UNSCEAR

United Nations Scientific Committee on the Effects of Atomic Radiation

UN environment programme

UNSCEAR 2020/2021 REPORT, ANNEX D
“EVALUATION OF OCCUPATIONAL EXPOSURE TO IONIZING RADIATION”

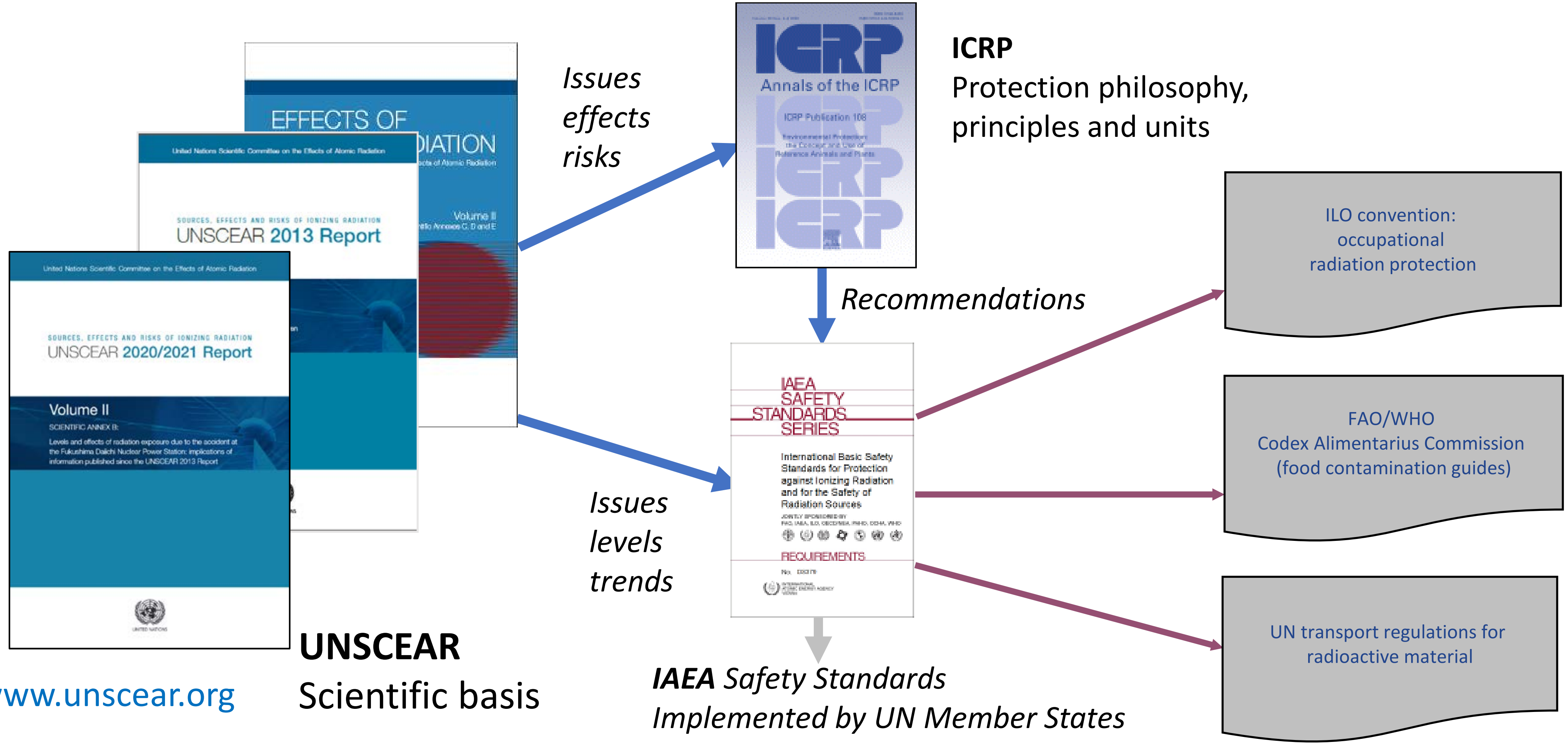
Opening:

Dr Jing Chen, Chair

Ms Borislava Batandjieva-Metcalf, Secretary

- Established by UN General Assembly (GA) resolution in 1955
- Scientists from 31 UN Member States
- Assess levels, effects & risks of ionizing radiation
  - identify emerging issues
  - improve knowledge
  - identify areas for future research
- Disseminate findings to UN GA, scientific community and public

International Radiation Safety Regime



www.unscear.org

UNSCEAR Occupational Exposure Evaluations

UNSCEAR evaluated levels of occupational exposure in 1962, 1972, 1977, 1982, 1988, 1993 and more recent in

- UNSCEAR 2000 (1990-1994)
- UNSCEAR 2008 (1995-2002)
- UNSCEAR 2020/2021 (2003-2014)

Questions and answers

Moderation

Dr Ferid Shannoun, Deputy Secretary UNSCEAR

Panel

Dr Peter Hofvander, Chair of the expert group, Sweden

Dr Vincent Holahan, Senior technical adviser, United States

Dr Dunstana Melo, Lead writer, United States

Dr Jing Chen, Contributing writer, Canada

Dr Cameron Lawrence, Contributing writer, Australia

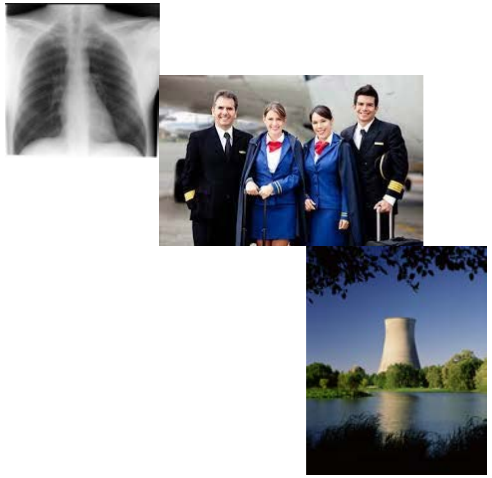
Dr Uwe Oeh, Contributing writer, Germany

Dr Steven Simon, Contributing writer, United States

Mr Halil Burçin Okyar, Contributing writer, IAEA (observer)

Committee’s strategy to improve collection, analysis and dissemination of data on radiation exposure (2022)

- **Establishment of small group of experts**
  - **Medical exposure** – 4 members, chaired Anja Almén
  - **Occupational exposure** – 4 members, chaired Peter Hofvander
  - **Public exposure** – to be established after publication ~2024



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unscear-survey@un.org

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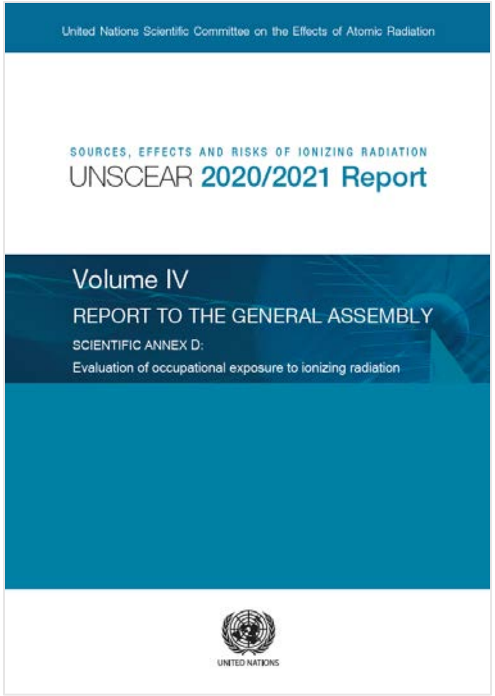
EVALUATING SCIENCE FOR INFORMED DECISION MAKING

UNSCEAR 2020/2021 REPORT VOLUME IV: “Evaluation of occupational exposure to ionizing radiation"



Timelines

- 2014: Committee endorsed the project plan
- 2016–2019: Secretariat conducted Global Survey
- 2021: Committee adopted the report
- 2022: Secretariat published the report

77th UN General Assembly

President of 77th UNGA, HE Kőrösi,
17 October

UNSCEAR Occupational Exposure Survey

- Two questionnaires
- Simplified: 57 MS responded
  - Essential data on no. of workers, and effective dose for work sectors/work categories
- Detailed: 44 MS responded
  - Annual data on no. of monitored workers, effective dose, collective dose and dose distribution for 2003–2014 for work sectors/work categories

United Nations Scientific Committee
on the Effects of Atomic Radiation
survey.unscear.org

Algeria	Greece	Norway
Argentina	Hungary	Pakistan
Australia	Iceland	Philippines
Bangladesh	India	Poland
Belarus	Iran (Islamic Republic of)	Republic of Korea
Belgium	Iraq	Russian Federation
Bosnia and Herzegovina	Ireland	San Marino
Brazil	Italy	Saudi Arabia
Canada	Japan	Slovenia
Chile	Kenya	South Africa
China	Kuwait	Spain
Croatia	Lebanon	Sweden
Cyprus	Lithuania	Switzerland
Czechia	Luxembourg	Thailand
Denmark	Madagascar	Turkey
Estonia	Mauritius	United Arab Emirates
Finland	Mexico	United Kingdom
France	Niger	United States
Germany	Nigeria	Uruguay

Additional sources of Information

- IAEA Power Reactor Information System
- ISOE database
- ICAO – Data on Aircrew
- World Nuclear Association

UNSCEAR
United Nations Scientific Committee on the Effects of Atomic Radiation

UN environment programme

Occupational exposure to ionizing radiation: UNSCEAR 2020/2021 Report, annex D

Dr Peter Hofvander, Chair Expert Group (Sweden)

Email: peter.hofvander@ssm.se

Scientific webinar
17 November 2022
at 13:00 CET

Expert Group on Occupational Exposure

Chair

- P. Hofvander (Sweden)

Senior Technical Advisor

- V. Holahan (United States)

Lead writers

- C. Lawrence (Australia)
- J. Chen (Canada)
- U. Oeh (Germany)
- T. Rosentreter (Germany)
- D. Kluszczynski (Poland)
- D. Melo (United States)
- S. Simon (United States)

Members

- M. Bercikova (Czechia)
- S. Saigusa (Japan)
- N. Juto (Japan)
- F. Ortega (Mexico)
- G. de With (Netherlands)
- J. Kim (Republic of Korea)
- S. Seo (Republic of Korea)

Secretariat

- F. Shannoun (UNSCEAR)

Observers

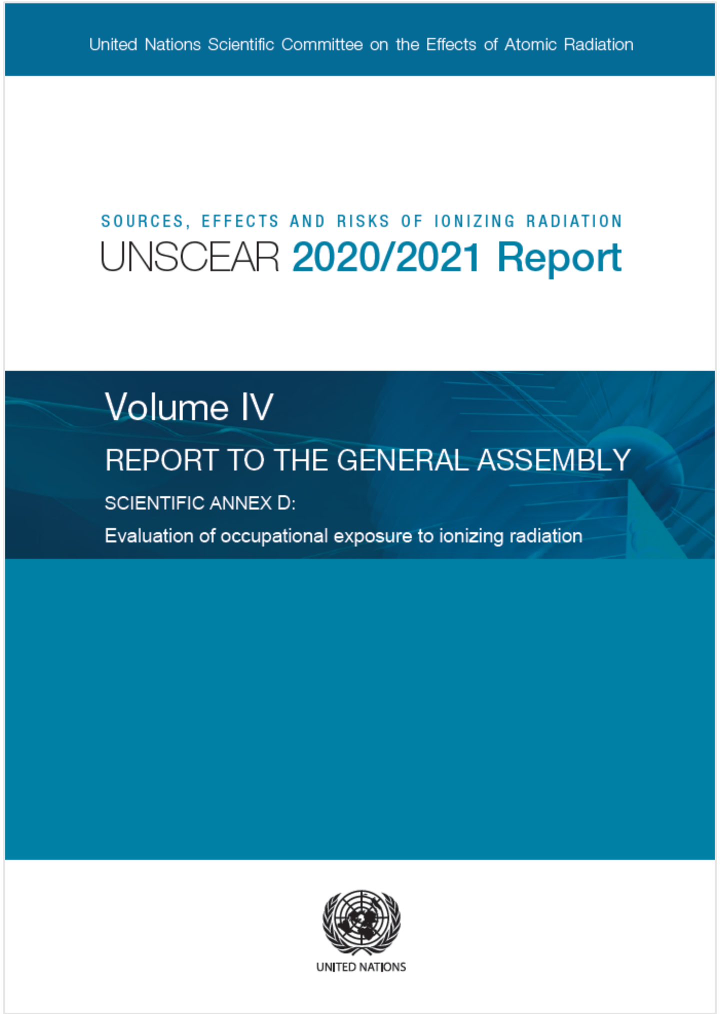
- J. Ma (IAEA)
- H. Okyar (IAEA)
- T. Zodiates (ILO)
- A. Jahnen (Luxembourg)

Critical reviewers

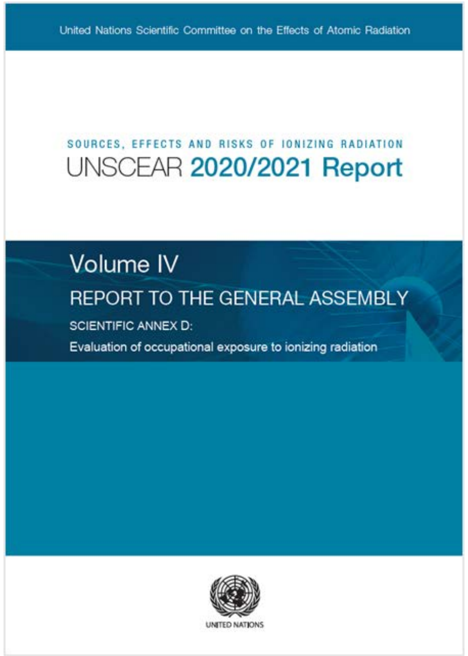
- D. de Souza Santos (Brazil)
- D. Chambers (Canada)
- G. Frasch (Germany)
- E. Salminen (Finland)
- I. Lund (Sweden)
- H. Okyar (IAEA)

Content of the presentation

- Introduction
- Methodology and sources of data
- Exposure to natural sources
- Exposure to human-made sources
- Assessment of global practices
- Implications for future evaluations
- Conclusions



UNSCEAR Occupational Exposure Evaluations



- United Nations General Assembly invited all Member States to provide data
- UNSCEAR secretariat established a network of national contact persons to collect information from Member States through the UNSCEAR online platform / questionnaires
- Carried out UNSCEAR survey (2016-2019) with 57 countries responses and IAEA supplementary survey in 2020 with 31 responses
- Data from the literature after a review process
  - Reviewed 692 articles, About 50% met the UNSCEAR quality criteria
- Supporting data directly from other organizations such as IAEA, OECD/NEA, ICAO, ISOE, WNA and national reports

Analysis of exposure in different sectors

- Natural sources of radiation
  - Cosmic ray exposure of aircrew and space crew
  - Exposure in extractive and processing industries
  - Exposure from oil and natural gas extraction industry
  - Radon exposure in workplaces other than mines
- Human-made sources of radiation
  - Nuclear fuel cycle
  - Medical uses of radiation
  - Industrial uses of radiation
  - Military uses
  - Miscellaneous uses of radiation

Scope and objectives of analysis

- To assess average annual effective doses and collective doses to workers for work sectors and subsectors
- To estimate the worldwide level of occupational exposure for different sectors involving exposure to natural and human-made sources of radiation
- To identify and analyse temporal trends in occupational exposure
- To identify possible new groups of workers receiving higher doses
- To address the level of exposure to the lens of the eye
- To identify research needs, and implications for future analysis

Dose assessment methodology

- Operational quantities as defined by ICRU
- Assessment of effective dose
  - Exposure from external sources of radiation
    - Including cosmic radiation
  - Exposure from intake of radionuclides
    - Including radon inhalation
- Equivalent dose
  - Lens of eye

Dose recording and challenges using the data

- Comparing exposure data between countries
  - Differences in protocols for monitoring and reporting
  - Type of technique for personal dosimetry
  - Formatting responses (different exposure intervals)
  - Evaluation of anomalous results (e.g., unexpectedly high dose values)
  - Whether or not internal exposure is included or assessed separately
  - Reliability of monitoring data

Dose distribution

- Distribution ratio for collective effective dose for certain doses, $SR_E = S(>E)/S$
  - *S* is the annual collective effective dose
  - S(>E) is the average annual collective effective dose delivered at annual individual doses exceeding *E* (mSv)
- Distribution ratio for number of workers for certain doses, $NR_E = N(>E)/N$
  - N is the total number of workers
  - N(>E) is the number of workers receiving annual doses exceeding E (mSv)

Estimation of worldwide levels of exposure

- Methodology of extrapolation and uncertainty assessment
  - Where collected data were not sufficient to derive estimates
  - Regression-based models for association between number of workers/average annual effective dose and predictor variables
  - The models used to estimate the number of workers/average annual effective dose
  - Examples of predictor variables used:
    - annual GDP, production of coal, generated energy, physician density
  - An uncertainty of each country’s estimate of average annual effective dose and number of workers, in the form of GSD, was subjectively assigned to be 1.15 for countries that reported data, and 1.4 for the estimates from countries for which extrapolation was used

Natural sources – Levels and trends of exposure

- Cosmic ray exposure of aircrew and space crew
- Exposure in extractive and processing industries
  - Coal mining and processing
  - Mineral mining and processing
- Oil and gas extraction
- Radon exposure at workplaces other than mines

Aircrew

- Average annual collective effective dose was estimated using the average annual effective dose from the survey data and the number of aircrew provided by ICAO
- Uncertainty interval in 2010–2014
  - no. of workers 570,000 to 990,000
  - effective dose 1.5 to 4.6 mSv

Estimates of worldwide exposure in civilian aviation

Period	Number of workers	Average annual collective effective dose (man Sv)	Average annual effective dose (mSv)
1995-1999	300 000	900	3
2000-2004	450 000	1 220	2.7
2005-2009	600 000	1 680	2.8
2010-2014	750 000	2 030	2.7

Coal mining

- Extrapolation of number of workers by linear regression model using total coal production as independent variable
- Estimates are based on about 60% of world coal production
- World estimates should be used with caution because of large uncertainties

Estimates of worldwide levels of annual occupational exposure for coal mining

Period	Average total primary coal production (million metric tonnes)	Number of workers (10^3)	Average annual collective effective dose (man Sv)	Average annual effective dose (mSv)
1990–1994[a]		3 910	2 737	0.7
1995–1999[a]		6 900	16 560	2.4
2000–2004	5 072	10 900	25 070	2.3
2005–2009	6 544	8 800	18 480	2.1
2010–2014	7 934	8 000	12 800	1.6

Mineral mining and processing

- Countries provided data 2010–2014, responsible for about 52% of the total production of the minerals
- The worldwide average production of minerals increased by a factor of 1.8 from 2000–2004 to 2010–2014
- Extrapolation of number of workers by linear regression model using total mineral production as independent variable
- Estimated worldwide number of workers for 2010–2014 is 3.8 million
- Weighted average annual effective dose is 2.5 mSv

Gas and oil extraction

- No extrapolation due to lack of correlation between dependent and independent variable(s)

Radon exposure in workplaces other than mines

- No extrapolation due to lack of data
- Data in literature showed that average annual effective doses vary from
  - 0.2 to 5.1 mSv for underground workplaces
  - 0.4 to 1.4 mSv for above-ground workplaces

Natural sources – Summary

- Values underestimated, since oil and gas extraction and radon in workplaces is not included
- Levels of exposure have decreased over time
- Majority of workers not individually monitored

Estimates of worldwide occupational exposure from natural sources for the period 2010-2014

Sector	*Number of monitored workers (10^3)[a]*	*Annual collective effective dose (man Sv)*	*Weighted average annual effective dose (mSv)*
Civil aviation	750	2 030	2.7
Coal extraction/processing	8 000	12 800	1.6
Mineral extraction/processing	3 800	9 500	2.5
Total (2010-2014)	**12 600**	**24 300**	**1.9**
Total (1995-1999)	*11 800*	*31 260*	*2.7*

[a] Values are rounded

Human-made sources – Levels and trends of exposure

- Nuclear fuel cycle:
  - U-mining, conversion/enrichment, fuel fabrication, reactor operation, decommissioning, reprocessing, research, waste management, transport, safety and safeguard inspection, other
- Medical uses:
  - Diagnostic radiology, nuclear medicine, radiation therapy, veterinary medicine, other
- Industrial uses:
  - Irradiation, radiography, luminizing, isotope production, well-logging, accelerator operation, gauges, other
- Military uses
- Miscellaneous uses:
  - Educational establishments, disused sources, transport, other

Nuclear fuel cycle

Uranium mining

- Different types of U-mining: Open pit, underground, ISL
- Worldwide exposure is based on
  - reported average annual effective dose
  - reported workforce data and data from Joint Report by NEA and IAEA
  - amount of extracted ore

Period	Annual amount of U production (kt U)	Number of monitored workers (10^3)	Average annual collective effective dose per unit mass (man Sv/kt U)	Average annual effective dose (mSv)
1990–1994[a]	39	69	8	4.5
1995–1999[a]	34	22	2.5	3.9
2000–2004	37	28	2.1	2.7
2005–2009	44	33	1.9	2.5
2010–2014	57	44	2.2	2.8

Uranium conversion and enrichment

- No worldwide estimation due to a lack of data
- Reported data represent 20-40 % of total activities

Fuel fabrication

- Survey data represents about 80% of the fuel fabrication workforce
- Exposure data not obtained from several countries, but the information is considered representative
- Global estimate based on
  - reported exposure data
  - amount of reactor fuel produced for LWRs and HWRs
  - generated energy

Period	Number of monitored workers (10^3)	Average annual collective effective dose (man Sv)	Average annual effective dose (mSv)
1990-1994	21	22	1.0
1995-1999	22	30	1.4
2000-2004	23	26	1.2
2005-2009	21	19	0.9
2010-2014	20	17	0.9

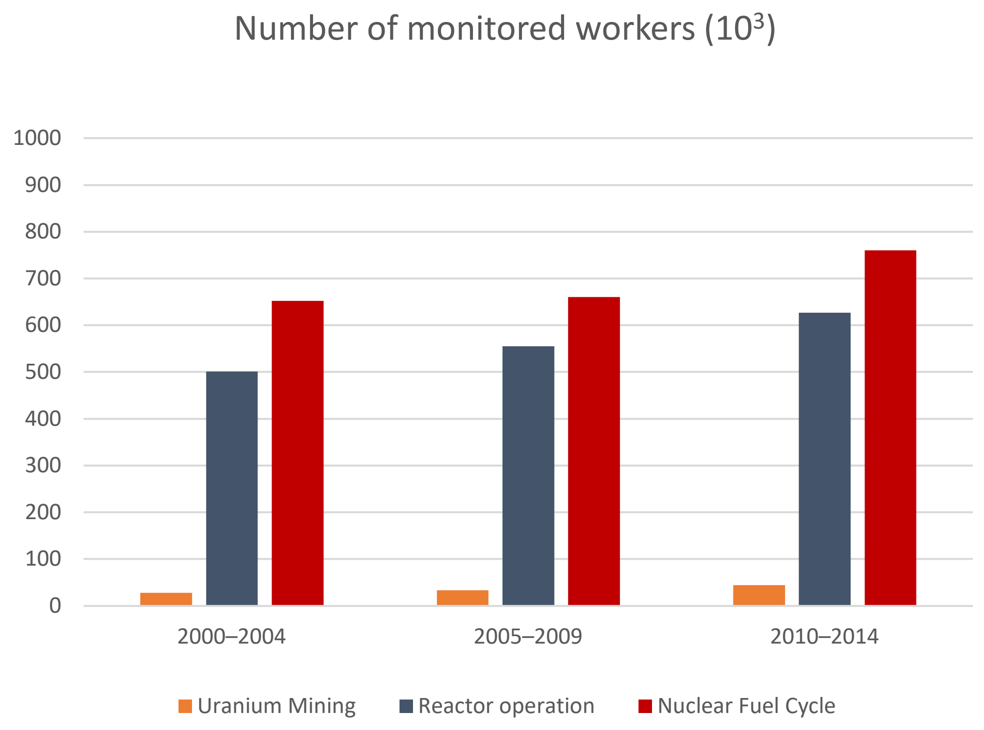
Nuclear power reactor operation

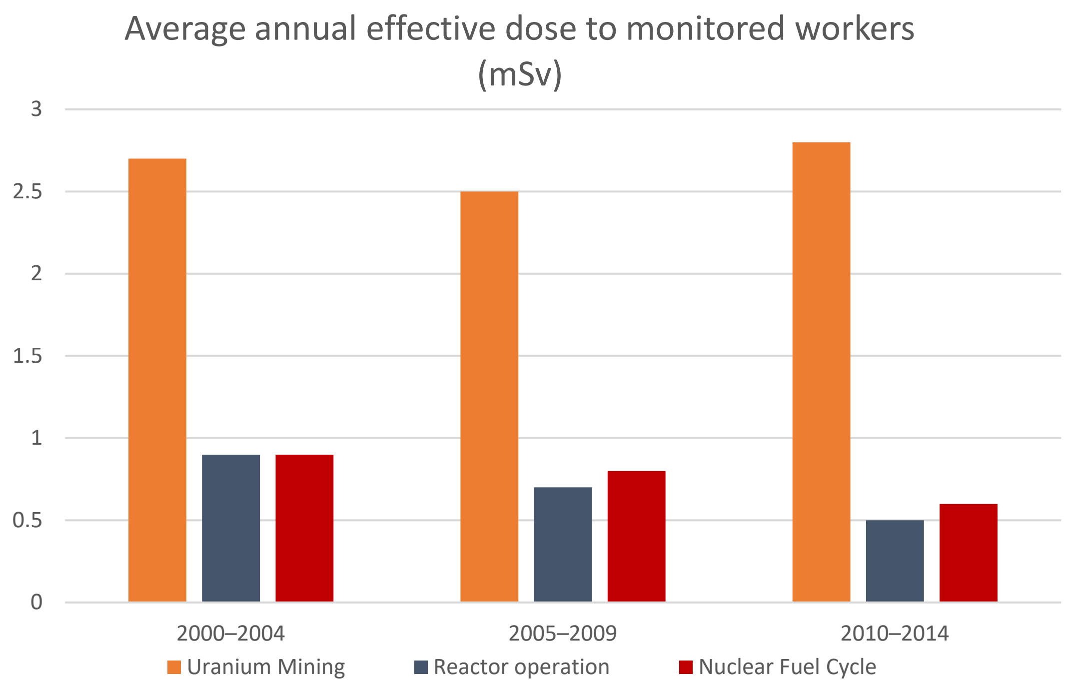
- Exposure data from UNSCEAR survey and ISOE database
- Reactor data from IAEA-PRIS
- Increase in number of reactors and workers
- Decrease in levels of exposure

Summary of worldwide estimates of occupational exposure due to reactor operation

	PWR		BWR		All	
Period	1995-1999	2010-2014	1995-1999	2010-2014	1995-1999	2010-2014
No. of reactors	254	274	91	87	414	451
No of monitored workers (10^3)	265	370	144	148	448	627
Average annual effective dose (mSv)	1.9	0.4	1.6	0.4	1.7	0.5
Annual collective effective dose (man Sv)	504	146	237	86	777	328

Nuclear fuel cycle





Medical uses

- Include subsectors: Diagnostic radiology, Radiation therapy, Nuclear medicine, Veterinary medicine, Dental radiology
- Estimate of worldwide number of workers in the subsectors was improved, using multivariate regression modelling
- Model not applied for average annual effective dose and collective effective dose
- Worldwide average annual effective dose derived as the average effective dose weighted by the number of workers in each country
- Weighted average annual effective dose assumed to reflect a worldwide value and used to estimate worldwide collective dose

Diagnostic radiology

- Include interventional and conventional radiology
- No worldwide estimate for periods between 2000-2009
- Very few countries provided data for dose to eye lens and extremities

Period	Number of monitored workers (10^3)	Average annual collective effective dose (man Sv)	Average annual effective dose (mSv)
1995-1999	6 670	3 335	0.5
2000-2004	-	-	-
2005-2009	-	-	-
2010-2014	8 000 (3 900-14 000)	3 200	0.4 (0.2-0.8)

Radiation therapy

Period	Number of monitored workers (10^3)	Average annual collective effective dose (man Sv)	Average annual effective dose (mSv)
1995-1999	264	132	0.5
2000-2004	200	80	0.4
2005-2009	200	60	0.3
2010-2014	300 (170 - 540)	90	0.3 (0.1 - 0.5)

Nuclear medicine

Period	Number of monitored workers (10^3)	Average annual collective effective dose (man Sv)	Average annual effective dose (mSv)
1995-1999	117	89	0.8
2000-2004	200	220	1.1
2005-2009	200	140	0.7
2010-2014	200 (110 - 370)	80	0.4 (0.2 - 0.8)

Summary of all medical uses

- Wide variation in reported effective doses and number of exposed workers
- Annual equivalent doses to extremities is unlikely to exceed the dose limit 500 mSv
- Derived average equivalent dose to the lens of the eye in all medical subsectors is 7 mSv,
  - but should not be assumed as representative

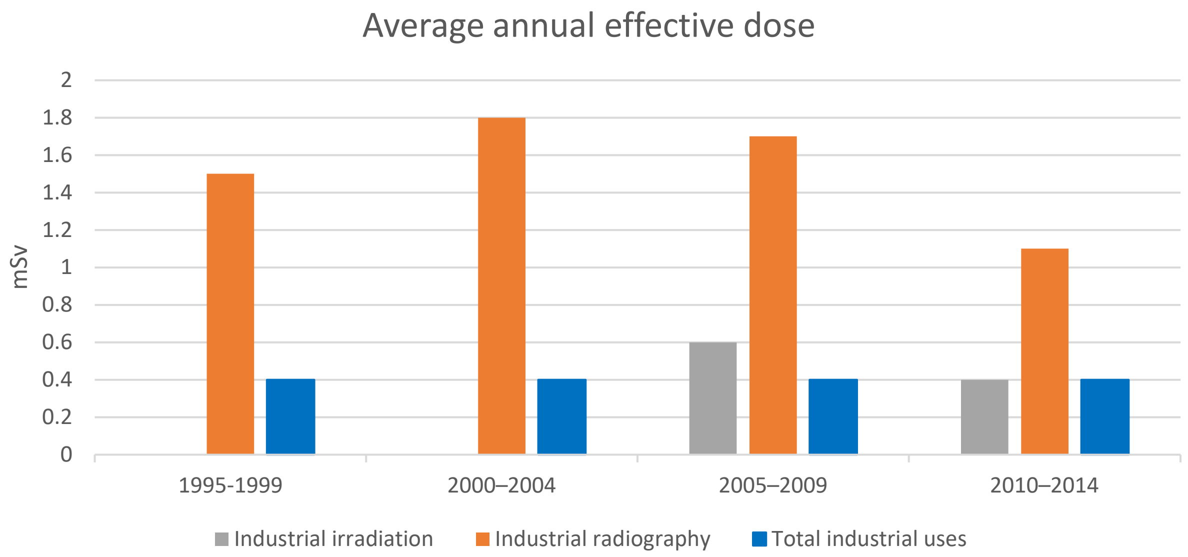
Period	Number of monitored workers (10^3)	Average annual collective effective dose (man Sv)	Average annual effective dose (mSv)
1980-1984	1 890	1 140	0.6
1985-1989	2 220	1 030	0.5
1990-1994	2 320	760	0.3
1995-1999	7 440	3 540	0.5
2010-2014	9 000 (5 000-17 000)	4 500	0.5 (0.26-1.0)

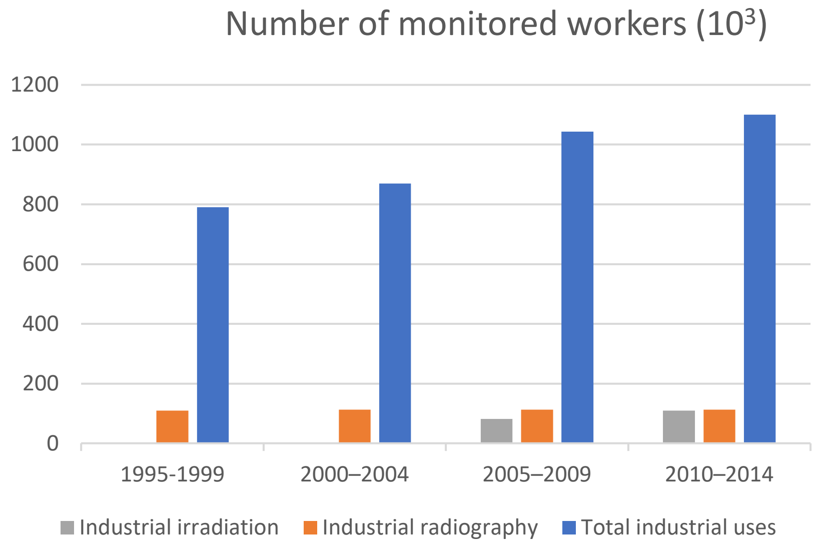
Industrial uses

- Estimate of worldwide levels of exposure for all industrial use is based on trends of reported data due to lack reliable predictor parameter
- Estimate is provided for Industrial irradiation and Industrial radiography
- But not for the subsectors: Luminizing, radioisotope production & distribution, well logging, accelerator operation, industrial gauges, other industrial uses

Summary of all industrial uses

- The average annual effective doses to monitored workers consistently is around 0.5 mSv, since the 1990s
- The uncertainty interval of the worldwide average annual effective dose ranges from 0.2 to 0.8 mSv





Miscellaneous uses

- Educational establishments
  - Estimate of worldwide levels based on trends in the sector
- Disused radioactive sources
  - No estimate of the worldwide level of exposure due to limited data
- Transport of radioactive material
  - No estimate of the worldwide levels of exposure due to limited data

Estimated worldwide levels of annual occupational exposure in the educational sector

Period	Number of monitored workers (10^3)	Average annual collective effective dose (man Sv)	Average annual effective dose (mSv)
1995-1999	372	36	0.10
2000-2004	446	27	0.06
2005-2009	482	34	0.07
2010-2014	540	38	0.07

Human-made sources – Summary

- 11.4 million estimated worldwide number of workers
  - Uncertainty interval 6.2 – 21 million
  - 80% working in the medical sector
- Average effective dose 0.5 mSv
  - Uncertainty interval 0.3 - 0.9 mSv

Estimates of worldwide occupational exposure associated from human-made sources for the period 2010–2014

Sectors	*Number of monitored workers (10^3)[a]*	*Annual collective effective dose (man Sv)*	*Weighted average annual effective dose (mSv)*
Nuclear fuel cycle	760	485	0.6
Medical use	9 000	4 500	0.5
Industrial use	1 100	437	0.4
Miscellaneous use	540	38	0.1
Total	**11 400**	**5 460**	**0.5**

[a] Values are rounded.

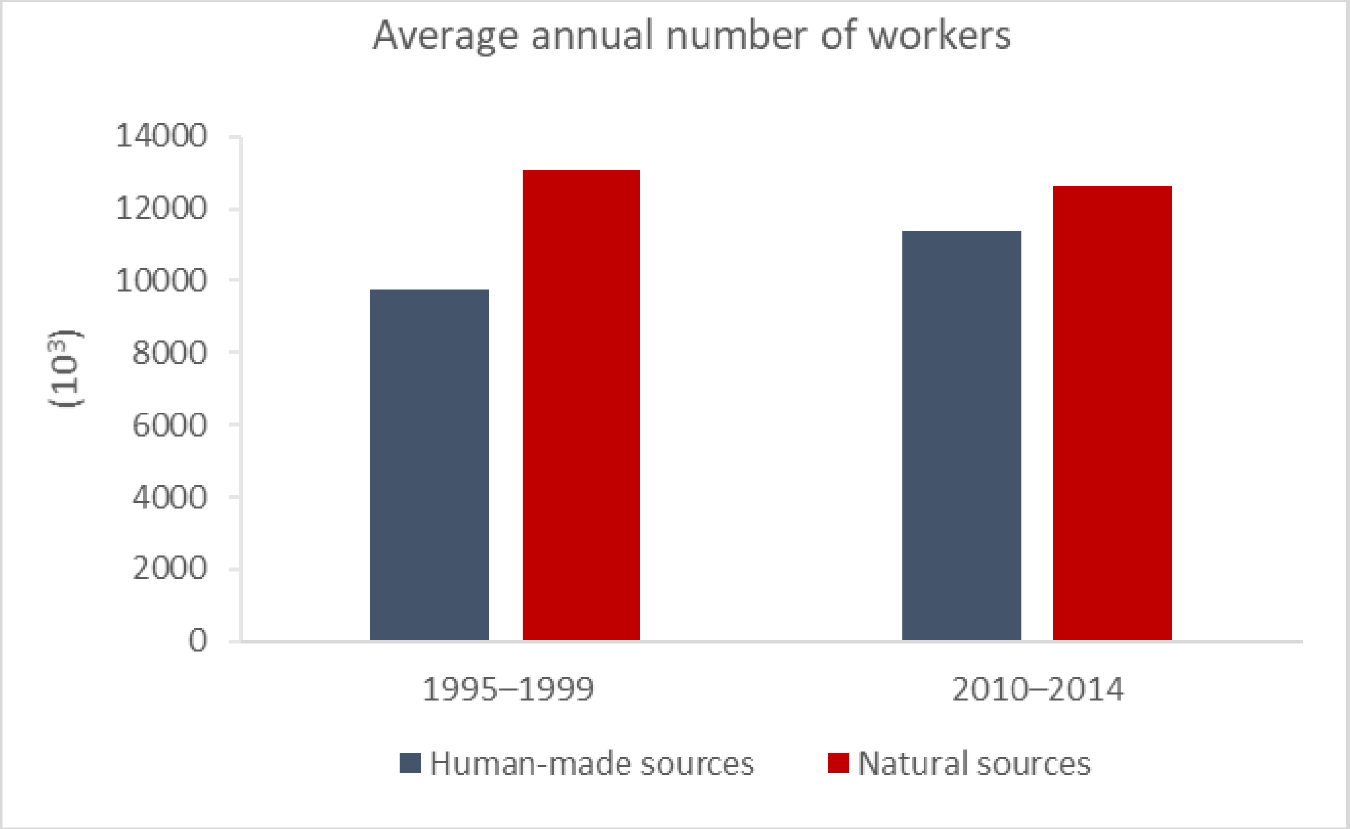
Human-made sources – Summary (cont.)

- Evaluation of level of occupational exposure for sectors in the category of human-made sources since 1975
- Nuclear fuel cycle is well documented
- Uncertainties higher for medical, industrial, and miscellaneous use
- No estimates on number of workers for several subsectors
  - either due to limited available data or lack of appropriate predictor parameters to derive extrapolation mathematical models
  - number of monitored workers is underestimated for the medical, industrial, and miscellaneous sectors

Overall results for period 2010-2014

Estimated total number of workers (worldwide)

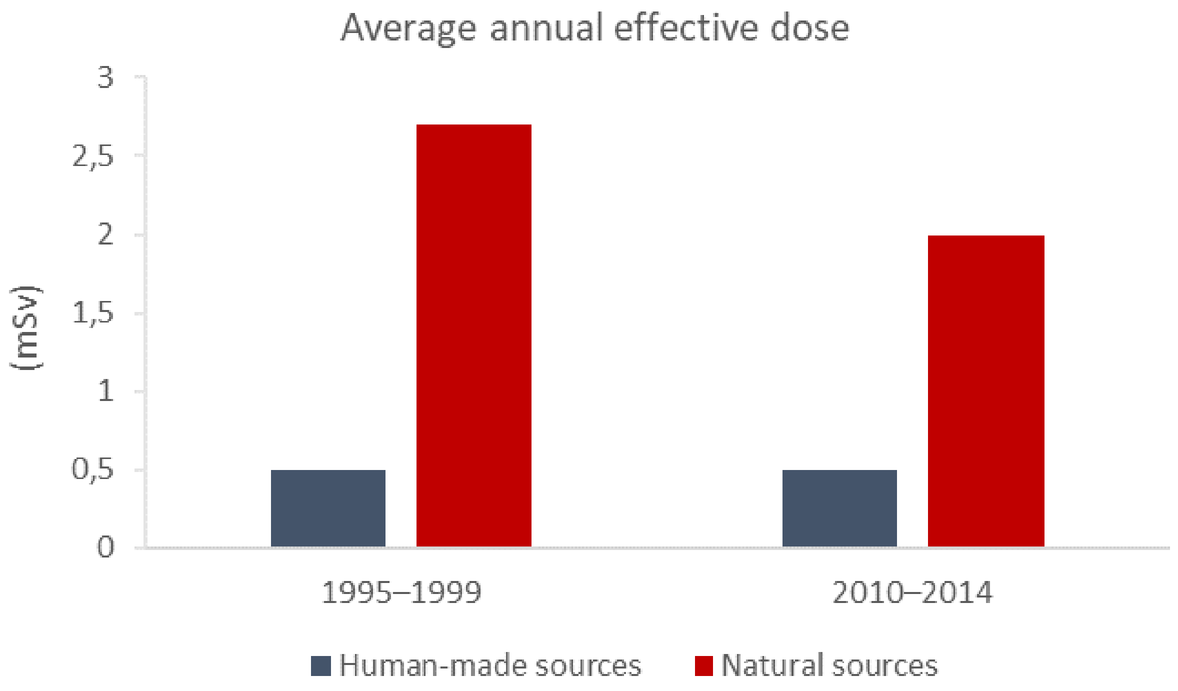
- ~ **24 million** annual number of workers exposed to natural and human-made sources of ionizing radiation
  - 52% exposed to natural sources
  - 48% exposed to human-made sources



Overall results for period 2010-2014

Estimated average annual effective dose

- The worldwide average annual effective dose for all workers was estimated to be around 1.2 mSv
  - about 2/3 of the estimated value for 1995-1999
- 0.5 mSv for workers exposed to human-made sources
- 2 mSv for workers exposed to natural sources



Dose to lens of eye

- Literature review showed that lowering the eye dose limit may potentially result in doses above the limit for some workers
  - in particular for personnel in interventional radiology and industrial radiography
- Equivalent doses to the lens of the eye in the UNSCEAR Survey were limited and provided only by a few countries
- All reported average annual values are lower than 20 mSv.
  - In diagnostic radiology doses are lower than 7 mSv,
  - in radiation therapy (brachytherapy) about 0.1 mSv, and
  - in veterinary medicine 1 mSv

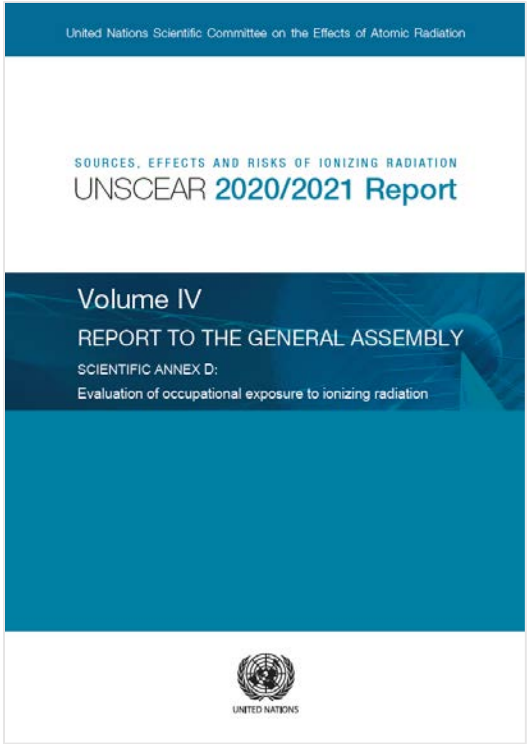
Implications for future evaluations

- The Committee highlighted the importance and the need for reporting from more Member States in the future. Their participation will
  - (a) maintain and extend the Committee’s network of national contact persons; and
  - (b) enhance the quality, representativeness and reliability of the Committee’s evaluations of sources and levels of exposure to ionizing radiation
- The collaboration with Member States and international organizations has been and will continue to be essential
- Monitoring of radon exposure of workers is not a requirement in many countries. Nevertheless, it is important to continue collecting exposure data and to include also type of workplaces where radon may be a source of exposure

Conclusions

- Overall improvement of estimates, specifically for sectors medical, civil aviation, and NFC
- First time uncertainties addressed
- Likely underestimation of number of workers and estimated collective effective doses due to incomplete data submission for some occupational sectors for the reporting periods
- Reported data on the equivalent doses for the lens of the eye and for the extremities (e.g., hand doses) were limited
- While the evaluation did not identify worker groups with high annual effective dose due to new techniques, it was observed that the significant decrease in average annual effective dose was attributed to improved working conditions in mines (e.g., ventilation)

Thank you for your attention!



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