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Ionising radiation exposure in the Netherlands

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Abstract

The Dutch population is exposed to ionising radiation from various sources, both natural and man-made. This is a review of the radiation exposure for members of the public from all sources for the year 2000. The average annual effective dose per capita is estimated at 2.5 mSv, which is almost the same value as in the previous review for 1988. In the previous review the radiation dose was presented in effective dose equivalent using the accompanying dose conversion coefficients. For a good comparison the 1988 data were reanalysed using the improved knowledge for the situation at that time and the current dose conversion coefficients. This reanalysis revealed the same value, 2.4 mSv, for the total average radiation exposure in 1988. Nevertheless, the underlying analysed exposure due to specific sources showed quite a few differences.

The main differences between the average annual radiation exposure in the current review and the reanalysed review for 1988 are ascribed to the increased medical diagnostic exposure (+0.12 mSv) and increased radon exposure (+0.05 mSv). The radiation exposure from other sources remained the same or showed a minor decrease (<0.03 mSv per source).

At present, 75% of the total exposure is ascribed to natural sources, although it should be noted here that building materials are included in this category. Building materials and radon exposure attribute 47% to the total average radiation dose. Other natural sources are cosmic radiation, including exposure during aircraft flights (11%), internal radiation from consumption of radioactivity in foodstuffs (15%) and external radiation from the soil (2%). Medical (diagnostic) uses of radiation account for 24% of the total exposure and is by far the most important component of the man-made sources. About 1% is ascribed to other man-made sources like fallout from nuclear weapon tests in the early 1960s, the Chernobyl accident (1986) and emissions of radionuclides from industries.

Comparing the radiation dose of the population in the Netherlands to that in surrounding countries, the total radiation dose in the Netherlands appears to be the lowest, due to the relatively low radon concentration indoors and the relatively low average exposure from medical diagnostic procedures.

Samenvatting

De Nederlandse bevolking wordt blootgesteld aan ioniserende straling door verschillende natuurlijke en antropogene bronnen. Hier wordt een overzicht gegeven van de stralingsdoses voor leden van de bevolking door alle bronnen voor het jaar 2000. De gemiddelde jaarlijkse effectieve dosis per hoofd van de bevolking wordt geschat op 2,5 mSv, hetgeen bijna dezelfde waarde is als geschat voor 1988. In de review voor 1988 is de dosis gepresenteerd als een effectief dosisequivalent, waarbij gebruik is gemaakt van de toenmalige dosisconversiefactoren. Om een goede vergelijking te maken met de gegevens uit 1988 zijn ze opnieuw geanalyseerd, gebruikmakende van een betere kennis van de toenmalige situatie en de huidige dosiscoëfficiënten. Deze herberekening gaf dezelfde waarde voor de totale gemiddelde jaarlijkse blootstelling: 2,4 mSv. Echter, de onderliggende geanalyseerde blootstelling ten gevolge van de specifieke bronnen vertoont behoorlijke verschillen.

De grootste verschillen tussen de gemiddelde jaarlijkse blootstelling aan straling tussen het huidige overzicht en dat van de herberekening voor 1988 betreffen de toegenomen medische diagnostische blootstelling (+0,12 mSv) en de toegenomen blootstelling aan radon (+0,05 mSv). De blootstelling aan straling ten gevolge van de andere bronnen bleef óf gelijk óf vertoont een kleine afname (<0,03 mSv per bron).

Tegenwoordig wordt 75% van de totale blootstelling aan straling toegeschreven aan natuurlijke bronnen, waarbij bouwmaterialen in deze categorie meegenomen worden. Bouwmaterialen en blootstelling aan radon dragen voor 47% bij aan de totale gemiddelde stralingsdosis. Andere natuurlijke bronnen zijn kosmische straling, inclusief de extra blootstelling aan kosmische straling in vliegtuigen (11%), interne bestraling door consumptie van radioactiviteit in voedsel (15%) en externe straling vanuit de bodem (2%). Medisch diagnostisch gebruik van straling draagt voor 24% bij aan het totaal en levert veruit de grootste bijdrage aan de stralingsbelasting door de antropogene bronnen. Ongeveer 1% wordt toegeschreven aan andere antropogene bronnen als fall-out door nucleaire wapenproeven in de beginjaren ’60 van de vorige eeuw, het Tjernobyl-ongeval van 1986 en radioactieve uitstoot door industriële activiteiten.

In vergelijking met de ons omringende landen is de stralingsdosis voor leden van de bevolking in ons land het laagst. Dit komt voornamelijk door de relatieve lage radonconcentratie in woningen en de relatief lage gemiddelde stralingsbelasting door medisch diagnostisch onderzoek.

1. Introduction

The population is exposed to ionising radiation from a number of sources, both natural and man-made. In 1991 RIVM produced its first review on this subject, revealing the radiation levels and exposures in the Netherlands [1]. In that report a comprehensive review was given of the sources and radiation levels, including background on radiation protection systematics.

One-page, yearly commentaries on the estimated radiation dose have been published in the Dutch Environmental Data Compendium since 1999 [2]. In support of these commentaries the RIVM was requested by the Ministry of Housing, Spatial Planning and the Environment to deliver a report that would provide an update of the information on radiation exposure in the Netherlands. The final product presented here is not the comprehensive document such as the first review [1], but does disclose the status representative for the year 2000 at a level comparable to recent international publications [3, 4, 5]. The Dutch-language articles of Brugmans et al., Blaauboer, Lembrechts and Janssen were used as background for the present report [6, 7, 8, 9].

Radiation exposure is directly or indirectly caused by natural sources such as cosmic rays and naturally occurring radionuclides, and man-made sources. Exposure to natural sources is described along two principal routes: external irradiation by photons, beta particles, electrons and alpha’s emitted as a result of cosmic rays, or radioactive decay processes and internal radiation following ingestion or inhalation. Chapter 2 describes the external radiation, subdivided into its cosmic and terrestrial radiation sources, and radiation from building materials. Internal radiation due to exposure to radon and ingestion is described in chapter 3, while exposure to man-made sources, with the exception of medical radiation, is the subject of chapter 4. Chapter 5 elucidates the dose consequences from medical radiation used diagnostically. The data for 1988 are recalculated to understand the trends in radiation exposure since the first review (for the year 1988) and to distinguish between true and methodological increases or decreases. The results of this comparison are given in chapter 6. The report winds up with a description of total annual exposure from all sources, in which the exposure in the Netherlands is compared with surrounding countries and worldwide averages.

2. External radiation

Described here are external radiation due to cosmic and terrestrial radiation and the exposure to radiation from building materials. Because the level of radiation exposure indoors is influenced by the production and choice of building materials, this exposure is also called 'technologically enhanced' exposure.

2.1 Cosmic radiation

Cosmic radiation as experienced on the planet earth is a result of reactions of high energetic ionised particles from outer space with various elements in the atmosphere. Most of the cosmic rays originate outside the solar system and produce secondary particles like neutrons, protons, pions and heavier particles such as ^{3}H, ^{7}Be and ^{14}C, the so-called cosmogenic radionuclides. The dose due to (mainly) ingestion of cosmogenic radionuclides is discussed in section 3.2. Particles originating from the sun are less energetic and affected by Solar Particle Events. The magnetic field during these events diverts the galactic rays and so causes the lowest cosmic radiation and ground level during the maximum solar activity.

The ambient dose equivalent rate due to cosmic radiation in the Netherlands at sea level amounts to 40 nSv.h^{-1}, see also Figure 1, resulting in an annual effective dose of 0.35 mSv.a^{-1} for an adult who is exposed to outdoor air 24 hours per day [8]. In effect, an inhabitant in the Netherlands is supposed to be indoors for 90% of the time [10]. Furthermore, UNSCEAR [11] proposes an average reduction factor of 20% (within a range of 0-60%) due to shielding. Consequently, the average annual dose for members of the public will be around 0.29 mSv, within a range of 0.16-0.35 mSv. With the use of the data in Figure 1 and reduction factors, the average annual effective dose for the year 2000 amounts to 0.27 mSv.

Besides being exposed to the cosmic radiation exposure at sea level most of the members of the public are exposed to much higher radiation levels at aircraft cruising altitudes. For short-haul flights within Europe and short residence times at cruising altitudes the dose is limited to 0.004 mSv per flight. For long-haul flights and long residence times at cruising altitudes of 10 to 12 km the dose amounts to 0.04-0.05 mSv per flight. The average dose for a return flight is estimated at 0.036 mSv. In the previous review (for year 1988) [1] the number of passengers reported on flights to and from Schiphol was almost 15 million. In the year 2000 this number had increased to 40 million for this airport. Not only had the total number of passengers increased but also the number of aircrew and frequent flyers. For aircrew (some 15 thousand in 2000), the dose was estimated for 1997 at 1.5-5 mSv, depending on the part of the world covered [8]. For the year 2000 this dose estimate will be lower due to the solar activity, which was at a maximum then. The estimated annual collective dose amounts to 200 manSv, resulting in an average annual effective dose per capita of 0.013 mSv.

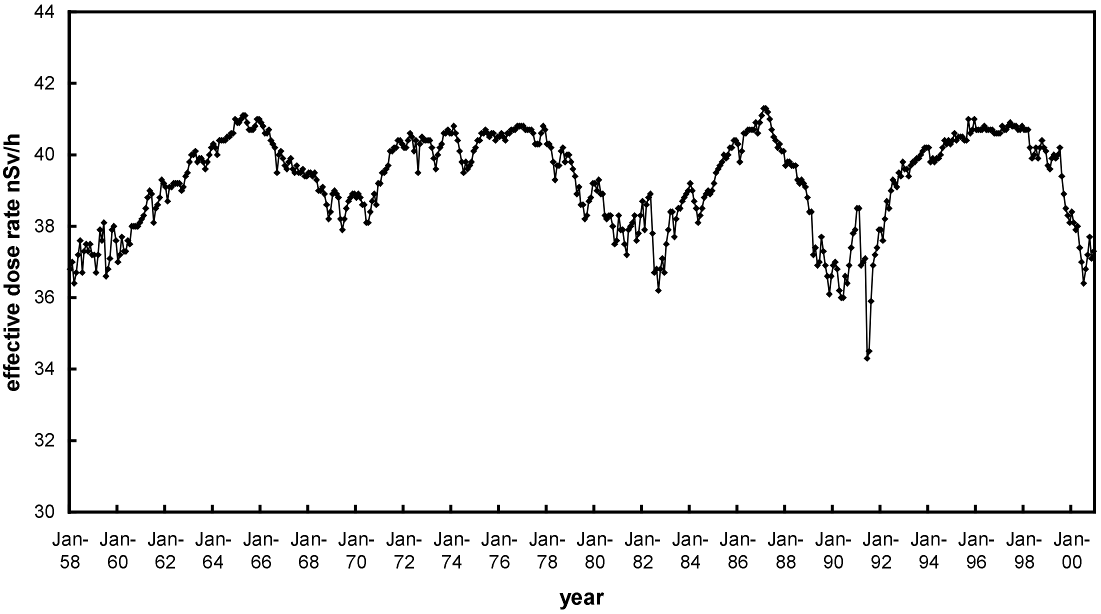

Figure 1 Average monthly effective dose rate from cosmic radiation at ground level in Bilthoven, as calculated by Blaauboer [8] for 1958-2000. The data are corrected for a standard atmospheric pressure of 1011 hPa.

2.2 Terrestrial radiation

Terrestrial radiation arises mainly from several primordial radionuclides in the uranium (^{235}U and ^{238}U) and thorium (^{232}Th) series and ^{40}K. These radionuclides are present in soil and building materials. The correlation between soil type and external radiation was examined by Blaauboer and Smetsers, which led to a radiation map of the soil in the Netherlands [12]. The average ambient dose equivalent rate outdoors due to terrestrial radiation is some 40 nSv.h^{-1}, matching the rate for cosmic radiation at sea level. In the Netherlands, this dose due to terrestrial radiation can vary within a factor of 2. The temporary effect of the enhancement on the dose equivalent rate due to washout of radon progeny in the air is an added ca. 1.5% on an annual basis [13].

Compared to cosmic radiation, terrestrial radiation contains lower energies. As a result, a considerable part of it is shielded by building materials (about 90% [1]). The effective dose outdoors is, dependent on the location in the Netherlands, between 0.06 and 0.39 mSv.a^{-1}. Indoors this dose is much lower, 0.04 mSv.a^{-1}, within a range of 0.01-0.07 mSv.a^{-1}. The dose due to fallout from nuclear weapon tests and the Chernobyl accident is described in section 4.2.

2.3 Building materials

The radionuclides in the uranium and thorium series and ^{40}K present in building materials are responsible for the indoor exposure to external radiation. The exposure to radon (and its progeny) emanating from building materials in dwellings is discussed in section 3.1; the sources of radiation and (potential) effects of countermeasures in dwellings were recently summarised [14].

The effect on the dose rate due to different building materials and building blocks in newly built houses is described in detail by Blaauboer and Pruppers [15, 16]. The results show that the average dose due to external radiation is between 0.32 and 0.40 $mSv.a^{-1}$. For timber frame buildings the dose is significantly less, about 0.10 to 0.15 $mSv.a^{-1}$; however, this kind of building has increased gamma radiation levels due to neighbouring (no timber frame) housing and cosmic and terrestrial radiation caused by a lower shielding factor of wood. The variations in dwellings can be substantial; however it is plausible that the dose in dwellings will be some 0.3 to 0.4 $mSv.a^{-1}$. As shown in a survey in the eighties [17] an average annual dose for members of the public was estimated as corresponding to an effective dose of 0.37 mSv, in which a 100% home occupancy factor was assumed. Using the 90% home occupancy factor [10], the average annual dose due to building materials is estimated at 0.34 mSv.

3. Internal radiation

This chapter describes the internal radiation due to exposure to radon and ingestion of naturally occurring radionuclides. In the Netherlands almost half the average radiation exposure is ascribed to ‘building and living’. The main exposure, amounting to 0.82 mSv, is attributed to the inhalation of short-lived decay products of radon [7]. External radiation due to building materials (including radon decay products) was already described in section 2.3. Radiation exposure due to inhalation of emissions from industry is one of the subjects in chapter 4.

3.1 Radon

Radon in open air

Uranium, thorium and their progeny are naturally occurring radionuclides in the soil. ^{222}Rn gas arises from the decay of ^{226}Ra, which is part of the ^{238}U decay chain. ^{220}Rn, or thoron, is a decay product in the ^{232}Th decay chain. Due to the relatively short half-life of 56 s, ^{220}Rn is radiologically less significant than ^{222}Rn. Only part of the radon gas, which is close to the surface, is able to exhale from the soil, depending on the soil type and moisture of the soil. A moisture-saturated soil will exhale little or no radon. The variations in air pressure and high wind speed also influence the outdoor radon concentration. Radon concentration at elevated levels is shown to be possible on calm summer nights [18]. Due to its coastal area the yearly averaged radon concentration of 3 Bq.m^{-3}, is low in the Netherlands compared to the world yearly averaged concentration above land of 10 Bq.m^{-3}. The low uranium concentration and relatively high groundwater level in the Netherlands are other important factors in this respect.

Radon in indoor air

Indoors the radon concentration is elevated due to radon exhalation from the soil via outdoor air and the crawl space, and to radon exhalation from building materials. In the second Dutch national survey on radon in dwellings, it was clear that building materials formed by far the most important source [19]. Depending on the building material itself, the walls in dwellings exhale more or less radon [20]. Radon exhales relatively more from concrete, nowadays more often applied in the building industry. Radon concentration has also increased due to the improvement in home insulation; however, mechanical ventilation installed in newly built houses to ensure acceptable indoor air quality lowers the concentration. At the moment the average radon concentration in Dutch dwellings amounts to some 24 Bq.m^{-3}, showing an increase of 5 Bq.m^{-3} since 1970. Determinations were made using the renewal in housing stock taking place after the measurements in 1995 and 1996 [19].

Although most of the surveys are focused on the measurement of ^{222}Rn, the damage by radiation is mainly caused by the short-lived, α–emitting radon progeny (^{218}Po and ^{214}Po). The uptake of radon in blood and body fluids is limited and will be mainly exhaled. The concentration of radon progeny that can be attached to aerosols (or particles) in air will be lower than the radon concentration due to deposition of these aerosols. The ratio of radon progeny and radon depends on the concentration of aerosols, the amount of ventilation and the area and roughness of surfaces to which the free radionuclides or radionuclides bound to aerosols can attach. Furthermore, the radionuclides bound to aerosols or particles remain longer in the air than the free radionuclides. On the other hand, attached radionuclides are less harmful. On evaluation of these advantages and disadvantages, the BEIR VI report [21] concludes that the radiation dose for members of the public can be estimated using the concentration of the radon progeny and the difference between indoors and outdoors deduced from the radon measurements. This equilibrium in terms of radon α–energy with the radon progeny is expressed in Equilibrium Equivalent radon Concentration (EEC).

Table 1 Different dose conversion factors for ^{222}Rn from different sources

	Sources		
	ICRP-65 (1993) [22]	UNSCEAR (1993, 2000) [11, 23]	ICRP-66 (1994) [24]
DCC (nSv per Bq.h.m^{-3} EEC)	6	9	15

In the scientific community there is no consensus on the dose conversion factor for radon. Table 1 gives three different values based on different sources. The factor of 6 nSv per Bq.h.m^{-3} published in the ICRP report 65 [22] is based on epidemiological studies. Based on a detailed lung model, ICRP report 66 [24] recommends 15 nSv per Bq.h.m^{-3}. Given the range of values for the dose conversion factor, UNSCEAR 2000 [11] considered a factor of 9 nSv per Bq.h.m^{-3} to be still appropriate for calculating average effective doses. This is the same value as what was used for the UNSCEAR committee's 1993 report [23]. The conversion factor for the exposure to ^{220}Rn progeny amounts to 40 nSv per Bq.h.m^{-3}.

Applying the UNSCEAR conversion factors to the results of the Dutch radon surveys produces the effective dose from Table 2. The information on ^{220}Rn is adopted from UNSCEAR because of a lack of specific information on the Dutch situation. This can be supported because (1) the ^{220}Rn concentration is affected by the superficial part of the soil in the direct surroundings, (2) the crawl space indoors hardly contributes to the exposure. In the case of ^{222}Rn the crawl space created the important difference between an UNSCEAR and a Dutch dwelling. The total average annual effective dose due to the exposure to radon and its progeny amounts to 0.82 mSv; 95% of this dose can be attributed to the exposure of the lungs, 10 to 15% of the dose is ascribed to ^{220}Rn and only 5% of the dose is ascribed to outdoor exposure.

Table 2 Estimation of the annual dose due to the two most important radon isotopes and their progeny, assuming 90% residence time indoors

		Residence time** (h.y^{-1})	Rn concen. (Bq.m^{-3})	EEC (Bq.m^{-3})	DCC*** (nSv per Bq.h.m^{-3} EEC)		Effective annual dose (μSv)	
					Lung*	Other	Lung*	Other
^{222}Rn	outdoors	880	3	1.8	9	0.17	14	0
	indoors	7880	23.5	9.4	9	0.17	667	31
^{220}Rn	outdoors	880	10	0.1	40	0.11	4	1
	indoors	7880	10	0.3	40	0.11	95	9
Sum							780	41

* 'Lung' represents the dose due to deposition from radon progeny in the lung and 'other' the dose due to radionuclides dissolved in blood.

**Lembrechts [7] used the 80% world average residence time from UNSCEAR to calculate the radon dose. For this review the more relevant value of 90% is taken from French data [10].

***From UNSCEAR 2000 [11]

Recently, the lower estimates based on ICRP publication 65 were published in the Dutch 1999 Environmental Data Compendium [25]. The choice was inspired by the fact the ICRP approach was adopted and laid down in EU Directive 96/29 [39]. Considering the uncertainties of the ICRP approach and the estimate using the lung model the UNSCEAR approach seems to be justified for not continuously adjusting (too fast and not well-founded) the dose conversion factors for this dominant component of the radiation exposure. Consequently, it is clear that the dose estimates have uncertainties of over 50%. To illustrate the uncertainties, the Health Council of the Netherlands reports [26] that on the basis of BEIR VI [21] between 100 and 1200 cases of lung cancer per annum might be attributable to radon exposure. The central estimate is 800.

3.2 Ingestion

Ninety per cent of the dose due to ingestion of naturally occurring radionuclides is ascribed to ^{40}K, ^{210}Pb and ^{210}Po. The ingestion of radionuclides has not significantly changed since the first review on radiation exposure [1, 9]. Furthermore, the amount of ^{40}K is regulated in the body by homeostatic control. However, the average annual effective dose due to ^{40}K in the human body has increased from 0.18 mSv to 0.24 mSv. This can be explained by the applied ingestion dose conversion coefficient of ^{40}K, which has increased by 24%. Also, the average body weight, important for the estimated ^{40}K inventory, has increased to 75.3 kg in 2000 in the Netherlands [27], whereas the reference man (70 kg) was used in previous calculations.

Recalculation of the average effective dose due to all ingested radionuclides using the current dose conversion coefficients [28, 29], gives an average annual effective dose of 0.37 mSv.a^{-1}, ranging from 0.15 to 0.53 mSv.a^{-1}. The cosmogenic radionuclides resulting in a dose of 0.012 mSv.a^{-1} are also taken into account in this evaluation. Of these, the ^{14}C ingestion is dominant.

4. Public and occupational exposure from man-made sources

This chapter describes the exposures of the population resulting from emissions to the environment of radioactive materials from all man-made sources, with the exception of medical exposures, which are described in the subsequent chapter. Emissions and discharges from industry, fallout from accidents and nuclear weapon tests are described here. Occupational exposure in industry and medical institutions is discussed in section 4.3.

4.1 Emissions, discharges from industry

Process industries

Process industries consist of enterprises that convert raw materials into intermediary or final products by means of chemical and physical processes. Emissions to air may contribute to radiation exposure, caused by processing and storage of naturally occurring radioactive materials (NORM). The radiation exposure for 1988 was estimated at 17.5 $\mu Sv.a^{-1}$ per capita at most, a value containing large uncertainties due to lack of information on nature and the magnitude of the emissions. Since 1990 a number of studies have been carried out on this subject [30, 31, 32] to improve the insight into the activities and emissions of the process industries. Janssen et al. [30] estimated the average annual effective dose per capita due to emissions to air to be 2 µSv. The main contribution is ascribed to an elementary phosphorus plant. The average effective dose due to emissions to water is shown to be lower for 2000 than in previous years [32, 33].

Nuclear installations

The dose to the public is estimated using the reported emissions of the nuclear installations. The external radiation due to the installations is confined to site surroundings, so the average effective dose will be far below 0.001 $\mu Sv.a^{-1}$. Emissions to air result in an average annual effective dose of about 0.0003 µSv, as estimated for 1992 [30]. Average effective dose due to emissions in water is shown to be even lower [32].

Consumer products

Consumer products are products in which radionuclides are intentionally incorporated and radiation-emitting devices are products that can be supplied to the public without special surveillance. Included in this group of products are, for instance, smoke detectors and radioactive gas mantles; these products can be responsible for a radiation dose to the public [34, 35, 36] in various phases of their existence. The estimated average effective dose due to these consumer products has decreased from 9 $\mu Sv.a^{-1}$ in 1988 [1] to 0.3 $\mu Sv.a^{-1}$ at present [36]. This reduction is attributed to: 1) a decrease in the number of radioactive products actually in use e.g. gas mantles, 2) lower estimates of the number of radioactive products in the Netherlands (camera lenses, smoke detectors containing ^{226}Ra) and 3) lower estimates for the dose rate for such products as cathode ray tubes (displays, TV screens) and smokedetectors.

4.2 Fallout from accidents and nuclear weapon tests

The contribution of ‘imported’ radioactivity to the radiation exposure in the Netherlands is split into ‘import’ via rivers, atmospheric nuclear weapon tests and the Chernobyl accident. In 1988 this was estimated at 3, 11 and 19 μSv.a^{-1} [1].

The concentration of radionuclides in rivers has decreased since the beginning of the 1970s [37]. Nowadays the average annual effective dose amounts to some 2 μSv [9]. The effective dose due to atmospheric nuclear weapon tests in the fifties and sixties can for over 80% be attributed to ^{14}C and ^{137}Cs. Extrapolation of data from the eighties and nineties results in an estimate of 9 μSv for the average annual effective dose in 2000 [9]. At present, the Chernobyl accident, which caused an average annual effective dose of 48 μSv in the Netherlands in 1986, contributes about 7 μSv.a^{-1} [9].

4.3 Occupational exposure

The occupational dose is registered in the database of the Dutch Dose Registration for Ionising Radiation (Dutch acronym: NDRIS). This database contains information on all so-called exposed workers since 1989. Van Dijk published the results of a recent survey on the radiation exposure of these workers [38]. The collective dose of the workers in 1998 amounted to 11.5 manSv, of which 76% is ascribed to the workers in medical institutions and 14% to workers on industrial sites like non-destructive testing companies. The dose of exposed workers in cardiological diagnostics contributed almost 30% to the collective dose.

The collective dose of all exposed workers decreased between 1989 and 1998 from 17 to 11.5 manSv.a^{-1}. Meanwhile the number of exposed workers increased by 20% to 33 thousand. Van Dijk does not explain this decrease in the collective dose [38]. Blaauboer et al. [1] expected lower individual and collective doses for workers in medical institutions as a result of improved shielding, medical systems with remote controls, and radiopharmaceuticals with shorter atomic half-lives and lower applied external doses. Of the average annual dose per capita, an estimated 0.0007 mSv.a^{-1} is due to occupational exposure.

In the near future, the calculated radiation dose of members of aircrews will also be reported in NDRIS to meet the obligations on the Decree on radiation protection [28], which came into force in March 2002 in accordance with an EU directive [39].

5. Medical radiation

The public's exposure to radiation from medical procedures forms the largest contribution to the effective dose from man-made radiation in the Netherlands and globally [6, 11, 40]. Generally, this exposure is attributed to the use of X-rays in diagnostic radiology. Using the ICRP publication 60 [41] the effective dose equivalent estimates for 1988 were converted to effective doses. The effective dose conversion factors of ICRP publication 62 [42] were applied to nuclear medicine, which resulted in an average annual effective dose of 0.47 mSv in 1988. Due to more frequent application of complex diagnostic procedures the dose has increased since the first review. Therapeutic use of medical radiation is not evaluated here because of its different purpose. Radiotherapy is used mainly for the treatment of cancer, where the intention is to deliver a lethal dose to malignant tissue.

In recent publications [6, 40] Brugmans et al. report dose estimates for the public on the basis of various sources and methods. A number of procedures have been obtained from different surveys, such as the one from the NZi (Netherlands Hospital Institute)[1] and the NVvR (Radiological Society of the Netherlands). Figure 2 shows the trends in the examination frequency for diagnostic procedures with ionising radiation in hospitals. The average patient dose per X-ray and CT procedures were taken from Kamman et al. [43] and Van Unnik et al. [44]. Information on radiopharmaceuticals and standard administered activities is used for the dose estimate pertaining to the nuclear medicine examinations, along with dose conversion factors from ICRP publication 80 [45]. Table 3 shows the results of dose estimates for 1988 and 1998 on the basis of the product of the examination frequencies and the average effective dose per examination, yielding the average effective dose per capita. The overall average annual effective dose per capita due to diagnostic use of ionising radiation has increased by 26% since 1988 to 0.59 mSv. From Table 3 it is clear that the attribution to the average annual effective dose from mammography screening and the extramural dental are limited, when compared to the dose from X-rays, CT examinations and nuclear medicine. In effect, the increase in the average annual effective dose is dominated by the increased use of CT procedures.

Patient as mobile source

Patients treated with radiopharmaceuticals might be responsible for a radiation dose to members of the public through the external radiation from the body and by excretion of radionuclides. To limit this dose, criteria for discharges from hospitals are being formulated e.g. the discharge criterion of 20 $\mu Sv.h^{-1}$ at a distance of 1 m.

The effective dose due to external radiation from patients being treated with ^{131}I can be limited to 1 mSv by simple rules of conduct. In 1998 some 4500 patients were treated with ^{131}I. Assuming that the patients had 2 to 3 housemates, the average effective dose per capita would be 0.0008 mSv [9]. Excretion of radiopharmaceuticals by patients outside hospitals results in an estimated average annual effective dose of 5.10^{-6} mSv [9], which is lower than the 4.10^{-5} mSv estimated for 1988 [1].

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[1] Since 1 January 2000, NZi has merged into a new organisation, "Prismant".

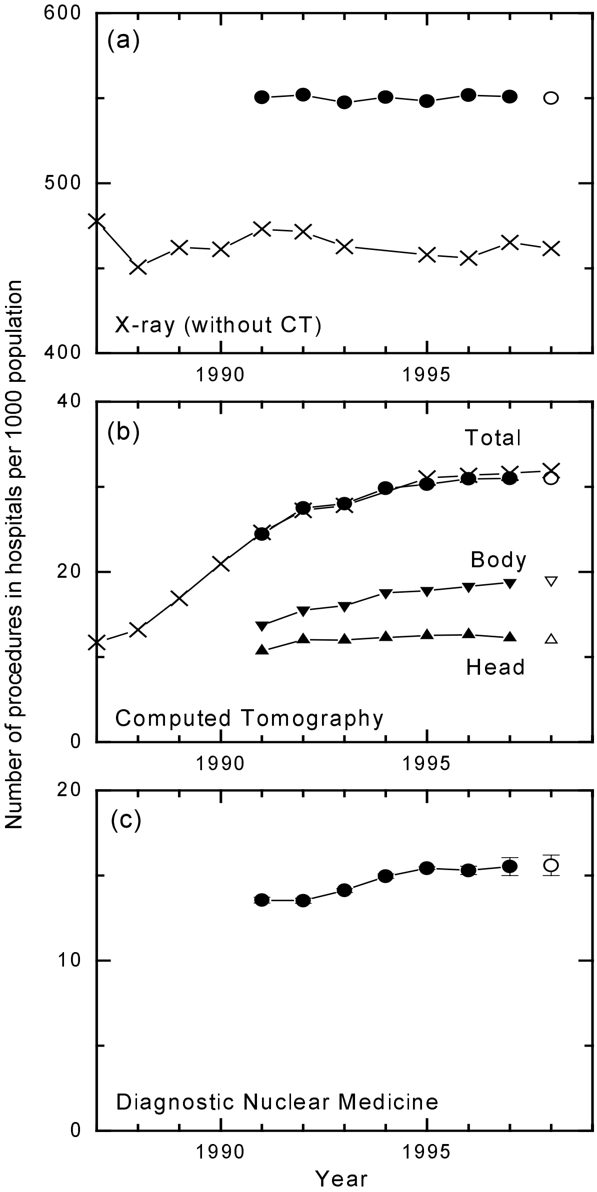

Figure 2 Trends in the examination frequency of diagnostic procedures using ionising radiation in hospitals in the Netherlands for (a) X-ray procedures (without CT), (b) CT examinations and (c) nuclear medicine examinations

The crosses represent examinations in radiology departments (Radiological Society in the Nethlerlands), and circles and triangles are taken from the Netherlands Hospital Institute Survey (NZi); open symbols represent estimates for 1998. Error bars indicate the standard deviation due to estimation of the data lacking in the survey and are only indicated if substantial on the graphic scale.

Table 3 Frequency of examinations, the average effective dose per procedure and the average effective dose per capita from medical diagnostic exposure for 1998 compared with the revised estimate for 1988, from [40].

	1998			1988		
	Number of exams per 1000 population	Average effective dose per exam (mSv)	Average effective dose per capita (mSv)	Number of exams per 1000 population	Average effective dose per exam (mSv)	Average effective dose per capita (mSv)
X-rays in hospitals	588	0.87	0.511	499	0.76	0.38
Nuclear medicine	14.9	4.3	0.064	16.2	5.2	0.085
Mammography screening	42.4	0.21	0.0088	-(a)	-	-
Extramural dental care	322	0.0042	0.0014	210	0.0086	0.0018
Total	967	0.60	0.585	725	0.64	0.47

(a) Implementation of the national screening programme started in 1990.

6. 1988 revisited

To compare the current radiation exposure with the previous estimates, the data for 1988 had to be reconsidered. Not only have the dose conversion coefficients been changed, but the estimated radon concentration and residence times for 1988 also turned out different than had been assumed for the previous review. For the recalculation, the same classification is used as in Blaauboer et al. [1]; see Table 4 for an overview. It is interesting to note that the total average annual effective dose remains the same for 1988, i.e. 2.4 mSv, despite the reconsideration.

Radon/thoron

Due to a systematic error in the results of the first radon survey in the Netherlands, the average radon concentration in dwellings was overestimated in 1988 by approximately 7 Bq.m^{-3} [19]. The corrected average radon concentration in living-rooms as applied for 1988 should have been 22 Bq.m^{-3}. The indoor residence time was taken to be 80% on the basis of the world average, as still used by UNSCEAR 1988 [11, 46]. Actually, for the Western European situation it is more likely to use 90% residence time [8, 10]. Furthermore, the dose conversion coefficient has changed for the exposure to radon and thoron outdoors, from 17 to 9 nSv per Bq.h.m^{-3} EEC radon and from 50 to 40 nSv per Bq.h.m^{-3} EEC thoron. In total, the average annual effective dose has therefore decreased arithmetically from 1 mSv to 0.77 mSv.

Medical radiation (excluding radiotherapy)

As was pointed out by Brugmans et al. [40] and discussed in chapter 5, the annual effective dose as attributed to diagnostic medical radiation has increased arithmetically from 0.40 mSv to 0.47 mSv.

Internal radiation

The average annual effective dose from internal radiation has been recalculated to be 0.37 mSv instead of 0.33 mSv [9].

Technologically enhanced natural radiation (excluding radon/thoron)

Technologically enhanced natural sources comprise power plants, the process industry, building materials and air traffic. These sources are dealt with below in this order.

In the 1988 review the radiation exposure due to power plants was estimated at 8.10^{-4} mSv. This relatively low value gives no reason to recalculate the dose. Using new dose conversion coefficients and new dispersion factors (for discharges) the process industry gives rise to an average annual effective dose of 0.022 mSv, instead of 0.021 mSv according to the first review. For external radiation exposure from building materials the conversion factor for absorbed dose in air to effective dose remains the same as 1988 [11, 46]. Nevertheless, using the current knowledge on residence time, the average annual effective dose increases arithmetically from 0.3 to 0.34 mSv. For 1988 the average annual effective dose due to air traffic was estimated at 0.01 mSv. In an RIVM report, Blaauboer [47] estimates that in 1988 only 35% of the passengers travelling from Schiphol Airport were Dutch (instead of 50% as estimated then) and uses a recalculated dose per flight, resulting in a collective dose of 80.5 manSv or an average annual effective dose of 0.0054 mSv.

Cosmic radiation

In the 1988 review a world average annual effective dose was used to calculate the radiation exposure in the Netherlands. The average annual effective dose was calculated at 0.20 mSv. Blaauboer [8] used a model to calculate the effective dose of cosmic radiation as a function of time and position (latitude, longitude), for example, and may be corrected for a certain atmospheric pressure. For 1988, an average effective dose rate for outdoor exposure was estimated at 0.35 mSv (see also Figure 1). Using the reduction factor of 0.8 for indoor shielding and the residence time of 90% the indoor exposure is estimated at 0.25 mSv. The average annual effective dose due to cosmic radiation is estimated at 0.28 mSv, including the 10% occupancy factor outdoors.

Terrestrial radiation

The average annual effective dose from terrestrial radiation (excluding the contribution of fallout, which is discussed in the next paragraph) should not vary from year to year. The new evaluation as described in section 2.2 shows an average annual effective dose of 0.04 mSv instead of the 0.05 mSv as given in the first review.

Fallout

The dose estimate due to fallout for 1988 has not changed. The external radiation component remains unchanged, as mentioned in the paragraph on technologically enhanced natural materials. The dose conversion coefficient for ingestion of ^{137}Cs has decreased from 1.4 10^{-8} Sv.Bq^{-1} to 1.3 10^{-8} Sv.Bq^{-1}. The average annual effective dose due to fallout remains at 0.02 mSv.

Other sources

Other radiation sources such as consumer products are not reconsidered because their contribution to the dose was calculated in the first review at less than 0.03 mSv.

Table 4 Original and recalculated average radiation exposure of the Dutch population in 1988

	1988 STRAVE (mSv)	1988 STRAVE (%)	1988 revisited (mSv)	1988 revisited (%)
radon/thoron	1.00	42	0.77	33
medical diagnostic	0.40	17	0.47	20
internal radiation	0.33	14	0.37	16
technologically enhanced natural sources	0.33	14	0.36	16
cosmic radiation	0.20	8.5	0.28	12
terrestrial radiation	0.05	2.1	0.04	1.7
fallout	0.02	0.8	0.02	0.9
other radiation sources	<0.03	<1.3	<0.03	<1.3
TOTAL	**2.4**		**2.4**	

7. Annual exposure of the Dutch population from all sources of ionising radiation

Annual doses to the Dutch population from all sources of ionising radiation for the year 2000 are summarised in Table 5 and Figure 3. The overall average annual effective dose is 2.5 mSv. This is almost the same value as was calculated for 1988 [1].

Table 5 Annual exposure of the Dutch population from all sources of ionising radiation in comparison with neighbouring countries as estimated for the year indicated

	The Netherlands 2000 (mSv)	UK [3] 1999 (mSv)	Belgium [4] 1999 (mSv)	Germany [5] 2002 (mSv)	Worldwide [11] 2000 (mSv)
Natural					
cosmic	0.28	0.32	0.35	0.3	0.4
gamma	0.38	0.35	0.40	0.4	0.5
internal*	0.37	0.27	0.30	0.3	0.3
radon	0.82	1.30	1.45	1.1	1.2
Artificial					
diagnostic medical	0.59	0.37	1.95	2.0	0.4
other man-made sources	0.02	<0.005	0.05	<0.05	0.07
occupational	<0.01	0.01	-	-	<0.01
TOTAL (rounded)	**2.5**	**2.6**	**4.5**	**4.1**	**2.9**

* internal radiation excluding radon
- dose unpublished

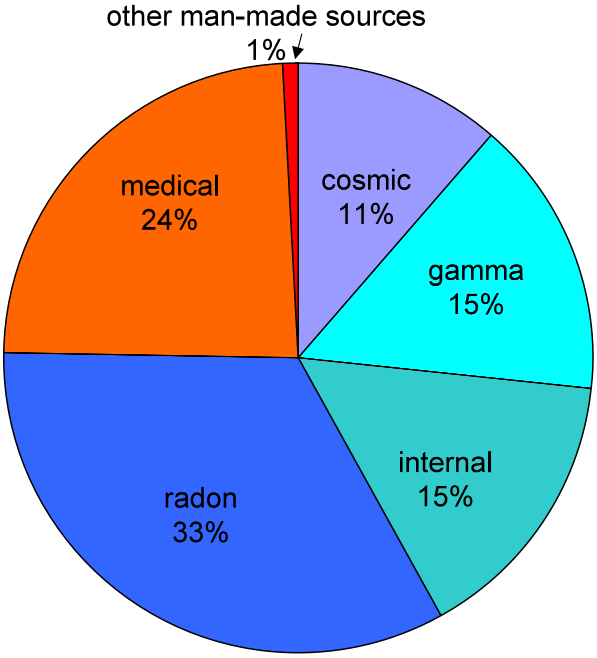

Figure 3 Average annual dose per capita of the Dutch population from all sources of ionising radiation: 2.5 mSv.

As shown in Table 5 and Figure 3, the natural radiation is divided into cosmic radiation (including the exposure to passengers and aircrews), gamma radiation (from building materials and external terrestrial radiation), internal radiation (mainly ingestion of radionuclides) and exposure to radon (and thoron).

It should be noted that although the medical exposure is estimated for 1998, we felt it would not be expedient to extrapolate the value for this exposure to the year 2000. For comparison with the current evaluation of the radiation exposure, the values for 2000 are rearranged using the previous approach and compared with the reanalysed data for 1988.

Table 6 Average radiation exposure of the Dutch population as recalculated for 1988 estimated for 2000

	1988 revisited (mSv)	1988 revisited (%)	2000 (mSv)	2000 (%)
radon/thoron	0.77	33	0.82	33
medical diagnostic	0.47	20	0.59	24
internal radiation	0.37	16	0.37	15
technologically enhanced natural sources*	0.36	16	0.36	14
cosmic radiation*	0.28	12	0.27	11
terrestrial radiation	0.04	1.7	0.04	1.6
fallout	0.02	0.9	0.02	0.7
Other radiation sources	<0.03	<1.3	0.001	0.04
TOTAL	**2.4**		**2.5**	

*It should be noted that the radiation exposure for passenger and aircrews is categorised under the technologically enhanced natural sources in this table.

The main difference with the previous review must be ascribed to the increased medical exposure (0.12 $mSv.a^{-1}$). Its relative importance has increased from 20% in 1988 to 24% in 2000 of the total radiation exposure, mainly because of the increased use of CT procedures. An increase of 0.05 mSv was identified due to the increased exposure to radon and thoron in dwellings because of improved home insulation. Other (minor) changes were less than 0.03 mSv.

The present classification (Table 5) has been adopted from the neighbouring countries thereby improving the comparison with them. For natural radiation exposure, the relative differences[2] in cosmic and gamma exposures of members of the public are each shown in the table to be less than 20% for the four countries; for the internal radiation this difference amounts to 27%, with the highest estimate for the Netherlands. As expected, the largest relative difference in the category 'natural radiation exposure' is found for radon, for which the lowest value estimated for the Netherlands is a factor 2 lower than the highest value estimated for Belgium. This difference must be ascribed to higher radon concentrations in dwellings in Belgium, partly due to different soil types in the countries. Not only is it possible to ascribe the enhanced levels of radon concentration in dwellings in the UK and Belgium to the soil type, but because the building materials are mostly from the same country the radon concentration in the dwellings is higher. In Switzerland the dose due to radon is estimated at 1.6 $mSv.a^{-1}$, also because of even higher radon concentrations indoors than in Belgium [48]. This value is even based on the lower ICRP dose conversion coefficient.

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[2] Relative difference = (maximum value – minimum value) / maximum value

For artificial exposure, the relative differences amount to 82% for the medical diagnostic exposures; the lowest value going to the UK and the highest to Germany and Belgium. The medical diagnostic exposure in the Netherlands, estimated at 0.59 mSv, is also relatively low at a mere 30% of the reported value for Germany and Belgium.

To compare the current radiation exposure with the one-page commentaries in the Dutch Environmental Data Compendia and the report of Lembrechts [2, 14] the annual exposure as previously classified is presented in Figure 4.

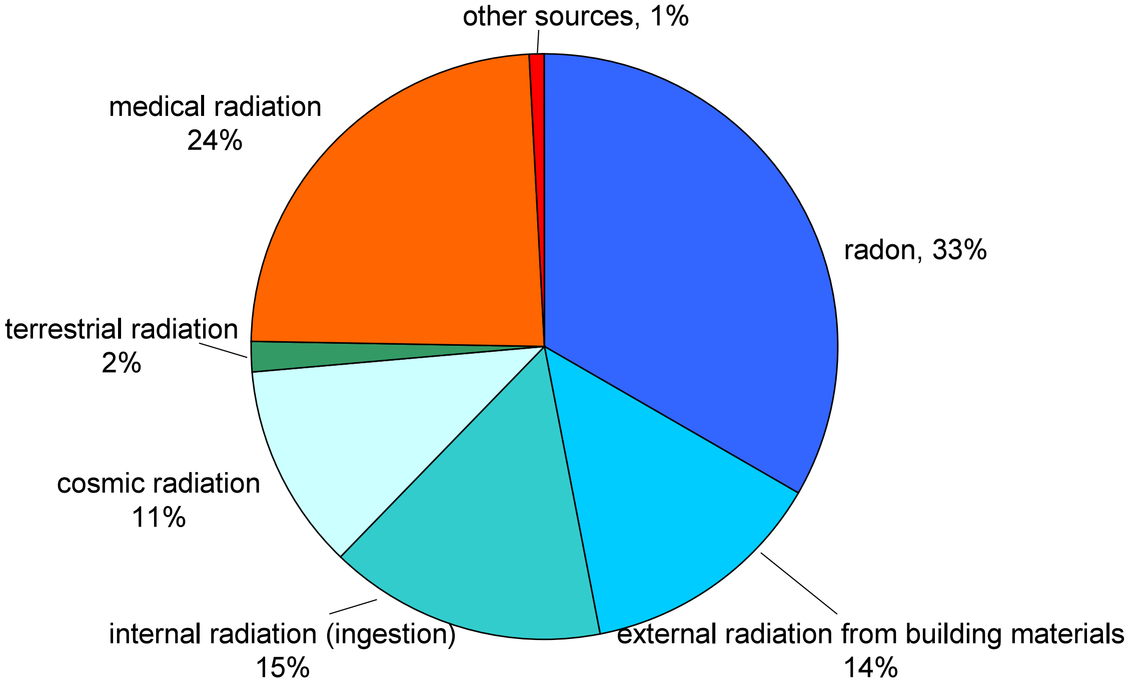

Figure 4 Average annual dose per capita of the Dutch population from all sources of ionising radiation, classification according to [14] is 2.5 mSv.

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