Radiation exposure from electricity generation technologies

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UNSCEAR

Radiation exposure from electricity generation technologies

- **Earlier UNSCEAR estimates outdated**
- Revised methodology for estimating public exposures
  Presented by Jane Simmonds
- Nuclear fuel cycle
- Coal cycle
- Other electricity generation technologies
- Comparison of individual and collective doses

Radiation exposures from electricity generation

UNSCEAR 2016 report: Annex B

Scope

- Comparative assessment of exposures to ionizing radiation in the life cycle of electricity-generating technologies
- Normal operations only *(nuclear accidents not included)*
- Individual and collective exposure of humans *(non-human biota not included)*
- Public exposure of adults and occupational exposure of workers

➡ Collective dose is not suitable for estimating health effects

- Aggregation of very low individual doses over extended time periods is inappropriate for use in risk projection models

Earlier UNSCEAR estimates outdated

Collective dose to the public per unit of electricity generated in power plants

UNSCEAR report	**Normalized collective effective dose to public** manSv/GWy					
	Nuclear power plant operation	**Coal**	**Peat**	**Gas**	**Oil**	**Geothermal**
1982	4.2	2	-	-	-	6
1988	2.5	4	2	0.03	0.5	2
1993	**1.34 ([1])**	**20 ([2])**	**-**	**(0.03) ([3])**	**(0.5) ([3])**	**(2) ([3])**
2000 (for 1990-1994)	0.45	-	-	-	-	-
2008 (for 1988-2002)	0.27	-	-	-	-	-

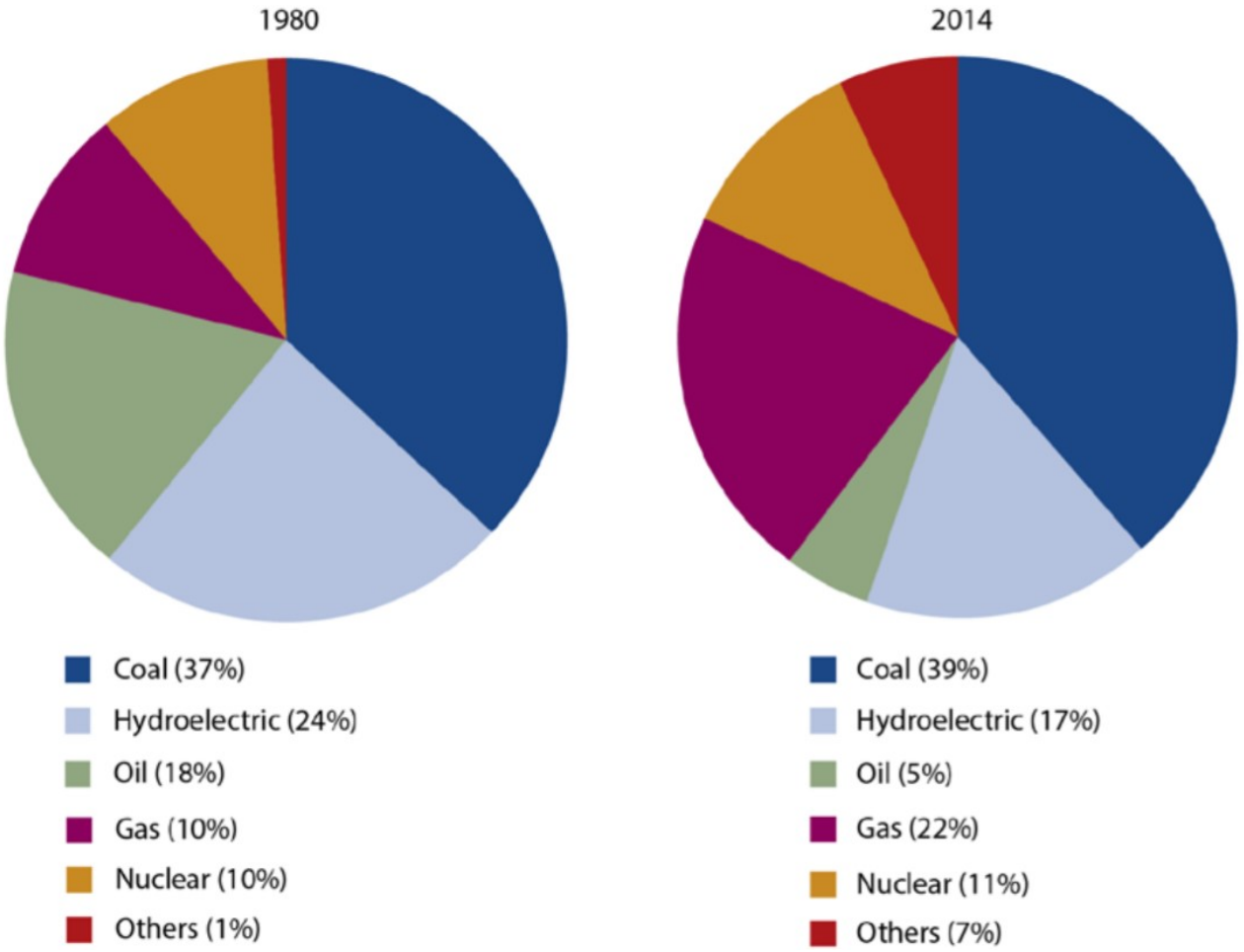
([1]) Not including: integration over 10,000 years of

- Globally-circulating radionuclides : 50 manSv/GWy
- Uranium mine and mill tailings: 150 manSv/GWy

([2]) Assuming: ⅓ modern-style, ⅓ old-style and ⅓ Chinese-style coal plants

([3]) From the UNSCEAR 1988 report

Trends in worldwide electricity generation



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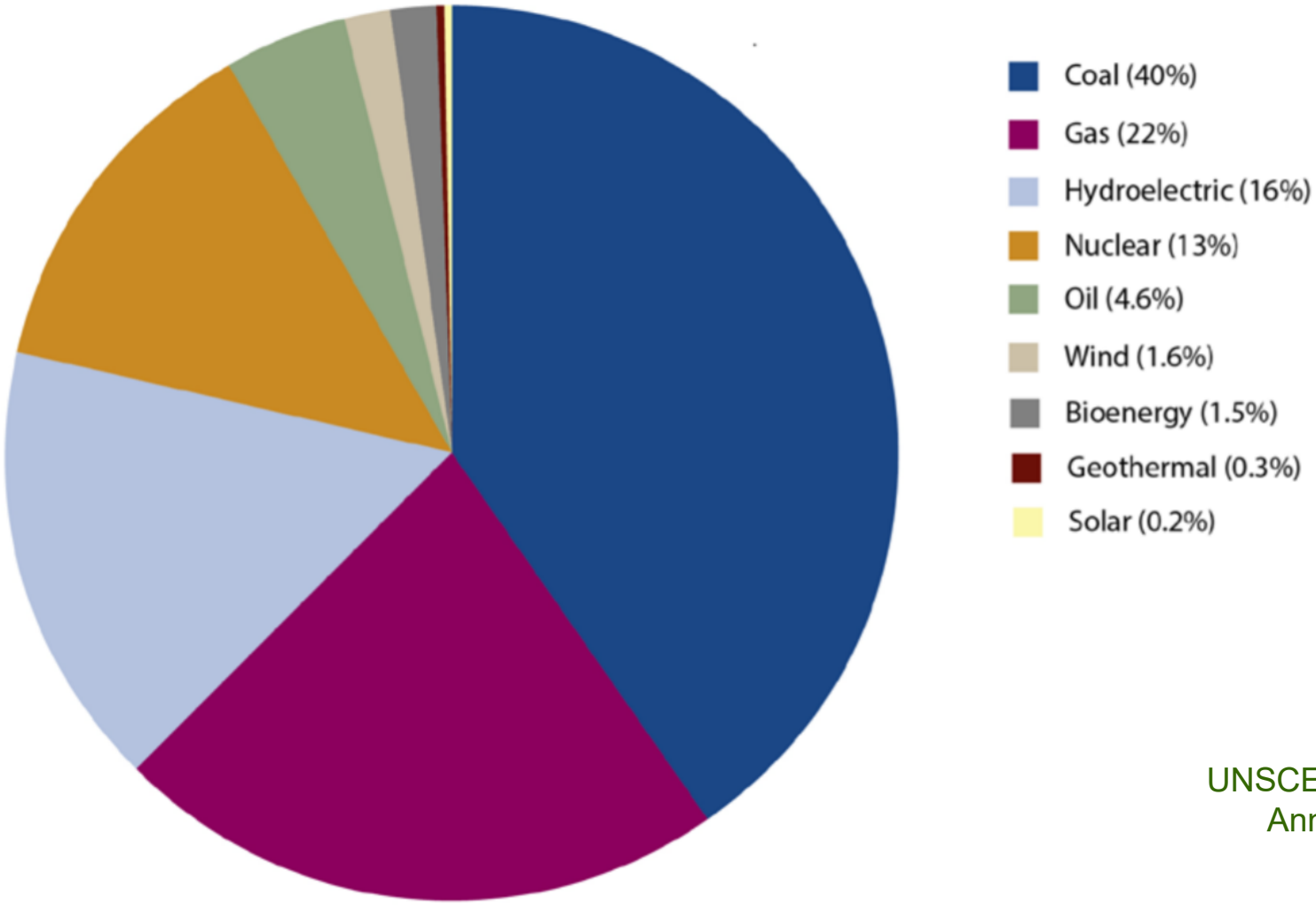
- Largest share from coal: ≈ 40%
- Oil replaced by gas

2010: reference year for assessments



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Assessment approach

- Detailed evaluation of nuclear fuel cycle
  - Uranium mining and milling
  - Mill tailings
  - Power plant operation
  - Reprocessing activities
- Detailed evaluation of coal cycle
  - Mining for coal
  - Power plant operation (modern and older coal plants)
  - Deposits of coal ash
- More rudimentary evaluation of other electricity-generating technologies: gas, oil, geothermal, solar PV, wind and biomass
  - lack of systematic data on these electricity-generating technologies

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UNSCEAR 2016: Annex A: Revised methodology for estimating public exposures due to radioactive discharges

- Used in annex B to calculate radiation exposures from different electricity-generating technologies
- Electronic workbooks that implement the current methodology available at UNSCEAR website

Presented by Jane Simmonds

Limitations of the models and data used

- Continuous discharge
  - Individual dose in the 100th year of continuous discharge
  - Collective dose in distance bands: 0-100 km (local) and 100-1500 km (regional)
- Generic models not intended for site-specific assessments
- Dose to an individual with typical habits and behavior living at 5 km from the discharge point consuming 25% local food
- Collective doses proportional to assumed population densities
  - World average: **160 km^{-2}**
  - Uranium mines and mill tailings: **5 km^{-2}**
- Uncertainties increase with time
  - Changes in population distribution
  - Globally-circulating radionuclides: integrated up to 10,000 years

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Nuclear fuel cycle
Uranium production in 2010

Country	**Uranium production** t U	Country	**Uranium production** t U	Country	**Uranium production** t U
Kazakhstan	**17,803 (33%)**	Russian Federation	3,563 (6.6%)	Malawi	681 (1.3%)
Canada	**9,775 (18%)**	Uzbekistan	2,874 (5.3%)	South Africa	582 (1.1%)
Australia	**5,900 (11%)**	United States	1,630 (3.0%)	Czech Republic	254 (0.5%)
Namibia	4,503 (8.3%)	China	1,350 (2.5%)	Brazil	148 (0.3%)
Niger	4,197 (7.6%)	Ukraine	837 (1.5%)	Iran	7 (0.01%)
Total	**54,104**				

- 41% in-situ leaching (ISL) in the period 2006 – 2012
- ISL increased to 51% in 2014

Discharges of radon and other airborne radionuclides from uranium mining and milling

	Normalized discharges GBq/GWy
Radon	
All mines except ISL	
➢ **Mining**	**66,000**
➢ Milling	3,000
➢ Operational mill tailings	3,000
➢ Mill tailings	100
ISL mines	
➢ Mining	3,000
➢ Milling	3,000
Other airborne discharges during milling: all mines	
➢ U-238, U-234	0.4
➢ Th-230, Ra-226, Pb-210, Po-210	0.02

Normalized discharges from nuclear power plants in 2010

Reactor type	**Discharges per unit of electricity generated** GBq/GWy						
	Discharges to **atmosphere**					**Aquatic** discharges	
	Noble gases	Tritium	I-131	C-14	Particu-lates	Liquid tritium	Other liquid
PWR **Doel (2009)**	**5,800** **6.6**	**1,500** **1,200**	**0.080** **0.026**	**83**	**0.036** **0.0035**	**18,000** **22,000**	**3.8** **1.4**
BWR	18,000	1,300	0.42	130	1.8	820	2.1
HWR	35,000	200,000	0.023	600	0.017	170,000	31
LWGR	460,000	26,000	9.9	1,300	2.7	780	2.0
AGR	19,000	4,000	0.032	1,400	0.022	410,000	810
GCR	1,700,000	5,000	0	5,500	0.30	4,700	1,200
FBR	44,000	49,000	0.20	120	0.14	1,700	23

Individual and collective doses to public from the nuclear fuel cycle per unit of electricity generated in 2010

Individual doses at 5 km from a 1000-MW facility

- Mining and milling: all mines except ISL — 6.9 µSv
- Mining and milling: ISL mines — 0.55 µSv
- Power plants (region dependent) — 1.3 – 0.0082 µSv
- Reprocessing (region dependent) — 0.75 µSv

Collective doses

	Collective dose manSv	Normalized dose manSv/GWy
Local and regional component (0-1,500 km)	**130**	**0.43**
+ global component (100 years) (*)	910	3.0
+ global component (500 years) (*)	1,700	5.5
+ global component (10,000 years) (*)	7,600	25

(*) Global component: worldwide exposure to H-3, **C-14**, Kr-85 and I-129

Annual **individual and collective doses to workers** from the nuclear fuel cycle (UNSCEAR 2008 for 2000-2002)

Worldwide practice	**Monitored workers** thousands	**Annual collective dose** manSv	**Normalized annual collective dose** manSv/GWy	**Annual effective dose to monitored workers** mSv
Mining	12	22	0.1	1.8
Milling	3	3	0.02	1.0
Enrichment	18	2	0.02	0.1
Fuel fabrication	20	31	0.1	1.6
Reactor operation	**437**	**617**	**2.5**	**1.4**
Reprocessing	76	68		0.9
Research	90	36	0.1	0.4
Total	656	**779**	**2.8**	1.2

2010 collective dose: 788 manSv (similar to the 2000-2002 result of 779 manSv)

- The collective medical dose in Belgium is many times greater ≈ **22,000 manSv** in 2006

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- Comparison of individual and collective doses

World coal production increased by 16% (million metric tons, Mt)

Country	2008	2009	2010	2011	2012
China (*)	**2,811**	**2,995**	**3,230**	**3,518**	**3,645**
United States	1,063	975	984	994	922
India	517	558	562	575	589
Australia	392	408	424	402	421
Russian Federation	305	276	322	322	354
South Africa	252	249	255	253	259
Indonesia	249	291	325	360	443
Poland	143	135	133	139	144
Kazakhstan	111	101	111	116	126
Colombia	74	73	74	86	89
World	6,778	6,896	**7,257**	7,660	7,881

(*) Chinese production increased by 30%

Radon emissions from coal mines in China

Type of coal mine	**Coal output** Mt/year	**Radon emissions per ton of coal** kBq/t	**Normalized radon emissions** GBq/GWy
Large-sized	1,600	190	570
Medium-sized	570	1300	3,600
Small-sized	390	3500	11,000
Typical value		930	**2,800**

Discharges of radon and other airborne radionuclides from coal-fired power plants

Radionuclide	**Normalized release from coal fired power plants** GBq/GWy	
	Older plants (1)	**Newer plants (2)**
Rn-222	**70 (100%)**	**70 (100%)**
Po-210	1.4 (2%)	0.093 (0.13%)
Pb-210	1.4 (2%)	0.093 (0.13%)
Ra-226	0.7 (1%)	0.047 (0.067%)
U-234	0.7 (1%)	0.047 (0.067%)
U-238	0.7 (1%)	0.047(0.067%)
Th-230	0.7 (1%)	0.047(0.067%)

Average U-238 concentration in coal: 20 Bq/kg

(1) Older plants from Hedvall and Erlandsson (1996)

(2) Newer plants (discharges to atmosphere (other than radon)**: 15 times lower)** from Zeevaert, Sweeck and Vanmarcke (2006) (measurements Genk-Langerlo power station, Belgium)

Individual and collective doses to public from the **coal cycle** per unit of electricity generated in 2010

Individual doses at 5 km from a 1000-MW facility

- Mining: 0.24 µSv
- Older coal plants (region dependent): 0.38 – 0.42 µSv
- Modern coal plants (region dependent): 0.031 – 0.034 µSv
- Ash: 0.15 µSv

Local and regional **collective doses** (0-1,500 km)

	Collective dose manSv		Normalized dose manSv/GWy	
	Modern plant	**Older** plant	**Modern** plant	**Older** plant
Mining (radon discharges)	370	370	0.4	0.4
Plant operation	**60**	**780**	**0.1**	**0.8**
Ash (radon emanation)	240	240	0.2	0.2
Total public	**670**	**1400**	**0.7**	**1.4**

Annual individual and collective doses to underground coal miners in **China**

Type of coal mine	Average **individual dose** in 2004 mSv	Number of miners in 2004 millions	**Number of miners** in 2010 millions	Collective dose 2002-2004 manSv	**Collective dose** in 2010 (1) manSv
Large-sized	0.32	1	1.26	315	403
Medium-sized	0.63	1	1.31	630	825
Small-sized	**3.78**	4	**2.27**	15,100	**8,581**
Bone-coal	11.3	0.05	Not available	567	Not available
Total	**2.75** (weighted average)	6.05	**4.84**	16,612	**9,809**

(1) Collective dose in 2010 using individual dose from 2004 and number of miners from 2010

- **Worldwide** collective dose to coal miners in 2010: **11,000 manSv**
  (China accounted for almost 90% of the underground coal miners in the world)
- **Much room for dose reduction** (40 % decrease despite increase in production)

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Radon emissions: common contributor to **public exposure**

Electricity-generating technology	% world electricity generation in 2010	**Normalized radon discharges** GBq/GWy
Nuclear, mining	13	**Uranium mining: non ISL: 66,000** Uranium mining: ISL: 3,000 Milling: 3,000 Operational mill tailings: 3,000 Mill tailings: 10,000
Coal	40	**Coal mining: 2,800** Power plants: 70 Coal ash deposits: 1,800
Natural gas	22	750
Oil	4.6	2
Geothermal	0.3	**150,000**

Collective dose for construction of electricity-generating plants (or devices)

Electricity-generating technology	Occupational collective dose **due to mining and processing of ores needed for construction** per unit of electricity generated manSv/GWy
Nuclear	0.02
Coal	0.01
Natural gas	0.01
Solar PV	**0.8**
Wind	**0.1**
Biomass	0.01

The amount of ore needed for solar power and wind power technologies is high

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Comparison of **collective doses to public**

Electricity-generating technology	**Collective dose** manSv	**Normalized collective dose** manSv/GWy	**% world electricity generation** in 2010	**Normalized radon discharges** GBq/GWy
Nuclear, total from mining to reprocessing, excluding global component	**130**	**0.43**	13	**Non ISL mining: 66,000** ISL uranium mining 3,000 Milling: 3,000 Operat. mill tailings: 3,000 Mill tailings: 10,000
Nuclear, + global component				
100 years	910	3.0		
500 years	1700	5.5		
10,000 years	7600	25		
Coal, older plants	1400	1.4	40	**Coal mining: 2,800** Power plants: 70 Coal ash deposits: 1,800
Coal, modern plants	**670**	**0.7**		
Natural gas	**55**	**0.10**	22	750
Oil	**0.03**	**0.0003**	4.6	2
Geothermal (low-density population = default population)	**5**-160	**1**-20	0.3	**150,000**

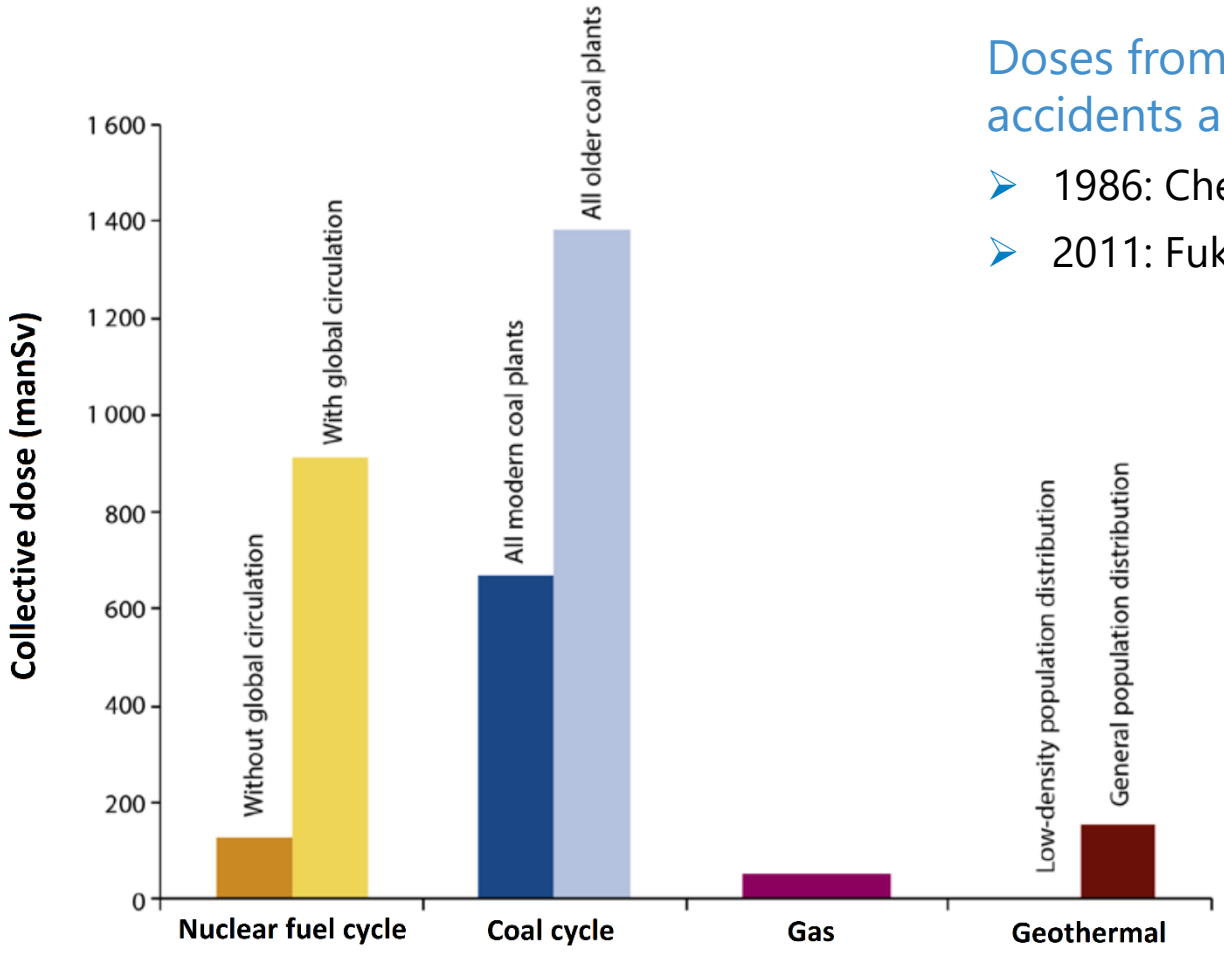
Comparison of doses to public from mining of coal and uranium

	Individual dose mSv/GWy	**Collective dose** manSv	**Collective dose** per unit of electricity generated manSv/GWy
Coal mining	**0.00024** (*)	370	**0.38**
Uranium mining: non ISL	**0.0055** (*)	40	**0.28**
Uranium mining: ISL	0.00025	1.3	0.012

(*) The higher radon discharges from non ISL uranium mines are offset by the lower population density around uranium mines (compared to coal mines)

➡ **Collective doses from coal and uranium mining are about the same** per unit of electricity generated

Collective doses to public from single year of electricity production (2010) integrated over 100 years



Doses from serious nuclear accidents are many times greater

- 1986: Chernobyl: **400,000 manSv**
- 2011: Fukushima: **48,000 manSv**

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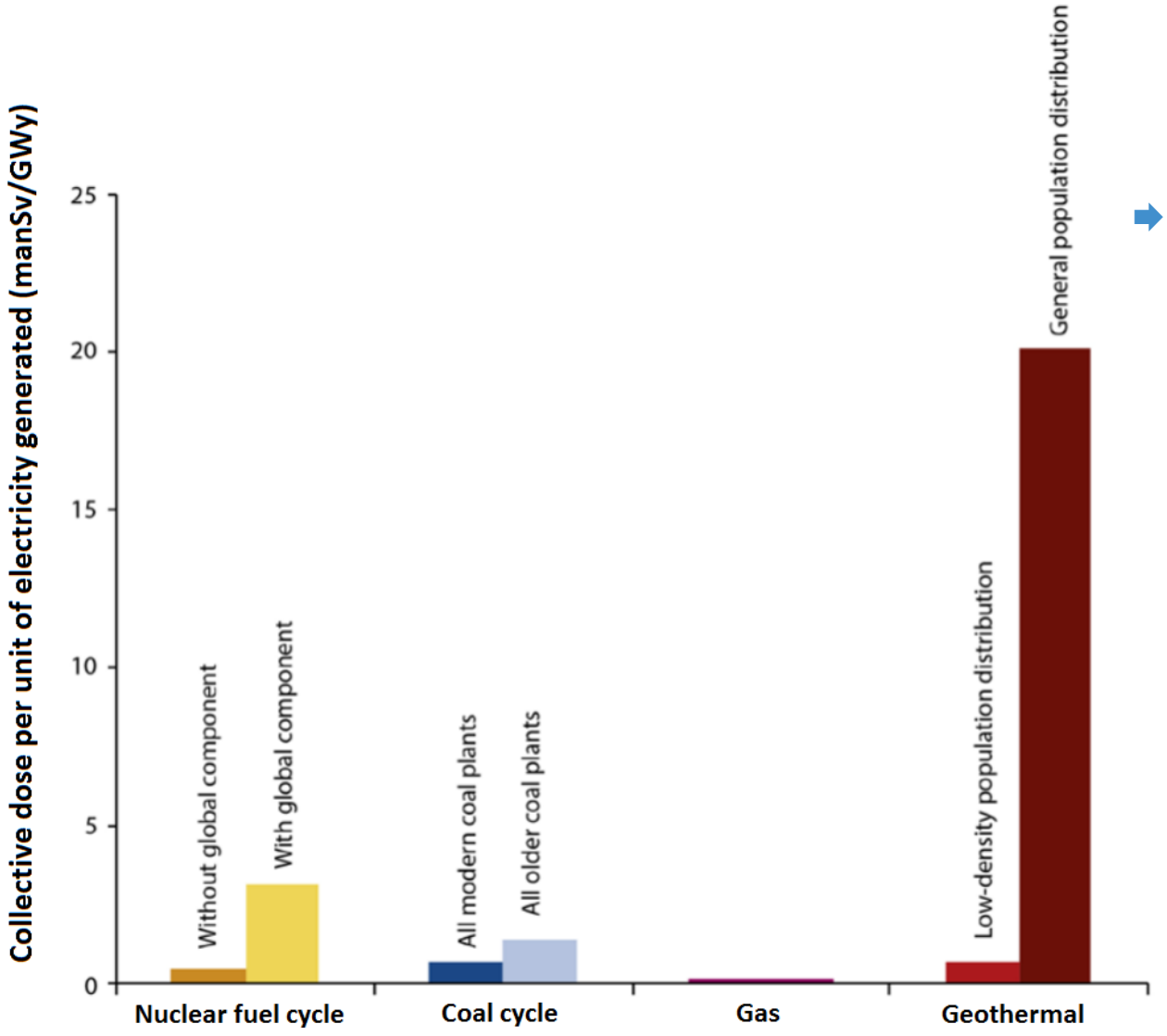
➡ Doses from nuclear fuel cycle and coal cycle are about the same

Normalized collective doses to public from single year of electricity production (2010) integrated over 100 years



- Very high radon discharges from geothermal

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Local and regional collective doses due to discharges from modern and old-style coal plants

Radionuclide	Collective dose from **modern coal plants** manSv		Collective dose from **old-style coal plants** manSv	
	Local 0-100 km	**Regional 100-1500 km**	**Local 0-100 km**	**Regional 100-1500 km**
Pb-210	2	9	28	135
Po-210	**3**	**14**	**46**	**216**
Rn-222	**2**	**8**	**2**	**8**
Ra-226	1	7	20	98
Th-230	2	8	26	122
U-234	0.5	2	7	34
U-238	0.4	2	6	29
Total	**11**	**50**	**135**	**641**

- Discharges to atmosphere (other than radon) 15 times larger in old-style coal plants

Collective and individual doses within 1500 km from coal ash versus uranium mill tailings

Time since disposal	**Collective dose** per unit of electricity generated manSv/GWy		**Individual dose** per unit of electricity generated µSv/GWy	
	Coal ash	**Mill tailings**	**Coal ash**	**Mill tailings**
100 years	0.2 (1)	0.04 (1)	0.15	0.84
500 years (2)	1.2	0.2		

(1) Population density around coal mines is much higher than around uranium mines (**160 km²** compared to **5 km²**)

(2) Radon emanation continues into the future (proportional to the period)

Comparison of **collective doses to public and to workers**

Electricity-generating technology	Public		Workers	
	Collective dose manSv	**Normalized collective dose** manSv/GWy	**Collective dose** manSv	**Normalized collective dose (1)** manSv/GWy
Nuclear	**130**	**0.43**	**788**	**2.7 (2)**
Coal, modern coal plants	**670**	**0.7**	**11,000**	**11**
Coal, older coal plants	1400	1.4	11,000	11
Natural gas	55	0.1	7	0.01
Oil	0.03	0.0003	17	0.15
Geothermal (low-density population = default population)	**5**-160	**1**-20	**0.4-0.8**	**0.05**

(1) Occupational exposure for **construction of solar PV: 0.8** manSv/GWy

(2) Nuclear, without decommissioning (decommissioning: 1.8 manSv/GWy)

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	Collective dose manSv	**Normalized collective dose** manSv/GWy	**Collective dose** manSv	**Normalized collective dose** manSv/GWy
Nuclear	**130**	**0.43**	**788**	**2.7**
Coal, modern coal plants	**670**	**0.7**	**11,000**	**11**

➡ **Doses from nuclear fuel cycle and coal cycle are about the same**

Doses from serious nuclear accidents are many times greater!

- 1986: Chernobyl: **400,000 manSv**
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