STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Exposures of the public and workers from various sources of radiation

Hans Vanmarcke

SCK•CEN

hvanmarc@sckcen.be

BVS/ABR
Brussels, April 15, 2011

Annex B of the UNSCEAR 2008 report: 245 pages + excel tables

Exposures of the public and workers from various sources of radiation

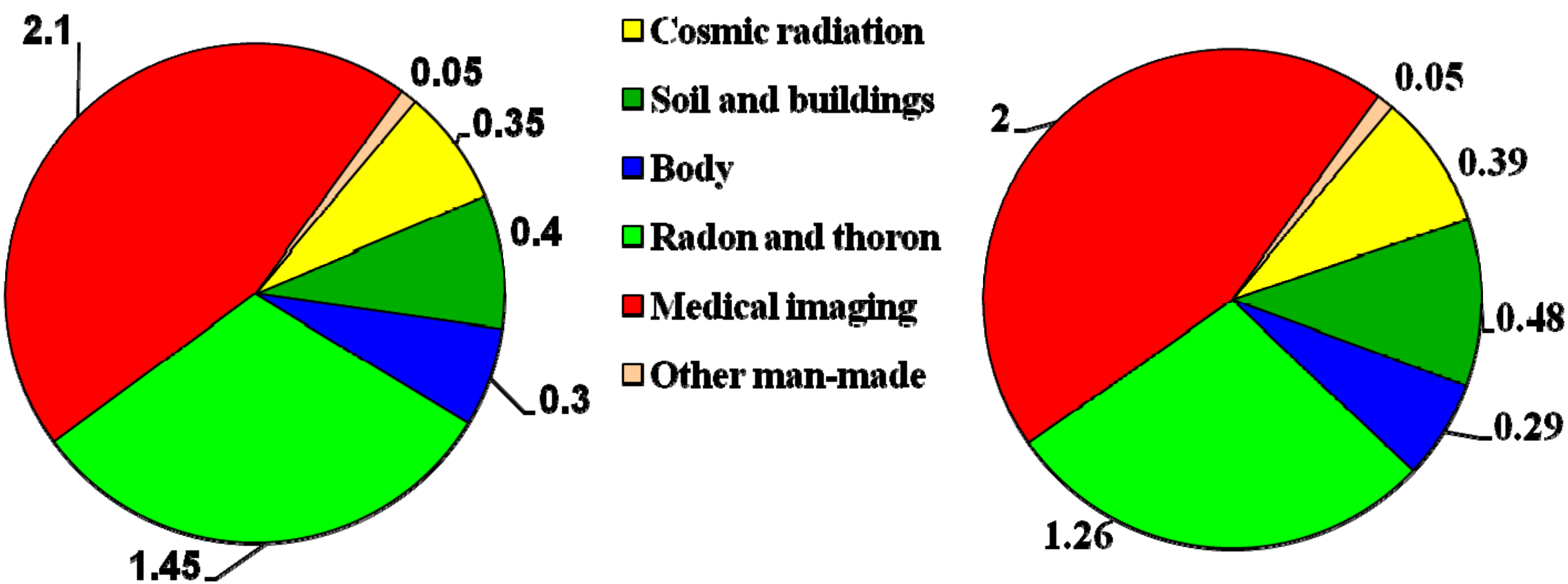
- Introduction and dose assessment issues (7 pages)
- Public exposure
  - Natural sources (8 pages)
  - Enhanced sources of natural occurring radioactive material (6 pages)
  - Use of man-made sources for peaceful purposes (13 pages)
  - Use of man-made sources for military purposes (21 pages)
  - Historical situations and exposure from accidents (1 page)
- Occupational radiation exposure
  - Assessment methodology (2 pages)
  - Natural sources of radiation (9 pages)
  - Man-made sources for peaceful purposes (27 pages)
  - Man-made sources for military purposes (2 pages)

Extra tables : Public: A-1 to A-14 and Workers: A-15 to A-31

Average radiation dose from natural and man-made sources

Belgium 2006
Total = 4.6 mSv/y

UNSCEAR 2008 Western countries
Total = 4.4 mSv/y



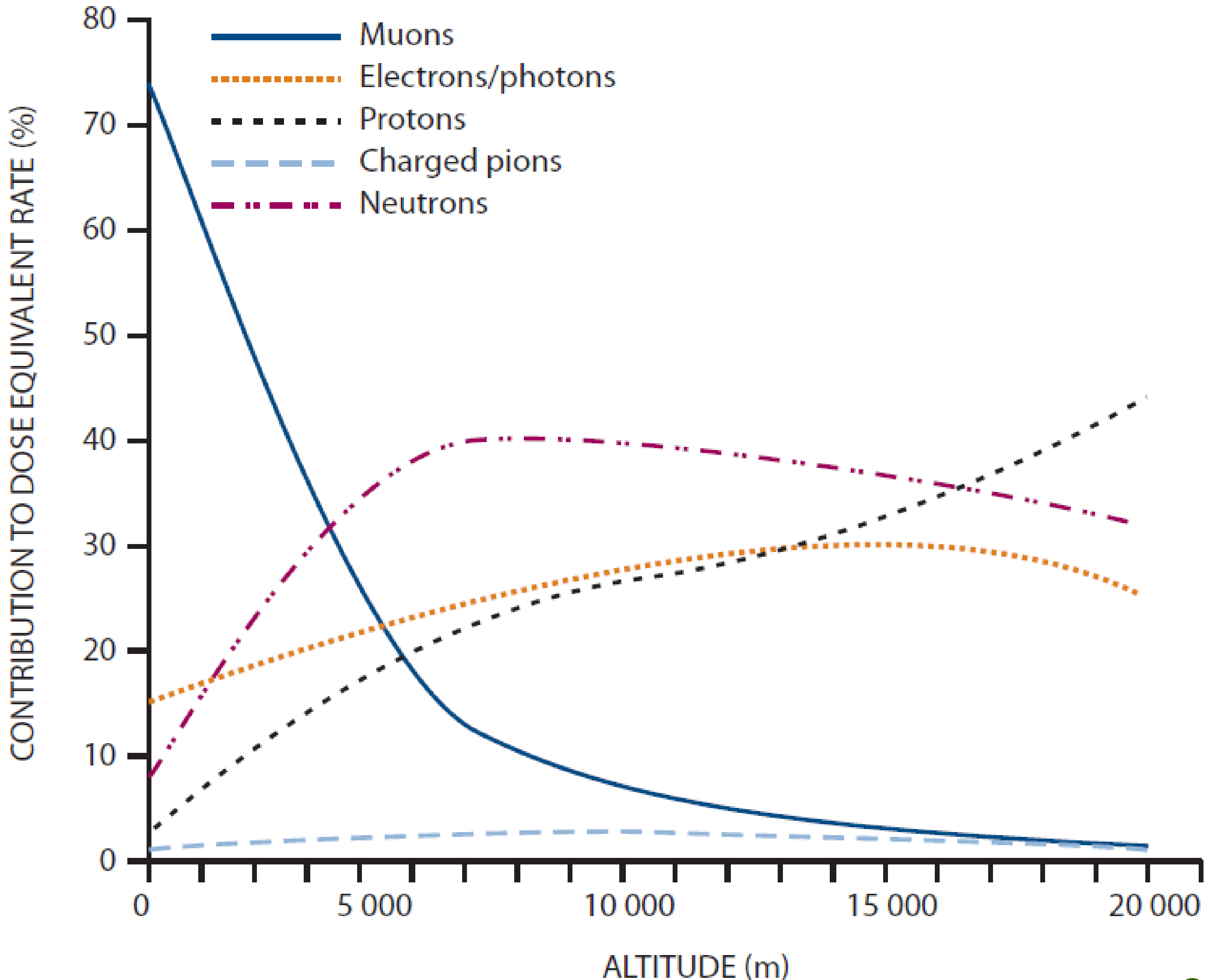
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Natural radiation sources

Natural source	Annual average dose (worldwide) mSv/y	Typical range of individual doses mSv/y	Comments
Inhalation (radon)	1.26	0.2 - 10	Much higher in some dwellings
External terrestrial	0.48	0.3 - 1	Higher in some locations
Ingestion	0.29	0.2 - 1	
Cosmic radiation	0.39	0.3 - 1	Increases with altitude
Total	**2.4**	**1 - 13**	**Sizeable populations groups receive 10 - 20 mSv/y**

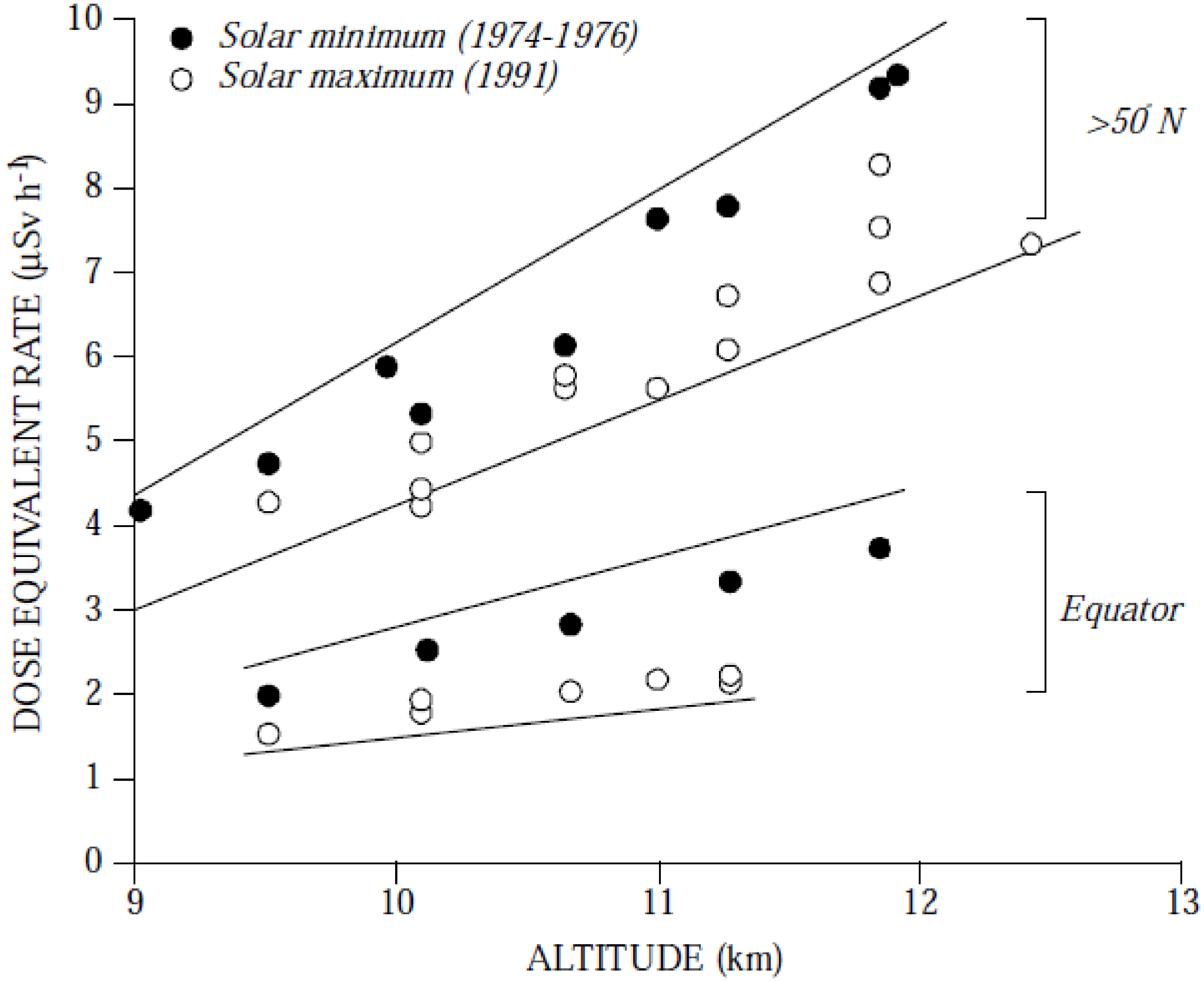
Source UNSCEAR

Composition of the cosmic radiation field as a function of altitude



Source UNSCEAR

Measurement results of cosmic ray exposure rate at aircraft altitudes



Source UNSCEAR

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Slight increase in cosmic radiation exposure from air travel and winter sports (UNSCEAR: world average)

- External exposure at sea level *and altitude correction*
  - Directly ionizing component: 32 nSv/h *and 1.02* (31 nSv/h *and 1.25*)
  - Neutron component: 9 nSv/h *and 1.1* (5.5 nSv/h *and 2.5*)
- External exposure
  - Dose rate outdoors: 32 x 1.02 +9 x 1.1 = 42.5 nSv/h (52 nSv/h)
  - Annual average dose: 42.5 (1760 + 7000 x 0.8) 10^{-6} = **0.31 mSv** (0.38 mSv)
- Internal exposure from cosmogenic radionuclides
  - Four main radionuclides: ^{14}C, ^{22}Na *(0.15 µSv/y)*, ^{7}Be *(0.03 µSv/y)*, ^{3}H *(0.01 µSv/y)*
  - Main contribution: carbon-14
    - Activity in the environment: 230 Bq per kg carbon
    - Annual dose: 0.012 mSv
- Brussels - Toronto round trip: 0.1 mSv
- Annual average effective dose: **0.35 mSv** **(0.39 mSv)**

External terrestrial radiation in Belgium (1) (UNSCEAR: world average)

Mean activity-concentration of Belgian soil

	Concentration (Bq/kg)	Dose coefficient (nGy/h)/(Bq/kg)	Absorbed dose rate (nGy/h)
^{40}K	380 (420)	0.0417	16 (18)
^{238}U (^{226}Ra)	26 (33)	0.462	12 (15)
^{232}Th	27 (45)	0.604	16 (27)

Total (mean outdoor absorbed dose rate from soil measurements) **44 (60) nGy/h**

Mean outdoor absorbed dose rate from direct measurements **43 (59) nGy/h**

Mean indoor absorbed dose rate from direct measurements: **60 (84) nGy/h**

External irradiation from soil and building materials (2) (UNSCEAR: world average)

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Mean absorbed dose rate and occupancy factor

- Outdoors: 43 nGy/h, 20% (59 nGy/h)
- Indoors: 60 nGy/h, 80% (84 nGy/h)

Conversion coefficients from absorbed dose in air to effective dose:
0.7 for adults, 0.8 for children and 0.9 for infants

Annual average effective dose for adults

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

Total = 0.35 mSv (0.48 mSv)

Entire population and rounded: **0.40 mSv/y (0.48 mSv/y)**

Internal exposure

Ingestion is the main exposure pathway of the population

Potassium is under homeostatic control

- A daily intake of more than 100 Bq ^{40}K
- Adults: 55 Bq/kg ⇒ 0.165 mSv/y
- Children: 61 Bq/kg ⇒ 0.185 mSv/y

Ingestion of uranium and thorium decay series (^{210}Po contribution)

- Adults: 0.11 mSv/y (0.07)
- Children: 0.20 mSv/y (0.10)
- Infants: 0.26 mSv/y (0.18)

Entire population and rounded: **0.3 mSv/y** **(0.29 mSv/y)**

Radon and radon decay products in Belgium (UNSCEAR: world average)

Average outdoor

- radon concentration in Belgium: 10 Bq/m³ (10 Bq/m³)
- equilibrium factor: 0.6 (0.6)

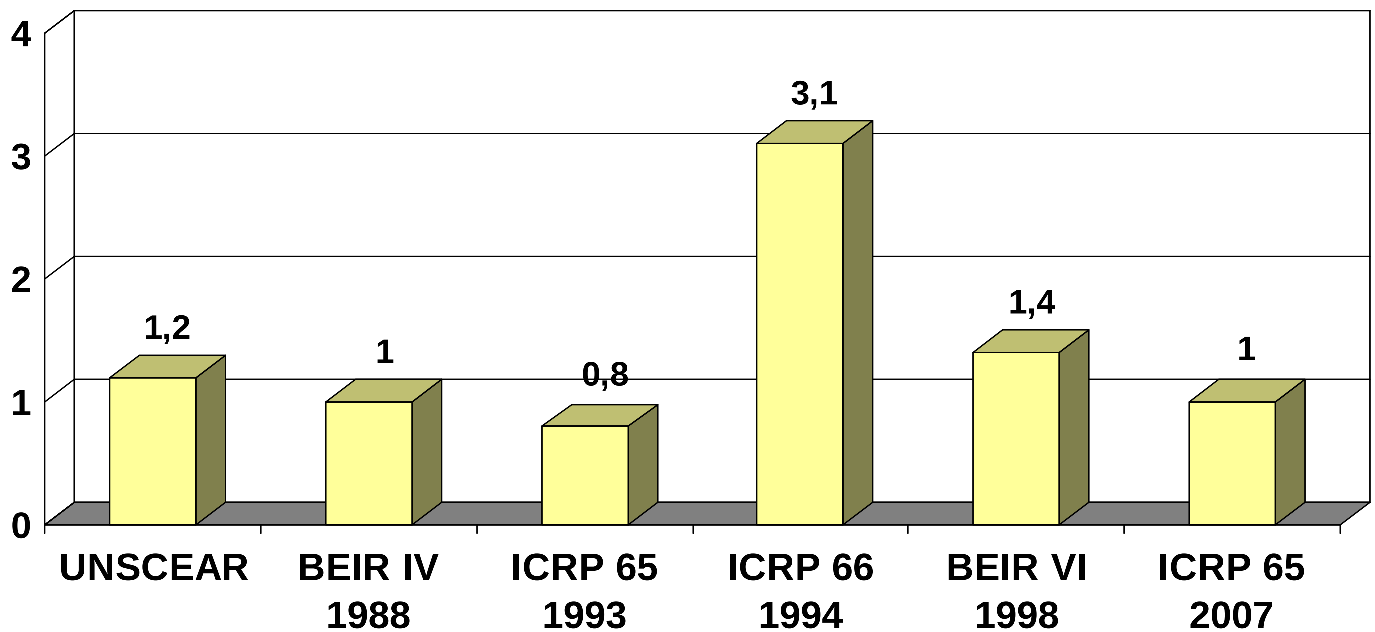
Average indoor

- radon concentration in Belgium: 48 Bq/m³ (*) (40 Bq/m³)
- equilibrium factor: 0.4 (0.4)

(*) The average indoor concentration has been revised by FANC to 53 Bq/m³

No consensus on the value of the dose conversion factor for radon

Indoor radon concentration in Belgium in mSv/y (48 Bq/m³, 40% equilibrium factor and 80% occupancy factor)



ICRP has issued in 2009 a statement to increase its dose conversion factors in the near future by about a factor of 2

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Radon and thoron exposure in Belgium (UNSCEAR: world average)

Radon and radon decay products

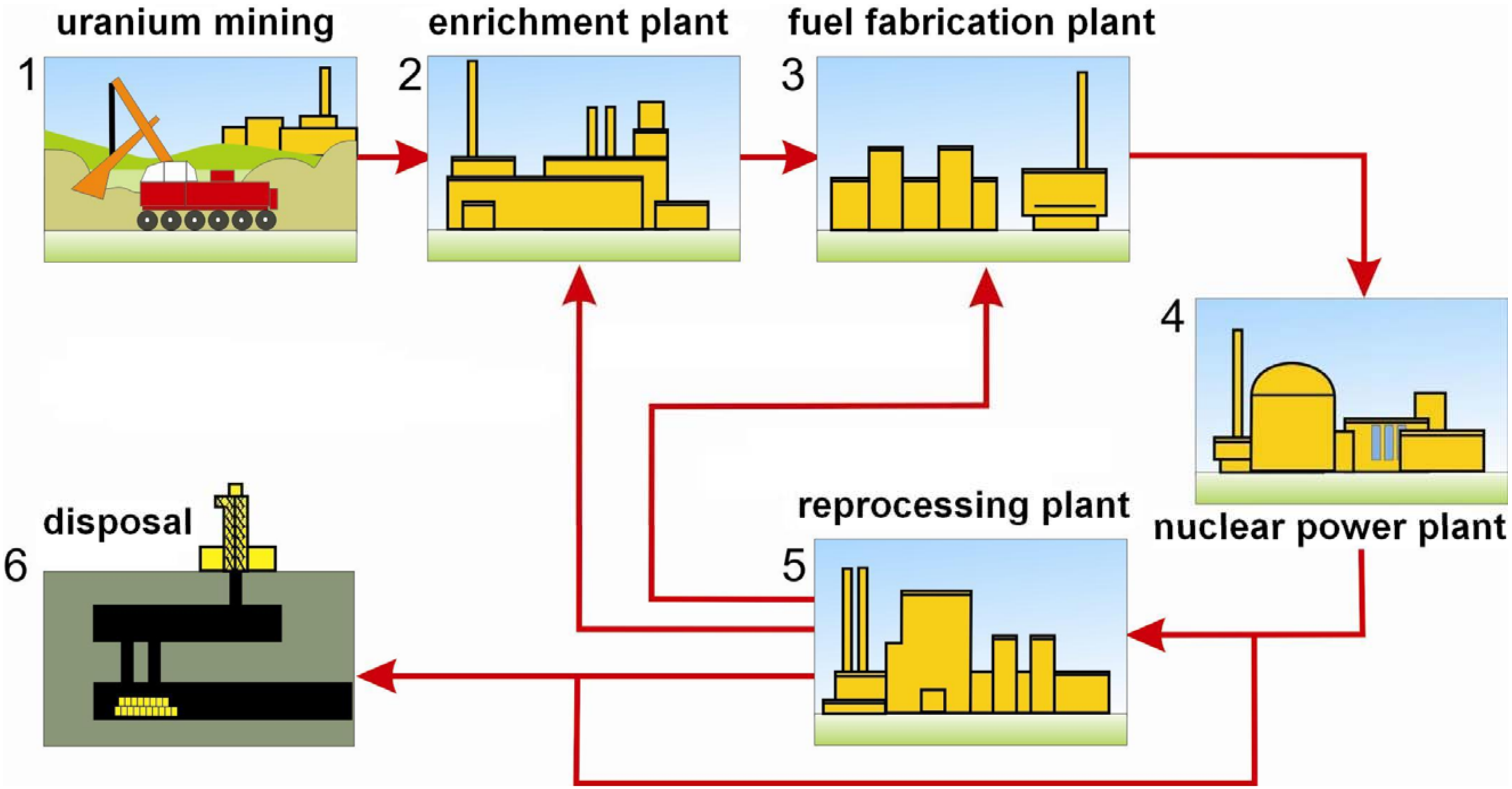
• Indoors: $48 \times 0.4 \times 7000 \times 9 \times 10^{-6}$	=	1.2	mSv/y	(1.0)
• Outdoors: $10 \times 0.6 \times 1760 \times 9 \times 10^{-6}$	=	0.1	mSv/y	(0.1)
• Radon dissolved in blood:		0.06	mSv/y	(0.05)
Total (rounded off)	=	1.35	mSv/y	(1.15)

Thoron decay products

• Indoors: $0.3 \times 7000 \times 40 \times 10^{-6}$	=	0.084	mSv/y	(0.084)
• Outdoors: $0.1 \times 1760 \times 40 \times 10^{-6}$	=	0.007	mSv/y	(0.007)
Total (rounded off)	=	0.1	mSv/y	(0.1)

Mean radon exposure in Belgium:	1.35	mSv/y	(1.15)
Mean thoron exposure in Belgium:	0.1	mSv/y	(0.1)
Total (rounded off)	**1.45**	**mSv/y**	**(1.26)**

The nuclear fuel cycle



Collective effective dose to members of the public from the nuclear fuel cycle (1998-2002)

Local and regional component during operation: **0.72 manSv/GWy**

1	Mining of uranium ore	**0.19**
	Milling of uranium ore	**0.008**
	Mine and mill tailings (release of radon over 5 years)	**0.04**
2&3	Enrichment and fuel fabrication	**0.003**
4	Reactor operation: atmospheric discharges	**0.22**
	Reactor operation: aquatic discharges	**0.05**
5	Reprocessing: atmospheric discharges	**0.028**
	Reprocessing: aquatic discharges	**0.081**
1&6	Transportation	**< 0.1**

The individual doses to the local population are in normal operation low

- Mining and milling 25 µSv/y
- Fuel fabrication 0.2 µSv/y
- Reactor operation 0.1 µSv/y
- Reprocessing 2 µSv/y

Reactor accidents are not included in the UNSCEAR figures

Long term global component and solid waste disposal

Long term global component (long-lived and easily dispersed radionuclides giving rise to dose to people across the whole planet)

The radionuclides of specific interest are:

- ^{3}H (T½ : 12.26 years)
- ^{14}C (T½ : 5730 years)
- ^{85}Kr (T½ : 10.7 years)
- ^{129}I (T½ : 16 million years)

Continued practice of nuclear power for 100 years at the present capacity
→ Maximum annual effective dose to the global population: **0.18 µSv/year**

Radioactive waste disposal

- Low- and intermediate-level waste: 0.5 manSv/GWy (mostly ^{14}C)
- No figures for the high-level waste because of the highly site specific nature of the calculations

Yearly releases of radionuclides in liquid and airborne effluents from the nuclear power plants of Doel

Source
Electrabel

	Liquid effluents		Airborne effluents			
	Tritium (GBq)	Other (GBq)	Noble gases (GBq)	Tritium (GBq)	I-131 (GBq)	Particulates (GBq)
Authorization	103 600	1480.0	2 960 000	88 800	14.8	148.0
1990	63 000	15.5	15 600	752	0.485	0.162
1991	38 100	30.1	31 300	548	0.657	0.100
1992	45 200	4.5	26 400	774	0.193	0.075
1993	34 300	23.6	5 190	553	0.097	0.008
1994	33 900	9.3	970	846	0.010	0.000
1995	47 000	37.8	4 140	613	0.032	0.004
1996	31 300	18.9	2 050	288	0.009	0.003
1997	38 400	26.4	74	227	0,006	0.002
1998	47 100	16.1	3 310	52	0.014	0.002
1999	48 400	27.8	2 660	60	0.003	0.000
2000	30 900	15.0	95	17	0.009	0.000
2001	37 500	6.7	33	329	0.004	0.001
2002	27 500	7.8	330	1030	0.009	0.005
2003	34 330	8.4	775	710	0.003	0.010
2004	42 108	5.2	25	30	0.006	0.001
2005	39 900	4.5	71	476	0.018	0.0006
2006	46 100	1.7	115	1975	0.036	0.052
2007	53 733	2.5	14	2927	0.034	0.0039
2008	41 705	3.1	22	2070	0.059	0.0033
2009	53 097	3.5	16	2940	0.062	0.0085

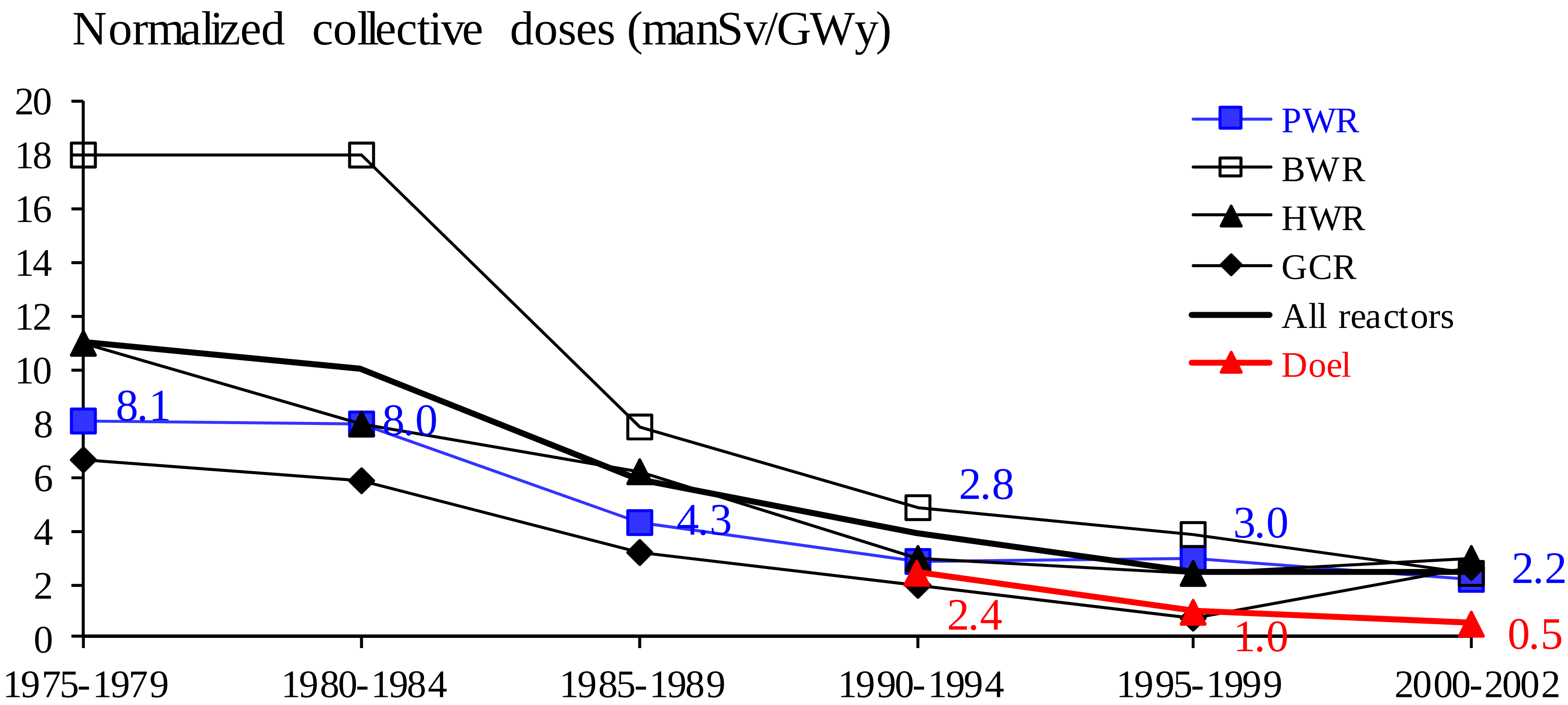
Releases of radionuclides from Doel and Tihange
(compared to UNSCEAR values from all PWRs)

	1998	1999	2000	2001	2002	Total	Normalized
	Noble gases in airborne effluents (GBq)					**(GBq)**	**(GBq/GWy)**
Doel 1-4	3 310	2 660	95	26	331	6 400	**510** **(11 000)**
Tihange 1-3	8 040	4 320	3 520	4 650	8 460	29 000	**2 200** **(11 000)**
	Tritium released in airborne effluents (GBq)					**(GBq)**	**(GBq/GWy)**
Doel 1-4	52	5 670	17	326	1 030	7 200	**570** **(2 100)**
Tihange 1-3	6 350	7 170	7 560	5 650	5 260	32 000	**2 500** **(2 100)**
	Iodine-131 released in airborne effluents (MBq)					**(MBq)**	**(MBq/GWy)**
Doel 1-4	14	3	9	4	9	39	**3.1** **(300)**
Tihange 1-3	5	6	0.6	8	0.8	20	**1.6** **(300)**
	Tritium released in liquid effluents (GBq)					**(GBq)**	**(GBq/GWy)**
Doel 1-4	47 000	48 000	30 900	38 000	27 500	191 000	**15 000** **(20 000)**
Tihange 1-3	32 900	66 600	33 100	41 000	56 600	233 000	**18 000** **(20 000)**
	Energy generated (GWy)					***(GWy)***	
Doel 1-4	*2.545*	*2.572*	*2.543*	*2.557*	*2.492*	*12.709*	
Tihange 1-3	*2.473*	*2.760*	*2.686*	*2.474*	*2.650*	*13.043*	

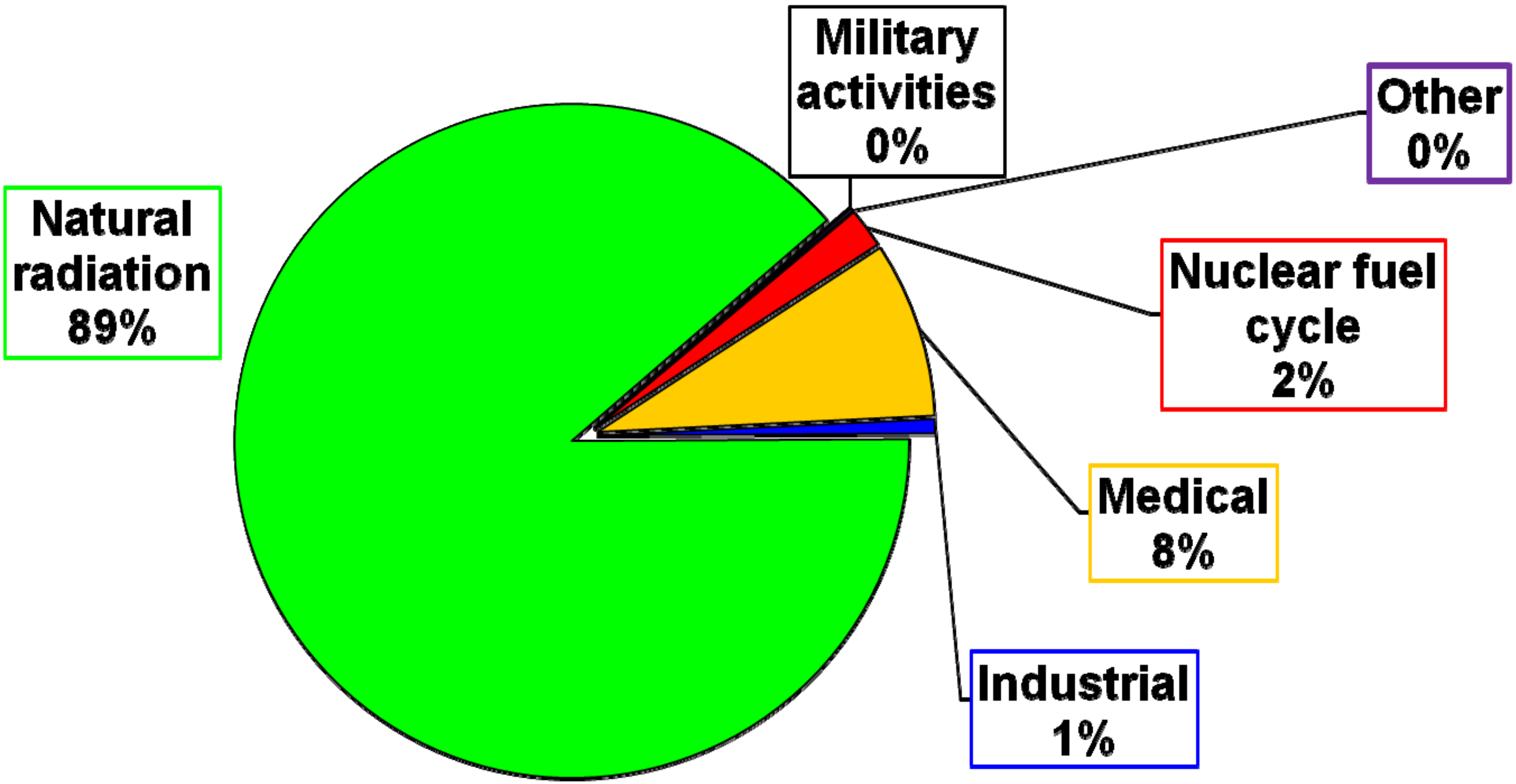
Source UNSCEAR

Occupational radiation exposures in nuclear power plants

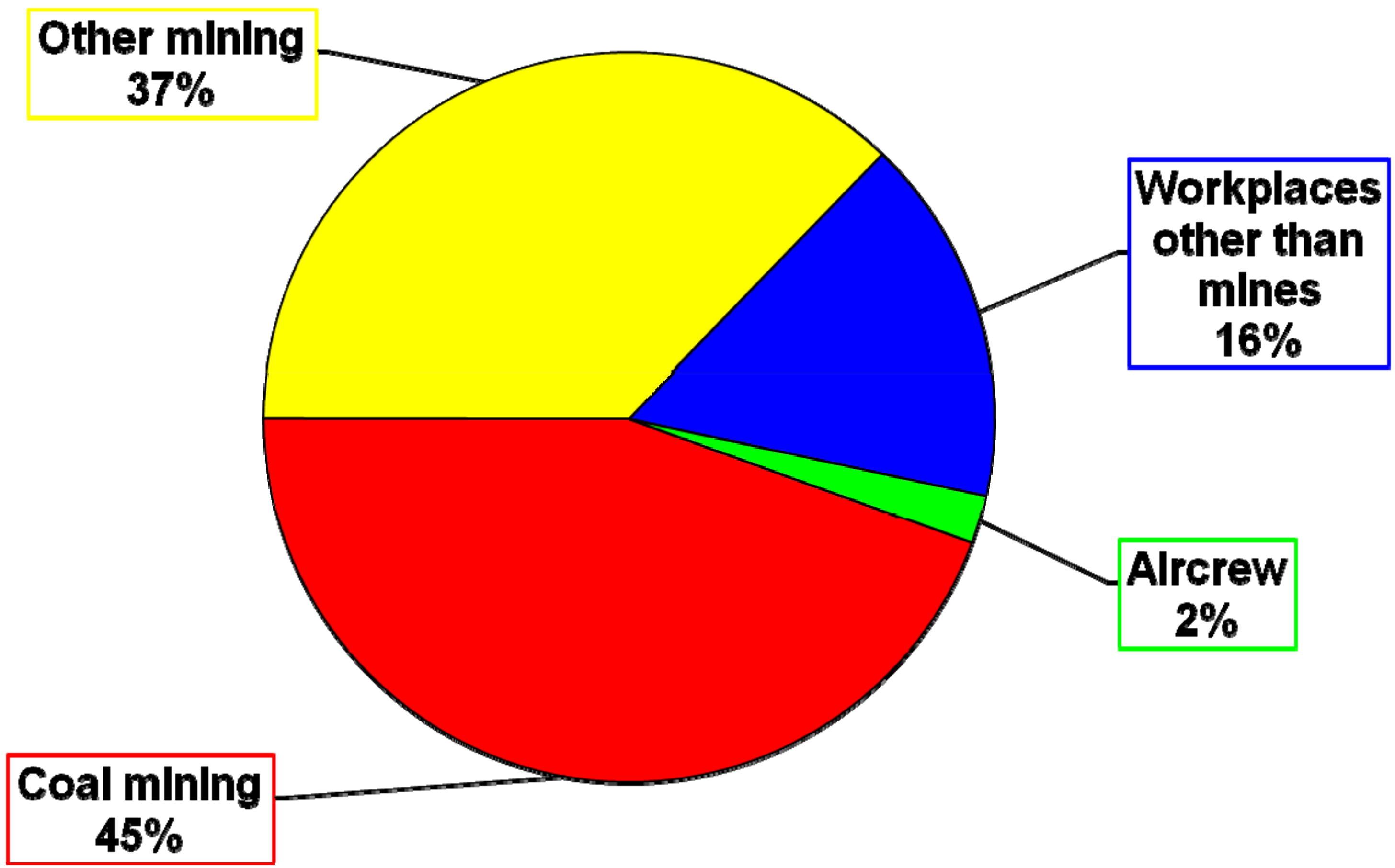
Doel 2009: 0.6 manSv/GWy



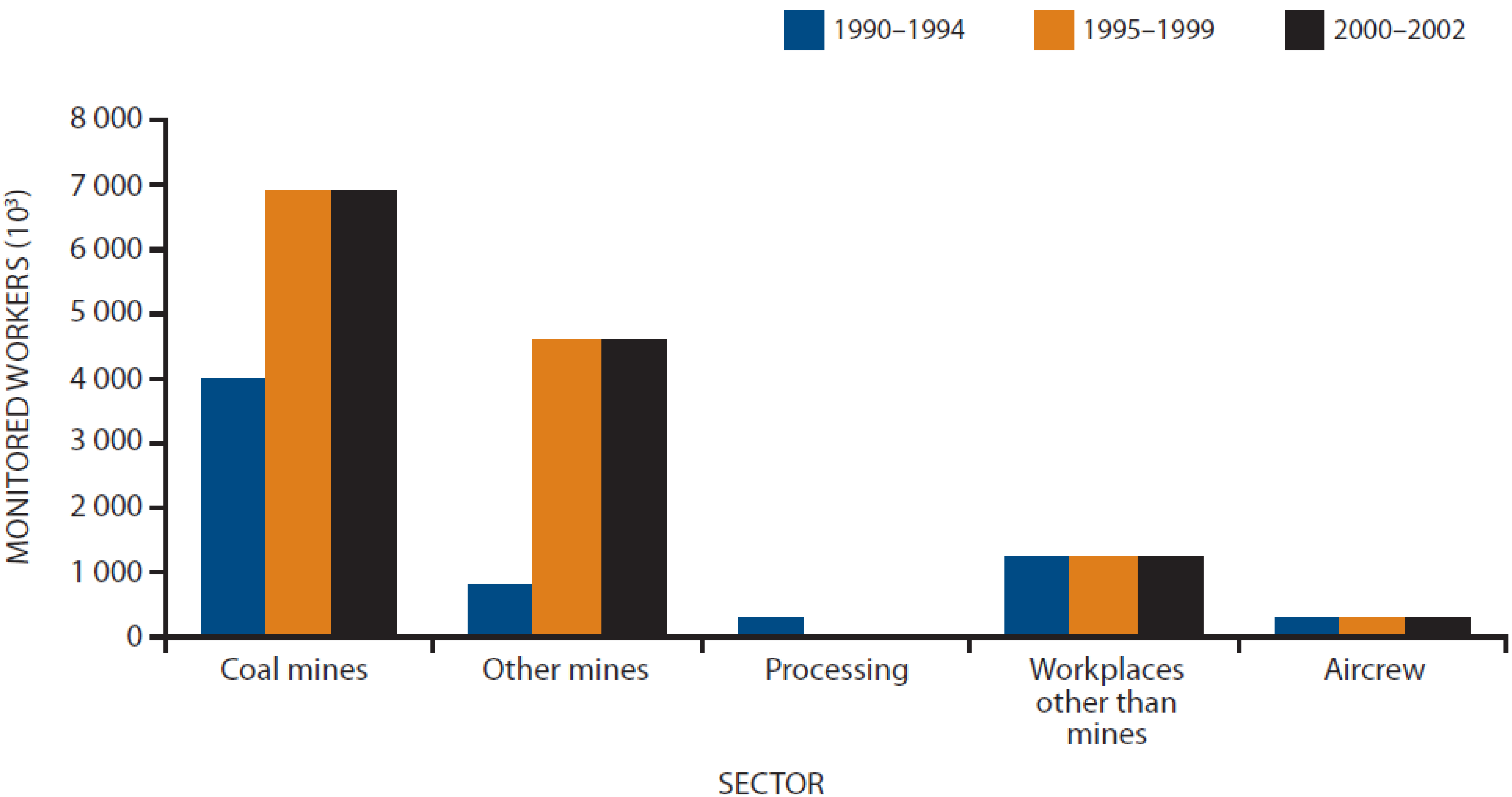
Global occupational exposures (2000-2002): 42 000 manSv/y



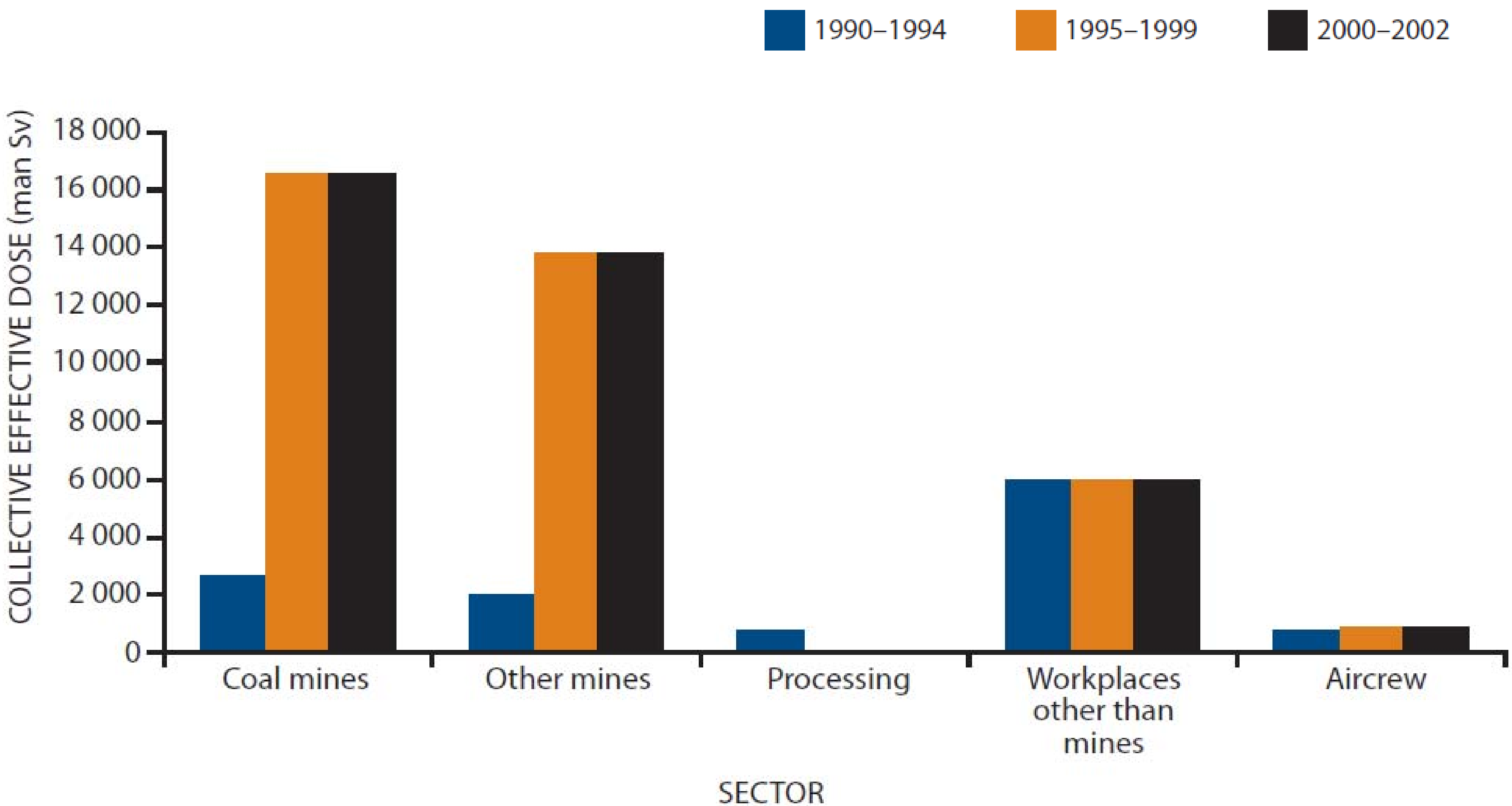
Global occupational exposures to natural sources (2000-2002): 37 260 manSv/y



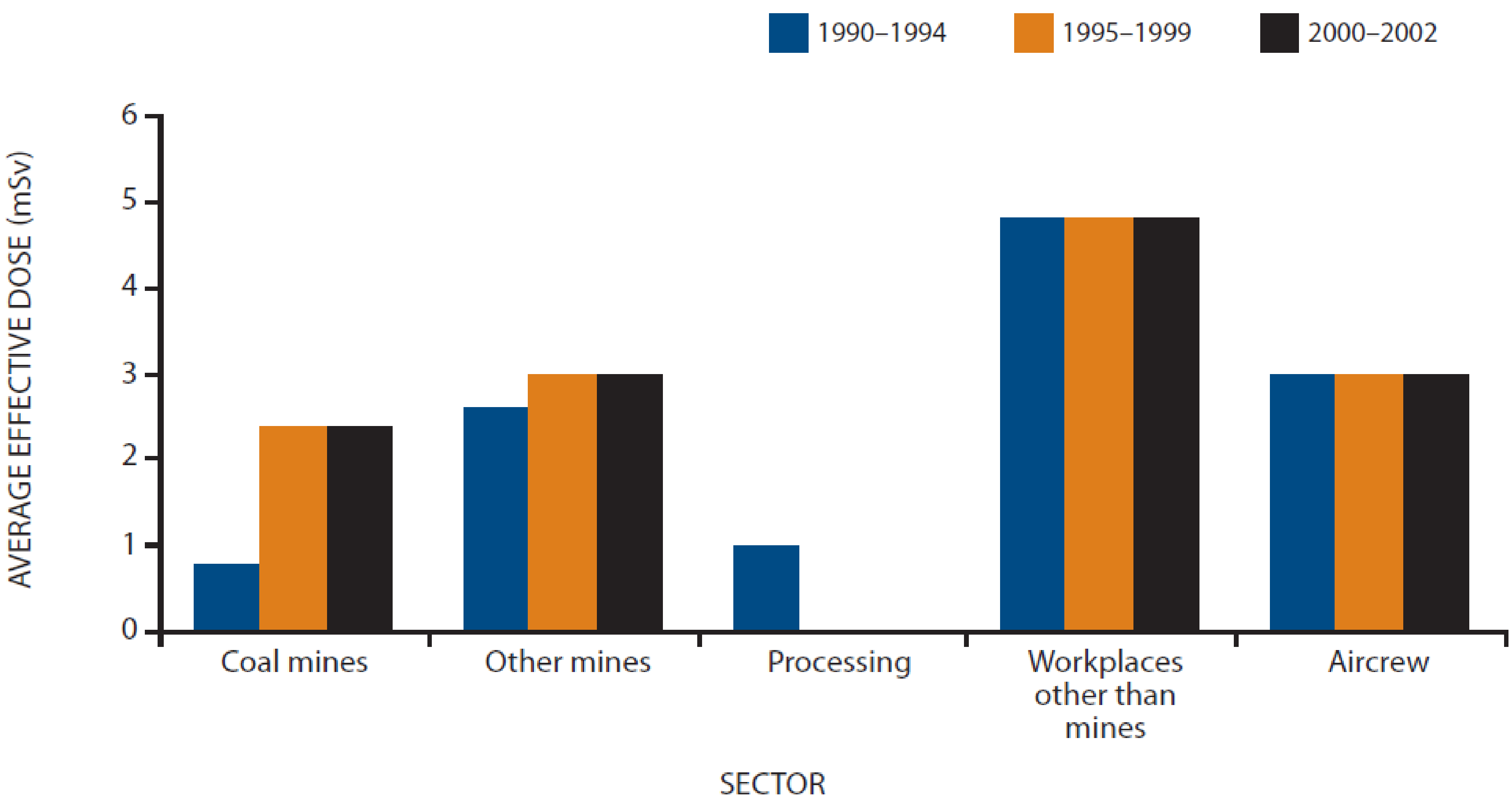
Worldwide trends in annual numbers of monitored workers due to natural sources



Worldwide trends in collective doses to monitored workers due to natural sources

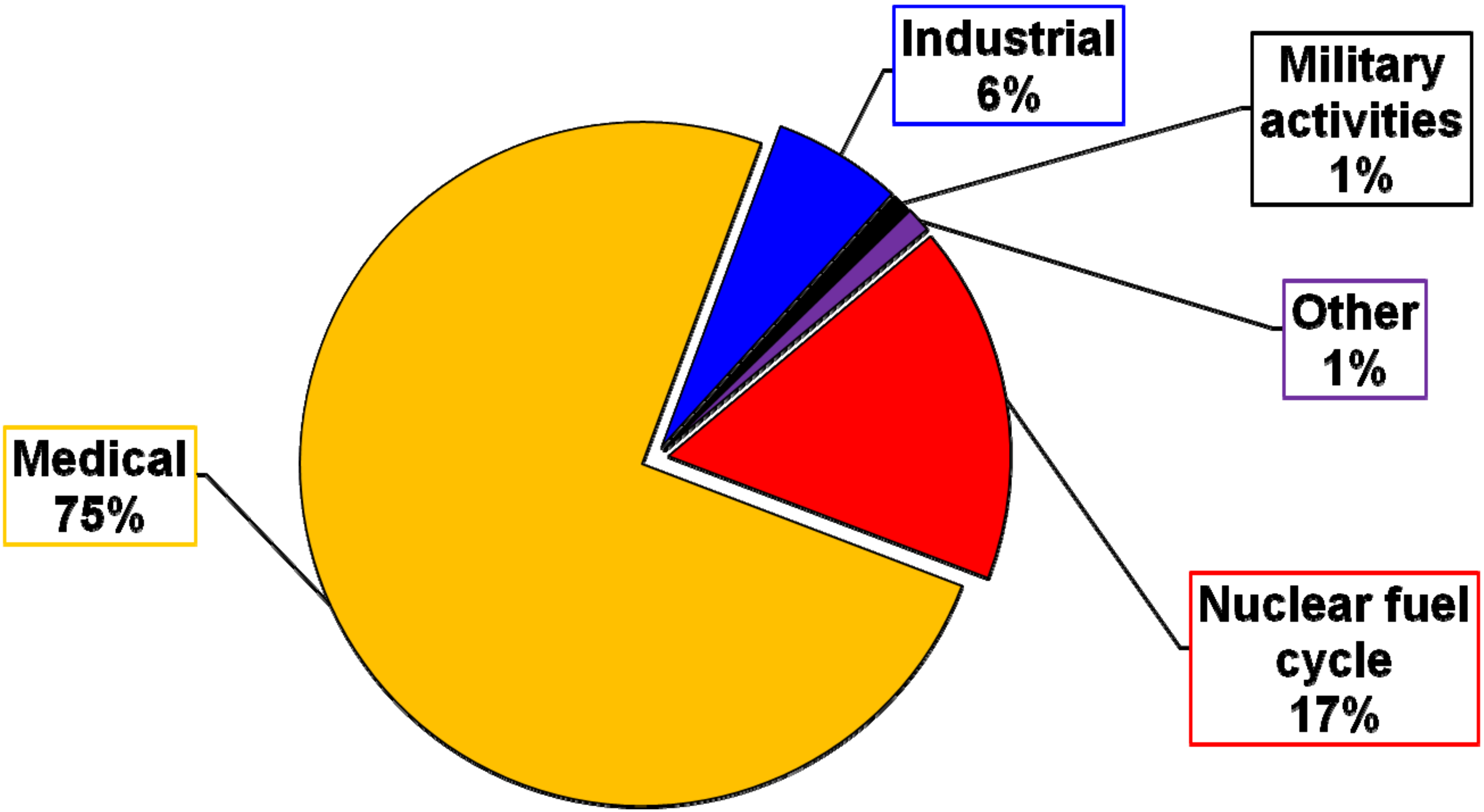


Worldwide trends in average effective doses to monitored workers due to natural sources

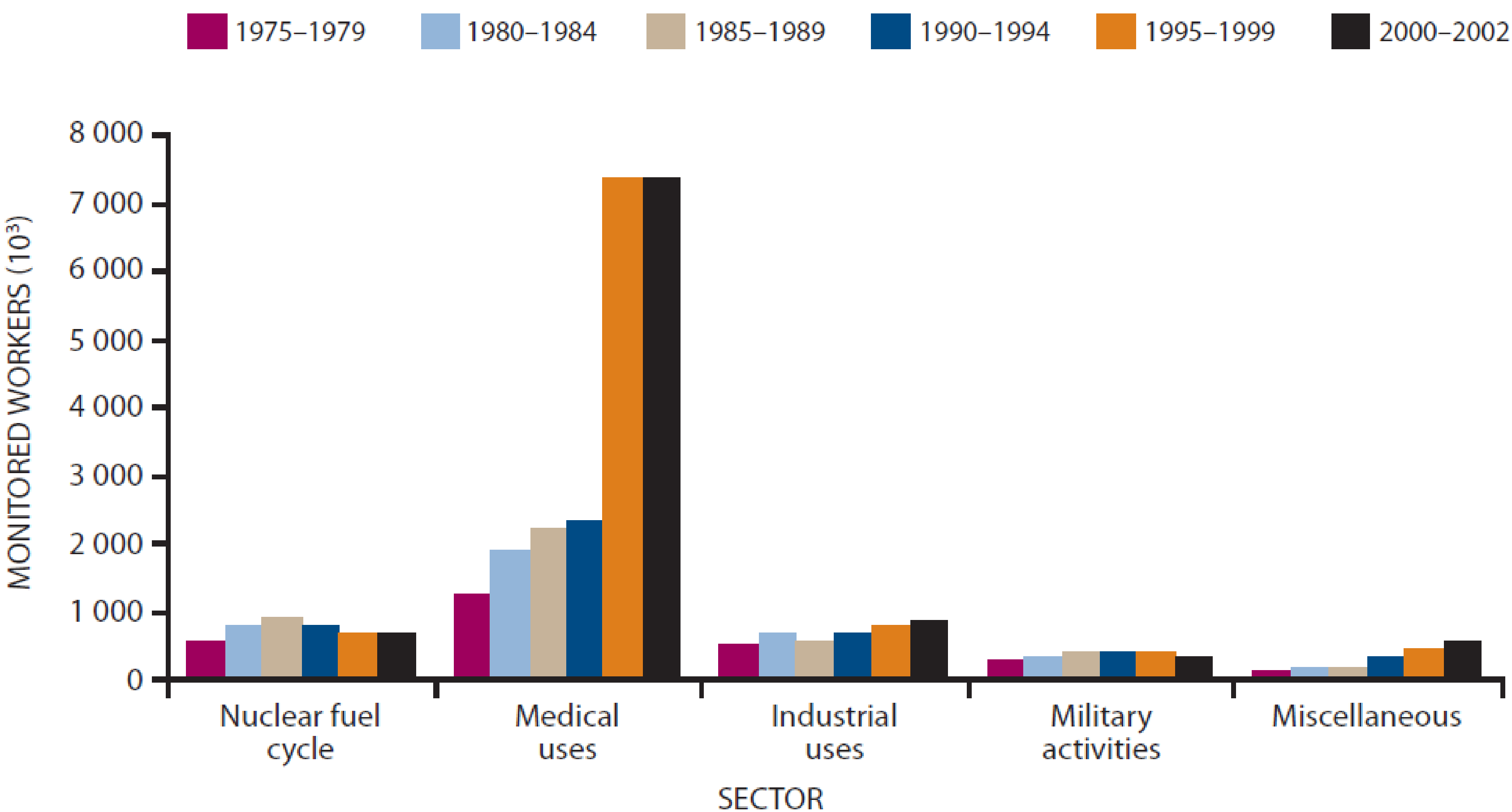


SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

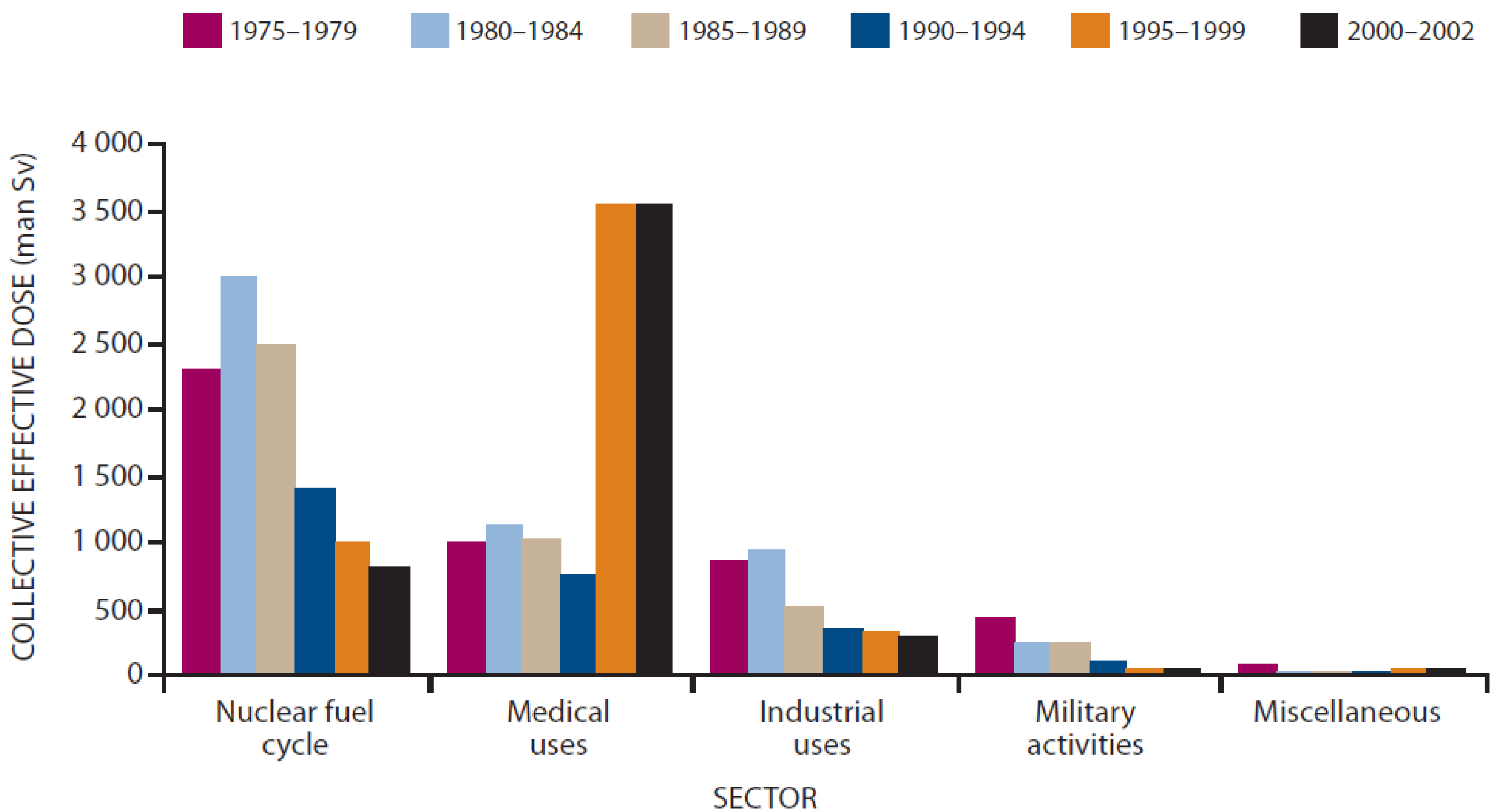
Global occupational exposures to man-made sources (2000-2002): 4 730 manSv/y



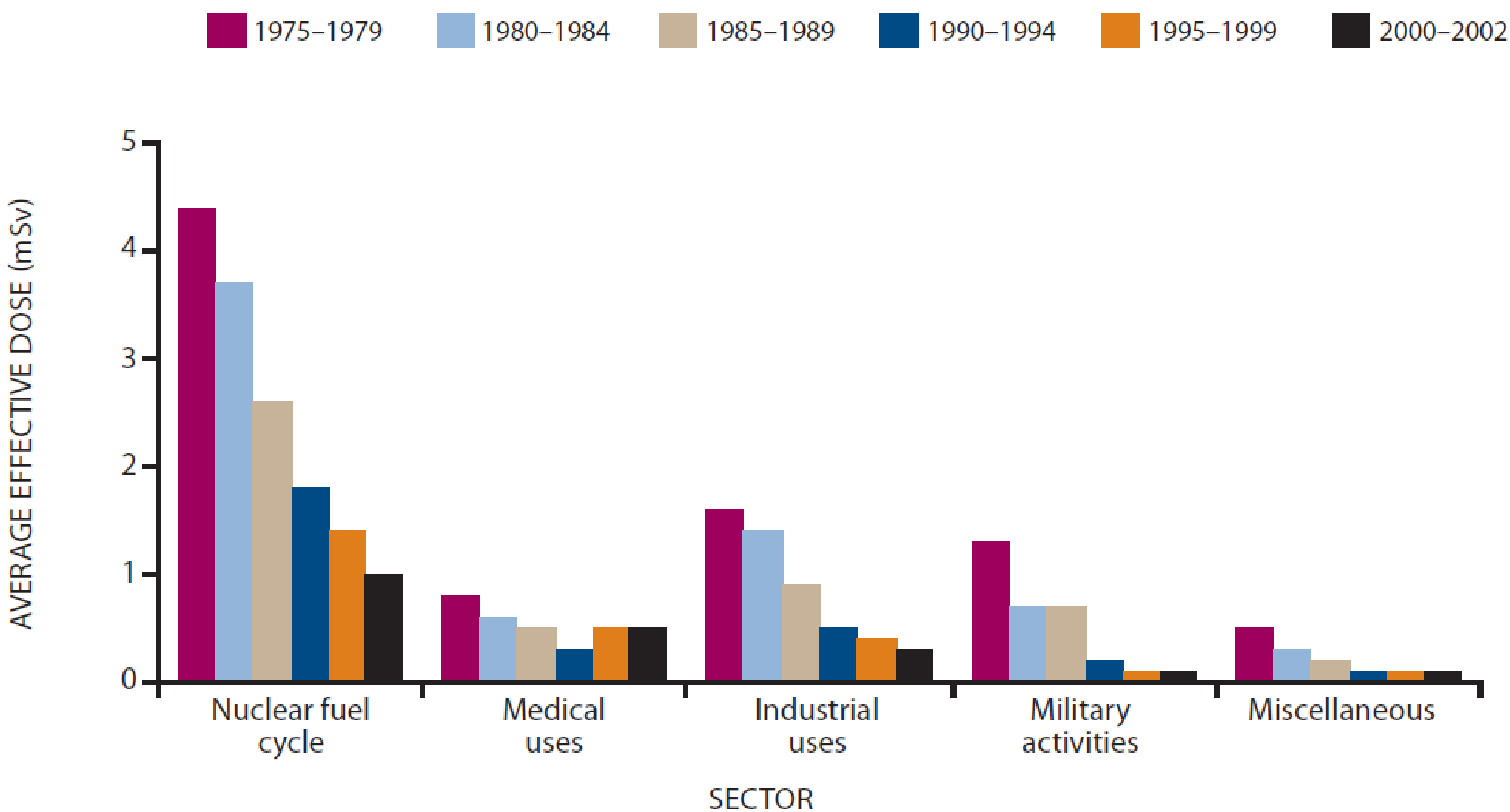
Worldwide trends in annual numbers of monitored workers due to man-made sources



Worldwide trends in collective doses to monitored workers due to man-made sources



Worldwide trends in average effective doses to monitored workers due to man-made sources



STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Copyright notice

SCK•CEN
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSEL
Operational Office: Boeretang 200 – BE-2400 MOL