UNSCEAR 2000: SOURCES OF IONIZING RADIATION

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ABSTRACT/résumé

Ce résumé décrit le contenu du rapport de l'UNSCEAR analysé et énumère les résultats les plus marquants

Volume I of the UNSCEAR 2000 report consists of 5 scientific annexes dealing with radiation sources and levels of exposure:

- Annex A: Dose assessment methodologies (64 pages)
- Annex B: Exposures from natural radiation sources (74 pages)
- Annex C: Exposures to the public from man-made sources of radiation (136 pages)
- Annex D: Medical radiation exposures (204 pages)
- Annex E: Occupational radiation exposures (157 pages)

The report to the General Assembly of the United Nations and the scientific annexes are available from the UNSCEAR website: http://www.unscear.org/reports.htm The annexes contain the expected wealth of data and evaluations. For each annex, there is only time to discuss one or two striking results.

- The use of more realistic values for the atmospheric dispersion model results in lower estimates of the population exposure around nuclear installations and uranium mill tailings.
- The worldwide annual average population exposure to natural sources remains at 2.4 mSv. The population exposure in Belgium is calculated using the UNSCEAR methodologies.
- The radon dose coefficient is maintained at 9 nSv per Bq h m^{-3} (in terms of radon decay products), which is 50% higher than the value given in the new Belgian regulation that is based on ICRP 65.
- The most comprehensive assessment yet is made of the worldwide exposures to fallout from atmospheric nuclear tests.
- The average level of radiation exposure due to the medical applications in developed countries is equivalent to 50% of the global average level of natural exposure. The widespread use of CT *(NB : les scanners)* in Belgium results in even higher values.
- The collective occupational exposure to natural sources, significantly above background levels, is higher than to man-made sources.

١. DOSE ASSESSMENT METHODOLOGIES

Cette section traite des méthodes d'estimations des doses et précède celle sur la radioactivité naturelle

This annex presents and reviews the dose estimation procedures used by the Committee to assess the radiation exposure of human populations. The main features are:

- The use of transfer coefficients or equilibrium modeling. There has been little need for detailed, time-dependent dose modeling because the Committee is in most cases only interested in evaluating the average annual doses.
- Preference for simple empirical methods that are not difficult to understand and relatively easy to apply and adapt by scientists throughout the world to local circumstances.
- The starting point of the calculations is where the fewest steps or assumptions are needed, for example, the concentrations of radionuclides in the human body or in the case of atmospheric nuclear tests the measured deposition densities from fallout radionuclides.

I want to draw your attention to the atmospheric dispersion model used by UNSCEAR to evaluate radiation doses. The average air concentration close to a specific source, such as a stack of a nuclear reactor, is calculated using the long-term sector-averaged Gaussian plume model. In this model, the plume is assumed to spread uniformly across a sector subtended by an angle, usually chosen to be 30°. The variation of air concentration, C_a, with downwind distance beyond 1 km can be approximated by the following simple function, which was also used in previous UNSCEAR assessments:

$$C_a(x) = D_1\ Q\ x^{-n}$$

where D_1 = the dilution factor at 1 km (s/m^3)
Q = the release rate (Bq/s)
x = the distance from the source (km)

When site-specific data are not available, the Committee recommends to use a value of $5\ 10^{-7}$ s/m^3 for the dilution factor D_1 and 1.4 for the index parameter n. For noble gases (which do not deposit) and tritium the recommended value for n is 1.2. The value for n is similar to the value of 1.5 used in previous UNSCEAR assessments. The value for the dilution factor is lower by a factor of 6 than the value of $3\ 10^{-6}$ s/m^3 suggested in the UNSCEAR 1982 report. The previous value reflected concentrations at a location toward which the wind blows about 50 % of the time, whereas the currently recommended value of $5\ 10^{-7}$ s/m^3 assumes a uniform wind rose at the point of release.

The lower dilution factor at 1 km decreases the collective dose estimates from atmospheric releases of nuclear reactors and uranium mill tailings. The latter decreased per unit electrical energy generated, from 150 manSv/(GWyear) in the UNSCEAR 1993 report to 7.5 manSv/(GWyear) in the 2000 report. The two main reasons are:

- a reduction in the dilution factor by a factor of 6 and;
- a reduction in the radon emission rate from abandoned uranium mill tailings by a factor of 3, because of improved decommissioning techniques.

٢. EXPOSURES FROM NATURAL RADIATION SOURCES

The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. There are two main contributors to natural radiation exposures: high-energy cosmic ray particles incident on the earth's atmosphere and radioactive nuclides that originated in the earth's crust and are present everywhere in the environment, including the human body itself.

The annual effective doses to the Belgian population are calculated with the methods given in the UNSCEAR 2000 report. *(The world average values of the UNSCEAR 2000 report are given between brackets and in italics.)*

٢,١. Cosmic radiation in Belgium

The earth is continually bombarded by high-energy particles that originate in outer space. These cosmic rays interact with the nuclei of atmospheric constituents, producing a cascade of interactions and secondary reaction products that contribute to cosmic ray exposures that decrease in intensity with depth in the atmosphere, from aircraft altitudes to ground level. The cosmic ray interactions also produce a number of radioactive nuclei known as comogenic radionuclides.

The external dose rate outdoors at sea level increases with geomagnetic latitude. The values for the two components of the cosmic radiation field in Belgium *(and worldwide)* are:

- photon and directly ionizing component: 32 nSv/h *(31)*;
- neutron component: 9 nSv/h *(5.5)*.

As Belgium is a low-lying country the altitude correction is small:

- photon and directly ionizing component: 1.02 *(1.25)*;
- neutron component: 1.1 *(2.5)*.

The total effective dose rate outdoors is 32 x 1.02 + 9 x 1.1 = 42.5 nSv/h *(52)*.
Applying the indoor shielding factor of 0.8 and assuming indoor occupancy to be 80 % of time or 7000 h/year the average effective dose is:
42.5 (1760 + 7000 x 0.8) 10^{-6} = 0.31 mSv/year *(0.38)*.

The Committee assessed the internal exposures from the four main cosmogenic radionuclides to be:

- ^{14}C: 0.012 mSv/year;
- ^{22}Na: 0.00015 mSv/year;
- ^{7}Be: 0.00003 mSv/year;
- ^{3}H: 0.00001 mSv/year.

The activity of cosmogenic ^{14}C in the environment, and consequently also in the human body is 230 Bq/kg of carbon.

Including a small contribution from air travel and holidays (for instance winter sports) the average exposure to cosmic radiation in Belgium can be estimated at:
0.31 + 0.012 + air travel and holidays = **0.35 mSv/year** *(0.4)*.

٢,٢. External terrestrial radiation in Belgium

External exposures arise from terrestrial radionuclides present at trace levels in soil and building materials. Only those radionuclides with half-lives comparable to the age of the earth, and their decay products, exist in significant quantities in these materials. Irradiation is mainly by gamma radiation from radionuclides in the ^{238}U and ^{232}Th series and from ^{40}K.

Hundreds of soil samples from all over Belgium were measured in the eighties by SCK and WIV (Gillard et al., 1988). The average values of the spectrometric analyses of the soil samples, the dose conversion coefficients from the UNSCEAR 2000 report and the resulting absorbed dose rates in air are given in table 1.

Table 1. External exposure rates calculated from the average radionuclide concentrations in soil in Belgium *(and worldwide)*

	Concentration in soil Bq/kg	Dose coefficient nGy/h / (Bq/kg)	Absorbed dose rate nGy/h
^{40}K	380 *(420)*	0.0417	16 *(18)*
^{226}Ra (^{238}U)	26 *(33)*	0.462	12 *(15)*
^{232}Th	27 *(45)*	0.604	16 *(27)*
Total absorbed dose rate outdoors from soil measurements:			44 *(60)*

The three components of the external radiation field make approximately equal contributions to the gamma radiation dose. At the same locations where the soil samples were taken direct measurements of absorbed dose rates in air were carried out. Excluding cosmic ray exposure, an average value of 43 nGy/h *(59)* was found, which is close to the value inferred from the soil concentration results.

Hundreds of absorbed dose rate measurements in air inside dwellings were performed in the same study (Gillard et al., 1988). A somewhat higher average value of 60 nGy/h *(84)* was found, because of the change in source geometry from half-space to a more surrounding configuration indoors.

To estimate annual effective doses, account must be taken of the conversion coefficient from absorbed dose in air to effective dose. Gamma radiation is less absorbed in children and infants resulting in a higher dose conversion coefficient (adults: 0.7, children: 0.8 and infants: 0.9). The annual average effective dose for adults assuming an occupancy factor indoors of 0.8 is:

- Indoors: $60 \times 7000 \times 0.7 \times 10^{-6}$ = 0.30 mSv *(0.41)*
- Outdoors: $43 \times 1760 \times 0.7 \times 10^{-6}$ = 0.05 mSv *(0.07)*

Total = 0.35 mSv *(0.48)*

The values for children and infants are in direct proportion to the increase in the dose conversion coefficient from absorbed dose in air to effective dose:

- Children: 0.40 mSv/year (0.55)
- Infants: 0.45 mSv/year (0.62)

The resulting average effective dose for the whole population from external terrestrial radiation in Belgium is **0.4 mSv/year** *(0.5)*.

٢,٣. Internal exposures other than radon

Ingestion is the main exposure pathway of the population with significant contributions from ^{40}K and from the ^{238}U and ^{232}Th decay series.

Potassium is more or less uniformly distributed in the body following intake in foods, and its concentration is under homeostatic control:

- Adults: 55 Bq/kg ⇒ 0.165 mSv/year
- Children: 61 Bq/kg ⇒ 0.185 mSv/year

The resulting annual effective dose for the whole population is 0.17 mSv.

There are no control mechanisms to keep the concentration of the uranium- and thorium-series radionuclides in the body at a fixed level, so that the doses are dependent on the intake. The main contributor to this dose is polonium-210. UNSCEAR estimates the effective doses from the ingestion of uranium- and thorium-series radionuclides at:

- Adults: 0.11 mSv/year (^{210}Po contribution = 0.07 mSv/year)
- Children: 0.20 mSv/year (^{210}Po contribution = 0.10 mSv/year)
- Infants: 0.26 mSv/year (^{210}Po contribution = 0.18 mSv/year)

The total effective dose from internal exposures other than radon is assessed at **0.3 mSv/year**.

٢,٤. Radon (^{222}Rn) and thoron (^{220}Rn) exposure in Belgium

The main contribution to the exposure of the population from natural radiation sources comes from the inhalation of the short-lived radon decay products.

Concentrations of radon in the outdoor environment are affected by the exhalation rates of the soil in the general area and by atmospheric mixing phenomena. Results of radon measurements in thermometer shelters in Belgium gave an average value of 10 Bq/m³ *(10)* (Poffijn, 2001). The radon concentrations indoors are somewhat higher and tend to be log-normally distributed. The average concentration in Belgium is estimated at 48 Bq/m³ *(40)* with a geometric mean of 38 Bq/m³ *(30)* and a geometric standard deviation of 2.0 *(2.3)* (Poffijn et al., 1991). The highest values, up to several thousands of Bq/m³, are found in the Ardennes.

Direct measurements of the concentrations of all short-lived decay products of radon are difficult and limited. They are estimated from considerations of equilibrium (or disequilibrium) between radon and its decay products. An equilibrium factor F is defined that permits the exposure to be estimated from the measurement of the radon gas concentration. The equilibrium factor is the ratio of the Equilibrium Equivalent radon Concentration (C_{EEC}) to the radon concentration (C_{Rn}). The equilibrium equivalent radon concentration is directly proportional to the Potential Alpha Energy Concentration (PAEC) in the following manner:

1 Bq/m³ (EEC) = $5.56\ 10^{-6}$ mJ/m³ (PAEC) = 0.27 mWL (Working Level)

$$F = C_{EEC}/C_{Rn} \qquad \text{with } C_{EEC} = 0.105\ C_{218Po} + 0.515\ C_{214Pb} + 0.380\ C_{214Bi}$$

where C_{218Po}, C_{214Pb} and C_{214Bi} are the concentrations of the short-lived decay products in air.

The Committee suggests a rounded value for the equilibrium factor of 0.6 for the outdoor environment and 0.4 indoors.

There is no consensus in the scientific community on the value of the dose conversion factor for radon. The epidemiologically based conversion factor of ICRP 65 (1993) is derived from the risk estimate of the superseded BEIR IV report of 1988. The more recent BEIR VI report (1998) suggests an increased risk per unit radon exposure. As the dosimetric evaluation using the ICRP lung model (ICRP 66, 1994) also shows higher values, the UNSCEAR Committee decided to keep its previous value of 3.6 (nSv/h)/(Bq/m³) (= 9 EEC x 0.4 equilibrium factor). *Note that the UNSCEAR dose conversion factor for radon at home is 50 % higher than the value given in the new Belgian regulation that is based on ICRP 65 (ARBIS, 2001):*

- *radon at home: 1.1 Sv per J h/m³, which is equivalent to 2.4 (nSv/h)/(Bq/m³);*
- *radon at work: 1.4 Sv per J h/m³, which is equivalent to 3.1 (nSv/h)/(Bq/m³).*

For the representative concentrations of radon, equilibrium and occupancy factors and the dose coefficient in terms of EEC, the following annual effective doses are derived:

- Indoors: 48 x 0.4 x 9 x 7000 x 10^{-6} = 1.2 mSv/year *(1.0)*
- Outdoors: 10 x 0.6 x 9 x 1760 x 10^{-6} = 0.1 mSv/year *(0.1)*

Total = 1.3 mSv/year *(1.1)*

For completeness, the contribution from a minor pathway of exposure to radon can be added, namely dissolution of radon gas in blood with distribution throughout the body. The dose estimate for the representative concentrations of radon in Belgium with the method given in the UNSCEAR report is 0.06 mSv/year *(0.05)*.

The much shorter half-life of thoron (55.6 seconds) compared to radon (3.82 days) limits the thoron exhalation of soil and building materials and thereby the contribution of thoron to the radiation exposure of the population. UNSCEAR estimates the average concentration of thoron outdoors at 10 Bq/m³ and approximately the same indoors. It is not possible to use the concentration of the thoron gas in dose evaluation, since the concentration is strongly dependent on the distance from the source. Starting with the estimated equilibrium equivalent concentrations of thoron indoors of 0.3 Bq/m³ and outdoors of 0.1 Bq/m³ and a dose conversion factor of 40 (nSv/h)/(Bq/m³), the annual effective dose may be derived as follows:

- Indoors: 0.3 x 40 x 7000 x 10^{-6} = 0.084 mSv/year
- Outdoors: 0.1 x 40 x 1760 x 10^{-6} = 0.007 mSv/year

Total (rounded off) = 0.1 mSv/year (including a minor contribution from thoron gas dissolved in blood)

Note that the UNSCEAR dose conversion factor of 40 (nSv/h)/(Bq/m³) is close to the value in the new Belgian regulation for thoron at work (ARBIS, 2001):
0.5 Sv per J h/m³, which is equivalent to 37.5 (nSv/h)/(Bq/m³).

The average exposure to radon, thoron and their short-lived decay products in Belgium is:
1.3 (radon in air) + 0.06 (radon in blood) + 0.1 (thoron) = **1.45 mSv/year** (rounded off) *(1.2)*.

٢,٥. Average radiation dose from natural radiation sources in Belgium

Table 2. Average exposure to natural sources in Belgium *(and worldwide)*

Source of exposure	Average annual effective dose mSv	Elevated (*) mSv
Cosmic radiation	0.35 *(0.4)*	2.0
External terrestrial radiation	0.4 *(0.5)*	4.3
Radon and thoron	1.45 *(1.2)*	10
Internal exposures other than radon and thoron	0.3 *(0.3)*	0.6
Total	**2.5 *(2.4)***	

(*) Representative of large regions (UNSCEAR, 1993)

Using the UNSCEAR methodologies, the average annual effective dose to the Belgian population from natural radiation sources is approximately 2.5 mSv/year *(2.4)*. The various components are summarized table 2.

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