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 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

٢. EXPOSURES FROM NATURAL RADIATION SOURCES

Cette section traite des expositions naturelles (voir la page radioactivité naturelle pour y accéder)

٣. EXPOSURES TO THE PUBLIC FROM MAN-MADE SOURCES OF RADIATION

This annex reviews the exposures of human populations resulting from releases to the environment of radioactive materials from man-made sources. I would like to draw your attention to the following two topics: the collective dose from the operation of nuclear fuel cycle installations and the worldwide exposure from the fallout of atmospheric nuclear tests.

٣,١. Nuclear fuel cycle

Table 3. Normalized collective effective dose to members of the public from radionuclides released in effluents from the nuclear fuel cycle for the period 1995-1997

Source	Normalized collective effective dose manSv/GWyear
Local and regional component	
Mining	0.19
Milling	0.008
Mine and mill tailings (releases over five years)	0.04
Fuel fabrication	0.003
Reactor operation	
Atmospheric	0.4
Aquatic	0.04
Reprocessing	
Atmospheric	0.04
Aquatic	0.09
Transportation	< 0.1
Total (rounded)	**0.9**
Solid waste disposal and global component	
Mine and mill tailings (releases of radon over 10 000 years)	7.5
Reactor operation	
Low-level waste disposal	0.00005
Intermediate-level waste disposal	0.5
Reprocessing solid waste disposal	0.05
Globally dispersed radionuclides (truncated to 10 000 years)	40
Total (rounded)	**50**

The generation of electrical energy by nuclear power reactors is the most important industrial application of ionizing radiation. In 2000, 57.1 % of the electrical energy in Belgium has been generated by this means. During routine operation of nuclear installations, the releases of radionuclides are low, and exposures must be estimated with environmental transfer models.

The collective doses for all fuel cycle operations are summarized in table 3. The estimate for the local and regional collective dose is 0.9 manSv/GWyear. The largest part of this dose is received within a limited number of years after the releases and is mainly due to the normal operation of nuclear reactors and mining operations.

The global dose, which is estimated for 10 000 years, amounts to 50 manSv/GWyear assuming a world population of 10 billion people. The main contribution is from globally dispersed ^{14}C (reactor operation and reprocessing). The collective dose from ^{14}C is delivered over a very long period and to the entire world population. The individual doses are small compared to the natural background radiation. A continuing practice of 250 GW electrical energy generation each year into the future, as at present, would result in a maximum dose rate of 1 μSv/year. A limited practice of nuclear power generation would result in progressively less annual dose, e.g. a 100 or 200 year practice would cause 0.1 or 0.16 μSv/year respectively.

The release of radon from uranium mill tailings is a source of exposure for the surrounding population. The global dose from these releases over 10 000 years is estimated to be 7.5 manSv/GWyear. As discussed in the annex on dose assessment methodologies, the various revisions in the parameters have led to a considerable reduction from the previously estimated value of 150 manSv/GWyear (UNSCEAR, 2000).

٣,٢. Fallout from nuclear weapons testing

The testing of nuclear weapons in the atmosphere, which took place from 1945 until 1980, involved unrestrained releases of radioactive materials directly to the environment and caused the largest collective dose thus far from man-made sources of radiation. The annual number of atmospheric and underground tests by all countries is summarized in figure 1.

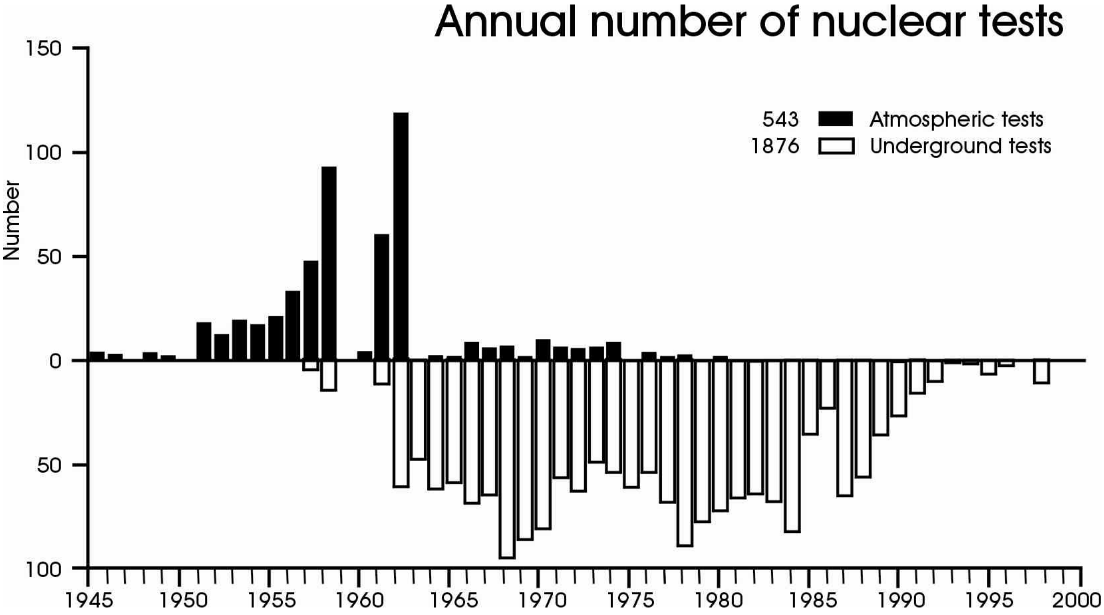

Figure 1. Annual number of tests of nuclear weapons in the atmosphere and underground

Many nuclear weapons were developed and tested during the cold war. A total number of 543 atmospheric tests were conducted by the United States, the Soviet Union and to a lesser extend by France, the United Kingdom and China. The United States detonated 3 nuclear bombs in 1945: a test conducted in the desert of New Mexico followed by combat use destroying the Japanese cities of Hiroshima and Nagasaki.

Underground testing caused exposures beyond the test sites only if radioactive gases leaked or were vented. Following the limited nuclear-test-ban treaty of 1963 between the United States and the former Soviet Union, which banned atmospheric tests, both countries conducted extensive underground test programs until the early 1990s. The underground test programs of France and China continued until 1996. India conducted a single underground test in 1974 and five further tests in 1998. Pakistan reacted some weeks later by conducting six tests. Although it is the intention of most countries to agree to ban all further tests, both atmospheric and underground, the comprehensive nuclear-test-ban treaty that was formulated in 1996, has not yet come into force. India and Pakistan but also Israel have not yet ratified the treaty, thus it cannot yet be stated that the practice of nuclear weapons testing has ceased.

The annual fission and fusion yields are summarized in figure 2. The total yield was 440 megatons of TNT equivalent (a chemical explosive). The most active years of testing from the standpoint of the total explosive yields were 1962, 1961, 1958 and 1954. The largest test, a 50 Mt hydrogen bomb, conducted by the former Soviet Union in 1961, was reported to have a fission yield of 3 % and a fusion yield of 97 %. The atomic bombs destroying the Japanese cities of Hiroshima and Nagasaki were relatively small nuclear weapons of 15 kt and 21 kt respectively. Most underground tests had a much lower yield than atmospheric tests and it was usually possible to contain the debris.

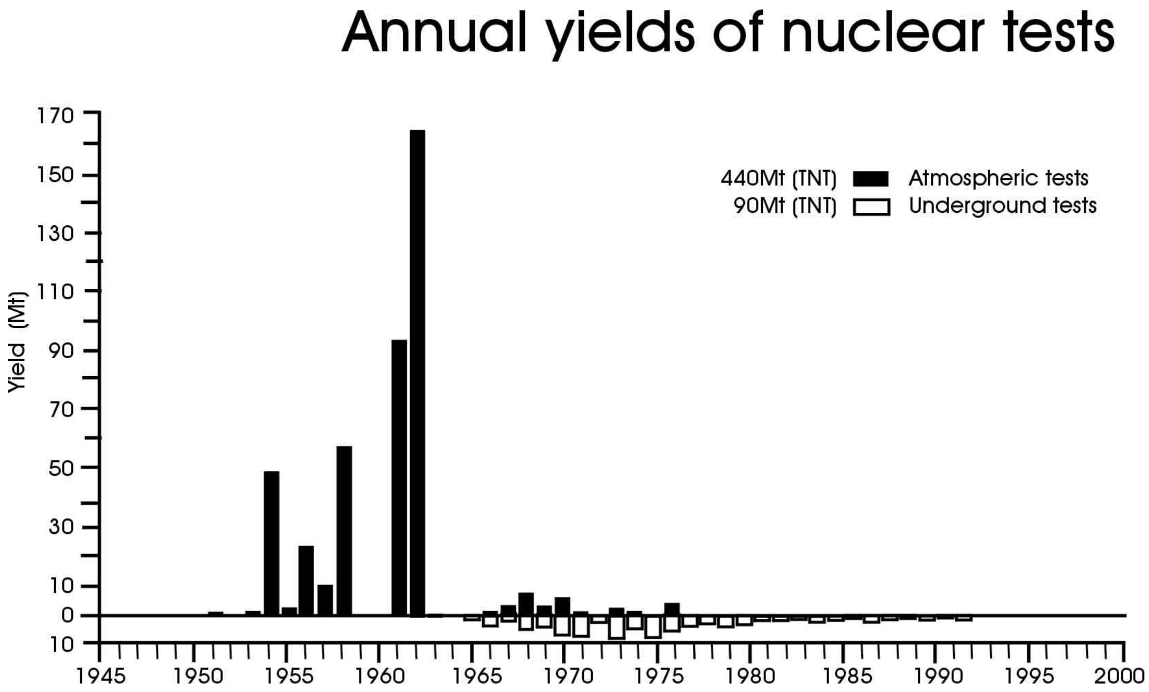

Figure 2. Annual yields of tests of nuclear weapons in the atmosphere and underground

The estimated dose from atmospheric nuclear testing was highest in 1962 and 1963 with a worldwide average exposure of 0.11 mSv/year, which is about 5 % of the background level from natural radiation sources. The doses have since decreased to about 0.005 mSv/year, from residual levels in the environment, mainly of ^{137}Cs, ^{90}Sr and ^{14}C. The cesium-137 and strontium-90 contamination of milk from a farm in Dessel (province of Antwerp) from 1963 through 1990 is illustrated in figures 3 and 4 (Vandecasteele et al., 1997). Both figures show a peak in the 1960s due to the rivalry between the United States and the Soviet Union to detonate the most powerful nuclear weapons. The cesium contamination shows another peak in 1986 from the accident with the Chernobyl nuclear power plant. This peak is absent in the strontium figure because of the small contribution of strontium-90 in the source term of the Chernobyl accident.

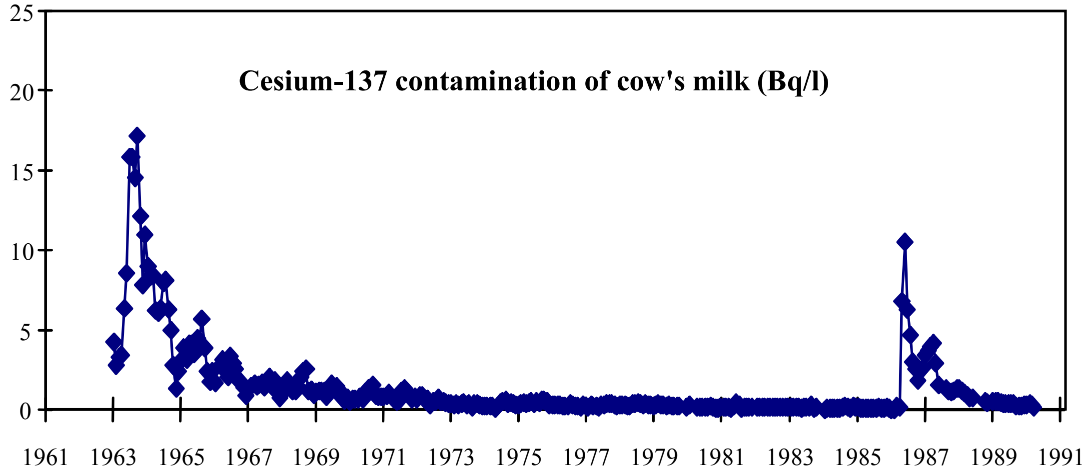

Figure 3. The cesium-137 contamination of milk from a farm in Dessel. For comparison, the potassium-40 content of milk is about 45 Bq/l.

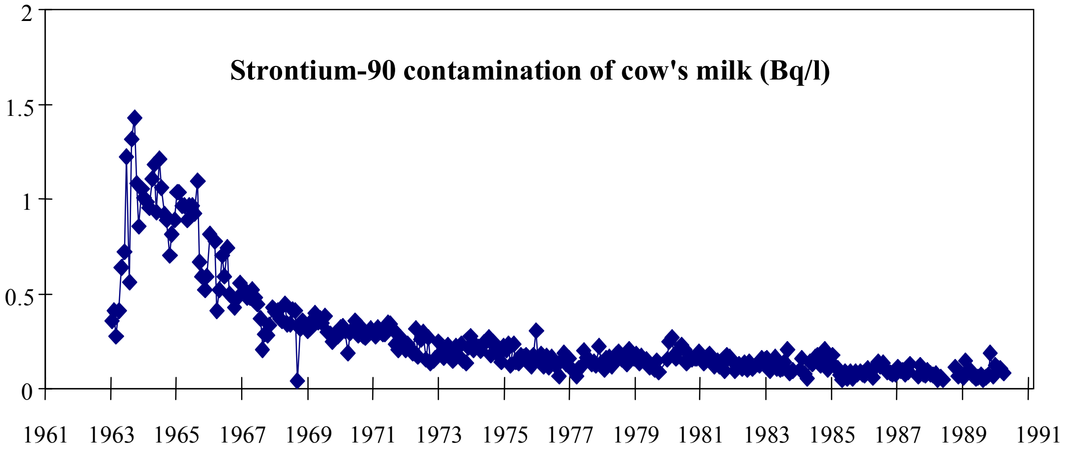

Figure 4. The strontium-90 contamination of milk from a farm in Dessel

The transfer to man of radioactive material dispersed in the environment is illustrated in figure 5. The contamination by cesium-137 in adults in the Mol-Dessel area is shown from 1959 through 1996. The decrease after the limited nuclear-test-ban treaty of 1963 is faster than the physical half-life of cesium-137 (30 years), but slower than the biological half-life of cesium in the human body (about 110 days). The contamination of the food chain decreases because the deposited cesium becomes more and more attached to the soil. The whole body contamination after the Chernobyl accident was 4 times less than in the 1960s.

Also shown in figure 5 is the aerosol activity in Mol from 1957 through 1996. The average value during the Chernobyl accident was 4 times higher than at the height of the atmospheric testing in the 1960s but the increase lasted only one month so that less cesium came available for transfer to man.

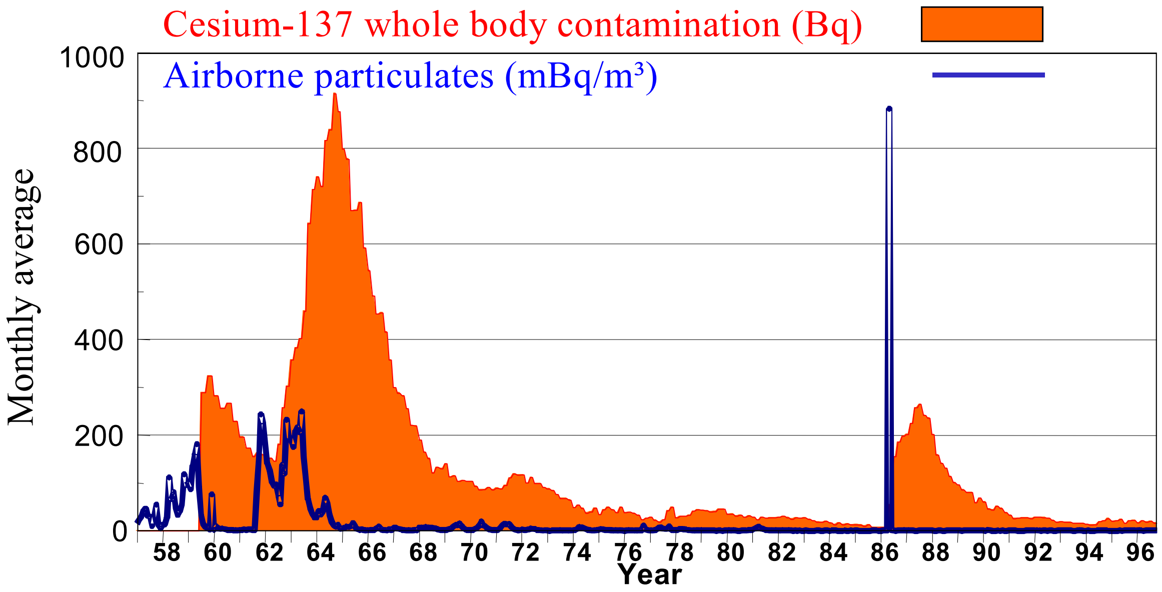

Figure 5. The colored area is the cesium-137 whole body contamination in the Mol-Dessel region. The results are normalized for a body weight of 70 kg (Genicot et al., 2001). The line represents the monthly average activity of airborne particulates in Mol in mBq/m^3

٤. MEDICAL RADIATION EXPOSURES

Over the last 100 years, ionizing radiation has been increasingly applied in medicine and is now firmly established as an essential tool for diagnosis and therapy. The overwhelming benefits accruing to patients from properly conducted procedures have fostered the widespread practice of medical radiology, with the result that medical radiation exposures have become an important component of the total radiation exposure of populations. In Belgium, like in most developed countries with an advanced health care system, medical exposures are now the most important single source of ionizing radiation. Recent Flemish data collected for the yearly report on the environment and nature in Flanders (Vanmarcke et al., 2001 (MIRA report)) will be given and compared to the world average values of the UNSCEAR 2000 report *(between brackets and in italics).*

The utilization of x-rays for diagnosis is the most widespread medical application. According to social security data (RIZIV) the average Fleming undergoes 1.2 examinations a year (excluding dental x-rays). Differences in the patterns of practice from 1990 through 1999 are shown in figure 6. Most notably, increases in the relative number of examinations are apparent from CT (computed tomography) and mammography, while the number of examinations of chest and extremities (limbs and joints) remained constant at a high level.

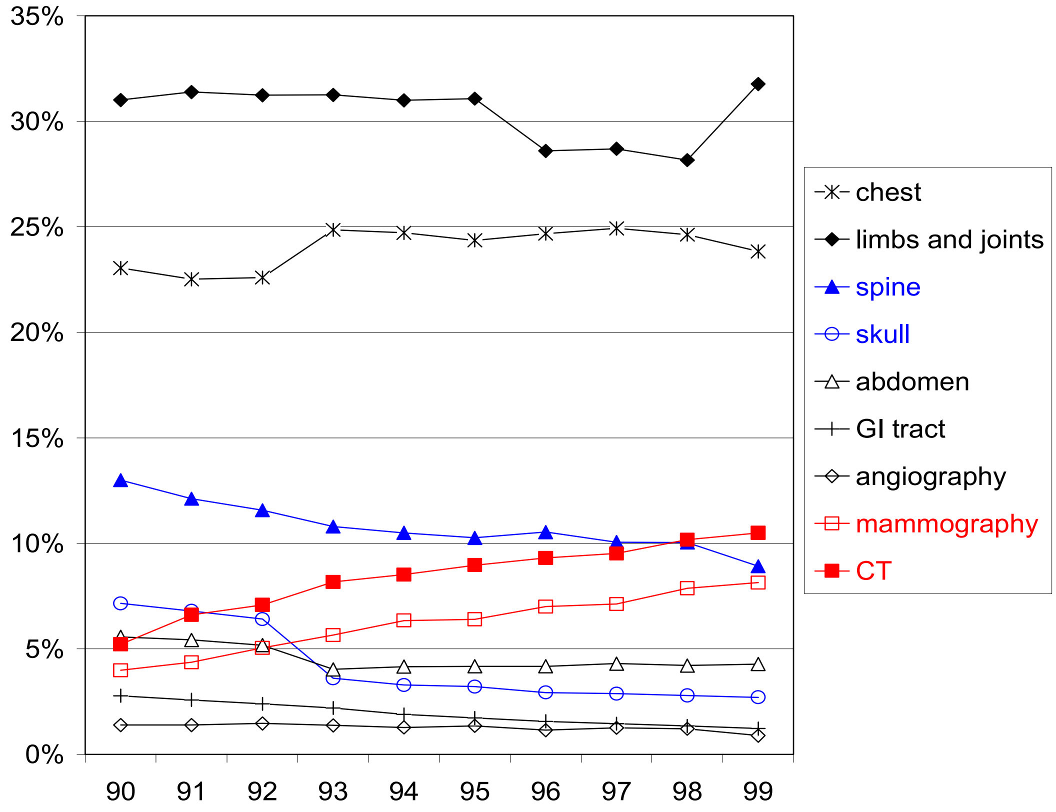

Figure 6. Trends in diagnostic radiology practice in Flanders

The average effective dose per type of examination is compared in table 4 from three different sources. The values of the UNSCEAR 1993 report have been adapted in the UNSCEAR 2000 report to the continuing developments in medical imaging. The results of a recent study in 20 Flemish hospitals for 5 important types of examinations, including CT, are in line with the values of the UNSCEAR 2000 report (Mol, 2001). Relatively high levels of patient doses are received with CT, GI tract, angiography and spine, while the doses from chest examinations and extremities are low.

Multiplying the RIZIV-data on the number of examinations with the effective dose per examination gives the dose distribution shown in figure 7. The dosimetric data from the UNSCEAR 2000 report was used when no local data was available (Mol, 2001). The population exposure is dominated by CT, which provides 54 % of the annual effective dose. With 123 CT-scans per year per 1000 population and an average dose of 7.7 mSv per examination, the average contribution from CT amounts to 0.95 mSv/year.

Table 4. Comparison of patient doses from diagnostic x-ray examinations (in mSv effective dose per examination)

Type of examination	UNSCEAR 1993	UNSCEAR 2000	Mol 2001
Chest	0.14	0.14	0.15
Limbs and joints	0.06	0.06	-
Spine	1.7	1.8	1.7
Pelvis and hips	1.2	0.83	-
Head	0.16	0.07	-
Abdomen	1.1	0.53	0.92
GI tract	5.7	5.0	-
Cholesystography	1.5	2.3	-
Urography	3.1	3.7	7.9
Angiography	6.8	12	-
PTCA	-	22	-
Mammography	1	0.51	-
CT	4.1	8.8	7.7

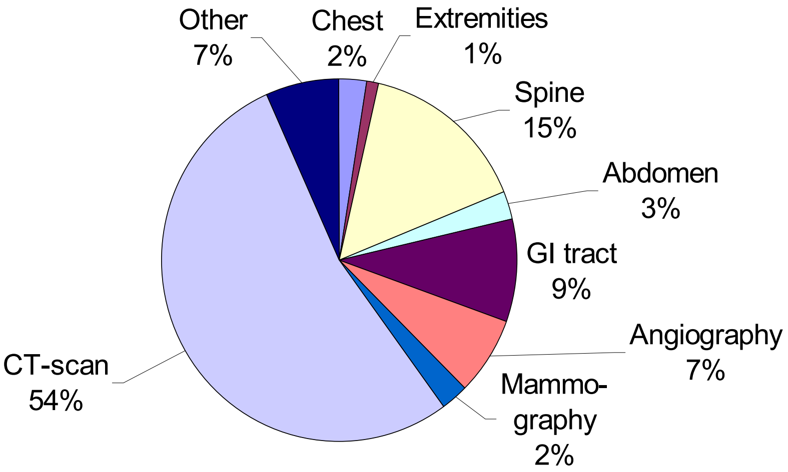

Figure 7. Dose distribution from diagnostic x-ray examinations in Flanders in 1999

Excluding dental x-rays, the Flemish population undergoes on average 1200 diagnostic x-ray examinations per 1000 population per year *(920)* resulting in an average effective dose of 1.78 mSv/year. *(The UNSCEAR estimate for countries with an advanced health care system is 1.2 mSv/year.)* The high value for Flanders comes from a higher number of examinations and in that a larger share of CT.

The number of diagnostic administrations of radiopharmaceuticals to patients, broadly referred to as nuclear medicine, in Flanders was 42 *(19)* per 1000 population per year in 1999. UNSCEAR estimates the mean effective dose per nuclear medicine procedure in countries with an advanced health care system at 4.3 mSv. Multiplying the two numbers results in an average dose of 0.18 mSv/year *(0.08)*.

Adding the contributions from radiology and nuclear medicine leads up to an average medical exposure in Flanders of **1.95 mSv/year** (rounded off) *(1.3)*. The medical practice in Brussels and in the Walloon provinces is quite similar so that the Flemish results can be extrapolated to the whole of Belgium.

٥. OCCUPATIONAL RADIATION EXPOSURES

There is a wide variety of situations in which people at work are exposed to man-made sources of radiation, such as nuclear installations or medical clinics, and some workers are exposed to enhanced levels of natural radiation. For this annex, I want to call your attention to the data on exposures of workers in nuclear power plants and to give an overview of all occupational exposures from man-made and natural sources of ionizing radiation.

٥,١. Reactor operation

The types of reactor used for electrical energy generation are characterized by their coolant system and moderator: light-water-moderated and -cooled pressurized or boiling water reactors (PWRs, BWRs), heavy-water-moderated and -cooled reactors (HWRs) and gas-cooled, graphite-moderated reactors (GCRs) in which the gas coolant, either carbon dioxide or helium, flows through a solid graphite moderator. These are all thermal reactors in which the moderator material is used to slow down fast fission neutrons to thermal energies. The collective doses of the main reactor types are summarized in figure 8. The data have been averaged over five-year periods and expressed per unit electrical energy generated. The collective doses have decreased by a factor of 3 over a period of 15 years.

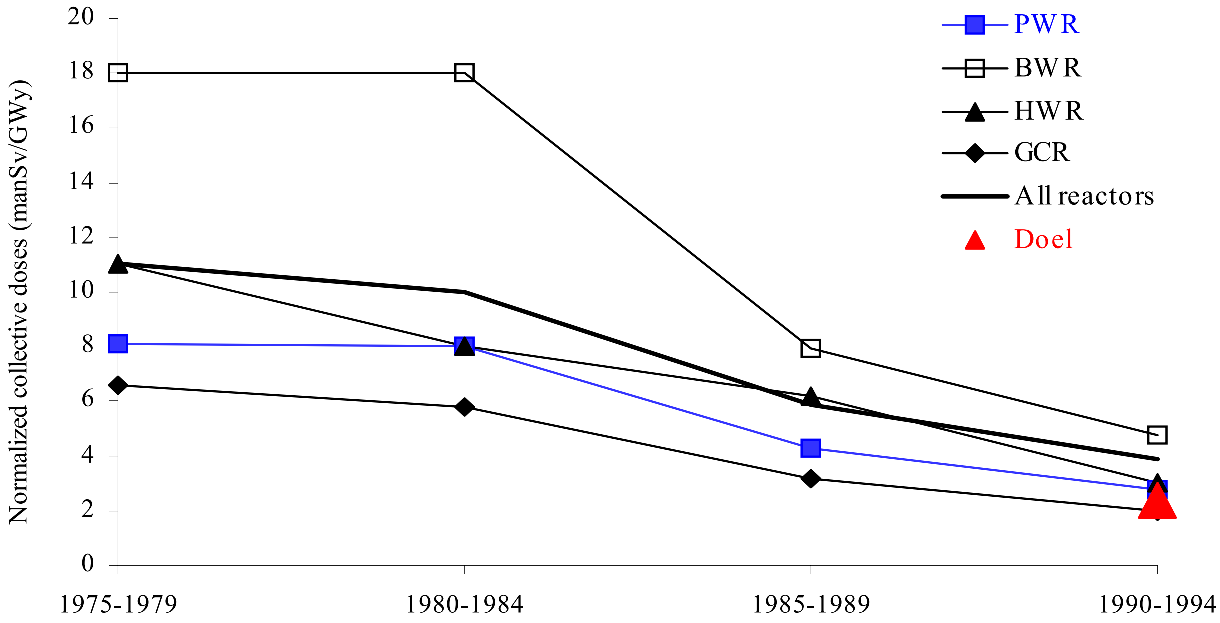

Figure 8. Trends in occupational radiation exposures in nuclear power plants. The collective dose at Doel is given for 1990 - 1994

Table 5. Worldwide occupational exposures for 1990 - 1994

Practice	Number of monitored workers thousands	Average collective effective dose manSv/year	Average effective dose mSv/year
Man-made			
Nuclear fuel cycle			
Mining	69	310	4.5
Milling	6	20	3.3
Enrichment	13	1	0.12
Fuel fabrication	21	22	1.03
Reactor operation	530	900	1.4
Reprocessing	45	67	1.5
Research	120	90	0.78
Total	*800*	*1 400*	*1.75*
Medical uses of radiation			
Diagnostic radiology	950	470	0.50
Dental practice	265	16	0.06
Nuclear medicine	115	90	0.79
Radiotherapy	120	65	0.55
Total	*2 320*	*760*	*0.33*
Industrial uses of radiation			
Radiography	106	170	1.58
Radioisotope production	24	47	1.93
Other	570	140	0.25
Total	*700*	*360*	*0.51*
Defense activities			
Weapons	380	75	0.19
Nuclear ships and support	40	25	0.82
Total	*420*	*100*	*0.24*
Miscellaneous uses			
Education	310	33	0.11
Veterinary medicine	45	8	0.18
Total	*360*	*40*	*0.11*
Total (man-made)	**4 600**	**2 700**	**0.6**
Natural radiation			
Coal mining	3 910	2 600	0.7
Other mining	760	2 000	2.7
Mineral processing	300	300	1.0
Radon in workplaces	1 250	6 000	4.8
Aircrew	250	800	3.0
Total (natural)	**6 500**	**11 700**	**1.8**
Total (man-made + natural)	**11 100**	**14 000**	**1.3**

The nuclear reactors of Doel and Tihange are pressurized water reactors (PWRs). The collective dose of the workers at the 4 reactors of Doel for 1990 - 1994 was 2.4 manSv/GWyear, comparable to the worldwide average for PWR reactors over the same period of 2.8 manSv/GWyear. Since then the doses at Doel have decreased by another factor of 4 to 0.6 manSv/GWyear in 2000.

٥,٢. Worldwide overview of occupational exposures

Occupational radiation exposures have been evaluated for six broad categories of work: the nuclear fuel cycle, medical uses of radiation, industrial uses, defense activities, education and veterinary uses, and occupations where enhanced exposures to natural sources of radiation may occur. The contribution of each category for 1990 - 1994 is summarized in table 5. The collective dose is estimated to be about 14 000 manSv/year: 2 700 manSv/year from man-made sources and 11 700 manSv/year from natural sources. The largest component of this, 6 000 manSv/year, comes from the exposure of workers to radon and its progeny significantly above background levels. *(As might be expected from the radon levels in residential buildings, the highest radon concentrations in aboveground workplaces in Belgium are found in the Ardennes.)* Of the remainder, the largest components are 2 600 manSv/year for coal mining and 2 000 manSv/year for other mining operations (excluding uranium mining, which is dealt with in the nuclear fuel cycle). There are contributions of 800 manSv/year to aircrew from exposure to cosmic radiation and 300 manSv/year to those involved in the minerals processing industries. The estimated collective dose from natural sources is, however, associated with much greater uncertainty than that from man-made sources of radiation.

Of the collective dose from exposure to man-made sources of radiation (2 700 manSv/year), about 50% arises from operations in the nuclear fuel cycle (1 400 manSv/year), about 30% from medical uses (760 manSv/year), about 14% from industrial uses of radiation (360 manSv/year), about 4% from defense activities (100 manSv/year), and about 2% from educational and veterinary activities (40 manSv/year).

٦. SOURCES AND TRENDS OF RADIATION EXPOSURE IN BELGIUM

The radiation exposure of the Belgian population from natural and man-made sources is compared in table 6 to the average exposure for countries with an advanced health care system. The average annual dose in Belgium is 4.5 mSv. The greatest contribution comes from diagnostic medical examinations, which is estimated on the basis of social security data to be 1.95 mSv in Flanders. The second largest contribution is from radon and thoron exposure. The annual dose, calculated with the UNSCEAR dose conversion factor, is 1.45 mSv. Note that the UNSCEAR dose conversion factor for radon is 50% higher than the ICRP 65 conversion convention that was adopted in the new Belgian regulation (ARBIS, 2001). Much more significant than the average values is the variability in the levels of radon concentration in indoor air and in the diagnostic exposures to patients. For instance, the dose limit for occupationally exposed workers of 20 mSv/year is equivalent to two or three CT-scans.

The average effective dose in Belgium has almost doubled over the last 100 years from 2.3 mSv/year in 1899 to 4.5 mSv/year in 1999. Of this increase about 0.2 mSv/year comes from natural sources and 2 mSv/year from human activities involving the use of radiation and radioactive substances, mainly in medicine:

- An increase of the radon exposure from about 1.3 mSv/year in 1899 to 1.45 mSv/year in 1999. The causes are the reduced ventilation of residential buildings and the application of building materials with enhanced radium levels, such as phosphogypsum and fly ashes.
- A small increase of the cosmic radiation of about 0.05 mSv/year from air travel and holidays (for instance winter sports).
- The medical use of radiation is the largest and a growing man-made source of radiation exposure. The contribution has increased from nothing in 1899, shortly after the discovery of x-rays by Röntgen, to 1.95 mSv/year in 1999.
- A small contribution from all other man-made sources of 0.05 mSv/year.

Table 6. Average exposure from radiation sources in Belgium and worldwide. The medical exposure is for developed countries with an advanced health care system

Source	Average annual effective dose Belgium mSv/year	Worldwide mSv/year
Natural radiation		
Cosmic radiation	0.35	0.4
External terrestrial radiation	0.4	0.5
Radon and thoron	1.45	1.2
Internal exposures other than radon	0.3	0.3
Total	2.5	2.4
Man-made		
Diagnostic medical examinations	1.95	1.3
Other man-made exposures	0.05	0.05
Total	2.0	1.35
Total	4.5	3.75

I would like to conclude this overview on sources of ionizing radiation with the trends in life-time exposure in Belgium. At the end of the nineteenth century the average life expectancy in Belgium for man and women was only 48 and 51 years, respectively. This increased in 1999 to 74 and 80 years. During the same period the annual doses doubled from 2.3 mSv to 4.5 mSv, resulting in a tripling of the average life-time exposure:

- for man from 110 mSv in 1899 to 338 mSv in 1999 and;
- for women from 117 mSv in 1899 to 360 mSv in 1999.

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