity indoors; therefore the dose is overestimated. The activities of alpha emitters and strontium isotopes were taken into account. Based on these assumptions the effective dose equivalent for adults was determined to be 0.04 mSv and the thyroid dose 0.6 mSv. For infants an effective dose of 0.07 mSv and a thyroid dose of 1.2 mSv were calculated.

In assessing the dose equivalent due to ingestion, it has to be considered that the food samples measured by the Institute for Radiation Hygiene were not representative, since the measured activities of the individual foodstuffs deviated widely. Nevertheless, an attempt was made to determine the mean specific activities as a function of time based on the measurement results of some hundred food samples collected in Munich and its vicinity.

The consumption rates for adults were taken from (13) and (14). It was assumed that the eating habits were not influenced by the reactor accident at Chernobyl. For leafy vegetables the dose was calculated both with and without taking into consideration the limits in food consumption recommended by the German Radiation Protection Committee. The mean activities measured in milk were below these limits.

Figures 12 and 13 show how various foodstuffs contribute to the ingestion dose. The main portion of the thyroid dose and the effective dose equivalent was due to the ingestion of leafy vegetables provided that the respective SSK limit was not considered. If only vegetables contaminated with less than 250 Bq/kg of ^{131}I were

Fig. 12. Contribution of individual foodstuffs to the effective dose equivalent for adults. The SSK limit value (see text) is included.

Fig. 13. Contribution of individual foodstuffs to the thyroid dose (by ingestion) for adults. The SSK limit value (see text) is included.

consumed (as recommended by the Radiation Protection Committee) the contribution to the effective dose equivalent and the thyroid dose was reduced by about 90%.

Highly contaminated foodstuffs (including ewe's milk products, venison, and mushrooms) were of minor influence on the total dose during the monitored period due to the low average consumption rate of these products. On the other hand, a significant portion of the total ingestion dose was due to pork even though its activity concentration was comparatively low. In this case the high consumption rate of pork was decisive.

The total effective dose equivalent due to ingestion for the time period between May 1 and August 31 was thus calculated. The value for adults was 0.2 mSv, if consumption of leafy vegetables had not been restricted and 0.1 mSv if the SSK-limits had been obeyed. For the thyroid dose the respective values were 3.3 mSv and -- based on the SSK-limit -- 0.8 mSv.

A thyroid dose of 11 mSv was calculated for infants based on a milk consumption of 100l during the above stated reference time period.

These estimates, however, result from modelling based on various assumptions such as eating habits and activities measured in foodstuffs.

The German Radiation Protection Committee has made an estimate for the total effective dose for the first year after the Chernobyl accident and for the 50 years thereafter (Table 4). These estimates also take into account the results from whole body counting measurements since dose estimates based on modeling from foodstuff contamination tend to be slightly overestimated (3).

Table 4. Effective dose equivalent for children for the first year after the Chernobyl accident and for the 50 years thereafter [taken from (3)].

	Effective dose equivalent (mSv)	Total effective dose equivalent for 50 years after the Chernobyl accident (mSv)
Alpine region	1.2	3.8
Area in the FRG south of the river Danube	0.6	1.9
Area in the FRG north of the river Danube	0.2	0.6

6. Summary

Analyses of air, water, and foodstuff samples, together with in situ gamma spectrometric measurements in the Federal Republic of Germany, have documented the deposition and exposure consequences of the Chernobyl accident. In some cases, exposure values are significantly higher than background levels.

Data compiled for the period from the initial identification of excess atmospheric radioactivity to the present, represent a unique resource for testing and validating models of environmental transport and human exposure. These data will serve as the bases for future studies of organism response, both somatic and genetic, to nuclear radiation. They will also prove useful in suggesting modifications to environmental sampling and monitoring systems.

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