United Nations Scientific Committee on the Effects of Atomic Radiation

SOURCES, EFFECTS AND RISKS OF IONIZING RADIATION

UNSCEAR 2020/2021 Report

Volume I

REPORT TO THE GENERAL ASSEMBLY

SCIENTIFIC ANNEX A:

Evaluation of medical exposure to ionizing radiation

UNITED NATIONS

SOURCES, EFFECTS AND RISKS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation

UNSCEAR 2020/2021
Report to the General Assembly,
with Scientific Annexes

VOLUME I
Scientific Annex A

UNITED NATIONS
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NOTE

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CONTENTS

Report of the United Nations Scientific Committee on the Effects of Atomic Radiation

Contents

Part one

Report of the United Nations Scientific Committee on the Effects of Atomic Radiation on its sixty-seventh session, held online from 2 to 6 November 2020

Chapter I

Introduction

1. Since the establishment of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) by the General Assembly in its resolution 913 (X) of 3 December 1955, the mandate of the Committee has been to undertake broad assessments of the sources of ionizing radiation and its effects on human health and the environment.[1] In pursuit of its mandate, the Committee thoroughly reviews and evaluates global and regional exposures to radiation. The Committee also evaluates evidence of radiation-induced health effects in exposed groups and advances in the understanding of the biological mechanisms by which radiation-induced effects on human health or on non-human biota can occur. Those assessments provide the scientific foundation used, inter alia, by the relevant agencies of the United Nations system in formulating international standards for the protection of the general public, workers and patients against ionizing radiation;[2] those standards, in turn, are linked to important legal and regulatory instruments.

2. Exposure to ionizing radiation arises from naturally occurring sources (such as radiation from outer space and radon gas emanating from rocks in the Earth) and from sources with an artificial origin (such as medical diagnostic and therapeutic procedures; radioactive material resulting from nuclear weapons testing; energy generation, including by means of nuclear power; unplanned events such as the nuclear power station accident at Chernobyl in April 1986 and that following the great east-Japan earthquake and tsunami of March 2011; and workplaces where there may be increased exposure to artificial or naturally occurring sources of radiation).

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[1] The United Nations Scientific Committee on the Effects of Atomic Radiation was established by the General Assembly at its tenth session, in 1955. The terms of reference of the Committee are set out in resolution 913 (X). The Scientific Committee was originally composed of the following States Members of the United Nations: Argentina, Australia, Belgium, Brazil, Canada, Czechoslovakia (later succeeded by Slovakia), Egypt, France, India, Japan, Mexico, Sweden, Union of Soviet Socialist Republics (later succeeded by the Russian Federation), United Kingdom of Great Britain and Northern Ireland and United States of America. The membership of the Scientific Committee was subsequently enlarged by the Assembly in its resolution 3154 C (XXVIII) of 14 December 1973 to include the Federal Republic of Germany (later succeeded by Germany), Indonesia, Peru, Poland and the Sudan. By its resolution 41/62 B of 3 December 1986, the General Assembly increased the membership of the Committee to 21 members and invited China to become a member. In its resolution 66/70, the General Assembly further enlarged the membership of the Committee to 27 and invited Belarus, Finland, Pakistan, the Republic of Korea, Spain and Ukraine to become members.

[2] For example, the International Atomic Energy Agency (IAEA) safety standard entitled *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards – General Safety Requirements Part 3*, co-sponsored by the European Commission, the Food and Agriculture Organization of the United Nations (FAO), IAEA, the International Labour Organization (ILO), the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (NEA/OECD), the Pan American Health Organization (PAHO), the United Nations Environment Programme (UNEP) and the World Health Organization (WHO).

Chapter II

Deliberations of the United Nations Scientific Committee on the Effects of Atomic Radiation at its sixty-seventh session

3. The Scientific Committee held its sixty-seventh session online from 2 to 6 November 2020.[3] The following served as officers of the Committee: Gillian Hirth (Australia), Chair; and Jing Chen (Canada), Anna Friedl (Germany) and Jin Kyung Lee (Republic of Korea), Vice-Chairs; and Anssi Auvinen (Finland) was elected as Rapporteur for the sixty-seventh session.

4. The Scientific Committee took note of and discussed General Assembly resolution 74/81 on the effects of atomic radiation, in which the Assembly, inter alia: (a) requested the United Nations Environment Programme (UNEP) to continue, within existing resources, to service the Committee and to disseminate its findings to Member States, the scientific community and the public and to ensure that the administrative measures in place are appropriate, including clear roles, so that the secretariat is able to adequately and efficiently service the Committee in a predictable and sustainable manner and effectively facilitate the use of the invaluable expertise offered to the Committee by its members in order that the Committee may discharge the responsibilities and mandate entrusted to it by the General Assembly; (b) welcomed the appointment of a new Secretary of the Committee by UNEP and urged UNEP to ensure that future recruitment processes are conducted in an efficient, effective, timely and transparent manner; (c) welcomed the establishment of the post of Deputy Secretary, which replaces the previous post of Scientific Officer, allows for the deputization of the Deputy Secretary as Secretary as appropriate and assists in the avoidance of disruptions in staffing; and (d) requested the Secretary-General to strengthen support for the Committee within existing resources, particularly with regard to the increase in operational costs in the case of a further increase in membership, and to report to the General Assembly at its seventy-fifth session on those issues.

5. In regard to points (c) and (d) above, the Scientific Committee's normal operation had been impacted by the coronavirus disease (COVID-19) pandemic. The Committee welcomed the establishment of the position of Deputy Secretary. However, the COVID-19 pandemic resulted in a delay in the appointment of an officer to the position of Deputy Secretary of the Committee, as the United Nations had implemented a recruitment freeze for all regular budget-funded United Nations posts. In addition, the Committee was unable to hold its sixty-seventh session in July 2020 as originally planned and postponed the session until 2–6 November 2020, when it was held online. Since it would not be timely to report to the General Assembly after the planned sixty-seventh session in November 2020, it was decided to report on the Committee's intersessional activities by means of a note by the Chair of the Committee (A/75/46) and an oral report before the conclusion of the seventy-fifth session of the General Assembly.

6. In regard to points (a), (b) and (c) above, the Scientific Committee heard a statement from the representative of UNEP, who acknowledged and thanked the Committee for its continued work and progress during the COVID-19 pandemic. He explained the budget difficulties leading to the freeze of all recruitments for posts under the United Nations regular budget, which had halted the recruitment of a Deputy Secretary for the Committee, and noted that UNEP was committed to

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[3] The sixty-seventh session of the Scientific Committee was attended by 212 participants from 27 States members of the Committee, observers for Algeria, Iran (Islamic Republic of), Norway and the United Arab Emirates, in accordance with paragraph 23 of General Assembly resolution 74/81, and observers for the Comprehensive Nuclear-Test-Ban Treaty Organization, the European Union, the International Agency for Research on Cancer, IAEA, the International Commission on Radiation Units and Measurements (ICRU), the International Commission on Radiological Protection (ICRP), FAO, ILO, NEA/OECD, UNEP and WHO.

completing the appointment of a Deputy Secretary for UNSCEAR as soon as the regular budget freeze was resolved. He expressed appreciation for the contributions to the UNSCEAR general trust fund that had been received from Australia, Belgium, Germany, Japan and Spain. The Committee also heard a statement from the representative of Indonesia. Issues raised by the Committee are reported in chapter II, section E ("Administrative issues").

A. Completed evaluations

7. The Scientific Committee discussed three scientific annexes to the present report (see chapter III), agreed on their findings and requested that the three scientific annexes be published in the usual manner, subject to the modifications agreed upon, and final adoption be conducted using a silence procedure due to the COVID-19 pandemic, as that procedure had been adopted by the Committee for use at the sixty-seventh session.

8. At its sixtieth session, the Scientific Committee had endorsed the plan for the collection and evaluation of data on medical exposure. Given that radiation exposures of patients worldwide are the main artificial source of human exposure to ionizing radiation, that there has been a continuing upward trend in collective doses to populations and that the pace of technological development in this field continues to accelerate, the Committee's regular evaluations of collective doses to populations and trends continue to be an important priority.

9. As at 30 September 2019, 58 countries had submitted data on medical exposures, and the Scientific Committee recognized the efforts of the expert group on medical exposure in carefully and systematically reviewing the submitted data and working with national contact persons to clarify any ambiguities.[4] The Committee discussed and approved for publication the scientific annex on the evaluation of medical exposure to ionizing radiation.

10. At its sixty-fifth session, the Scientific Committee considered the project plan to produce an update to annex A of the UNSCEAR 2013 report.[5] The aim was to produce a report summarizing all information that was available by the end of 2019, on levels and effects of radiation exposure due to the accident at the Fukushima Daiichi nuclear power station, and the implications of the new information for the UNSCEAR 2013 report. At its sixty-sixth session, the Committee endorsed having a more focused scope of the detailed analyses of doses to the public and concurred that the outreach material on issues of considerable media or public interest should be dealt with separately, as part of the secretariat's outreach plan. At its sixty-seventh session, the Committee discussed and approved for publication the scientific annex on the levels and effects of radiation exposure due to the accident at the Fukushima Daiichi nuclear power station: implications of information published since the UNSCEAR 2013 report.

11. At its sixty-third session, the Scientific Committee decided to compile an up-to-date overview of the following: up-to-date knowledge of biological mechanisms by which radiation influences the development of disease, in particular at low incremental doses and low dose rates; the implications for the dose-response relationships for health effects at low doses; and thus the relevance for estimating associated risks to health, as well as the relevance for the inference of cancer risks. An expert group was established that submitted progress reports to the Committee for consideration at its sixty-fourth, sixty-fifth and sixty-sixth sessions. At its sixty-seventh session, the Committee discussed and approved for publication the

[4] To put this in perspective, 58 countries is a small number of the total of 193 States Members of the United Nations.

[5] *Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 2013 Report to the General Assembly*, vol. I (United Nations publication, 2014), annex A.

scientific annex on the biological mechanisms relevant for the inference of cancer risks from low-dose and low-dose-rate radiation.

B. Present programme of work

12. The Scientific Committee took note of the progress report by the secretariat on the collection, analysis and dissemination of data on radiation exposures of the public, patients and workers, obtained from reviews of the scientific literature and the data submissions by Member States. The Committee recognized the efforts of the secretariat in: (a) conducting outreach about the global surveys, which has contributed to an increased number of nominations of national contact persons; and (b) supporting the production of a simplified questionnaire to assist in the preparation of data submissions, which has had a positive impact on the number of submissions on public, medical and occupational exposures. As at 30 September 2020, 90 countries had nominated national contact persons for public exposure; 87 countries in the field of medical exposure; and 68 countries in the field of occupational exposure. Although this is a significant increase in participation in recent years, more participation and contributions by Member States would be useful to ensure that the data are representative.

13. The Scientific Committee expressed its continued support for the creation of a network of national contact persons, using the UNSCEAR online platform as a tool for communication among them for exchanging experiences on the process of data collection. It also encouraged States Members of the United Nations to provide data on medical, occupational and public exposures and encouraged continued future cooperation of the Committee's secretariat with Member States and relevant international organizations, in particular in the new UNSCEAR Global Survey of Public Exposure, planned to commence in December 2020.

14. The Scientific Committee also noted that future evaluations of medical exposures should focus on motivating Member States not represented in the present global assessment to submit essential information. Actions should target, in particular, countries with developing levels of health care and those with large populations because those countries are potentially significant contributors to global medical exposure practice. A regional approach that facilitates data collection for the assessment of population dose could form the basis for surveys in regions whose countries have similar health and economic indicators, such as in Africa, Asia and Latin America; that regional approach could include training and support on data collection and evaluation for national contact persons. Data collection could be focused on the types of examinations that contribute most to the overall population dose, which could help to increase future participation in the UNSCEAR Global Survey of Medical Exposure.

1. Occupational exposure to ionizing radiation

15. The Scientific Committee's evaluations of worldwide occupational exposure to ionizing radiation provide information relevant for policy and decision-making regarding the use and management of radiation. The resulting dose distributions and trends give insight into the main sources and situations of exposure and provide information about the main factors influencing exposures. The evaluations assist in identifying emerging issues and may indicate situations that should be subjected to more attention and scrutiny.

16. The Scientific Committee has conducted evaluations of worldwide occupational exposure and trends on the basis of two sources: (a) data from the UNSCEAR Global Survey of Occupational Radiation Exposure; and (b) reviews of analyses published in peer-reviewed literature. At its sixty-sixth session, the Committee agreed to extend the deadline for data collection to 30 September 2019. This resulted in data being submitted by an additional 18 countries between April 2019 and October 2020.

17. The Scientific Committee acknowledged the work of the expert group in conducting its systematic review of the literature and that the work of the expert group had been delayed by one year owing to both the insufficient data provided by Member States and the extended quality checks and corrections of available data. The report on the evaluation of occupational exposure to ionizing radiation is envisaged to be prepared for approval for publication at the Committee's sixty-eighth session, in June 2021.

2. Public exposure to ionizing radiation

18. The Scientific Committee recalled that at its sixty-fourth session, the proposal to evaluate public exposure to ionizing radiation had been discussed. The Committee decided at that time to postpone project initiation until its evaluation of lung cancer from exposure to radon had been completed. At its sixty-sixth session, the Committee decided to commence its evaluation of public exposure to ionizing radiation, including quality criteria for sources and exposure.

19. The Scientific Committee noted the commencement of the evaluation in 2020 and discussed the progress report. It recognized the progress made and agreed the proposed revised plan for completion in 2024. The Committee noted the increased importance and broad interest in this new evaluation, which will review and analyse scientific information since 2007. As of October 2020, 36 experts from 17 Member States and observers from four international organizations were working on the update of the methodologies to be applied and the literature review.

20. The Scientific Committee encouraged all Member States to participate and respond to the UNSCEAR Global Survey of Public Exposure that is planned to commence at the end of 2020.

3. Second primary cancer after radiotherapy

21. At its sixty-third session, the Scientific Committee considered the issue of second primary cancer after radiotherapy and discussed preliminary plans to launch a project based on a proposal by the delegation of France. After further discussions at the sixty-fourth session, the Committee reached agreement at its sixty-fifth session on a project plan to evaluate second primary cancer after radiotherapy, emphasizing that while the project was a priority, the work could not be started until after the appointment of the new Secretary. At its sixty-sixth session, the Committee endorsed the plan presented by the expert group for initiating the work in late 2019 and requested that the expert group provide a progress report at its sixty-seventh session, including a first selection of literature on second primary cancer after radiotherapy, an updated timetable and an advanced table of contents.

22. At its sixty-seventh session, the Scientific Committee took note of the launch of the evaluation in 2019 and of the progress made to date and agreed with the updated timetable for completion. That progress report included a description of the literature research process and an update of the table of contents to include risk projections based on patient-specific organ doses, meta-analyses to provide site-specific pooled risk estimates and an assessment of the quality of dosimetry reporting. The expert group will provide a progress report at the next session.

4. Epidemiological studies of radiation and cancer

23. At its sixty-third session, the Scientific Committee discussed a preliminary plan to provide a comprehensive scientific review of epidemiological studies of radiation and cancer to update annex A of the UNSCEAR 2006 report.[6] The Committee agreed at its sixty-fifth session to initiate the comprehensive scientific review after both the appointment of the new Secretary and the initiation of the project on second primary cancer after radiotherapy are finalized.

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[6] *Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 2006 Report to the General Assembly*, vol. I (United Nations publication, 2008), annex A.

24. At its sixty-sixth session, the Scientific Committee approved the project plan, requesting that the final report also include a summary written in language that could be understood by members of the public. The Committee noted that the expert group would commence work in the third quarter of 2019 and requested that the expert group provide a progress report at its sixty-seventh session, including a first selection of literature on epidemiological studies on radiation and cancer, an updated timetable and an advanced table of contents.

25. At its sixty-seventh session, the Scientific Committee took note of the launch of the project in 2019 and the progress report on the project. That report included a description of the literature search process and a revised workplan in which a report would be submitted for approval in 2024. The Committee confirmed that the evaluation should be limited to cancer and not consider other health effects.

5. Public information and outreach strategy (2020–2024)

26. At its sixty-sixth session, the Scientific Committee endorsed the secretariat's proposal for a new strategy on outreach activities for the period 2020–2024. The latter complements the secretariat's planned outreach activities on the update of annex A of the UNSCEAR 2013 report on the levels and effects of radiation exposure due to the accident at the Fukushima Daiichi nuclear power station.

27. At its sixty-seventh session, the Scientific Committee took note of a progress report of the secretariat on the implementation of outreach activities in the period 2020–2024. That report included a summary of: (a) ongoing and future activities for the dissemination of the Committee's findings to a broader audience; (b) the strengthening of collaboration and development of framework agreements with international organizations; and (c) improvement of the UNSCEAR website (including its translation into all official languages of the United Nations). The Committee acknowledged the postponement of outreach activities on the update of the UNSCEAR 2013 report due to the COVID-19 situation and encouraged close collaboration with international organizations to further promote the Committee's findings. It also took note of the plans of the secretariat related to the celebration of the sixty-fifth anniversary of UNSCEAR in 2021 and noted that the dissemination of the Committee's findings [7] is increasingly dependent on the availability of extrabudgetary funds.

C. Update on the implementation of the Committee's long-term strategic directions

28. At its sixty-sixth session, the Scientific Committee approved its long-term strategic directions and plan for the period 2020–2024. That plan included the following:

(a) Establishing working groups focused on sources and exposure, and effects and mechanisms;

(b) Inviting, on an ad hoc basis, scientists from other States Members of the United Nations to participate in the Committee's evaluations;

(c) Increasing the Committee's efforts to present its evaluations and summaries thereof in a manner that attracts readers without compromising scientific rigour and integrity;

[7] For example, the translation of the UNEP booklet entitled *Radiation: Effects and Sources* and participation in international events such as the International Conference on a Decade of Progress After the Fukushima-Daiichi: Building on the Lessons Learned to Further Strengthen Nuclear Safety, originally to be held on 22–25 February 2021 and now rescheduled for 8–12 November 2021.

(d) While maintaining the lead in providing authoritative scientific evaluations to the General Assembly, liaising closely with other relevant international bodies to avoid duplication of efforts.

(a) Establishing working groups focused on the areas of sources and exposure, and effects and mechanisms

29. At its sixty-sixth session, the Scientific Committee: (a) established the ad hoc working group on sources and exposure; and (b) prolonged the activities of the ad hoc working group on effects and mechanisms until the Committee's sixty-seventh session in 2020, in order to finalize the proposal for the future programme of work on effects and mechanisms of radiation exposure for the period 2020–2024.

30. Bearing in mind the high-quality, important work conducted by the ad hoc working group on effects and mechanisms in developing the Scientific Committee's future programme of work (2020–2024), the Committee, at its sixty-seventh session, extended the mandate of the ad hoc working group on effects and mechanisms for one year to support and monitor progress in the implementation of the programme of work and to evaluate new scientific developments relevant for the Committee at its sixty-eighth session in 2021.

31. At its sixty-seventh session, the Scientific Committee also acknowledged the high-quality, important work by the ad hoc working group on sources and exposure and endorsed the proposal for an extension of the work of the ad hoc working group on sources and exposure for one more year to continue support and guide the implementation of the processes for collection, analysis and dissemination of data on radiation exposures of the public, patients and workers. Both working groups will continue to consist of scientists selected for their competence, commitment and objectivity.

32. The Scientific Committee emphasized that, except for the administrative support from the secretariat, the extension of the work of the ad hoc working groups would incur no additional costs for the United Nations.

(b) Inviting, on an ad hoc basis, scientists from other States Members of the United Nations to participate in the Committee's evaluations

33. The Scientific Committee noted that the secretariat and the Bureau had taken steps to involve scientists from other States Members[8] of the United Nations in supporting the secretariat in conducting ongoing evaluations. This is particularly relevant for the ongoing evaluation of public exposure to ionizing radiation from natural and other sources.

(c) Increasing the Committee's efforts to present its evaluations and summaries thereof in a manner that attracts readers without compromising scientific rigour and integrity

34. The Scientific Committee referred to the outreach activities reported in section B.5 above.

(d) While maintaining the lead in providing authoritative scientific evaluations to the General Assembly, liaising closely with other relevant international bodies to avoid duplication of efforts

35. The importance of the Scientific Committee's findings in providing the scientific evidence upon which decisions are made by the international community and the safety standards are developed was also demonstrated in the period since the sixty-fifth session. The Committee noted that in 2020, UNSCEAR was invited to participate as an observer of the International Atomic Energy Agency (IAEA) Commission of Safety Standards and as a member of the Steering Committee of the

[8] Austria, Italy, Norway, Singapore and Switzerland.

Global Nuclear Safety and Security Network of IAEA. UNSCEAR is also cooperating with a number of organizations, including IAEA, the International Commission on Radiological Protection (ICRP) and the International Radiation Protection Association (IRPA) in relation to the dissemination of the UNSCEAR 2020 report on the Fukushima accident. In addition, the 2019 report of the Secretary-General highlighted the importance of the Committee's work for the scientific evaluation of radiation exposure and the health effects of the Chernobyl accident.[9]

36. The Scientific Committee welcomed and supported the continued cooperation of the secretariat with the United Nations and other international organizations[10] with a view to promoting the Committee's work and exploring synergies and joint activities that would contribute to that work and support the collection and analysis of scientific data.

D. Future programme of work

37. At its sixty-fifth session, the Scientific Committee established the ad hoc working group on effects and mechanisms. Since the sixty-fifth session, the ad hoc working group has collected and analysed the experience of and lessons learned by the Committee in recent years and developed a draft future programme of work for the period 2020–2024, which was first discussed by the Committee at its sixty-sixth session. The ad hoc working group on effects and mechanisms also supported the Bureau and the secretariat in monitoring progress on the current projects and in evaluating new scientific developments that occurred between the sessions, for consideration by the Committee.

38. At its sixty-seventh session, the Committee reviewed the draft future programme of work for the period 2020–2024 and agreed that priority should be given to evaluations already initiated or planned to be started in 2020. This includes an evaluation of diseases of the circulatory system from radiation exposure, which, due to the delay of the sixty-seventh session caused by the COVID-19 pandemic, is now planned to begin in 2021. In approving the new programme of work, the Committee agreed, in order to achieve a more balanced workload for the Committee and its secretariat, to follow a general principle of starting one evaluation per year. Therefore, the Committee is planning to initiate the evaluation of radiation effects on the nervous system in 2022 and the evaluation of eye lens opacities from radiation exposure in 2023. In 2024, however, to ensure thematic consistency, the evaluation of radiation effects on the immune system will start simultaneously with an overarching evaluation of non-cancer effects, which will include the following topics: acute radiation syndrome, respiratory disease, endocrine disease, transgenerational effects and other relevant non-cancer effects.

39. The Scientific Committee emphasized that timely programme implementation in the period 2020–2024 depends on having sufficient available resources in the secretariat. The Committee acknowledged the request of the Executive Director of UNEP for support in the form of financial contributions to the general trust fund.[11] Therefore, the Committee welcomed the contributions of five States members of the Committee and encouraged other Member States to make use of the possibility to strengthen the secretariat's capacity through regular voluntary contributions to the general trust fund and/or in-kind contributions, for example, experts working as non-reimbursable loans, junior professional officers or United Nations volunteers.

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[9] See A/74/461.

[10] For example, UNEP, IAEA, the European Union, the International Civil Aviation Organization (ICAO), NEA/OECD, the Inter-Agency Committee on Radiation Safety (IACRS), the International Radiation Protection Association, ICRP and ICRU.

[11] The programme for the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) general trust fund for the period 2019–2021 has been prepared, and a note verbale in that regard has been sent to the Member States.

40. The Scientific Committee requested the two ad hoc working groups to develop a proposal for the scope and contents of a guidance document detailing the principles and criteria for ensuring the quality of the Committee's use of radiation protection quantities and units (including the use of collective effective doses), with a view to holding a discussion at the sixty-eighth session on how this guidance could be published in the future.

E. Administrative issues

41. The Scientific Committee took note of General Assembly resolution 74/81 on the effects of atomic radiation, in which the Assembly:

(a) Requested UNEP to continue, within existing resources, to service the Committee and to disseminate its findings to Member States, the scientific community and the public and to ensure that the administrative measures in place were appropriate, including clear roles, so that the secretariat is able to adequately and efficiently service the Committee in a predictable and sustainable manner and effectively facilitate the use of the invaluable expertise offered to the Committee by its members in order that the Committee might discharge the responsibilities and mandate entrusted to it by the General Assembly;

(b) Welcomed the appointment of a new Secretary of the Scientific Committee by UNEP and urged UNEP to ensure that future recruitment processes were conducted in an efficient, effective, timely and transparent manner;

(c) Welcomed the establishment of the post of Deputy Secretary, which replaces the previous post of Scientific Officer, allows for the deputization of the Deputy Secretary as Secretary as appropriate, and assists in the avoidance of disruptions in staffing;

(d) Requested the Secretary-General to strengthen support for the Committee within existing resources, particularly with regard to the increase of operational costs in the case of a further increase in membership, and to report to the General Assembly at its seventy-fifth session on those issues.

42. In considering the requests of the General Assembly, the Scientific Committee noted the statement by UNEP and strongly encouraged the finalization of the post of Deputy Secretary as soon as possible. The Committee also noted that the budget of the UNSCEAR secretariat was at its lowest level ever, and expressed concern about the Committee's ability to successfully implement its future programme of work, particularly with regard to the increase in the number of experts involved in the ongoing evaluations and the operational costs in the case of further membership. The Committee also noted the statement by the representative of Indonesia and welcomed the ongoing commitment of Indonesia to the Committee's work and outreach activities in that country.

43. The Scientific Committee acknowledged the significant effort of the Chair and secretariat to conduct the sixty-seventh session and adopted a procedure for taking decisions during the COVID-19 pandemic. The Committee also agreed to hold its sixty-eighth session in Vienna from 21 to 25 June 2021, or, if required to be online, an extension of the session duration will be considered, if necessary.

Chapter III

Scientific reports

44. The following three scientific annexes were approved by the Committee at its sixty-seventh session: (a) evaluation of medical exposure to ionizing radiation; (b) levels and effects of radiation exposure due to the accident at the Fukushima Daiichi nuclear power station: implications of information published since the UNSCEAR 2013 report; and (c) biological mechanisms relevant for the inference of cancer risks from low-dose and low-dose-rate radiation.

A. Evaluation of medical exposure to ionizing radiation

45. The Scientific Committee expresses its gratitude to the expert group which conducted the evaluation of medical exposure to ionizing radiation and to delegations for the technical discussions on this subject. The Committee also expresses its gratitude to the national contact persons and the national experts who were involved in collecting, submitting and checking the national data. Without reliable national data, it would not have been possible to conduct the evaluation. The Committee emphasizes that Member States' efforts are needed in the future to maintain and further extend the UNSCEAR network of national contact persons and improve reporting of medical exposure data for enhanced quality and reliability of future evaluations of sources and levels of exposure to ionizing radiation.

46. The Scientific Committee has considered the results of the evaluation of medical exposure in the light of its past UNSCEAR 2008 report[12] and has reached the following conclusions contained in paragraphs 47–53 below.

47. Medical exposure remains by far the largest human-made source of radiation exposure of the population. In the period 2009–2018, about 4.2 billion medical radiological examinations were performed annually. The collective effective dose was estimated to be 4.2 million man sieverts (man Sv) for the global population of 7.3 billion people, resulting in an effective dose per caput of 0.57 mSv (excluding radiotherapy). In addition, an estimated 6.2 million courses of radiation therapy treatment were performed each year, about 5.8 million by external beams and 0.4 million by brachytherapy. An estimated 1.4 million radionuclide therapy treatments were performed each year. Doses from radionuclide therapy and radiation therapy treatments were not included in the global estimate of collective effective dose, because effective dose is not an appropriate measure for these types of procedures. Uncertainties in the overall number of examinations and in the collective effective dose were estimated at ±30 per cent. The main sources of uncertainty were the gaps in the knowledge of both the number of examinations and the dose per examination, especially where no data were provided and modelled estimates were used instead, and the variations in dose per procedure both within and between countries.

48. The estimated annual effective dose per caput from medical radiological examinations has fallen slightly compared with the Committee's previous UNSCEAR 2008 report (from 0.65 to 0.57 mSv). The difference is, however, within the bounds of the estimated uncertainty. This trend stands in contrast to the trends observed in the previous two UNSCEAR reports, which showed notable increases (see figure I).

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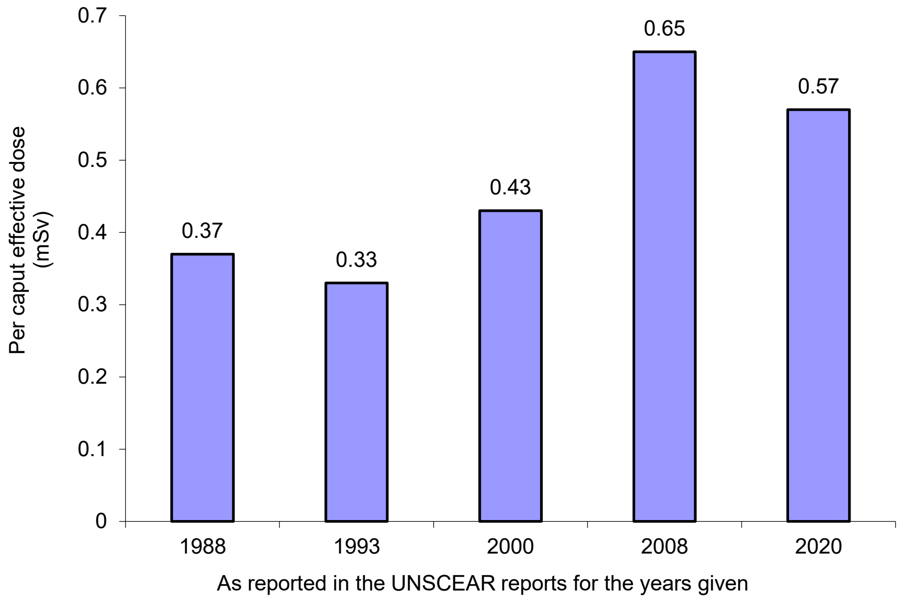
[12] *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 2008 Report to the General Assembly*, vol. I (United Nations publication, 2010), annexes A and B.

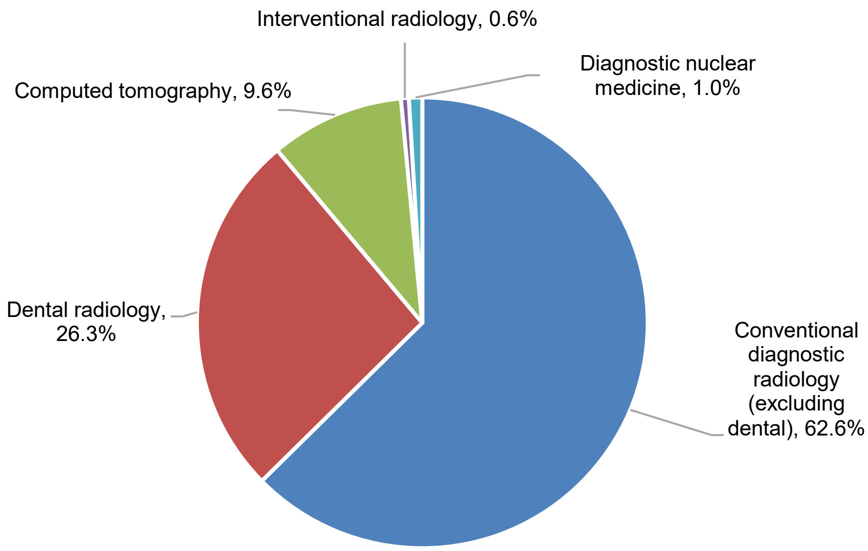
Figure I
Annual effective dose per caput from different UNSCEAR medical exposure evaluations



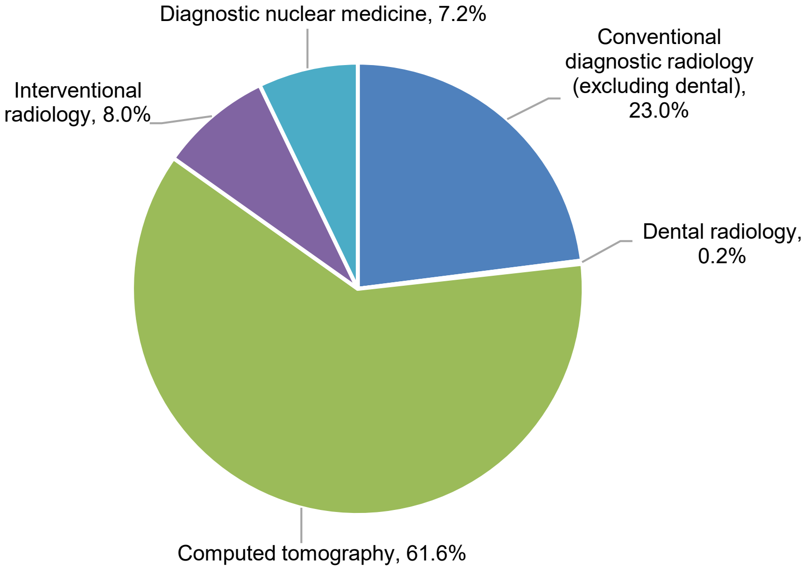
49. Conventional radiology (excluding dental examinations) accounts for 63 per cent of procedures and 23 per cent of the collective effective dose. Dental radiology accounts for 26 per cent of procedures, but only 0.2 per cent of the collective effective dose. Computed tomography makes the largest contribution (about 62 per cent) to the collective effective dose but accounts for only about 10 per cent of all procedures. Interventional radiology accounts for only 0.6 per cent of all procedures but contributes 8 per cent of the collective effective dose. Diagnostic nuclear medicine accounts for about 1 per cent of all procedures and about 7 per cent of the collective effective dose (see figure II).

Figure II
Distribution of (a) examinations/procedures by imaging modality and their contribution to (b) the collective effective dose from medical exposures (excluding radiotherapy)

(a) Examinations/procedures



(b) Collective effective dose



50. The use of computed tomography has continued to expand and has replaced some of the older radiography and fluoroscopy examinations. The total number of computed tomography examinations has increased by about 80 per cent, and its contribution to the collective effective dose has increased from 37 per cent to 62 per cent. However, a major reduction has been reported in radiography and fluoroscopy examinations of the gastrointestinal tract (about 90 per cent), as well as a reduction in fluoroscopy examinations of the biliary and urinary systems and of the chest region. Overall, the number of conventional radiology examinations has decreased by 10 per cent, and the collective effective dose has fallen by 60 per cent. The contribution of interventional radiology procedures has increased considerably and now accounts for 8 per cent of the collective effective dose (compared with 1 per cent in the previous assessment), despite accounting for only 0.6 per cent of the total number of procedures. Nuclear medicine continues to account for about 1 per cent of all procedures, and its contribution to the collective effective dose has risen from 5 per cent to 7 per cent. The number of radionuclide therapy treatments is estimated to have increased by 60 per cent since the previous UNSCEAR report, while the number of courses of radiation therapy has increased by 22 per cent.

51. Table 1 below shows the breakdown of the annual number and frequency of medical radiological examinations by the World Bank classification of income levels and the associated annual collective effective dose and annual effective dose per caput.

Table 1

Estimated average annual per caput dose and annual collective effective dose from reported medical radiological examinations in the 2009–2018 period by income level

Category by income level	*Population (millions)*	*Number of examinations (millions)*	*Frequency (per 1,000 population)*	*Annual per caput dose (mSv)*	*Annual collective effective dose (1,000 man Sv)[a]*
High	1 149	1 852	1 612	1.71	1 966
Upper-middle	2 619	1 197	457	0.46	1 195
Lower-middle	2 882	1 044	362	0.31	902
Low	662	101	153	0.13	89
Global	**7 312**	**4 194**	**574**	**0.57**	**4 152**

[a] Values have been rounded.

52. The use of medical radiation for diagnosis and therapy continues to be strongly weighted towards high- and upper-middle-income countries. Those countries account for around 70 per cent of all medical radiological examinations and 75 per cent of the collective effective dose. This disparity is even more noticeable in nuclear medicine, where high- and upper-middle-income countries account for over 90 per cent of procedures and more than 95 per cent of the collective effective dose. Access to radiation therapy is similarly concentrated, with around 95 per cent of all treatments occurring in high- and upper-middle-income countries.

53. The Committee underlined that the compilation of a global assessment of medical exposure was a complex task and relied on the collection of quality-assured data from Member States. As national surveys of medical exposure require adequate planning and significant time and resources, the Committee recommends the use of its survey questionnaires (especially the essential data sets) to collect such information on a regular basis. Also, the Committee intends to update its assessments more often by focusing on the essential data.

B. Levels and effects of radiation exposure due to the accident at the Fukushima Daiichi nuclear power station: implications of information published since the UNSCEAR 2013 report

54. The Scientific Committee has considered the implications of the significant amount of relevant information that has been published since the UNSCEAR 2013 report and reached the following conclusions.

1. The accident and the releases of radioactive material into the environment

55. The Fukushima Daiichi nuclear power station lies in Fukushima Prefecture of the Tōhoku region in Japan. It is located about 230 km north-east of Tokyo on the east coast of Japan. On 11 March 2011, an earthquake with a magnitude of 9.0 occurred along the Japan Trench. The earthquake and the following tsunami triggered a severe nuclear accident at the Fukushima Daiichi nuclear power station. The measures taken by the Japanese authorities included immediate (pre-emptive) and late (deliberate) evacuation, sheltering in homes, restricting distribution and consumption of contaminated foodstuffs (milk, vegetables, grains, meat, fish, etc.) and water, instructions to take stable iodine, and the remediation of affected areas. These actions were supported by radiation surveys of people and places.

56. More recent estimates of the total releases to the atmosphere from the accident using all the information now available remain consistent with the total release of ^{131}I being within the range of about 100 to about 500 PBq, and that of ^{137}Cs being within the range of 6 to 20 PBq, namely the same ranges as estimated in the UNSCEAR 2013 report. About 20 per cent of the total release to the atmosphere was estimated to have been dispersed over land, and a substantial fraction of this was deposited on land; and about 80 per cent was dispersed over, and deposited in, the Pacific Ocean. The estimated releases of these radionuclides from the Fukushima Daiichi nuclear power station accident (based on the averages of the ranges) were about 10 per cent (^{131}I) and 20 per cent (^{137}Cs) of the releases estimated for the Chernobyl accident.

57. There were also direct releases to the ocean (from leakage and deliberate release of water containing radionuclides) of about 10 to 20 PBq of ^{131}I and 3 to 6 PBq of ^{137}Cs in the first one to three months after the accident, followed by lower amounts thereafter.

2. Levels in the environment and food

58. The Scientific Committee has evaluated the information on the transfers of released radioactive material through the terrestrial, freshwater and marine environments. Some of the more pertinent findings are:

(a) Measurements of ^{137}Cs in seawater around the Fukushima Daiichi nuclear power station site, across the Pacific Ocean and in neighbouring seas showed rapid dispersion and dilution of the released material in seawater and its general movement eastwards. By 2012, the concentrations of ^{137}Cs, even in the coastal waters off the Fukushima Daiichi nuclear power station site, were little above the levels prevailing before the accident;

(b) Extensive monitoring programmes that began immediately after the accident enabled timely restrictions to be applied to prevent the sale of foodstuffs from areas where the radionuclide concentration exceeded provisional regulation values and standard limits [13] established by the Government of Japan. The radionuclide concentrations in most monitored foodstuffs have declined rapidly since the accident. Since 2015, no samples of livestock and crop products and only a few samples of monitored wild food and of freshwater and marine fish products have been found to exceed the limits established by the Government of Japan to apply as of 1 April 2012. It is noteworthy that the Japanese standard limit for caesium radionuclides is an order of magnitude lower than the levels recommended by the Codex Alimentarius Commission for the purpose of international trade.

3. Dose assessment

(a) Members of the public

59. Because of the availability of much more information than was available at the time of the UNSCEAR 2013 report, the Scientific Committee has been able to make more realistic and robust estimates of doses to members of the public, avoiding the need for the conservative assumptions applied in its earlier assessment.

60. In updating its dose assessment, the Scientific Committee has chosen to rely, to the extent possible, on measurements of ambient levels of radiation, as well as of radioactive material in people and the environment.

61. The main changes and/or improvements in the approach adopted by the Scientific Committee and their implications were as follows:

(a) An improved estimate of the temporal pattern of releases to the atmosphere (the “source term”) derived from the totality of measurements in the environment was used, together with an improved atmospheric transport, dispersion and deposition model, to estimate the concentrations of radionuclides in the air, for which only limited measurements were available; this resulted in a different spatial and temporal pattern of concentrations of radionuclides in the air compared with those in the UNSCEAR 2013 report;

(b) A new, validated model was developed to estimate external doses from radionuclides deposited on the ground based on extensive measurements of the variation of dose rate over time in the conditions in Japan; this resulted in a moderate increase in estimated external doses, typically by several tens of per cent compared with the UNSCEAR 2013 report, and a slower decrease in the dose rates with time;

(c) Revised and improved modelling of inhalation and ingestion doses, including more realistic factors and elements of data specific to the affected Japanese population, resulted in decreases in some estimated doses. These changes resulted in a decrease in the estimated thyroid doses in the first year after the accident by a factor of about two and a decrease in the estimated average doses from the inhalation of radionuclides by a factor of about two compared with the UNSCEAR 2013 report;

[13] The terms “provisional regulation value” and “standard limit” are those used in the English version of handbooks providing information on the effects of the Fukushima Daiichi nuclear power station accident published by the Radiation Health Management Division, Ministry of the Environment of the Government of Japan and the National Institute for Quantum and Radiological Science and Technology of Japan. The terms used in Japan may not correspond exactly with the Japanese translation of these terms.

(d) Improved information about people's actual diet, purchases and consumption of food and drink in Japan was used as a basis for revised dose estimates from ingested radionuclides. Over the longer term, the estimates were based on measurements made over 45 years of radiocaesium in food products and the whole diet in Japan from fallout from atmospheric nuclear weapons testing. These changes have reduced the estimated doses received from ingestion of food and drinking water by a factor of at least 10 compared with the UNSCEAR 2013 report.

62. Taken together, these changes led to a reduction in the estimated average doses in the first year compared with the estimated doses in the UNSCEAR 2013 report for the more highly exposed municipalities and groups of evacuees by a few tens of per cent for effective doses and by up to about a factor of two for thyroid doses. The general reduction in the current estimates of effective doses in the first year compared with those in the UNSCEAR 2013 report are largely due to the more realistic and lower estimates of doses from ingestion, and consideration of specific conditions in Japan and the use of dose coefficients that are specific to the Japanese population. However, estimated effective doses to adults over a lifetime remain similar to the estimated doses in the UNSCEAR 2013 report for many municipalities, but for municipalities with higher doses the current estimates are higher (by up to 30 per cent). Over the longer term, those decreases in the estimated effective doses in the first year are counterbalanced by an increase in the estimated dose from external exposure to deposited radionuclides.

63. Groups of evacuees were estimated to have received average effective doses in the first year of up to about 8 mSv and average absorbed doses to the thyroid of up to about 30 mGy. These doses are additional to those doses from natural sources of exposure that are estimated to result in average effective doses to the Japanese population of around 2 mSv.

64. Residents of municipalities in Fukushima Prefecture were estimated to have received average effective doses in the first year of up to about 5 mSv and average absorbed doses to the thyroid of up to about 20 mGy. Average effective doses due to the accident in the first year in other prefectures were estimated to be less than about 1 mSv and absorbed doses to the thyroid less than about 6 mGy. By 2021, annual average effective doses were estimated to have declined to less than 0.5 mSv in areas that were not evacuated, and, following remediation work and the lifting of evacuation orders, to less than 1 mSv in areas that were evacuated. Average effective doses over a lifetime due to the accident were, in all municipalities and prefectures, estimated to be less than 20 mSv; and were highest for residents of Fukushima Prefecture.

65. The Scientific Committee estimated the distributions of doses among individuals within a municipality or prefecture, taking account of all major sources of uncertainty and variability. In general, 90 per cent of the individuals in each population group were estimated to have received doses within a range from about three times lower than the average dose to about three times higher.

66. The Scientific Committee's estimates of radiation exposures in countries neighbouring or close to Japan have not changed: effective doses were less than 0.01 mSv.

67. While the uncertainties in the estimated doses remain large, the Scientific Committee does not believe that further research is likely to reduce them significantly or change the central estimates, except in specific circumstances (e.g., to take account of better information on the efficacy of remediation).

(b) Workers

68. Although the reported doses to workers as a result of the Fukushima Daiichi nuclear power station accident have been subject to some revision since the UNSCEAR 2013 report, the general findings of that report remain valid: the average effective dose of the 21,135 workers involved in mitigation and other activities at the Fukushima Daiichi nuclear power station site from March 2011 to the end of March 2012 was about 13 mSv, while 174 workers (0.8 per cent) received doses of more than

100 mSv. Annual effective doses have been considerably lower since April 2012, with average annual effective doses declining from about 6 mSv in the year ending March 2013 to 2.5 mSv in the year ending March 2019, and no individual has received an annual effective dose of more than 50 mSv since April 2013.

69. For the period March–December 2011, 1,757 workers (8.3 per cent) received absorbed doses to the thyroid greater than 100 mGy, with an average dose for this group of 370 mGy, and 13 workers were estimated to have received thyroid doses of 2 Gy or more.

70. A recent re-evaluation of the absorbed doses to the thyroid of the six workers who received the highest doses has revealed that their absorbed doses to the thyroid, estimated using individual-specific measurements of thyroid size, are, with one exception, higher than previously reported (using population average thyroid size), in one case by a factor of almost three. The highest assessed absorbed dose to the thyroid due to internal exposure from inhalation of ^{131}I is now 32 Gy. However, the Committee believes that the absorbed doses to the thyroid reported in the UNSCEAR 2013 report for the workers as a whole remain valid because there is evidence indicating that the mean thyroid volumes for adults in Japan do not differ significantly from the standard reference values used in dosimetry.

4. Health implications

71. In the years since the UNSCEAR 2013 report, no adverse health effects among Fukushima residents have been documented that are directly attributable to radiation exposure from the Fukushima Daiichi nuclear power station accident. The updated estimates of doses to members of the public have either decreased or are comparable with the Scientific Committee's previous estimates. The Committee therefore continues to consider that future health effects directly related to radiation exposure are unlikely to be discernible.[14]

72. Although approximately 200 cases of thyroid cancer have been detected by three rounds of screening among exposed children, the Scientific Committee believes that, on the balance of evidence, these cases are not the result of radiation exposure. Rather, their detection is the result of sensitive ultrasound screening procedures which have detected cases of latent disease that would not have been diagnosed in the absence of screening, as has been observed in other populations without any increased radiation exposure. The Committee has assessed the incidence of thyroid cancer that could be inferred from the estimated radiation exposures and has concluded that this is not likely to be discernible in any of the age groups considered.

73. While the updated estimated doses to the red bone marrow have not increased, the Scientific Committee's estimate of leukaemia risk per mGy has increased somewhat compared with what was stated in the UNSCEAR 2013 report. However, any increased incidence of leukaemia is still unlikely to be discernible among Fukushima residents of any age. Likewise, the levels of exposure of members of the public have been too low for the Committee to expect discernible increases in the incidence of breast cancer or other solid cancers.

74. There has been no evidence of excess congenital anomalies, stillbirths, preterm deliveries or low birthweights among newborns related to radiation exposure. Increases in the incidence of cardiovascular and metabolic conditions have been observed among adults evacuated following the accident, but they are probably associated with

[14] As stated in the UNSCEAR 2013 report (annex A, appendix E), the Committee considers quantitative and qualitative estimates of potential disease outcomes among the exposed populations that may or may not be observable in future disease statistics. For the purpose of this study, the Committee has also used the phrase "no discernible increase" where, although a disease risk in the longer term can be theoretically inferred on the basis of existing risk models, an increased incidence of effects is unlikely in practice to be observed in future disease statistics using currently available methods, because of the combination of the limited size of population exposed and low exposures, i.e., consequences that are small relative to the baseline risk and their uncertainties.

concomitant social and lifestyle changes and are not attributable to radiation exposure. Excess psychological distress also occurred in the aftermath of the combined earthquake, tsunami and Fukushima Daiichi nuclear power station accident.

75. The health of the Fukushima Daiichi nuclear power station emergency workers is being monitored in the nuclear emergency workers study sponsored by the Ministry of Health, Labour and Welfare of Japan. The majority of workers received effective doses within the first year of less than 10 mSv, and only a small fraction of workers received effective doses within the first year of 100 mSv or more. Thus, a discernible increase in the incidence of leukaemia or solid cancers is unlikely. Approximately 1,750 workers received absorbed doses to the thyroid greater than 100 mGy, and 13 workers received thyroid doses greater than 2 Gy. Because these thyroid doses were received by adults rather than children, an excess of thyroid cancers in the workers is also unlikely to be discernible.

5. Radiation exposures and effects on non-human biota

76. The Scientific Committee continues to consider that regional impacts on wildlife populations with a clear causal link to radiation exposure resulting from the Fukushima Daiichi nuclear power station accident is unlikely, although detrimental effects on individual organisms might have been possible. Indeed, various cytogenetic, physiological and morphological (sublethal, individual-level) effects in some plants and animals have been observed in areas of enhanced radiation levels following the Fukushima Daiichi nuclear power station accident, in the absence of any reported wide-scale group impacts. In contrast, substantial population-level impacts on biota were observed following the Chernobyl accident. A few studies have indicated population impacts on selected wildlife groups following the Fukushima accident. However no strong conclusions can be made from these studies, as there is also radiobiological evidence to the contrary, and doubts remain about the robustness of those findings, including uncertainty about reproducibility and control of confounding factors.

C. Biological mechanisms relevant for the inference of cancer risks from low-dose and low-dose-rate radiation

77. Since the establishment of the Scientific Committee in 1955, its mandate has been to undertake broad estimates of the sources of ionizing radiation and its effects on human health and the environment. In 1973,[15] the mandate was expanded to include scientific estimates of radiation risk. These assessments of the Committee provide the scientific foundation used, inter alia, by the relevant agencies of the United Nations system in formulating international standards for the protection of the general public and workers against ionizing radiation.[16] Those standards, in turn, are linked to important legal and regulatory instruments.[17] In its 2012 report to the General Assembly, the Committee considered the attribution of health effects and the inference of risks from radiation exposure,[18] as well as on the uncertainties in risk estimates. The understanding of the biological mechanisms by which radiation-induced effects such as cancer may occur is a relevant element for the inference of radiation risk. This report is intended to synthesize the current knowledge on biological mechanisms of radiation actions at doses mostly in the low to moderate range relevant for cancer risk inference. It is emphasized that this is not a report on radiation effects; in particular, it is not a report on cancers that can be attributed to radiation exposure situations.

[15] General Assembly resolution 3154 (XXVIII).

[16] The European Atomic Energy Community, FAO, IAEA, ILO, the International Maritime Organization, NEA/OECD, PAHO, UNEP and WHO, “Fundamental safety principles: safety fundamentals” (IAEA, Vienna, 2006), para. 1.6.

[17] Ibid., para. 1.5.

[18] *Official Records of the General Assembly, Sixty-seventh Session, Supplement No. 46* (A/67/46).

78. In its annex on biological mechanisms relevant for the inference of cancer risks from low-dose and low-dose-rate radiation, the Scientific Committee has undertaken a comprehensive evaluation of the biological mechanisms that are considered to contribute to or modulate carcinogenesis following radiation exposure, particularly at low exposure levels (dose of 100 mGy and below for low-linear energy transfer (low-LET) radiation (X- and gamma-rays) and at dose rates of 0.1 mGy/min and below). The understanding of the mechanisms and modulators of carcinogenesis following low-dose and low-dose-rate radiation exposures remains incomplete. An appendix that considers principles and criteria for ensuring the quality of the Committee's reviews of experimental studies of radiation exposure is included, which serves as a companion to the "Principles and criteria for ensuring the quality of the Committee's reviews of epidemiological studies of radiation exposure" (annex A to the UNSCEAR 2017 report).[19]

79. There is very robust and reliable evidence that incomplete, failed or otherwise dysfunctional responses to DNA damage contribute to induced mutation and chromosome damage and thereby affect the occurrence of cancers after exposures at all doses and dose rates studied. These responses relate to: (a) direct damage to DNA; and (b) damage attributable to the generation of reactive oxygen and related species, both of which can contribute to double-strand breaks, complex lesions and effects on mitochondria.

80. The Scientific Committee concluded the following:

(a) There are limited robust data that can be identified at this time that would prompt the need to change the current approach taken for low-dose radiation cancer risk inference as used for radiation protection purposes and in consideration of the allocation of resources in health-care settings, as well as for the purpose of comparison with other risks. The potential contributions of phenomena such as transmissible genomic instability, bystander phenomena, induction of abscopal effects and adaptive response remain unclear. The dose-response relationships for mutations and micronuclei are linear in form in the low-dose region down to at least 50 and 10 mGy low-LET radiation, respectively. Similarly, the dose-response for DNA damage response activation is best represented by a linear form down to 10 mGy low-LET radiation. It is notable that since the Committee's last major evaluation of contributory mechanisms for radiation oncogenesis (UNSCEAR 1993 report),[20] there have been substantial new data on low-dose and low-dose-rate radiation risk from epidemiological investigations, in particular of occupational and medical cohorts. These studies have added to the epidemiological evidence underpinning low-dose and low-dose-rate cancer risk estimation and are supported by the mechanistic findings in this annex;

(b) There remains good justification for the use of a non-threshold model for risk inference for radiation protection purposes, given the present robust knowledge on the role of mutation and chromosomal aberrations in carcinogenesis. However, there are ways that radiation could act that might lead to a re-evaluation of the use of the Committee's approach to inference of radiation cancer risks. Some experimental animal studies indicate that low-dose and low-dose-rate exposures can shorten lifespan and possibly increase tumour burdens, but others indicate the extension of lifespan and reduced tumour burdens. The Committee also noted that generally, there is insufficient mechanistic understanding of these observations. This situation may be improved if, for example, low-dose exposures were shown consistently and unequivocally to stimulate DNA damage response/repair, or immune responses modulating cancer development; such a consistent evidence base has not been found

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[19] *Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 2017 Report to the General Assembly* (United Nations publication, 2018).

[20] *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 1993 Report to the General Assembly* (United Nations publication, 1994), annex E.

in this review. In this case, some elements of risk reduction might have to be taken into consideration alongside the established DNA damage – mutational damage and potential promotional pathways. Other examples where additional evidence would help the assessment of risk include the findings relating to the stimulation of tumour vascularization by low-dose exposures, where there is greater consistency and coherence of the available data. Stimulation of tumour vascularization would be expected to serve to promote tumour development;

(c) There is long-standing evidence that the number of mutational steps required for leukaemia is less than in the case of solid cancers, and this impacts on the time to presentation of leukaemia by comparison with solid cancers.

81. As mentioned above, the implications of the studies on the induction of transmissible genomic instability, bystander effects, abscopal effects and adaptive responses are still not clear. Some studies suggest thresholds for the induction of transmissible genomic instability and bystander effects at around 100 mGy low-LET radiation; if confirmed, this would indicate that the phenomena are not relevant for low-dose cancer risk inference. Adaptive response studies remain without a confirmed mechanistic basis and are of mixed outcome; similarly, studies of samples from persons inhabiting areas with high natural background radiation levels that are interpreted by some as providing evidence for adaptive response are insufficiently coherent to be adopted for risk assessment purposes.

82. Looking to the future, the recommended approach for combining a mechanistic understanding of low-dose radiation carcinogenesis with epidemiological studies is to use mathematical modelling integrating data from experimental systems (e.g., dose-response data for induction of key mutations or epimutations). For this purpose, there exist good multistage model frameworks that have the flexibility to include data on somatic events and germline influences on risk. These approaches may be used to test hypotheses and provide further insights for risk inference. Consideration should be given to the use of adverse outcome pathway approaches, as applied in chemical toxicology and risk assessment, to help define and formalize key mechanistic steps in carcinogenesis following low-dose exposures. In addition, experimental investigations may identify cancer risk indicators that, when validated, could be integrated into epidemiological investigations to improve statistical power or be used for population screening.

Part two

Report of the United Nations Scientific Committee on the Effects of Atomic Radiation on its sixty-eighth session, held online from 21 to 25 June 2021

Chapter IV

Introduction

83. Since the establishment of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) by the General Assembly in its resolution 913 (X) of 3 December 1955, the mandate of the Committee has been to undertake broad assessments of the sources of ionizing radiation and its effects on human health and the environment.[21] In pursuit of its mandate, the Committee thoroughly reviews and evaluates global and regional exposures to radiation. The Committee also evaluates evidence of radiation-induced health effects in exposed groups and advances in the understanding of the biological mechanisms, by which radiation-induced effects on human health or on non-human biota can occur. Those assessments provide the scientific foundation used, inter alia, by the relevant agencies of the United Nations system in formulating international standards for the protection of the general public, workers and patients against ionizing radiation;[22] those standards, in turn, are linked to important legal and regulatory instruments.

84. Exposure to ionizing radiation arises from naturally occurring sources (such as radiation from outer space and radon gas emanating from rocks in the Earth) and from sources with an artificial origin (such as medical diagnostic and therapeutic procedures; radioactive material resulting from nuclear weapons testing; energy generation, including by means of nuclear power; unplanned events such as the nuclear power station accidents at Chernobyl in April 1986 and that following the great east-Japan earthquake and tsunami of March 2011; and workplaces where there may be increased exposure to artificial or naturally occurring sources of radiation).

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[21] The United Nations Scientific Committee on the Effects of Atomic Radiation was established by the General Assembly at its tenth session, in 1955. The terms of reference of the Committee are set out in Assembly resolution 913 (X). The Scientific Committee was originally composed of the following Member States: Argentina, Australia, Belgium, Brazil, Canada, Czechoslovakia (later succeeded by Slovakia), Egypt, France, India, Japan, Mexico, Sweden, Union of Soviet Socialist Republics (later succeeded by the Russian Federation), United Kingdom of Great Britain and Northern Ireland and United States of America. The membership of the Scientific Committee was subsequently enlarged by the Assembly in its resolution 3154 C (XXVIII) of 14 December 1973 to include the Federal Republic of Germany (later succeeded by Germany), Indonesia, Peru, Poland and the Sudan. By its resolution 41/62 B of 3 December 1986, the Assembly increased the membership of the Committee to 21 members and invited China to become a member. In its resolution 66/70, the Assembly further enlarged the membership of the Committee to 27 and invited Belarus, Finland, Pakistan, the Republic of Korea, Spain and Ukraine to become members.

[22] For example, the international basic safety standards for radiation protection and safety of radiation sources, currently co-sponsored by the European Commission, FAO, IAEA, ILO, NEA/OECD, PAHO, UNEP and WHO.

Chapter V

Deliberations of the United Nations Scientific Committee on the Effects of Atomic Radiation at its sixty-eighth session

85. The Scientific Committee held its sixty-eighth session online from 21 to 25 June 2021.[23] Due to the extended period of disruption to the Committee's normal mode of operation due to the COVID-19 pandemic, and the need to hold a second session online, the Committee agreed to extend the term of the current officers of the Bureau for one additional session. The following were elected as officers of the Committee for its sixty-eighth session: Gillian Hirth (Australia) as Chair; Jing Chen (Canada), Anna Friedl (Germany) and Jin Kyung Lee (Republic of Korea) as Vice-Chairs; and Anssi Auvinen (Finland) as Rapporteur.

86. The Scientific Committee acknowledged its sixty-fifth anniversary, and heard statements of congratulations, support and appreciation from (a) the Executive Director of UNEP, Inger Andersen, who congratulated the Committee on its sixty-fifth anniversary and for its long contribution to protecting people and the environment, while thanking the Committee for its hard work, and also acknowledged the long history of engagement between UNEP and the Committee, which she hoped would continue and be strengthened; (b) the Executive Director of the United Nations Office on Drugs and Crime and Director-General of the United Nations Office at Vienna (UNOV), Ghada Fathi Waly, who stated that UNOV was proud to support the Committee's mission through the provision of a range of administrative-, information technology- and procurement-related support; and (c) the Director General of IAEA, Rafael Mariano Grossi, who highlighted the cooperation between IAEA and the Committee. He noted that it was the thirty-fifth year following the Chernobyl accident and 10 years since the accident at the Fukushima Daiichi nuclear power station, and that the work of IAEA and the assessments of UNSCEAR provided international organizations and the countries concerned with high-quality and scientifically rigorous conclusions and recommendations. He noted that the IAEA International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, in particular, rely on the comprehensive data provided by UNSCEAR. The Committee welcomed those statements.

87. The Scientific Committee took note of and discussed a number of paragraphs of General Assembly resolution 75/91 on the effects of atomic radiation. The issues raised and discussed by the Committee are reported below in chapter V, section E ("Administrative issues").

A. Completed evaluations

88. The Scientific Committee discussed one scientific annex and agreed on the findings and requested that the scientific annex be published in the usual manner (see chapter VI), subject to the modifications agreed upon, and that the final adoption be conducted using a silence procedure due to the COVID-19 pandemic, as that procedure had been adopted by the Committee for use at the sixty-eighth session.

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[23] The sixty-eighth session of the Scientific Committee was attended by observers for Algeria, Iran (Islamic Republic of), Norway and the United Arab Emirates, in accordance with General Assembly, resolution 75/91, para. 24, and the observers for the European Union, FAO, IAEA, ILO, the International Agency for Research on Cancer, ICAO, ICRP, ICRU, NEA/OECD, the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization, UNEP and WHO.

B. Present programme of work

1. Second primary cancer after radiotherapy

89. At the sixty-eighth session, the Scientific Committee discussed and further clarified the structure and content of the evaluation of second primary cancer after radiotherapy and recommended that the radiobiology section would not cover in detail all mechanisms possibly involved in carcinogenesis after radiation exposure, since these were addressed in the UNSCEAR 2020 report, annex C,[24] but rather would focus on issues relevant for cancer risk after radiotherapy. The Committee also clarified that the meta-analysis of second cancer risks after radiotherapy should be based on absorbed organ doses after quality control of dosimetric data in the publications to be evaluated. The expert group on second primary cancer after radiotherapy is to provide a first draft annex at the sixty-ninth session.

2. Epidemiological studies of radiation and cancer

90. At its sixty-eighth session, the Scientific Committee discussed the progress report on cancer epidemiology and took note of an update of the workplan, which was revised due to circumstances associated with the COVID-19 pandemic. Submission of the report for approval is now planned in 2025. The evaluations will be based on the Committee's principles and criteria for ensuring the quality of the Committee's reviews of epidemiological studies of radiation exposure and clearly distinguish between attribution of effects and inference of risks, as outlined in the UNSCEAR 2012 report.[25] The expert group will provide a first draft annex at the sixty-ninth session.

3. Public exposure to ionizing radiation from natural and other sources

91. At its sixty-eighth session, the Scientific Committee discussed the progress report on public exposure and noted that 22 Member States and four international organizations (European Commission, IAEA, the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (NEA/OECD) and the World Health Organization (WHO)) had participated as members and observers in the expert group. The Committee recognized the progress made since the previous session, suggested revisions to the structure and content of the draft scientific annex and agreed the proposed schedule for completion of the appendix on quality criteria for evaluating public exposure to ionizing radiation by 2022 and the annex by 2024. The Committee requested for the sixty-ninth session in 2022 a progress report from the expert group on the work carried out, as well as an updated timetable for completion of the project.

4. Implementation of the Committee's strategy to improve collection, analysis and dissemination of data on radiation exposure, including consideration of the Committee's ad hoc working group on sources and exposure

92. The General Assembly encouraged the Scientific Committee in several resolutions[26] to work towards continuing implementation of its strategy for optimizing working arrangements for its scientific evaluations, which includes the establishment of working groups with specific tasks. At its sixty-eighth session the Committee agreed to continue the activities of the ad hoc working group on sources and exposure to ionizing radiation to support the advancement of the Committee's evaluation of public, occupational and medical exposures.

93. The Committee stressed the importance of motivating Member States to fully participate in the UNSCEAR surveys by underscoring and communicating their

[24] To be published.

[25] *Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 2012 Report to the General Assembly* (United Nations publication, 2015).

[26] General Assembly resolutions 71/89, 72/76, 73/261 and 74/81.

utility. The results of UNSCEAR surveys may benefit Member States in many ways, including:

(a) A better understanding of national and regional levels of radiation exposures to the public, workers and patients;

(b) Assisting in the development of national policies, strategies and programmes to manage exposures as appropriate;

(c) Providing Member States with comparative information on their levels of radiation exposure in relation to the global and regional levels and thereby identify challenges and priorities where improvements can be made;

(d) Providing other national and international institutions with reliable information that can be used in the development of recommendations on protection and safety for processes and procedures that use ionizing radiation;

(e) Providing data to the scientific community that can be used in research and the development of training tools.

94. The Committee, through the ad hoc working group on sources and exposure, has analysed progress since the sixty-seventh session and has collected feedback from the expert groups on public, occupational and medical exposures. The findings from the feedback survey, alongside lessons learned from previous surveys, have been used to develop the following key recommendations to further improve future and ongoing data collection, analysis and dissemination:

(a) Formulation of a clear statement of assessment objectives and better elucidation of the benefits to Member States to improve participation and ensure adequate resources are directed to data collection;

(b) Establishment of approaches and methodologies based on realistic expectations of the data available, and documenting lessons learned from previous evaluations;

(c) Procedural improvements, with feedback checking at various stages, in data collection and exposure assessment;

(d) Provision of adequate resources (i) to maintain the network of national contact persons from the Member States and facilitate the coordination of the collection and submission of exposure data from Member States on a more regular basis, and (ii) to establish small expert groups to sustain the assessment process by monitoring the literature, identifying changes in exposure situations or the uses of radiation, identifying areas where updated evaluations are necessary and refining the approach to be better prepared for the next updates on the global assessment;

(e) The Committee's outreach strategy should highlight the importance of the Committee's surveys and evaluations for understanding radiation exposure and the role they have in providing an up-to-date scientific basis to support the worldwide radiation protection system.

95. In view of the fact that the recommendations elaborated by the ad hoc working group on sources and exposure represent a modified approach to the data collection and analysis process, the Committee extended the mandate of the ad hoc working group until its sixty-ninth session in 2022 to support the implementation of these recommendations. During this extended term, the ad hoc working group will continue to monitor progress of the data collection in the public exposure project, consolidate recommendations made at the sixty-seventh and sixty-eighth sessions, and present a draft updated strategy for data collection, analysis and dissemination to the Committee for consideration and endorsement at the sixty-ninth session in 2022.

5. Implementation of public information and outreach strategy for 2020–2024

96. At its sixty-sixth session, the Scientific Committee adopted the public information and outreach strategy for the period 2020–2024 to guide the work of the

secretariat and the Committee in outreach and communication activities with different stakeholders. The strategy complemented the outreach activities planned for the UNSCEAR 2020 report, annex B.[27] At its sixty-seventh session the Committee noted the progress report and acknowledged the postponement of outreach activities on the update of the UNSCEAR 2013 report due to the COVID-19 situation and encouraged close collaboration with international organizations to further promote the Committee's findings.

97. At its sixty-eighth session, the Scientific Committee noted the progress report from the secretariat and provided feedback on the ongoing and planned future outreach activities. The Committee also noted the updated outreach plan for planned activities in Japan for October 2021 or the first quarter of 2022. The Committee acknowledged the sixty-fifth anniversary of UNSCEAR and expressed support to the secretariat to continue dissemination of the Committee's work. The Committee noted the new proposed initiatives (such as webinars when launching publication of a new report, involvement of a public relation expert, translation of the UNEP booklet *Radiation: Effects and Sources* and development materials for children and adolescents), including the need to update the UNSCEAR public information and outreach strategy. The Committee proposed to discuss in more detail the new information and outreach strategy to be considered beyond 2024 at its sixty-ninth session in 2022 so that a new strategy can be launched in a timely manner. These activities are currently being funded exclusively from the UNSCEAR general trust fund.

C. Update on the Committee's long-term strategic directions

98. At its sixty-sixth session, the Scientific Committee approved its long-term strategic directions and plan for the period 2020–2024. That plan included the following:

(a) Establishing working groups focused on sources and exposure, and effects and mechanisms;

(b) Inviting, on an ad hoc basis, scientists from other States Members of the United Nations to participate in the Committee's evaluations;

(c) Increasing the Committee's efforts to present its evaluations and summaries thereof in a manner that attracts readers without compromising scientific rigour and integrity;

(d) While maintaining the lead in providing authoritative scientific evaluations to the General Assembly, liaising closely with other relevant international bodies to avoid duplication of efforts.

(a) Establishing working groups focused on the areas of sources and exposure, and effects and mechanisms

99. At its sixty-eighth session, the Scientific Committee prolonged the mandate of both the ad hoc working group on effects and mechanisms and the ad hoc working group on sources and exposure to continue their activities until the Committee's sixty-ninth session in 2022. The prolongation of these groups would allow for (a) the ad hoc working group on effects and mechanisms to continue to support and monitor progress in the implementation of the programme of work, to evaluate new scientific developments relevant for the Committee and to work with the secretariat to prepare a meeting on the use of radiation protection quantities and units in the Committee's report; and (b) the ad hoc working group on sources and exposure to update the Committee's strategy to improve the processes for collection, analysis and dissemination of data on radiation exposures of the public, patients and workers.

[27] To be published.

(b) Inviting, on an ad hoc basis, scientists from other States Members of the United Nations to participate in evaluations regarding the above areas

100. The Scientific Committee noted that the secretariat and the Bureau had taken steps to involve scientists from other States Members[28] of the United Nations in supporting the secretariat in conducting ongoing evaluations. This is particularly relevant for the ongoing evaluation of public exposure to ionizing radiation from natural and other sources.

(c) Increasing the Committee's efforts to present its evaluations, and summaries thereof, in a manner that attracts readers without compromising scientific rigour and integrity

101. The Scientific Committee referred to the outreach activities reported in chapter V, section B.5 above.

(d) While maintaining its lead in providing authoritative scientific evaluations to the General Assembly, liaising closely with other relevant international bodies to avoid duplication of efforts

102. The importance of the Scientific Committee's findings in providing the scientific evidence upon which decisions are made by the international community and the safety standards are developed was also demonstrated in the period since the sixty-seventh session. The Committee noted that since 2020, UNSCEAR has been participating as an observer of the IAEA Commission of Safety Standards and as a member of the Steering Committee of the Global Nuclear Safety and Security Network of IAEA. The Committee continues to collaborate with IAEA and remains an observer of the Emergency Preparedness and Response Standards Committee and Radiation Safety Standards Committee in the current 2021–2023 cycle. UNSCEAR is also cooperating with a number of other organizations, including ICRP, WHO, the International Agency for Research on Cancer, the Inter-Agency Committee on Radiation Safety and IRPA, among others. In addition, the 2019 report of the Secretary-General highlighted the importance of the Committee's work for the scientific evaluation of radiation exposure and the health effects of the Chernobyl accident.[29] The secretariat also attended the United Nations Inter-Agency Task Force on Chernobyl event held on 23 April 2021 to commemorate the thirty-fifth anniversary of the Chernobyl accident.

103. The Scientific Committee welcomed and supported the continued cooperation of the secretariat with the United Nations and other international organizations[30] with a view to promoting the Committee's work and exploring synergies and joint activities that would contribute to that work and support the collection and analysis of scientific data. The Committee specifically acknowledged the ongoing development of framework agreements with the European Commission, IAEA and WHO and requested the secretariat to report on this matter at its next session.

D. Future programme of work

104. Since the sixty-fifth session, the ad hoc working group on effects and mechanisms has collected and analysed the experience of, and the lessons learned by, the Scientific Committee in recent years and developed a draft future programme of work for the period 2020–2024 that was approved by the Committee at its sixty-seventh session. The ad hoc working group also supported the Bureau and the secretariat in monitoring progress on the current projects, evaluating new scientific

[28] Austria, Italy, Norway, Singapore and Switzerland.

[29] See A/74/461.

[30] For example, the European Commission, IACRS, IAEA, ICAO, ICRP, ICRU, the International Radiation Protection Association, NEA/OECD and UNEP.

developments between the sessions and preparing a proposal for a new evaluation for consideration by the Committee.

105. As agreed at the sixty-seventh session, the Committee will start in 2021 an evaluation of diseases of the circulatory system resulting from radiation exposure. At its sixty-eighth session, the Committee approved a project plan, developed by the ad hoc working group on effects and mechanisms, to initiate in 2022 the evaluation on diseases of the nervous system from radiation exposure. Furthermore, it was agreed to begin preparation of a new future programme of work (2025–2029) in 2022.

106. Recognizing the limitations of radiation protection quantities, the Scientific Committee agreed to continue the use of the effective dose and collective effective dose as simple and manageable quantities to allow recording and comparing exposures to a variety of sources and under a variety of circumstances. However, it recommended that all future reports using effective dose or collective effective dose include a clear statement summarizing how the Committee intends to use these quantities and which uses are not appropriate. When reporting effects and mechanisms, the Committee agreed that exposure quantities should be based on absorbed doses in relevant organs and tissues.

107. The Scientific Committee recalled the Committee's unique mandate within the United Nations family and emphasized that the timely implementation of the programme for the period 2020–2024, and beyond, depended on sufficient and reliable long-term resources being available in the secretariat and that obtaining additional scientific expertise and support for the planned outreach and administrative tasks was essential to ensuring the feasibility and timely delivery of the planned programme of work. This is particularly relevant in view of delays due to the COVID-19 pandemic and proposed new activities related to data collection and analysis for medical and occupational exposures. The Committee also noted that implementation of the proposed ongoing work related to the collection of data on radiation exposures of the public, patients and workers required additional resources that the secretariat needs at least one additional in-kind expert or temporary position post, for example, either a United Nations volunteer, expert working as a non-reimbursable loan or a junior professional officer working on implementing the Committee's programme of work for the period 2020–2024 in the area of sources and exposure.

108. Further, the Scientific Committee took note with concern of the secretariat's need to use the general trust fund contributions for additional scientific expertise, outreach and administrative tasks related to the implementation of the Committee's programme of work. That is particularly relevant in view of maintaining and improving the existing data collection system and network for medical and occupational exposures, and the new data collection and evaluation for public exposure to ionizing radiation that started in March 2021. The Committee will be able to implement a range of initiatives to motivate Member States to participate in these important surveys only if it is able to strengthen its approach to collection and analysis of essential data on radiation exposure on a regular basis. Such initiatives would have considerable benefit for the Member States, the Committee, international organizations and other stakeholders. That intent will be realized only if the secretariat can be assured of regular and sustainable resources that are not reliant on general trust fund contributions. The Committee will consider those challenges when the implementation of the Committee's programme of work for the period 2020–2024 and the initial preparations for the future programme of work for the period 2025–2029 are discussed at the sixty-ninth session.

109. The Scientific Committee took note of the request of the Executive Director of UNEP[31] for Member States to support the Committee's work through the provision of financial resources to the general trust fund. While the Committee welcomed the contributions of three States members[32] of the Committee and the part-time in-kind

[31] See note verbale dated 12 February 2020.

[32] Australia, Canada and Germany.

support provided by Canada since November 2020, it encouraged other Member States to use the possibility to strengthen the secretariat's capacity through regular voluntary contributions to the UNSCEAR general trust fund and/or in-kind contributions (either United Nations volunteers, experts working as non-reimbursable loans or junior professional officers).

E. Administrative issues

110. The Scientific Committee took note of General Assembly resolution 75/91 on the effects of atomic radiation, in which the Assembly:

(a) Requested UNEP to continue, within existing resources, to service the Committee and to disseminate its findings to Member States, the scientific community and the public and to ensure that the administrative measures in place were appropriate, including clear roles and responsibilities of the various actors, so that the secretariat is able to adequately and efficiently service the Committee in a predictable and sustainable manner and effectively facilitate the use of the invaluable expertise offered to the Committee by its members in order that the Committee may discharge the responsibilities and mandate entrusted to it by the General Assembly;

(b) Urged UNEP to ensure that future recruitment processes are conducted in an efficient, effective, timely and transparent manner;

(c) Recalled that the establishment of the post of Deputy Secretary in 2019, which upgraded the previous post of Scientific Officer, allowed for the deputization of the Deputy Secretary as Secretary as appropriate and assisted in the avoidance of disruptions in staffing;

(d) Noted that the appointment of a Deputy Secretary had not yet been finalized due to the ongoing impact of the COVID-19 pandemic, and urged UNEP to finalize that process as soon as possible so as to avoid further disruption to the important work of the secretariat and the Scientific Committee;

(e) Requested the Secretary-General to strengthen support for the Committee within existing resources, in particular with regard to the increase of operational costs in the case of a further increase in membership, and to report to the General Assembly at its seventy-sixth session on those issues;

(f) Recalled the procedure for the possible further increases in membership of the Scientific Committee as adopted in paragraph 21 of General Assembly resolution 73/261, pursuant to paragraph 19 of Assembly resolution 66/70.

111. In regard to the points in paragraph 110 (b), (c), (d) and (e) above, the Scientific Committee's normal operation had continued to be impacted by the COVID-19 pandemic. The Committee recalled that the position of Deputy Secretary had been established in 2019 and noted that due to the COVID-19 pandemic the appointment of an officer to the position of Deputy Secretary was delayed as a consequence of a recruitment freeze for all regular budget-funded United Nations posts. However, while the Committee acknowledged this position had continued to be filled temporarily, it expressed frustration that the freeze of recruitment of United Nations regular budget posts had been lifted in February 2021 and yet the appointment of an officer to the position of Deputy Secretary had still not been finalized before the sixty-eighth session.

112. In regard to the points in paragraph 110 (a), (b), (c), (d) and (e) above, the Executive Director of UNEP, Ms. Andersen, acknowledged the delays with the recruitment of a Deputy Secretary for the Committee and informed the Committee that the recruitment of the Deputy Secretary was under way, and gave her assurance that UNEP would do everything within its power to support the Committee's financial and human resources. She also expressed appreciation for the contributions to the UNSCEAR general trust fund that had been received from Australia, Canada and Germany since the last session in November 2020.

113. In considering the requests of the General Assembly and the statement from the Executive Director of UNEP, the Committee strongly encouraged the finalization of the appointment to the post of Deputy Secretary as soon as possible. The Committee expressed grave concerns about the delays in permanently filling the position of Deputy Secretary, which continued to pose a threat to the continuity of the work of the Committee. The Committee expressed concern that the budget of the UNSCEAR secretariat for carrying out scientific evaluations continued to decrease on a year-by-year basis and remained at its lowest level in the past 10 years and that the UNSCEAR general trust fund contributions were being increasingly relied upon to address the decline in regular budget funds for the recruitment of consultants. The Committee also expressed serious concern about the Committee's ability to successfully implement its planned programme of work in a timely manner, in particular with regard to the increased number of experts involved in the ongoing evaluations, the need for enhanced data collection, outreach activities and the operational costs in the case of an increased membership. The Committee again recalled the point in paragraph 110 (a) above and that UNEP had been requested by the General Assembly to adequately and efficiently service the Committee in a predictable and sustainable manner, and noted that regular funding allowed the full independence of the Committee to be observed.

114. In regard to the point in paragraph 110 (f) above, the Scientific Committee recalled the procedure for possible further increases in membership of the Scientific Committee and discussed the advice to be provided to the General Assembly. The advice from the Committee is summarized in the following paragraphs.

115. In preparing its advice to the General Assembly, the Scientific Committee heard statements from the scientific representatives of the observer countries Algeria, Iran (the Islamic Republic of), Norway and the United Arab Emirates on their experiences as observers of the Committee and on their continued ability and willingness to contribute to the work of the Committee. The Permanent Mission of the Islamic Republic of Iran had also submitted a note verbale prior to the sixty-eighth session confirming the interest of the Islamic Republic of Iran in joining the Committee as a member.

116. The Scientific Committee gave due consideration to the degree of participation of the observer countries and to the other matters outlined in the Secretary-General's suggested framework of criteria and indicators for membership, as detailed in the report of the Secretary General (A/66/524, para. 16).

117. The Scientific Committee recalled that it was established by the General Assembly at its tenth session, in 1955. As set out in Assembly resolution 913 (X), the Committee was originally composed of 15 member States. The membership of the Committee was subsequently enlarged by the Assembly in its resolution 3154 C (XXVIII) of 14 December 1973 to include a further five member States. By its resolution 41/62 B of 3 December 1986, the Assembly increased the membership of the Committee to 21 members and invited China to become a member. In its resolution 66/70 of 2011, the Assembly further enlarged the membership of the Committee to 27 member States.

118. In 2018, in paragraph 21 of its resolution 73/261, the General Assembly adopted admission procedures for any future increases in the membership of the Committee. Paragraph 21 (e) of that resolution states that the General Assembly shall consider the advice of the Scientific Committee with regard to the adoption of the observers as States members of the Committee in the fourth year of attending the Committee's sessions as observers. The advice shall be based on due consideration of a fair degree of participation in accordance with the Secretary-General's suggested framework of criteria and indicators for membership.[33]

119. The Scientific Committee considered the four observer States using the criteria adopted by the General Assembly, referred to above, and the Committee

[33] A/66/524, para. 16.

acknowledged the consistent participation and contribution to its work by the representatives and experts of each observer State, including contributions to evaluations and data collection throughout the past four years. The Committee noted that the four observer States reflected the principle of equitable geographical distribution, and it expected that each State would continue to make a valuable contribution to the Committee's work, as members, as they had demonstrated throughout the past four years as observers.

120. The Scientific Committee also reported in its report to the General Assembly[34] that it had heard presentations from the scientific representatives of the observer States on their research programmes and potential contribution to the Committee's work. The Committee noted that the contributions would enhance the United Nations regional networks in Africa and Asia and support the Committee's work on the collection, analysis and dissemination of data on exposure and levels of ionizing radiation and assist with mapping radionuclide concentrations in the environment, in accordance with its long-term strategic directions.

121. In particular, the Scientific Committee noted that the four observer States had been invited to attend, and their representatives had actively participated at, each of the sixty-fifth to sixty-eighth sessions (2018–2021) of the Committee. All four observer States submitted data to the Committee's global surveys on medical and occupational exposure, were participating in the ongoing global survey on public exposure and had advertised the global surveys in their respective regions.

122. Accordingly, the Scientific Committee considered that the four observer States had demonstrated their active participation and commitment to the work of the Committee. Further, the Committee advised the General Assembly that, in its opinion, all four observer States compared favourably against the framework of objective criteria for membership, noting that Committee membership was ultimately to be a decision for the General Assembly. The Committee recalled paragraph 21 (g) of Assembly resolution 73/261, which stated that any further increases in membership were to occur only after financial aspects were fully reviewed and if the secretariat of the Scientific Committee was appropriately strengthened, in accordance with conclusions drawn in previous reports of the Secretary-General.[35]

123. The Scientific Committee adopted a silence procedure for taking decisions during the COVID-19 pandemic. The Committee agreed to hold its sixty-ninth session in Vienna from 9 to 13 May 2022.

[34] *Official Records of the General Assembly, Seventy-third Session, Supplement No. 46* (A/73/46).
[35] Including Assembly resolutions 63/478, 66/524 and 69/350.

Chapter VI

Scientific report

124. The scientific annex on the evaluation of occupational exposure to ionizing radiation was approved by the Committee at its sixty-eighth session.

Evaluation of occupational exposure to ionizing radiation

125. The Scientific Committee has been collecting and evaluating sources and levels of occupational exposure since 1975. Occupational exposure to ionizing radiation can occur as a result of activities utilizing radiation or radioactive substances in industry, medicine, education and research and can also occur when workers[36] are exposed to natural sources of radiation. The Committee's evaluations of worldwide occupational exposure to ionizing radiation provide information relevant for policy- and decision-making regarding the safe use of radiation. The resulting dose distributions and trends provide insight into the main sources and situations of exposure and information about the main factors influencing exposures. The evaluations assist in identifying emerging issues and may identify situations that should be subjected to more attention and scrutiny by different stakeholders.

126. The Scientific Committee has conducted evaluations of worldwide occupational exposure levels and trends based on two sources: (a) data from the UNSCEAR Global Survey of Occupational Radiation Exposure; and (b) reviews and analyses published in peer-reviewed literature. The evaluation of occupational exposure to ionizing radiation by the Committee is based on the individual monitoring of workers or their workplaces and the recording of their exposure. Data on occupational radiation exposure in Member States are generally collected in terms of effective dose as it is used for radiation protection purposes. Therefore, occupational exposure is expressed in operational terms like "effective dose" and "collective effective dose". These are the radiation protection quantities used by the international safety standards established under the aegis of IAEA with the co-sponsorship of relevant international intergovernmental organizations.[37]

127. At its sixty-second session in 2015, the Scientific Committee recommended to start work on the next UNSCEAR Global Survey of Occupational Radiation Exposure. The Committee issued a global survey using the same structure as used for the previous one on medical exposures, requesting Member States to appoint national contact persons, promoting meetings to clarify uncertainties and facilitating data collection in order to promote greater participation of the Member States. In addition, efforts for greater geographical coverage of data from different countries and regions of the world were made, in order to better assess and reduce uncertainties in the analysis of exposures. Despite those efforts, the commitment of the Member States, even those that are members of the Committee, was not at the desired level, thereby delaying the evaluation and conclusion of the annex. The Committee noted that not more than 57 Member States had submitted data for the UNSCEAR Global Survey of Occupational Radiation Exposure.

128. In the scientific annex, the Scientific Committee has analysed new available data up to 2014. The Committee expressed its gratitude to the expert group on evaluation of occupational exposure to ionizing radiation and to the delegations for the technical discussions on this very important subject. The Committee welcomed the arrangements with the International Civil Aviation Organization (ICAO) which resulted in the provision of data on aircrew by additional Member States and for

[36] An occupationally exposed worker is any person who is employed, whether full time, part time or temporarily, by an employer and who has recognized rights and duties in relation to occupational radiation protection.

[37] IAEA, *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards – General Safety Requirements Part 3* (2014).

additional years. The Committee also expressed its appreciation to the Member States and their national contact persons and experts who were involved in collecting, reporting and analysing the national data on occupational exposure in a broad range of sectors. Without reliable national data, it would not have been possible to conduct the evaluation, perform worldwide extrapolation and identify trends. However, a limitation of the assessment is that the data submission rate remained low and the lack of data continues to be a serious issue in a number of job sectors and for a number of exposure situations.

129. The Scientific Committee has considered the results of the evaluation on occupational exposure in comparison with the results in its previous UNSCEAR 2000 report [38] and UNSCEAR 2008 report [39] and reached the following conclusions contained in paragraphs 130–141 below.

130. The evaluation of the level of occupational radiation exposure has improved substantially for certain occupational sectors, for example, the medical, mineral extraction (including coal and uranium), nuclear fuel cycle and civilian aviation sectors, as compared with the evaluation in the UNSCEAR 2008 report. Collaboration with international organizations (e.g., IAEA, NEA/OECD and ICAO) is credited with much of this improvement because of the provision of additional information. The responses from States members of the Committee and United Nations Member States were marginally improved. In spite of these improvements, the overall number of occupationally exposed workers and their collective radiation exposure are underestimated for some occupational sectors due to limited data, and therefore the Committee has provided the best estimates. Another challenge for evaluating the levels of regional and global occupational exposure is to improve the consistency of reported data as well as improving the representativeness of the data through the participation of more countries. Initiatives for future assessments should focus on encouraging and supporting Member States to submit their available data.

131. The worldwide annual number of workers exposed to natural and human-made sources of ionizing radiation is estimated by the Committee to be approximately 24 million in the period 2010–2014. About 52 per cent of those were employed in the sectors that involve exposure to natural sources of radiation and about 48 per cent were employed in sectors that involve exposure to human-made sources of radiation. That total number of workers is a slight increase compared with the period 1995–1999, when the annual number estimated by the Committee was about 23 million workers for both sources combined (see figure III).

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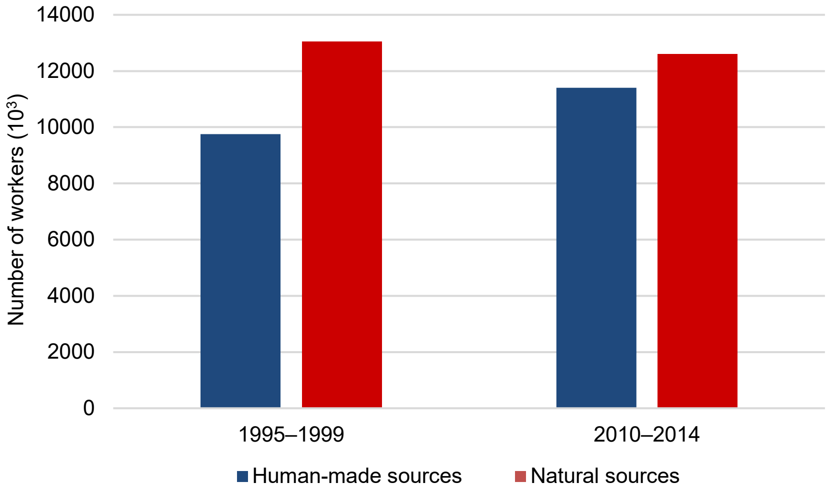
[38] *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 2000 Report to the General Assembly*, vol. I (United Nations publication, 2000).

[39] *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 2008 Report to the General Assembly*, vol. I (United Nations publication, 2010).

Figure III
Estimated annual number of workers exposed to radiation by source of exposure



132. For exposure to natural sources of radiation during the period 2010–2014, the extraction and processing of coal and minerals other than coal and uranium accounted for 94 per cent of the annual number of workers. About 12 million were employed in mining operations: 70 per cent in coal mining and 30 per cent in other mining operations, excluding uranium mining. The estimated number of people employed in civilian aviation (who are mainly exposed to cosmic radiation) was 0.7 million. The annual collective effective dose for natural sources was about 24,300 man Sv (excluding oil and gas extraction and radon exposure in workplaces other than mines due to lack of data).

133. The estimated worldwide annual number of monitored workers exposed to human-made sources increased to over 11.4 million in 2010–2014 compared with about 10 million in the period 1995–1999. The medical sector dominated the workforce exposed to human-made sources, accounting for about 80 per cent of the total. The average annual effective dose for the period 2010–2014 for all human-made sources was about 0.5 mSv, a substantial decrease from 1.7 mSv some 40 years ago, and the average annual collective effective dose was about 5,500 man Sv (see table 2).

Table 2
Estimates of worldwide occupational exposure associated from human-made sources for the period 2010–2014

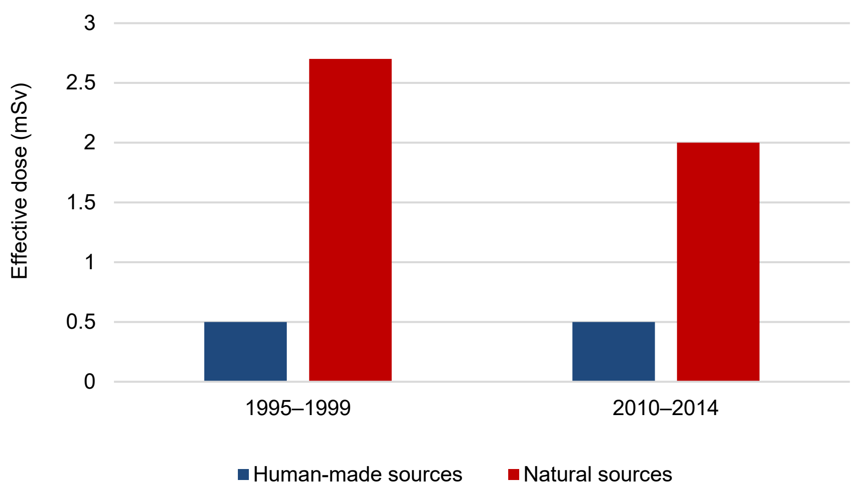
Sectors	*Number of monitored workers (10^3)[a]*	*Annual collective effective dose (man Sv)*	*Weighted average annual effective dose (mSv)*
Nuclear fuel cycle	760	485	0.6
Medical use	9 000	4 500	0.5
Industrial use	1 100	437	0.4
Miscellaneous use	540	38	0.1
Total	**11 400**	**5 460**	**0.5**

[a] Values are rounded.

134. The worldwide average annual effective dose for all workers during the period 2010–2014 was estimated to be around 1.2 mSv – about two thirds of the value estimated for the period 1995–1999. The annual effective dose was estimated to be around 2.0 mSv for workers exposed to natural sources and 0.5 mSv for workers exposed to human-made sources. In the period 1995–1999, the estimated annual effective dose to workers exposed to natural sources was 2.7 mSv (excluding radon

exposure in workplaces other than mines), while the exposure from human-made sources remained at 0.5 mSv (see figure IV).

Figure IV
Estimated average annual effective dose of workers by radiation source (mSv)



135. The values presented in this report for natural and human-made sources are estimates because many Member States did not provide data. The estimates of the Committee are based on a process of mathematical and statistical extrapolation using the limited available data provided by the countries in response to the UNSCEAR Global Survey of Occupational Radiation Exposure. However, for the first time, in this report, uncertainty estimates for occupational exposures are provided to characterize the precision and accuracy of the reported estimates of number of workers, expressed as a range of the average annual effective dose, and the annual collective effective dose. Occupational sectors with more data generally have a narrower range, clearly demonstrating the value of having more data, from more countries, available for analysis.

136. Improvements for the period 2010–2014 were possible for several reasons, including the cooperation of international organizations and use of improved mathematical and statistical techniques. For example, (a) the improvement in the estimation of crew exposure in civilian aviation was due to the detailed information on worldwide air traffic and civilian aviation personnel provided by ICAO; (b) the improvement in the estimates for the subsectors of the nuclear fuel cycle was due to availability of information from the Information System on Occupational Exposure database (jointly maintained by IAEA and NEA/OECD), IAEA and the World Nuclear Association; and (c) in the medical sector, improvements were due to use of mathematical multivariable models with mathematical derivation of uncertainties.

137. While some improvements were possible, limited data received through the UNSCEAR Global Survey of Occupational Radiation Exposure and the lack of correlations between the data and available predictor variables resulted in the inability to estimate the worldwide level of exposure for all subsectors. Relatively complete data submission for the nuclear fuel cycle worker sectors and the reliability of this information is well documented. The Committee noted that there was a likely underestimation of the number of workers and estimated collective effective doses, owing to the incomplete data submission for some occupational sectors for the reporting period. For most of the subsectors of the industrial sector, military, occupations involving exposure to radon and several subsectors of the nuclear fuel cycle, the reported data did not allow the Committee to make sufficiently robust worldwide estimates, and this remains an area for the Committee's future work.

138. Although the data received by the Committee from Member States for this evaluation are limited, extensive new data have been reviewed for some sectors. Essential data collection with a larger number and broader representation of Member States (e.g., regions, income level) has been identified as a future area of work for the Committee in order to reduce uncertainties, to allow the extrapolation of estimated occupational exposure for sectors with limited data (e.g., for gas and oil extraction, exposure to radon in workplaces other than mines) and to enhance estimates of trends in different work sectors. The Committee recommended the use of its occupational questionnaire to collect such information on a regular basis.

139. The Committee noted that reported data on the equivalent doses for the lens of the eye and for the hands (skin dose) were limited. It is expected that for the Committee's next evaluation of occupational exposure, more countries will be in a position to provide reliable data on this topic.

140. The current evaluation of occupational radiation exposure has not identified any group of workers receiving high annual effective doses due to implementation of new techniques in using radiation sources. As the assessment of the worldwide occupational exposure is a complex task, the Committee relies on the collection of up-to-date data on occupational exposure from all States Members of the United Nations and continued collaboration with international organizations.

141. 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.

Appendix I

Members of national delegations attending the sixty-fourth to sixty-eighth sessions of the United Nations Scientific Committee on the Effects of Atomic Radiation in the preparation of its scientific reports for 2020 and 2021

Argentina	A. J. González (Representative), D. Álvarez, A. Cánoba, P. Carretto, M. Ermacora, M. di Giorgio
Australia	G. Hirth (Representative), C. Lawrence, S. Solomon, P. Thomas, A. Wallace, I. Williams
Belarus	A. Razhko (Representative), A. Stazharau (Representative), S. Sychik (Representative), A. Aventisov, V. Drobyshevskaya, A. Nikalayenka, L. Sheuchuk, V. Ternov
Belgium	H. Vanmarcke (Representative), S. Baatout, H. Bosmans, F. Dekkers, H. Engels, F. Jamar, L. Mullenders, H. Slaper, P. Smeesters, P. Willems
Brazil	L. Vasconcellos de Sá (Representative), D. de Souza Santos, P. Rocha Ferreira
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ANNEX A

EVALUATION OF MEDICAL EXPOSURE TO IONIZING RADIATION

CONTENTS

The attachments cited in this annex and its appendices are electronically available for download from http://www.unscear.org/unscear/en/publications/2020_2021_1_Attachments.html

LIST OF ABBREVIATIONS

CBCT	Cone beam computed tomography
CT	Computed tomography
CTA	Computed tomography angiography
CTCA	Computed tomography coronary angiography
$CTDI_{vol}$	Volume-weighted computed tomography dose index
DAP	Dose-area product
DIRAC	IAEA Directory of Radiotherapy Centres Database
DLP	Dose-length product
ECG	Electrocardiogram
EC DDM	European Commission Dose Data Med project
EPI-CT	Epidemiological study to quantify risks for paediatric computerized tomography
ERCP	Endoscopic retrograde cholangiopancreatography
ESD	Entrance surface dose
HCL	Health-care level
HDR	High dose rate
HERO	Health Economics in Radiation Oncology study
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IEC	International Electrotechnical Commission
IGRT	Image-guided radiation therapy
IMRT	Intensity-modulated radiation therapy
INCAPS	IAEA Nuclear Cardiology Protocols Cross-Sectional Study
IOMP	International Organization for Medical Physics
IR	Interventional radiology
IVU	Intravenous urography
KAP	Kerma area product
LDR	Low dose rate
LSJ	Lumbosacral junction
MIRD	Medical Internal Radiation Dosimetry
MPI	Myocardial perfusion imaging
MRI	Magnetic resonance imaging
MSCT	Multi-slice computed tomography
NCI	National Cancer Institute

NCRP	National Council on Radiation Protection and Measurements
NM	Nuclear medicine
NRPB	National Radiological Protection Board
NUMDAB	IAEA Nuclear Medicine Database
OECD	Organisation for Economic Co-operation and Development
PCI	Prophylactic cranial irradiation
PET	Positron emission tomography
PSMA	Prostate-specific membrane antigen
PTCA	Percutaneous transluminal coronary angioplasty
QI	Quality indices
SAFRAD	IAEA Safety in Radiological Procedures Database
SAFRON	IAEA Safety in Radiation Oncology Database
SPECT	Single photon emission computed tomography
TIPS	Transjugular intrahepatic portosystemic shunt
TOP 7	Top 7 nuclear medicine procedures contributing most to the collective dose
TOP 20	Top 20 radiological examinations contributing most to the collective dose
VMAT	Volumetric modulated arc therapy
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization

I. INTRODUCTION

1. Medical exposure evaluations of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have aimed to determine the annual frequencies of medical examinations and procedures involving the use of ionizing radiation and their associated radiation doses to patients.[1] Past reports of the Committee [U4, U5, U6, U7, U9] have encompassed exposure and practice in diagnostic radiology, nuclear medicine and radiation therapy. Data have been analysed to deduce temporal trends, to evaluate the population dose due to medical exposure, and to identify the major contributing procedures to the total collective dose to patients.

2. The overall purpose of this annex is to assess the magnitude of the medical exposure of patients to ionizing radiation worldwide since the UNSCEAR 2008 Report [U9], to determine the relative contributions to dose from various modalities and procedures, and to assess trends. The annex does not assess the benefits or risks arising from medical exposure nor occupational exposure resulting from work involving the medical use of ionizing radiation.

3. This annex presents a comprehensive, up-to-date review of medical exposure worldwide. The review is based on an analysis of *(a)* the responses of United Nations Member States to the UNSCEAR Global Survey on Medical Exposure[2] for the years 2009–2018, with a majority of data provided for the period 2014–2017, and on *(b)* a review of the published literature on medical exposure, also since the UNSCEAR 2008 Report [U9]. The annex also presents estimates of the frequency (per 1,000 population) of diagnostic examinations and therapeutic medical procedures, and the associated radiation doses.

4. Details of the methodology of the global assessment used are presented in appendix A, while detailed results from the UNSCEAR Global Survey, and the comprehensive review of the published literature are presented in appendices B to E.

II. SCOPE AND OBJECTIVES OF ANALYSIS

5. Medical exposure covers: *(a)* exposure of patients as part of their medical diagnosis or treatment; *(b)* exposure of asymptomatic people as part of health screening programmes or individual health assessment; and *(c)* exposure of healthy individuals or patients voluntarily participating in medical, biomedical, diagnostic or therapeutic research programmes [I3]. The latter is not included in the evaluation as it is not part of exposure resulting from medical diagnosis or treatment.

6. This evaluation considers four general categories of medical practice using ionizing radiation: *(a)* diagnostic radiology, including dental radiology and computed tomography; *(b)* image-guided interventional procedures (interventional radiology); *(c)* nuclear medicine; and *(d)* radiation therapy. The Committee further divided diagnostic radiology into subcategories for the purpose of deriving an improved global assessment. More details are presented in section III. Doses from radiation therapy and radionuclide therapy are not included in the global estimate of collective effective dose as effective

[1] The term "patient" refers only to those individuals undergoing radiological procedures with regard to medical exposure as defined in the International Basic Safety Standards [I3].

[2] "UNSCEAR Global Survey" is used throughout the document where possible (see also https://www.survey.unscear.org).

dose is only suitable for use in the low to medium dose range, where stochastic effects predominate, not the high dose range where tissue reactions become significant. However, frequencies of courses of radiation therapy treatment and radionuclide therapy treatments are considered in the trend analyses. The annex addresses mainly medical radiological imaging for the estimation of population doses from ionizing radiation; therefore, the use of non-ionizing radiation imaging such as magnetic resonance imaging (MRI) is not included in the scope of this evaluation. The appendices present additional supporting information on radiological equipment and associated medical staff. Uncertainties in the Committee's global estimate of medical exposure are also addressed. More detailed information on uncertainties, the models tested, and data used in the evaluation are presented in electronic attachments.

7. Diagnostic radiology generally refers to the analysis of images obtained using X-rays. These include projection radiography (e.g., chest X-rays, mammography), images obtained using fluoroscopy (e.g., barium swallow, barium meal or barium enema examinations) and images obtained by devices using computerized reconstruction techniques such as computed tomography (CT). Dental radiology is also included in diagnostic radiology; however, for this analysis it was presented separately as it affects the estimation of frequencies of radiological examinations.

8. Interventional radiology refers to procedures where X-ray imaging is used to guide the placement of devices in the body to repair structures, excise or clear pathology, or otherwise treat disease. Such procedures may be performed by clinicians other than radiologists, such as cardiologists, orthopaedic surgeons, gastroenterologists, urologists and vascular surgeons.

9. Nuclear medicine procedures involve the introduction of unsealed radioactive substances into the body, most commonly to obtain images that provide information on either structure or function of an organ. The radioactive substance may be administered intravenously, orally or by inhalation. A radionuclide is usually combined with a targeting chemical to form a radiopharmaceutical that will be distributed in the body according to physical or chemical characteristics (e.g., a radionuclide incorporated in a phosphate will localize in the bone, making a bone scan possible). Radiation emitted from the body is analysed to produce diagnostic images. Less commonly, radionuclides are administered to treat certain diseases such as hyperthyroidism, thyroid cancer, bone metastasis, primary or metastatic liver cancer, lymphomas and neuroendocrine tumours.

10. Radiation therapy refers to the use of ionizing radiation produced by a sealed source or a radiation generator to treat various diseases (usually cancer). Sometimes radiation therapy is referred to as radiation oncology; however, benign diseases may also be treated. Radiation therapy is delivered through external beams of radiation (teletherapy) or by placing sealed radioactive sources in or near the tumour tissue (brachytherapy). External radiation beams may consist of high-energy X- or gamma rays, electrons, protons, neutrons, or heavier charged particles. Gamma-ray beams are often produced by high-activity sources of ^{60}Co while all other external radiation beams are produced by electrical equipment. Radiation therapy (especially teletherapy) for a particular patient is frequently delivered over a course of several separate exposures (treatment fractions). Here, as in previous UNSCEAR reports (e.g. [U9]), the global annual total number of treatment courses (radiation therapy treatments) is estimated, rather than the number of treatment fractions. It is important to note that second malignancies following radiation therapy are not included in the scope of this evaluation. However, the Committee has commenced a specific evaluation dealing with the dosimetric, biological and epidemiological aspects pertaining to the risks of second primary cancer after radiation therapy.

11. The objectives of the evaluation are to:

- Provide comprehensive global estimates of frequency and dose for medical exposure, and the distribution by medical exposure categories, age, sex, and specified levels of health care and income;
- Evaluate the uncertainties in the estimates and identify gaps in the data coverage;
- Examine trends in practice and in the contributions to dose made by various techniques to derive benchmarks for comparison purposes and to manage exposure;
- Summarize supporting contextual evidence on devices and staff levels and associated trends;
- Identify emerging issues and areas for future research that may warrant more attention and scrutiny, including opportunities to improve future evaluations of global medical exposure.

12. These objectives were met by providing:

- Estimates of annual collective effective dose and associated annual effective dose per caput from medical radiological imaging worldwide, with separate assessments in relation to diagnostic radiology, interventional radiology and nuclear medicine;
- Estimates of annual total numbers and associated frequencies (per 1,000 population) of diagnostic radiology examinations, interventional radiology procedures, nuclear medicine procedures and radiation therapy treatments;
- Evaluations of the uncertainties in the estimates of the numbers of examinations/procedures and collective effective dose;
- Analyses of the distributions of common types of examinations/procedures in terms of age, sex, typical average doses and frequencies of examinations/procedures and the collective dose, together with analysis of national/regional variations in practice;
- Analyses of temporal trends in frequency of examinations/procedures and dose across the periodic results provided by the Committee's global assessments of medical exposure;
- Identification of areas for future analysis and for consideration in improving future global assessments of medical exposure.

13. The Committee previously addressed the subject of accidental exposure of patients, particularly in relation to radiation therapy in its UNSCEAR 2008 Report [U9]. Therefore, accidental exposure is out of the scope of this evaluation. Accidental exposure can occur in all types of medical use of ionizing radiation, though the consequences of such exposure in radiation therapy are usually the most severe due to the high doses involved. The International Atomic Energy Agency (IAEA) runs widespread incident reporting and learning systems for tracking the frequency of incidents and for developing improved practice to minimize the likelihood and consequence of such incidents: Safety in Radiological Procedures (SAFRAD) and Safety in Radiation Oncology (SAFRON) databases record incidents and "near-miss" data anonymously [I4].

III. METHODOLOGY AND SOURCES OF DATA

14. Evaluation of medical exposure consists in assessing the annual frequencies of the types of examinations/procedures being undertaken and evaluating the radiation doses for each type. Annual frequency and dose data are derived from two main sources: *(a)* the UNSCEAR Global Survey on Medical Exposure and *(b)* the comprehensive peer-reviewed scientific literature, supplemented by reports from relevant national authorities within Member States of the United Nations.

A. UNSCEAR Global Survey on Medical Exposure

15. A detailed questionnaire was developed for the UNSCEAR Global Survey on Medical Exposure, which sought collection of all available national information concerning annual numbers of procedures and measures of typical exposure (including effective dose and physical dose quantities, as discussed in appendix A), together with additional supporting information on national practice. In the case of radiotherapeutic exposure, information was requested on the total prescribed absorbed dose to the planning target volume over an entire course of treatment or the administered activity in the case of radiopharmaceutical therapy.

16. To improve the efficacy of the UNSCEAR Global Survey, an online UNSCEAR platform was developed. The platform provides a structure to capture the data provided for the present and future surveys. The UNSCEAR online platform is comprised of tools for *(a)* data collection via spreadsheets; *(b)* data processing and storage via a database; *(c)* data analysis via a specific module; and *(d)* data descriptions to assist contributing countries via the user manual for the UNSCEAR Global Survey [U11].

17. The UNSCEAR Global Survey was launched in 2014. To encourage increased participation of United Nations Member States and secure the collection of all available data, particularly from countries that could supply only less detailed information, a simplified version of the questionnaire was introduced in 2017 asking for essential data. The essential data included key indicators of practice: annual total numbers of examinations/procedures within each broad type of radiological discipline (all diagnostic radiology with categorization into conventional radiology, dental radiology, interventional radiology, and computed tomography separately), together with totals for broad types of equipment and staffing levels. Similar information was sought in relation to nuclear medicine and radiation therapy. The responses to the current survey cover the years 2009–2018, with a majority of data provided for the period 2014–2017.

B. Literature review

18. A comprehensive review of published literature related to medical exposure was conducted, covering the period 2005–2018, with inclusion of additional relevant recent articles and reports. Publications were deemed suitable for pre-screening if there was a match on one or more of the following search terms: population dose, collective effective dose (medical), frequencies of examinations, procedures or treatments (radiology, nuclear medicine and radiation therapy),

examination codes, patient dose and radiology, automatic dose management. Screening sought to identify publications that might demonstrate changes and updates in practice since the previous UNSCEAR 2008 Report [U9]. A total of 640 articles were identified for review, of which 373 were assessed as meeting the criteria for inclusion in this evaluation.

19. Table 1 summarizes national or regional evaluations of medical exposure published since the previous UNSCEAR 2008 Report [U9] representing the contributions of the main imaging categories to the total frequencies (number of examination per 1,000 population) and to the population dose from medical radiological imaging (collective effective dose). This also includes data focussing on the 20 examinations and procedures that contribute most to the overall collective dose (TOP 20), a methodology developed by the European Commission Dose Data Med 1 project (EC DDM 1) [E3] and applied in its follow-up project Dose Data Med 2 (EC DDM 2) [E5]. The published literature indicates that contributions of computed tomography to total frequencies are typically much lower than their contribution to the total collective effective dose, while dental examinations typically make a high contribution (up to 40%) to the total frequency of diagnostic examinations but less than 1% to the total collective effective dose from medical exposure. Interventional radiology is typically less than 1% of the total frequency but the mean contribution to the total collective effective dose is ~8%.

Table 1. Evaluations of medical exposure for main imaging categories published since the UNSCEAR 2008 Report [U9]

CT: Computed tomography; IR: Interventional radiology; NM: Nuclear medicine; PET: Positron emissions tomography; SPECT: Single photon emission computed tomography

Country	*Year (period)*	*Contributions to total frequencies (%) (including dental and NM when percentage is given separately)*						*Contribution to population dose (%) (including dental and NM when percentage is given separately)*						*Reference*
		Conventional radiology			*CT*	*IR*	*NM*	*Conventional radiology*			*CT*	*IR*	*NM*	
		Radio-graphy	*Fluoro-scopy[a]*	*Dental*				*Radio-graphy*	*Fluoro-scopy[a]*	*Dental*				
Australia[b]	2010	66.1	3.2		25.5	0.3	4.9[c]	15.7	9.6		66.7	1.4	6.7[c]	[H6]
Bulgaria	2010	72.1	7.8	12	7.1	0.4	0.5	19.1	28.6	0.3	43	7.2	2.1	[E5]
Finland	2008				8			14.6	12.5	0.6[d]	54.2	12.5	6.3	[B19]
Finland	2008	54.1	0.8	39	5.1	0.5	0.5	15.1	10.8	0.7	55.9	12.9	5.4	[E5]
France	2007	63		24.7	10.1	0.6	1.6	26.1		0.2	58	5.5	10.2	[E10]
France[e]	2010	55.3		42.3	2.1	0.3		69.4		1	26.7	2.9		[E11]
France	2012	54		33.8	10.4	0.5	1.3	17.7		0.2	71.3	3.1	7.8	[D10]
Germany	2009	58.2	3.1	26.6	9	0.8	2.4	13.7	17.1	0.3	57.7	6.9	4.6	[E5]
Ireland	2010-2013	68.5	0.9	23	5.7	0.9	1	10	3	<1	55	23	9	[O1]
Italy[f]	2006	83[g]			15		2	12[g]			78		10	[C12]
Kenya	2011	94.3[h]	2.36		3.3	0.04		55.8[h]	4.9[i]		35.6	3.6[j]		[K13]
Republic of Korea[k]	2013	85	1	10.7	2.9		0.3	29.6	7.6	0.3	53		9.7	[L3]
Luxembourg	2002	58.4		27.7	10.4	0.7	2.8	36			50	6	7.6	[S12]
Norway	2002	73.8			14.1			41			59			[B25]
Romania	2012	73	8.4[i]	11.3	7	0.3[j]	0.3	10	9		79	2		[G5]
Russian Federation	2015	95.6[l]	0.7		2.9	0.6[m]	0.2	36.7[n]	6.8		44.9	9.9[o]	1.7	[B6]
Slovenia	2011	92.8	1.5		5.1 (9.8)[p]	0.6		19	6		64	11 (4.8)[p]		[Z1]
Sudan[q]	2010	99	0.1		1	0.03		83	0.7		16	0.5		[S24]
Switzerland	2008	50.2	1.2	41.3	6	0.8	0.6	15.5	4.1	0.7	65.2	11.4	3.8	[E5]

Country	Year (period)	Contributions to total frequencies (%) (including dental and NM when percentage is given separately)						Contribution to population dose (%) (including dental and NM when percentage is given separately)						Reference
		Conventional radiology			CT	IR	NM	Conventional radiology			CT	IR	NM	
		Radio-graphy	Fluoro-scopy[a]	Dental				Radio-graphy	Fluoro-scopy[a]	Dental				
Switzerland	2008	49.7	1.2	41.9	6	0.8[r]		15.3	4.6	0.7	67.6	11.9[r]		[S3]
Switzerland	2013	41.4	1.25	47.4	9.6	0.36		11.5	11	0.9	70.4	6.2		[L2]
Taiwan, China[h]	2008	73.7		15	7.4	2.1	1.8	15.9	3.5	0.2	50.8	16.2	13.6	[C6]
United Kingdom	2008	61.5	2.3	27	7.3	0.7	11.1	14.1	9.4	0.4	63.5	7.1	5.9	[E5]
Ukraine	2009-2012	97[n]	2.3		0.7 (1.3)[p]	0.03		73.3[n]	20.9		5.3	0.5 (0.2)[p]		[S22]
United States	2006	74			17	4	5	11		0.3[s]	49	14	26	[N1]
United States[k,t]	2016	39	1	46	10	1	2	8	4	2	59	9	17	[N2]
Europe (36 countries)	2007-2010							22[u]	13		52	8	5	[B20]

[a] Fluoroscopy includes angiography examinations (e.g., coronary angiography).
[b] TOP 20 assessment, data for extremity radiography and dental radiography not included.
[c] Excluding contribution from PET examinations.
[d] Dental procedures were not included in the calculation of the other percentages.
[e] Paediatric examinations only.
[f] Emilia-Romagna region.
[g] Computed radiography only.
[h] Proportion of mammography: 0.38% frequency and dose.
[i] Excluding angiographies.
[j] Including angiographies.
[k] Calculation with ICRP 103 tissue weighting factors [I11].
[l] Includes chest screening 31.9%.
[m] Includes angiography and "other".
[n] Includes chest fluorography for tuberculosis screening as the most frequently performed type of X-ray examination, whereas it is not performed on a routine basis in other European countries.
[o] Includes chest screening 9.6%.
[p] Extrapolated value, TOP 20 value in parenthesis when differs from original values.
[q] Data not available for dental examinations and nuclear medicine procedures.
[r] Diagnostic and therapeutic interventional procedures.
[s] Dental bitewing and full-mouth procedures only.
[t] Data re-categorized (PET/CT and SPECT/CT moved to NM, gastrointestinal tract, urogenital and diagnostic coronary angiography moved to fluoroscopy).
[u] Includes dental procedures.

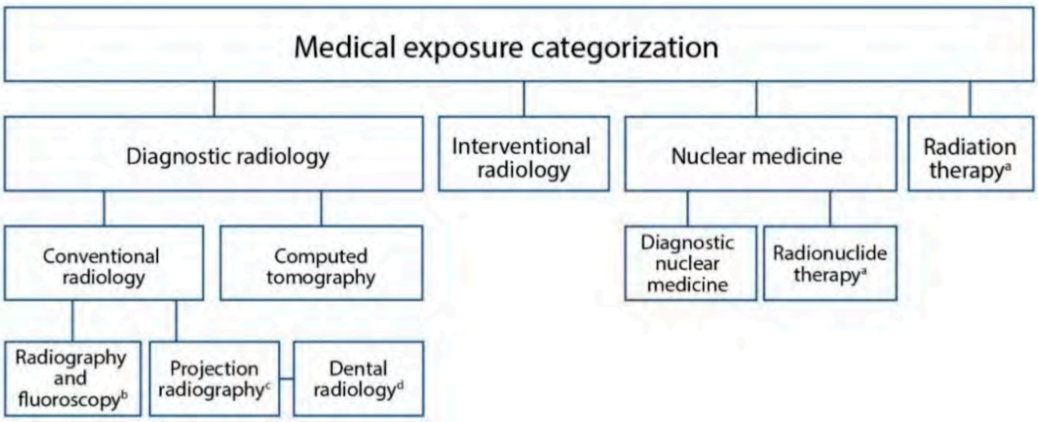
C. Methodology for global assessment

20. In previous UNSCEAR reports (e.g. [U9]), annual frequency data on procedures were stratified by health-care level (HCL) I, II, III or IV, according to the number of physicians per head of population (see also appendix A). The number of physicians had previously been shown to correlate well with the number of medical radiological examinations [M7]. The health-care levels are defined as *(a)* HCL I: >1 physician per 1,000 population; *(b)* HCL II: 0.334–1 physician per 1,000 population; *(c)* HCL III: 0.1–0.333 physician per1,000 population; and *(d)* HCL IV: <0.1 physician per 1,000 population. Previous global estimates were derived by determining both the population-weighted average frequencies for procedures and the population-weighted average dose per procedure within each health-care level and then extrapolating these population-weighted averages to the whole population within each health-care level. This approach worked well when the world population was relatively evenly distributed throughout health-care levels and when sufficient, representative data could be obtained for each level. In the present assessment, however, 53% of the total world population is in countries categorized as HCL I and very few data have been received from countries in other health-care levels.

21. An alternative to classification by health-care level is to use income classifications for countries as published by the World Bank [F3]. The World Bank income classification also comprises four levels: high, upper middle, lower middle and low. It is based on gross national income per capita valued annually in US dollars using a three-year average exchange rate. Cut-off points between classifications are fixed in real terms; they are adjusted each year in line with price inflation. The distribution of the global population using these levels (16%, 36%, 39% and 9%, respectively) is more even than is the case for HCLs I–IV (53%, 31%, 9% and 7%, respectively). Another advantage of using the World Bank classification is the possibility of comparing medical exposure with other health indicators as the World Health Organization (WHO) uses the same classification.

22. Assessment within particular classifications can be expected to yield good results when practice within a classification is relatively consistent. An alternative is to construct a mathematical model of the observed variation and use the model to predict practice in countries that have not supplied data. In this assessment, mathematical models of procedure frequencies within seven broad modality categories have been developed to generate projections for those countries that did not provide data to the UNSCEAR Global Survey. The modality categories used hereby are conventional radiology (including projection radiography without contrast, and radiography and fluoroscopy with contrast, but excluding dental radiology), dental radiology, computed tomography, interventional radiology, diagnostic nuclear medicine, radionuclide therapy and radiation therapy (figure I). While it would be desirable to include population demographics in such models to account for possible variations in procedure frequencies due to different age and sex distributions, it was not possible to adopt such an approach as only a limited number of countries were able to provide examination/ procedure counts with detailed age and sex distributions.

Figure I. Modality categorization scheme used for UNSCEAR medical exposure global assessment



[a] Not part of the collective effective dose assessment because such therapeutic doses are intentionally high enough to cause deterministic effects, however, included in the frequency trend analyses.

[b] Mostly with contrast media.

[c] Without contrast media.

[d] Analysed separately for the global assessment.

23. Diagnostic radiology was divided into the two main subcategories of conventional radiology and computed tomography. In the UNSCEAR Global Survey, dental radiology was included as a component of projection radiography within conventional radiology (figure I), but it was treated as a separate category in the assessment because it typically makes a major contribution to the total number of examinations but usually only a very small contribution to the collective dose. In contrast, the contribution of computed tomography to the total number of examinations was typically low but the collective dose may be high. The category of conventional radiology (excluding dental) typically makes the largest contribution to the total number of examinations/procedures.

24. For this assessment, interventional radiology procedures included minimally invasive procedures performed under fluoroscopy guidance with therapeutic purpose for any cerebral, cardiac, pulmonary, hepatobiliary, gastrointestinal, genitourinary, musculoskeletal and central nervous system diseases. Other minimally invasive procedures performed under fluoroscopy guidance with diagnostic purpose were included in the subcategory conventional radiology as part of radiography and fluoroscopy (mostly with contrast media).

25. Many nuclear medicine imaging procedures are now performed using hybrid systems such as Single photon emission computed tomography with a CT component (SPECT/CT) or Positron emission tomography with a CT component (PET/CT). For this assessment the CT component was considered to be an integral part of the total nuclear medicine procedure, thus, the CT radiation dose has been added to the dose resulting from the radiopharmaceutical to estimate a total dose per nuclear medicine procedure. Such CT components were not included in the CT subcategory of diagnostic radiology.

26. For this assessment, a continuous mathematical model, in the form of a power function of the physician density (all physicians per 1,000 population) in each country, was selected and applied for each medical exposure category. This choice was motivated by the availability of the physician density data, as WHO regularly publishes such values provided by its Member States, and the close relation to the HCL model used in previous UNSCEAR evaluations [U4, U5, U6, U9]. More sophisticated modelling involving multiple parameters was also performed, however the results from the single

parameter power function were generally preferred due to the simple interpretation, satisfactory predictive power, and the wide availability of data. Further details of the methodology of the global assessment of medical exposure and the models used are discussed in appendix A.

27. The global assessment of medical exposure was derived from the combination of *(a)* the UNSCEAR Global Survey data, supplemented by literature data where this was available for countries that did not provide a response to the survey, and *(b)* the results of the mathematical modelling (continuous model), and not from extrapolation of average frequency values within the HCL model as in previous UNSCEAR evaluations [U4, U5, U6, U9]. Uncertainties were assessed as standard uncertainties [J8] for the estimated examination/procedure frequencies and the corresponding mean dose values. Each uncertainty component is represented as a standard deviation and then combined into an overall standard deviation (see also appendix A and electronic attachment A-1). The assessment results are presented with breakdowns by health-care level and by income level to facilitate comparison with past UNSCEAR evaluations and to provide data that may be useful in comparing trends over time or between different countries or regions.

IV. ASSESSMENT OF GLOBAL PRACTICE

28. According to the UNSCEAR 2008 Report [U9], approximately 3.1 billion diagnostic radiology examinations, 0.48 billion diagnostic dental examinations, 3.6 million interventional radiology procedures, 33 million diagnostic nuclear medicine procedures, 5.1 million courses of radiation therapy treatment, and 0.9 million radionuclide therapy treatments were undertaken annually worldwide. The 24% of the population living in HCL I countries received approximately two thirds of these examinations.

29. Since the UNSCEAR 2008 Report [U9], there has been a major demographic shift (table 2) such that now more than 50% of the world population lives in HCL I countries. The principal reason for this shift is the movement of several countries, notable among them Brazil and China, from HCL II to HCL I. Nonetheless, there remains wide variation in health-care services and access to them within these broad groupings, and while large countries may meet the criterion for HCL I as a whole, many regions within them would rank at lower health-care levels. Therefore, this evaluation seeks to model the variation, rather than apply average values across whole health-care levels.

Table 2. Comparison of current world population distribution by health-care level with UNSCEAR 2008 Report [U9]

Health-care level category	*UNSCEAR 2008* [a] *(millions)*	*Proportion (%)*	*Current evaluation* [a] *(millions)*	*Proportion (%)*
I	1 540	24	3 908	53
II	3 153	49	2 256	31
III	1 009	16	622	9
IV	744	11	526	7
Total	**6 446**	**100**	**7 312**	**100**

[a] Values are rounded.

30. In the period covered by this evaluation (2009–2018), the annual number of medical radiological examinations/procedures, including diagnostic radiology, interventional radiology and nuclear medicine, is estimated to be 4.2 billion, corresponding to an annual collective effective dose of 4.2 million man Sv (table 3). The standard uncertainty in both results is estimated to be ±15%. Taking twice the standard uncertainty as an estimate of the overall uncertainty, the ranges for the total number of examinations and the total collective effective dose are thus ±30% (table 4). The estimated collective effective dose is approximately the same as for the previous assessment. As the global population has increased (from 6.4 to 7.3 billion), the resulting annual per caput effective dose from medical exposure has fallen slightly from 0.65 mSv in the UNSCEAR 2008 Report [U9] to 0.57 mSv, however the difference is within the bounds of the associated uncertainties. Uncertainties were not derived for the previous assessment, however the survey data in that case covered only 10–30% of the total world population in contrast to the 40–60% of the world population covered by the current UNSCEAR Global Survey (see also appendix A). It is therefore estimated that uncertainties in the current assessment are likely lower than in the previous UNSCEAR 2008 Report [U9]. In addition, there are an estimated 1.4 million therapeutic nuclear medicine treatments, and 6.2 million courses of radiation therapy treatment delivered each year.

31. Table 3 shows a breakdown of the total annual collective effective dose from medical radiological examinations/procedures, categorized by health-care level. Compared to the previous UNSCEAR 2008 Report [U9], the estimated annual per caput effective dose for HCL I has decreased markedly. However, this change is due largely to the demographic changes mentioned above, with several countries with large populations moving from HCL II to HCL I. Table 3 also shows the categorization by World Bank income levels [F3]. The annual per caput effective dose for high-income countries estimated in this assessment (1.71 mSv) is similar to the value for HCL I countries in the UNSCEAR 2008 Report [U9] (~2 mSv).

Table 3. Estimated annual per caput effective dose and annual collective effective dose from medical radiological examinations/procedures (2009–2018) by health-care level and by income level

The estimates are based on a continuous mathematical model (physician density per country)

Category	*Population (millions)*	*Annual per caput effective dose (mSv)* [a,b]	*Frequency (per 1 000 population)*	*Number of examinations/ procedures (millions)*	*Annual collective effective dose (1 000 man Sv)* [a,b]
Categorization by health-care level					
I	3 908	0.83	823	3 216	3 263
II	2 256	0.34	369	833	774
III	622	0.14	173	108	88
IV	526	0.05	71	37	27
Categorization by income level					
High	1 149	1.71	1 612	1 852	1 966
Upper middle	2 619	0.46	457	1 197	1 195
Lower middle	2 882	0.31	362	1 044	902
Low	662	0.13	153	101	89
Global	**7 312**	**0.57**	**574**	**4 194**	**4 152**

[a] For the effective dose determination, ICRP 60 tissue weighting factors were applied [I9].

[b] Values are rounded; however extended precision has been preserved to illustrate differences.

32. The contribution of the various modality categories to the overall number of examinations/procedures and the collective effective dose is shown in table 4 and the relative proportions are shown in figure II. Conventional radiology (excluding dental) accounts for 62.6% of procedures and 23.0% of the collective dose. Dental radiology accounts for 26.3% of procedures but only 0.2% of the overall collective dose. Computed tomography makes the largest contribution (61.6%) to the overall collective dose but accounts for only 9.6% of all procedures. Interventional radiology and diagnostic nuclear medicine make small contributions (0.6% and 1%, respectively) to the number of procedures but significant contributions (8% and 7.2%, respectively) to the overall collective dose.

33. The estimations presented in tables 3 and 4 were derived by applying a continuous model of the examination frequencies as a function of the physician density (all physicians per 1,000 population) in each country and using the model to estimate examination frequencies for countries that did not provide data to the UNSCEAR Global Survey. Arithmetic mean doses per examination were determined from the survey data and applied to all countries that did not provide dose information to the survey. Uncertainties for the total number of examinations were derived by combining the estimated uncertainties for examination counts included in country submissions to the survey with the uncertainties in the predictions of the continuous model. Uncertainties in the average doses per examination were determined from the provided data and combined with the uncertainties for the numbers of examinations to derive the uncertainty in the collective effective dose (see appendix A).

Table 4. Estimated annual number of medical radiological examinations/procedures (2009–2018) and contribution to collective effective dose by modality categories

Estimates are based on a continuous mathematical model (physician density per country). Uncertainties are expressed as 2-standard deviations

Modality category	*Examinations/ procedures (millions)* [a]	*Uncertainty (%)*	*Collective effective dose (1 000 man Sv)* [a,b]	*Uncertainty (%)*
Conventional radiology (excluding dental)	2 626	35	955	45
Dental radiology	1 101	60	10	70
Computed tomography	403	40	2 556	45
Interventional radiology	24	80	334	90
Diagnostic nuclear medicine	40	70	297	75
Radionuclide therapy [c]	1.4	35	Not included	
Radiation therapy [c]	6.2	25	Not included	
Total	**4 194**	**30**	**4 152**	**30**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] For the effective dose determination, ICRP 60 tissue weighting factors were applied [I9].

[c] Not included in the total.

34. The collective dose estimates presented in tables 3 and 4 are based on effective dose determined using the tissue weighting factors from International Commission on Radiological Protection (ICRP) Publication 60 [I9]. Table 5 presents a comparison between estimates based on the ICRP 60 tissue weighting factors (E-60) and estimates based on the ICRP Publication 103 [I11] tissue weighting factors (E-103). The estimated doses based on ICRP 103 tissue weighting factors were derived by multiplying the mean doses per procedure by E-103/E-60 ratios taken from the literature [A6, A7, H5,

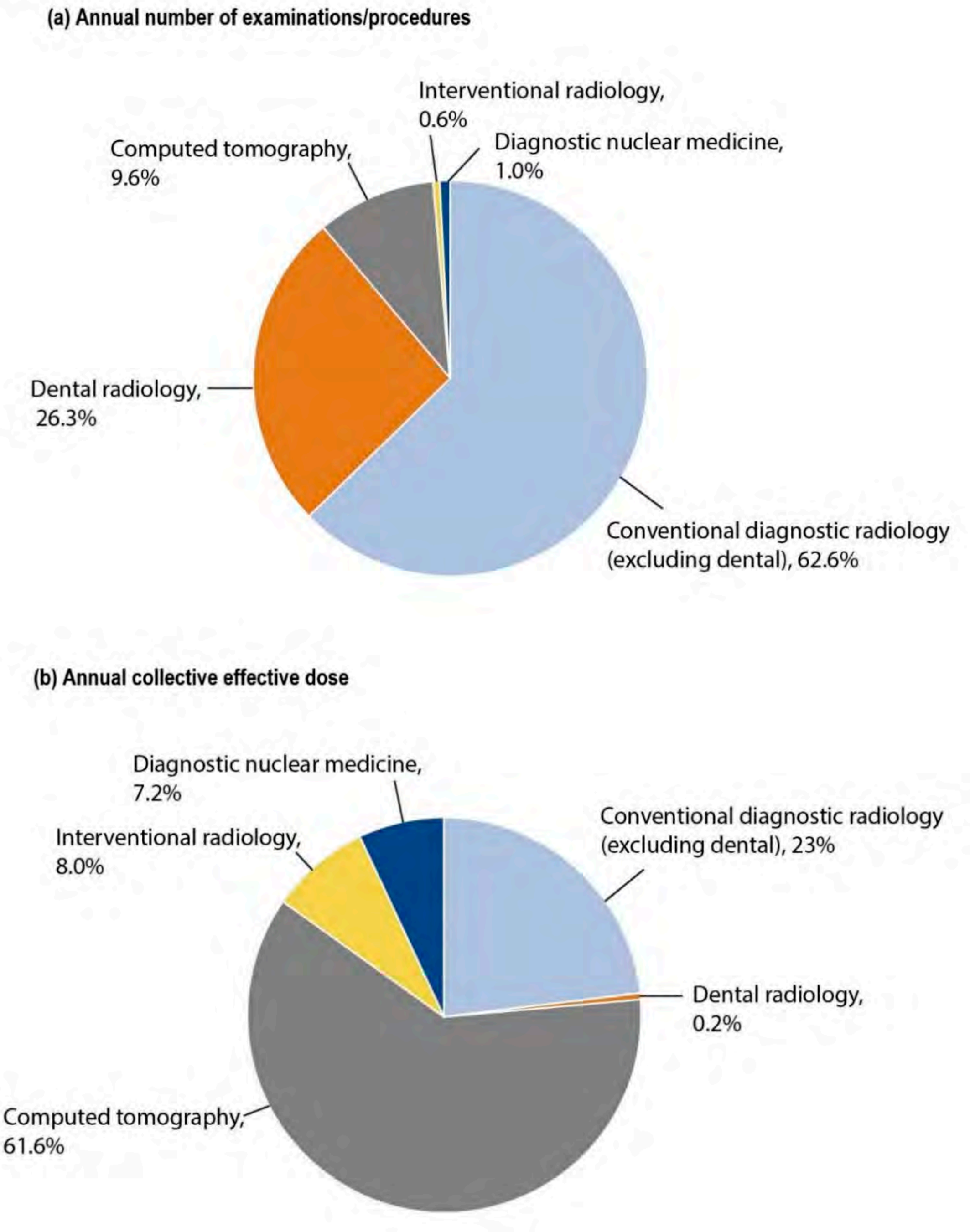
S14, W1]. While this approach is not as accurate as a full evaluation of organ doses for each procedure type, the impact of any additional uncertainty on the overall comparison is expected to be minor. The changes in the category totals when using the ICRP 103 weighting factors are quite small, except for diagnostic nuclear medicine and dental radiology. The total collective effective dose for diagnostic nuclear medicine is lower by 15% when using the ICRP 103 tissue weighting factors [I11], whereas the total collective effective dose for dental radiology rises by 88%. The dramatic rise for dental radiology is due to the inclusion of the salivary glands, the extra-thoracic airways, and the oral mucosa in the tissue weighting scheme of ICRP 103 [L10]. The reduction in effective dose for diagnostic nuclear medicine is largely due to changes in the reference computational phantom, rather than the changes in tissue weighting factors [A6]. The overall collective dose for medical radiological examinations/ procedures is lower by 1.6%. Similar results were found by the National Council on Radiation Protection and Measurements (NCRP) in its recent evaluation of medical exposure in the United States [N2]. NCRP reported a 5% reduction in the collective dose from computed tomography, a 20% reduction in the collective dose from nuclear medicine, and no change in the collective dose for radiography, fluoroscopy and interventional radiology. Doses for dental bitewing X-rays increased by 400%, while doses for full mouth series and panoramic X-rays increased by 200%. The overall estimated collective dose was 5% lower when using the ICRP 103 [I11] compared to ICRP 60 [I9] tissue weighting factors.

Table 5. Comparison of estimated annual collective effective dose (2009–2018) by imaging modality using ICRP 60 [I9] and ICRP 103 [I11] tissue weighting factors

Modality category	*Collective dose$_{ICRP60}$ (1 000 man Sv)* [a]	*Collective dose$_{ICRP103}$ (1 000 man Sv)* [a]	*Variation (%)*
Conventional radiology (excluding dental)	955	964	+0.9
Dental radiology	9.7	18.2	+88
Computed tomography	2 556	2 519	−1.5
Interventional radiology	334	332	−0.5
Diagnostic nuclear medicine	297	252	−15
Total	**4 152**	**4 085**	**−1.6**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

Figure II. Relative contributions by modality category to *(a)* estimated annual number of examinations/procedures and *(b)* estimated annual collective effective dose (2009–2018)



V. ANALYSIS OF FREQUENCY DATA

35. The global assessment of medical exposure was derived from analysis of the data submitted to the UNSCEAR Global Survey, supplemented with data from the published literature and national reports. The survey included requests for essential information (total number of examinations/procedures for broad survey modality categories); and responses containing this essential information were received from 58 countries. Replies to the detailed questionnaire on examination frequencies and data on radiation dose for diagnostic radiology were received from 33 countries. Only 11 countries submitted complete information including age and sex distribution by examination/procedure. Further, 54 countries provided information on nuclear medicine procedures and 51 countries on radiation therapy treatments. While there were a large number of contributions to the UNSCEAR Global Survey from HCL I countries, there were only few responses from HCL II–IV countries.

A. Diagnostic radiology

36. In extrapolating the data from the UNSCEAR Global Survey to derive a global estimate, diagnostic radiology was considered in three main subgroups: *(a)* conventional radiology (excluding dental); *(b)* dental radiology; and *(c)* computed tomography. Detailed data on diagnostic radiology are analysed and discussed in appendix B. Examination frequencies per 1,000 population for the three subgroups were available from countries that submitted essential data to the UNSCEAR Global Survey, as well as from countries that submitted more detailed data on the frequencies of specific examination types. Survey data, supplemented with similar data on overall frequencies from the EC DDM 2 project [E5], from recent published literature (e.g., [K13, S24]), databases maintained by other international organizations (e.g., IAEA, WHO), and from previous UNSCEAR reports [U6, U9] dealing with medical exposure, were used in the analysis.

1. Conventional radiology (excluding dental)

37. For conventional radiology (excluding dental), survey data from 43 countries were included in the evaluation. After inclusion of data from the EC DDM 2 project [E5] and from UNSCEAR reports [U6, U9], data from 65 countries, covering 48% of the total world population, contributed to the assessment.

38. The estimated total annual number of conventional radiography (excluding dental) examinations is 2.63 billion, with an uncertainty of ±35%. The total estimate was derived by combining the assessed data with the predictions of a continuous model for countries that did not submit data to the UNSCEAR Global Survey. The continuous model was a power-law fit to the examination frequencies in the assessed data as a function of physician density (all physicians per 1,000 population). A detailed summary is shown in table 6, with categorization by health-care level and by income level. The number of examinations in the assessed data is summarized, along with the estimates using the continuous model for the remaining countries, the resulting total and the overall average examination frequency. The uncertainties stated by countries in their survey submissions and the uncertainties of the predictions from the continuous model were combined to derive an uncertainty in the overall total estimate of ±35%. Further details of the modelling methodology and related uncertainties are given in appendix A and in electronic attachments A-1 to A-3.

39. The estimated annual total of 2.63 billion conventional radiology (excluding dental) examinations is a reduction of 9% from the 2.87 billion examinations per annum estimated in the UNSCEAR 2008 Report [U9]. The global average annual frequency has decreased from 445 to 359 examinations per 1,000 population. These differences are within the bounds of the estimated uncertainties.

Table 6. Global estimate of number of conventional radiology (excluding dental) examinations per annum derived from assessed data (2009–2018) and predictions from continuous model

Category	*Population (millions)*	*Examinations from assessed data (millions)* [a]	*Examinations from modelled data (millions)* [a]	*Total number of examinations (millions)* [a]	*Average examinations per 1 000 population*
Categorization by health-care level					
I	3 908	1 568	285	1 853	474
II	2 256	0.3	645	645	286
III	622	19	75	94	151
IV	526	0.04	34	34	65
Categorization by income level					
High	1 149	961	22	983	855
Upper middle	2 619	539	225	764	292
Lower middle	2 882	87	714	801	278
Low	662	0.3	78	78	118
Global	**7 312**	**1 587**	**1 039**	**2 626**	**359**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

2. Dental radiology

40. UNSCEAR Global Survey data from 36 countries were included in the assessment for dental radiology. After inclusion of data from the EC DDM 2 project [E5] and from UNSCEAR reports [U6, U9], data from 49 countries, covering 41% of the total world population, contributed to the assessment.

41. The estimated total annual number of dental radiology examinations is 1.1 billion, with an uncertainty of ±60%. The total estimate was derived by combining the assessed data with the predictions of a continuous model for countries that did not submit data to the UNSCEAR Global Survey. The continuous model was a power-law fit to the examination frequencies in the assessed data as a function of physician density. Details of the modelling are discussed in appendix A. A detailed summary is shown in table 7, with categorization by health-care level and by income level. The number of examinations in the assessed data is shown, along with the estimated number predicted by the continuous model for the remaining countries, the resulting total number of estimated examination and the overall average examination frequency per 1,000 population. The uncertainties stated by countries in their survey submissions and the uncertainties of the predictions from the continuous model were combined to derive an overall uncertainty of ±60%. Further details of the modelling methodology and related uncertainties are given in appendix A and in electronic attachments A-1 to A-3.

42. The estimated annual total of 1.1 billion dental radiology examinations is an increase of 130% from the 480 million examinations per annum estimated in the UNSCEAR report [U9]. The global average frequency has increased from 74 to 151 examinations per 1,000 population per year.

Table 7. Global estimate of number of dental radiology examinations per annum derived from assessed data (2009–2018) and predictions from continuous model

Category	*Population (millions)*	*Examinations from assessed data (millions)* [a]	*Examinations from modelled data (millions)* [a]	*Total number of examinations (millions)* [a]	*Average examinations per 1 000 population*
Categorization by health-care level					
I	3 908	809	173	982	251
II	2 256	0.07	111	111	49
III	622	0	6.9	6.9	11
IV	526	0	1.1	1.1	2
Categorization by income level					
High	1 149	628	16	644	561
Upper middle	2 619	164	125	289	110
Lower middle	2 882	17	137	154	53
Low	662	0	14	14	21
Global	**7 312**	**809**	**292**	**1 101**	**151**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

3. Computed tomography

43. UNSCEAR Global Survey data for computed tomography examinations were received from 43 countries. Additional data on examination frequencies were obtained from the EC DDM 2 project [E5] and from data reported to the Organisation for Economic Co-operation and Development (OECD) [O3]. Further data, particularly for HCL III and HCL IV countries, were used from UNSCEAR reports [U6, U9]. The assessment included data from 69 countries, covering 48% of the total world population.

44. The estimated total annual number of computed tomography examinations is about 400 million, with an uncertainty of ±40%. The total estimate was derived by combining the assessed data with the predictions of a continuous model for countries that did not submit data to the UNSCEAR Global Survey. The continuous model was a power-law fit to the examination frequencies in the assessed data as a function of physician density. Details of the modelling are discussed in appendix A. A detailed summary is presented in table 8 with categorization by health-care level and by income level. The number of examinations in the assessed data is also presented, along with the estimated number predicted by the continuous model for the remaining countries, the resulting total and the overall average examination frequency. The uncertainties stated by countries in their survey submissions and the uncertainties of the predictions from the continuous model were combined to derive an overall uncertainty of ±40%. Further details of the modelling methodology and related uncertainties are given in appendix A and in electronic attachments A-1 to A-3.

Table 8. Global estimate of number of computed tomography examinations per annum derived from assessed data (2009–2018) and predictions from continuous model

Category	*Population (millions)* [a]	*Examinations from assessed data (millions)* [a]	*Examinations from modelled data (millions)* [a]	*Total number of examinations (millions)* [a]	*Average examinations per 1 000 population*
Categorization by health-care level					
I	3 908	278	46	324	83
II	2 256	0	70	70	31
III	622	0.5	6.5	7.0	11
IV	526	0.06	1.88	1.9	3.7
Categorization by income level					
High	1 149	181	1.3	183	159
Upper middle	2 619	92.6	38.7	131	50
Lower middle	2 882	4.4	77	81	28
Low	662	0.01	7.8	7.8	12
Global	**7 312**	**278**	**125**	**403**	**55**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

45. Computed tomography makes the largest contribution to the overall collective dose from medical exposure, so uncertainties in the estimation of computed tomography examination frequencies are very important. The assessed data includes 278 million examinations in HCL I countries, approximately 86% of the overall total estimate of examinations in that HCL category, implying a relatively robust projection. The most critical point is the absence of survey data for HCL II, where the entire estimate of 70 million examinations derives from the modelling. Obtaining data on computed tomography scanning frequency in HCL II countries is an important future goal to produce robust estimates of collective dose from medical exposure. Equivalently, in the categorization by income levels, the lack of data for lower middle-income countries is the most significant source of uncertainty in the overall total estimate. More data from countries in the lower middle-income and low-income classifications would yield a better estimate in the future. The estimated annual total of about 400 million computed tomography examinations is an increase of 82% from the 220 million examinations per annum estimated in the previous UNSCEAR assessment [U9]. The global average frequency has increased from 34 to 55 examinations per 1,000 population per year.

B. Interventional radiology

46. UNSCEAR Global Survey data were received from 39 countries. After inclusion of data from the EC DDM 2 project [E5] and other sources, a total of 57 countries, covering 46% of the total world population, contributed to the assessment.

47. The estimated total annual number of interventional radiology procedures is about 24 million, with an uncertainty of ±80%. The total estimate was derived by combining the assessed data with the predictions of a continuous model for countries that did not submit data to the UNSCEAR Global

Survey. The continuous model was a power-law fit to the procedure frequencies in the assessed data as a function of physician density. Details of the modelling are discussed in appendix A. A detailed summary is presented in table 9 with categorization by health-care level and by income level. The number of procedures in the assessed data is presented, along with the estimated number predicted by the continuous model for the remaining countries, the resulting total and the overall average procedure frequency. The uncertainties stated by countries in their survey submissions and the uncertainties of the predictions from the continuous model were combined to derive an overall uncertainty of ±80%. Further details are given in appendix A and in electronic attachments A-1 and A-2.

48. The estimated annual total of about 24 million interventional radiology procedures represents an approximately sixfold increase from the 3.6 million procedures in the UNSCEAR 2008 Report [U9]. The annual global average frequency has increased from 0.6 to 3.2 procedures per 1,000 population. This large increase is partly due to difficulties in making an appropriate comparison; other procedures (cerebral and vascular) were included in the previous UNSCEAR 2008 Report [U9], which are not included in the total interventional procedures of this evaluation as they are considered as diagnostic and not therapeutic procedures (see also appendix C and electronic attachment C-1).

Table 9. Global estimate of number of interventional radiology procedures per annum derived from assessed data (2009–2018) and predictions from continuous model

Category	*Population (millions)* [a]	*Procedures from assessed data (millions)* [a]	*Procedures from modelled data (millions)* [a]	*Total number of procedures (millions)* [a]	*Average procedures per 1 000 population*
Categorization by health-care level					
I	3 908	16.5	2.8	19.3	4.9
II	2 256	0	3.9	3.9	1.7
III	622	0.01	0.3	0.31	0.5
IV	526	0	0.087	0.087	0.17
Categorization by income level					
High	1 149	13.5	0.44	13.9	12
Upper middle	2 619	3.04	1.93	4.97	1.9
Lower middle	2 882	0.03	4.32	4.35	1.5
Low	662	0	0.44	0.44	0.7
Global	**7 312**	**16.5**	**7.1**	**23.6**	**3.2**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

C. Nuclear medicine

49. The assessment for diagnostic nuclear medicine included UNSCEAR Global Survey data from 46 countries. With data from the EC DDM 2 project [E5] and from two UNSCEAR reports [U6, U9], data from 68 countries covering 52% of the total world population contributed to the assessment.

50. The estimated total annual number of diagnostic nuclear medicine procedures is 40 million, with an uncertainty of ±70%. The total estimate was derived by combining the assessed data with the

predictions of a continuous model for countries that did not submit data to the UNSCEAR Global Survey. The continuous model was a power-law fit to the procedure frequencies in the assessed data as a function of physician density. Further details of the modelling methodology and related uncertainties are given in appendix A and electronic attachments A-1 to A-3.

51. A detailed summary is shown in table 10 with categorization by health-care level and by income level. The number of procedures in the assessed data is shown, along with the estimated number predicted by the continuous model for the remaining countries, the resulting total and the overall average procedure frequency. The uncertainties stated by countries in their survey submissions and the uncertainties of the predictions from the continuous model were combined to derive an overall uncertainty of ±70%.

Table 10. Global estimate of number of diagnostic nuclear medicine procedures per annum derived from assessed data (2009–2018) and predictions from continuous model

Category	*Population (millions)* [a]	*Procedures from assessed data (millions)* [a]	*Procedures from modelled data (millions)* [a]	*Total number of procedures (millions)* [a]	*Average procedures per 1 000 population*
Categorization by health-care level					
I	3 908	33.9	3.9	37.8	10
II	2 256	0.26	1.82	2.1	0.9
III	622	0.004	0.072	0.076	0.12
IV	526	0.002	0.007	0.009	0.02
Categorization by income level					
High	1 149	28.1	0.39	28.5	25
Upper middle	2 619	5.4	2.8	8.2	3.1
Lower middle	2 882	0.6	2.2	2.8	1.0
Low	662	0.0006	0.39	0.39	0.6
Global	**7 312**	**34.1**	**5.8**	**39.9**	**5.5**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

52. The estimated annual total of 40 million diagnostic nuclear medicine procedures represents an increase of 22% from the 32.7 million procedures in the UNSCEAR 2008 Report [U9]. The global average frequency has increased from 5.1 to 5.5 procedures per 1,000 population per year.

53. Data on radionuclide therapy treatments were received from 41 countries, covering 47% of the global population. The estimated annual number of radionuclide therapy treatments is 1.4 million, with an uncertainty of ±35%. The total was derived by combining the assessed data with the predictions of a continuous model for countries that did not submit data to the UNSCEAR Global Survey. The continuous model was a power-law fit to the treatment frequencies in the assessed data as a function of physician density. Details of the modelling are discussed in appendix A. A detailed summary is shown in table 11 with categorization by health-care level and by income level.

Table 11. Global estimate of number of radionuclide treatments per annum derived from assessed data (2009–2018) and predictions from continuous model

Category	*Population (millions)* [a]	*Treatments from assessed data (millions)* [a]	*Treatments from modelled data (millions)* [a]	*Total number of treatments (millions)* [a]	*Average treatments per 100 000 population*
Categorization by health-care level					
I	3 908	0.874	0.207	1.081	28
II	2 256	0.060	0.227	0.287	13
III	622	0.002	0.042	0.044	7
IV	526	0	0.020	0.020	4
Categorization by income level					
High	1 149	0.268	0.073	0.341	30
Upper middle	2 619	0.619	0.110	0.729	28
Lower middle	2 882	0.049	0.274	0.323	11
Low	662	0	0.039	0.039	6
Global	**7 312**	**0.936**	**0.496**	**1.432**	**20**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

54. The estimated annual total of 1.4 million radionuclide treatments is an increase of 63% from an annual total of 880,000 treatments estimated in the UNSCEAR 2008 Report [U9]. The global frequency of radionuclide therapy has also increased from 14 to 20 treatments per 100,000 population per year. Data on therapeutic administrations of radionuclides are analysed and discussed in detail in appendix D and electronic attachment D-1.

D. Radiation therapy

55. The UNSCEAR Global Survey data were received from 44 countries, covering 66% of the total world population. Although the number of countries providing data was low, the proportion of the world population covered was quite high and, therefore, no additional data were incorporated in the assessment. Data on radiation therapy treatment courses do not include radionuclide therapy treatments, which were discussed in the previous section on nuclear medicine.

56. The estimated total annual number of radiation therapy treatment courses is 6.2 million, with an uncertainty of ±25%. The total estimate was derived by combining the assessed data with the predictions of a continuous model for countries that did not submit data to the UNSCEAR Global Survey. The continuous model was a power-law fit to the treatment course frequencies in the assessed data as a function of physician density. Details of the modelling are discussed in appendix A. Table 12 presents a detailed summary of the results with categorization by health-care level and by income level. The number of treatment courses in the assessed data is also presented, along with the estimated number predicted by the continuous model for the remaining countries, the resulting total and the overall average frequency of treatment courses per million population. The uncertainties stated by countries in their survey submissions and the uncertainties of the predictions from the continuous model were combined to derive an overall uncertainty of ±25%. Further details are given in appendix A and electronic attachments A-1 and A-2.

Table 12. Global estimate of number of radiation therapy treatment courses per annum derived from assessed data (2009–2018) and predictions from continuous model

Category	*Population (millions)* [a]	*Treatment courses from assessed data (millions)* [a]	*Treatment courses from modelled data (millions)* [a]	*Total number of treatment courses (millions)* [a]	*Average treatment courses per million population*
Categorization by health-care level					
I	3 908	4.50	1.29	5.79	1 480
II	2 256	0.225	0.154	0.379	168
III	622	0.004	0.050	0.054	85
IV	526	0	0.010	0.010	19
Categorization by income level					
High	1 149	2.71	0.30	3.01	2 620
Upper middle	2 619	1.82	0.80	2.63	1 000
Lower middle	2 882	0.19	0.30	0.50	172
Low	662	0.0002	0.10	0.10	148
Global	**7 312**	**4.7**	**1.5**	**6.2**	**853**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

57. The estimated annual total of 6.2 million treatment courses represents an increase of 22% from the value of 5.1 million treatment courses per annum in the previous UNSCEAR 2008 Report [U9]. The overall rate of treatment courses has increased from 800 per million in the previous assessment to 850 per million. A comprehensive review of the published literature and further analyses of the UNSCEAR Global Survey data on treatment frequencies, doses delivered during treatment, equipment and staffing numbers are contained in appendix E. The UNSCEAR Global Survey data discussed in appendix E and electronic attachment E-1 indicate that, on average, brachytherapy accounts for 6.7% of all treatment courses. On this basis, the estimated total of 6.2 million treatment courses comprises 5.8 million external beam treatment courses and 0.4 million brachytherapy treatment courses.

VI. ANALYSIS OF DOSIMETRY DATA

58. Analysis of dosimetry data was based on dose information from the UNSCEAR Global Survey. These data included average values of physical dose quantities (such as entrance surface dose, dose-area product, dose-length product and administered activity) and assessments of typical effective dose per examination/procedure. Physical dose quantities were converted to effective dose using the conversion factors referenced in appendices B to D. These appendices also present detailed analyses of the country data and comparisons with dose estimates reported in the literature.

59. The effective doses presented in the following sections are based on the tissue weighting factors from ICRP Publication 60 [I9]. This approach was adopted because the conversion factors relating practical dose quantities to effective dose available in the literature have generally been derived using the ICRP 60 weighting factors. There were insufficient data to derive separate estimates of effective dose for each procedure using the tissue weighting factors from ICRP Publication 103 [I11]. In

addition, where countries submitted estimates of effective dose, it was not always clear which set of tissue weighting factors were used. As discussed in section IV, an evaluation of the overall total collective effective dose based on ICRP 103 weighting factors was derived by multiplying the mean doses per procedure by E-103/E-60 ratios taken from the literature [A6, A7, H5, S14, W1].

A. Diagnostic radiology

60. As described above (figure I), diagnostic radiology was considered in three subgroups: *(a)* conventional radiology (excluding dental), encompassing projection radiography as well as radiography and fluoroscopy, but excluding dental radiography; *(b)* dental radiology; and *(c)* computed tomography. To ascribe doses for countries that submitted only procedure frequencies and no dose data, and for countries where the procedure frequencies were estimated using the modelling results, the UNSCEAR Global Survey data were used to establish typical values of effective dose for each examination and the mean relative frequency of each examination within the whole subgroup. These data were combined to yield a frequency-weighted mean effective dose per subgroup examination. This frequency-weighted mean effective dose per examination was used for all countries that did not provide dose information to the current survey.

61. The typical effective doses and relative frequencies within conventional radiology (excluding dental), dental radiology and computed tomography are shown in table 13. The frequency-weighted effective dose for conventional radiology (excluding dental) was 0.37 mSv per examination. The most common procedures were chest (two projections), limbs and joints, mammography, and pelvis and hip. The frequency-weighted effective doses were 0.01 mSv for dental radiography and 6.4 mSv for computed tomography examinations. The most common computed tomography examinations were head (brain), chest and abdomen. The uncertainties in the typical dose per examination and the uncertainties in the relative proportions were combined to derive an overall uncertainty in the frequency-weighted effective dose. The uncertainties in the frequency-weighted effective dose per examination were ±20% for conventional radiography, ±40% for dental radiography, and ±20% for computed tomography.

62. Applying a single frequency-weighted dose per procedure for all countries that did not provide dose information assumes that procedures are performed at identical relative rates across all health-care and income levels and also that doses do not vary across these categories. These assumptions were necessary as there were insufficient data available from the UNSCEAR Global Survey to establish separate procedure frequencies and doses across the different health-care or income level categories. However, the relative frequencies shown in table 13 indicate a significant contribution from mammography (13.2%, combining both clinical and screening mammography). This high frequency for mammography reflects the fact that the survey data came mostly from HCL I countries. Survey data from Islamic Republic of Iran and Philippines indicated very low levels of mammography, as do data for Kenya reported in the literature [K13]. To correct this bias, revised relative frequencies for conventional radiology (excluding dental) were calculated by replacing the relative frequencies for mammography with the arithmetic mean of the data from Islamic Republic of Iran, Philippines and Kenya and then re-calculating the frequencies relative to the revised total. The revised frequencies for procedures other than mammography, therefore, increased to cover the missing proportion. The frequency-weighted mean effective dose for conventional radiology (excluding dental) using the revised frequencies was 0.39 mSv per procedure. This revised value was ascribed to all HCL II, III and IV countries that did not provide dose data.

Table 13. Typical effective doses and average relative frequencies of procedures within diagnostic radiology subcategories reported to UNSCEAR Global Survey

Examination type	*Typical effective dose (mSv)* [a,b]	*Relative frequency (%)* [b]
CONVENTIONAL RADIOLOGY (EXCLUDING DENTAL)		
Projection radiography (excluding dental)		
Head (skull and facial bones)	0.08	2.3
Head (soft tissue)	0.15	0.06
Neck (cervical spine)	0.13	2.6
Neck (soft tissue)	0.51	0.05
Chest-thorax	0.08	32
Chest (thoracic spine)	0.45	1.9
Chest (shoulder girdle and ribs)	0.06	2.9
Mammography[c]	0.22	6.0
Mammography (screening)[c]	0.28	7.2
Lumbar spine	1.0	6.1
Lumbo-sacral joint only	0.33	0.37
Abdomen	0.61	2.9
Pelvis and hips (bone)	0.49	7.5
Pelvis (soft tissue)	1.5	0.35
Limbs and joints	0.02	21
Whole spine (trunk)	1.5	0.20
Skeletal (head and trunk)	0.5	0.29
Others[d]	0.22	2.9
Radiography and fluoroscopy		
Gastrointestinal tract (barium studies)	3.4	0.59
Gastrointestinal tract (defecography)	8.8	0.04
Biliary tract (cholangiography)	8.5	0.02
Biliary tract (endoscopic retrograde cholangiopancreatography)	4.9	0.06
Biliary tract (cholecystography)	1.4	0.01
Urogenital tract (Intravenous urography)	2.4	0.23
Urogenital tract (kidney, bladder and urethra)	1.6	0.12
Myelography	5.5	0.01
Arthrography	2.1	0.09
Cerebral angiography	6.9	0.03
Cardiac angiography	7.0	0.78
Thoracic angiography	4.8	0.08

Examination type	*Typical effective dose (mSv)* [a,b]	*Relative frequency (%)* [b]
Abdominal angiography	8.0	0.03
Pelvic angiography	7.5	0.02
Peripheral angiography	3.2	0.09
Lymphangiography	1.0	0.0002
Others[d]	4.8	1.1
Weighted dose per examination for conventional radiology (excluding dental)	**0.37**	
Dental radiology		
Dental intraoral	0.006	74
Dental panoramic	0.024	26
Weighted dose per examination for dental radiology	**0.01**	
Computed tomography (CT)		
CT-head (skull and facial bones)	1.5	13.6
CT-head (soft tissue and brain)	1.9	16.4
CT-neck (cervical spine)	3.1	2.9
CT-neck (soft tissue)	2.8	1.2
CT-chest (thoracic spine)	8.0	1.4
CT-chest (thorax)	6.4	15.7
CT-abdomen (lumbar spine)	9.4	4.2
CT-abdomen (abdomen)	11	15.4
CT-abdomen (liver, pancreas, kidneys)	10	3.2
CT-pelvis (pelvic bones)	8.8	2.4
CT-pelvis (pelvic soft tissue and vascular)	11	2.8
CT-pelvis (pelvimetry)	5.0	0.05
CT-full spine (neck, chest, abdomen)	14	1.4
CT-trunk (chest, abdomen, pelvis)	17	3.9
CT-limbs	2.1	2.4
CT-dental	0.7	0.3
Cone beam CT-dental	0.13	1.0
Cone beam CT-others	0.06	0.1
Others[d]	6.4	11.5
Weighted dose per examination for computed tomography	**6.4**	

[a] For the effective dose determination, ICRP 60 [I9] tissue weighting factors were applied.

[b] Values are rounded; however extended precision has been preserved to illustrate differences.

[c] Effective doses for mammography reported to UNSCEAR Global Survey were assumed to be based on ICRP 103 [I11] tissue weighting factors and were divided by 2.4 to adjust them to ICRP 60 [I9] for consistency with doses for all other procedures.

[d] Procedures categorized as "Others" were assigned a dose equal to the frequency-weighted average dose for all other procedures within the category.

63. The total annual number of examinations worldwide is assessed as 2.6 billion for conventional radiography, 1.1 billion for dental radiography and 400 million for computed tomography (table 4). The global collective dose for conventional radiology (excluding dental), dental radiology and computed tomography is 955,000 man Sv, 9,700 man Sv, and 2,556,000 man Sv, respectively. The distribution of collective dose between health-care and income levels, along with the contribution to the per caput effective dose, is presented in table 14. Combining the uncertainties in the number of procedures with the uncertainties in the dose per procedure, as described in appendix A, leads to an overall uncertainty in the collective dose of ±45% for conventional radiology (excluding dental), ±70% for dental radiography, and ±45% for computed tomography.

64. A comprehensive review of the published literature, and further analyses of the UNSCEAR Global Survey data on procedure frequencies, doses per procedure, equipment and staff in diagnostic radiology are discussed in appendix B.

Table 14. Comparison of estimated annual collective dose and annual per caput effective dose between health-care and income levels for conventional radiology (excluding dental), dental radiology and computed tomography

The estimates are based on survey data and the continuous mathematical model (physician density)

Category	*Conventional radiology (excluding dental)*		*Dental radiology*		*Computed tomography*	
	Collective dose (1 000 man Sv) [a]	*Effective dose per caput (mSv)* [a]	*Collective dose (1 000 man Sv)* [a]	*Effective dose per caput (mSv)* [a]	*Collective dose (1 000 man Sv)* [a]	*Effective dose per caput (mSv)* [a]
Categorization by health-care level						
I	651	0.17	8.5	0.0022	2 050	0.52
II	254	0.11	1.1	0.0005	449	0.20
III	37	0.059	0.07	0.0001	45	0.073
IV	13	0.026	0.01	0.00002	12	0.024
Categorization by income level						
High	355	0.31	5.0	0.0044	1 178	1.02
Upper middle	265	0.10	2.9	0.0011	812	0.31
Lower middle	305	0.11	1.6	0.0005	516	0.18
Low	30	0.046	0.15	0.0002	50	0.075
Global	**955**	**0.13**	**9.7**	**0.0013**	**2 556**	**0.35**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

B. Interventional radiology

65. A frequency-weighted effective dose per interventional radiology procedure was established for the purpose of ascribing doses for countries that submitted only procedure frequencies and no dose data, and for countries where the procedure frequencies were estimated using the continuous model. The submitted UNSCEAR Global Survey data were used to establish typical values of effective dose for each procedure and the mean relative frequency of the procedure within all interventional radiology

procedures (table 15). This frequency-weighted effective dose per procedure was used for all countries that did not provide dose information to the UNSCEAR Global Survey. The frequency-weighted effective dose derived for interventional radiology was 14.9 mSv per procedure. Combining the uncertainties in the typical doses for procedures and the uncertainty in the relative proportions gives an overall uncertainty in the frequency-weighted effective dose per procedure of ±50%.

Table 15. Typical effective doses and average relative frequencies of procedures for interventional radiology

PTCA: Percutaneous transluminal coronary angioplasty; TIPS: Transjugular intrahepatic portosystemic shunt

Examination type	*Typical effective dose (mSv)* [a]	*Relative frequency (%)*
Head (cerebral intervention)	12.6	1.0
PTCA	20.6	37.6
Chest (pacemaker)	1.4	4.8
Thoracic intervention (other)	2.8	8.1
Abdomen (biliary and urinary intervention)	7.2	3.3
Abdomen (TIPS)	27.8	0.1
Abdominal interventions (other)	32.0	1.8
Pelvic interventions	7.0	1.0
Limb interventions	13.6	3.8
Other interventional procedures	13.9	38.5
Weighted dose per procedure	**14.9**	

[a] For the effective dose determination, ICRP 60 [I9] tissue weighting factors were applied.

66. The global number of interventional radiology procedures is assessed at 24 million and the global collective effective dose is assessed at 334,000 man Sv. The distribution of collective dose between health-care and income levels, along with the contribution to the per caput dose, is shown in table 16. Combining the uncertainty in the number of procedures with the uncertainty in the dose per procedure, as described in appendix A, leads to an overall uncertainty in the collective effective dose from interventional radiology of ±90%. A comprehensive review of the literature and a detailed analysis of data on procedure frequencies, doses per procedure, equipment and staff are discussed in appendix C.

Table 16. Comparison of estimated annual collective dose and annual per caput effective dose between health-care and income levels for interventional radiology

The estimates are based on survey data and the continuous mathematical model (physician density)

Category	*Collective dose (1 000 man Sv)* [a]	*Per caput effective dose (mSv)* [a]
Categorization by health-care level		
I	269	0.069
II	59	0.026
III	4.7	0.008
IV	1.3	0.002
Categorization by income level		
High	193	0.168
Upper middle	69	0.026
Lower middle	65	0.023
Low	7	0.010
Global	**334**	**0.046**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

C. Nuclear medicine

67. In diagnostic nuclear medicine, a more complicated process of ascribing doses for countries that submitted only procedure frequencies and no dose data, and for countries where the procedure frequencies were estimated using the continuous model, was chosen. The UNSCEAR Global Survey data were used to establish typical values of effective dose for each procedure and the average relative frequency of the procedure within the categories of gamma camera and SPECT procedures, and PET procedures, respectively. The relative frequencies with which different radiopharmaceuticals and different radionuclides were used for a given procedure were included in the assessment of effective dose for that procedure. The proportion of procedures including an accompanying attenuation correction or localization computed tomography scan, and the fraction of PET procedures within the overall total procedures (table 17) were included in the calculation of the overall frequency-weighted effective dose per procedure. The frequency-weighted effective dose derived for diagnostic nuclear medicine was 6.8 mSv per procedure. This weighted effective dose per procedure was used for all countries that did not provide dose information to the UNSCEAR Global Survey. For countries with no reported PET equipment, only the weighted dose for gamma camera and SPECT procedures (5.1 mSv per procedure) was used in the assessment. The uncertainties in the typical doses for nuclear medicine procedures and the uncertainty in the relative frequencies were combined to derive an overall uncertainty in the weighted effective dose. The estimated overall uncertainty in the weighted effective dose per procedure is ±20%.

Table 17. Typical effective doses and average relative frequencies of nuclear medicine procedures

CT: Computed tomography; PET: Positron emission tomography; SPECT: Single photon emission computed tomography

Procedure	*Radiopharmaceutical component*[a]			*CT component*[a]	
	Isotope	*Typical effective dose (mSv)*	*Relative frequency (%)*	*Typical effective dose (mSv)*	*Fraction of CT (%)*
GAMMA CAMERA AND SPECT PROCEDURES					
Nervous system	^{99m}Tc	6.6	1.8	0.3	54
Nervous system	^{123}I	9.2	1.9		
Skeletal	^{99m}Tc	3.6	28.4	3.0	34
Cardiovascular	^{99m}Tc	6.8	23.7	1.0	55
Cardiovascular	^{201}Tl	14.4	3.4		
Pulmonary	^{99m}Tc	2.3	6.3	1.9	30
Endocrine	^{99m}Tc	3.0	12.8	1.4	24
Endocrine	^{123}I	24.5	1.6		
Gastrointestinal	^{99m}Tc	2.9	2.3	3.2	6
Genitourinary	^{99m}Tc	1.1	8.7		
Oncology	All	6.8	3.6	2.7	54
Infection, inflammation	^{99m}Tc	6.8	2.0	2.5	81
Lymphatics	^{99m}Tc	0.08	3.5		
Weighted dose per procedure (mSv)		4.9		0.6	
Fraction of SPECT systems with CT			32.2		
Weighted CT component				0.2	
Weighted dose per gamma camera and SPECT				**5.1**	
PET PROCEDURES					
Oncology	^{18}F	15.9	90.7	All procedures assumed to include CT Doses include CT component	
Oncology	^{68}Ga	12.4	1.3		
Cardiovascular	^{18}F	15.4	1.7		
Cardiovascular	^{15}O	1.6	0.3		
Skeletal	^{18}F	16.9	1.3		
Nervous system	^{18}F	5.4	2.6		
Infection, inflammation	^{18}F	16.8	0.5		
Weighted dose per PET procedure (mSv)		15.3			
Fraction of PET in all nuclear medicine procedures			17		
Combined weighted dose for nuclear medicine including PET				**6.8**	

[a] For the effective dose determination, ICRP 60 [I9] tissue weighting factors were applied.

68. The total number of procedures worldwide in diagnostic nuclear medicine (including PET) is assessed as 40 million. The global collective effective dose is assessed at 297,000 man Sv. The distribution of collective dose between health-care and income levels, along with the contribution to the per caput effective dose, is shown in table 18. Combining the uncertainty in the number of procedures with the uncertainty in the dose per procedure, as described in appendix A, leads to an overall uncertainty in the collective effective dose from diagnostic nuclear medicine of ±75%. A comprehensive review of the literature and further analyses of the survey data on procedure frequencies, doses per procedure, equipment and staff in nuclear medicine are discussed in appendix D.

Table 18. Comparison of estimated annual collective dose and annual per caput effective dose between health-care and income levels for diagnostic nuclear medicine

The estimates are based on survey data and the continuous mathematical model (physician density)

Category	*Collective effective dose (1 000 man Sv)* [a]	*Effective dose per caput (mSv)* [a]
Categorization by health-care level		
I	285	0.073
II	11.1	0.005
III	0.44	0.0007
IV	0.05	0.0001
Categorization by income level		
High	235	0.20
Upper middle	46	0.018
Lower middle	14	0.005
Low	2	0.003
Global	**297**	**0.041**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

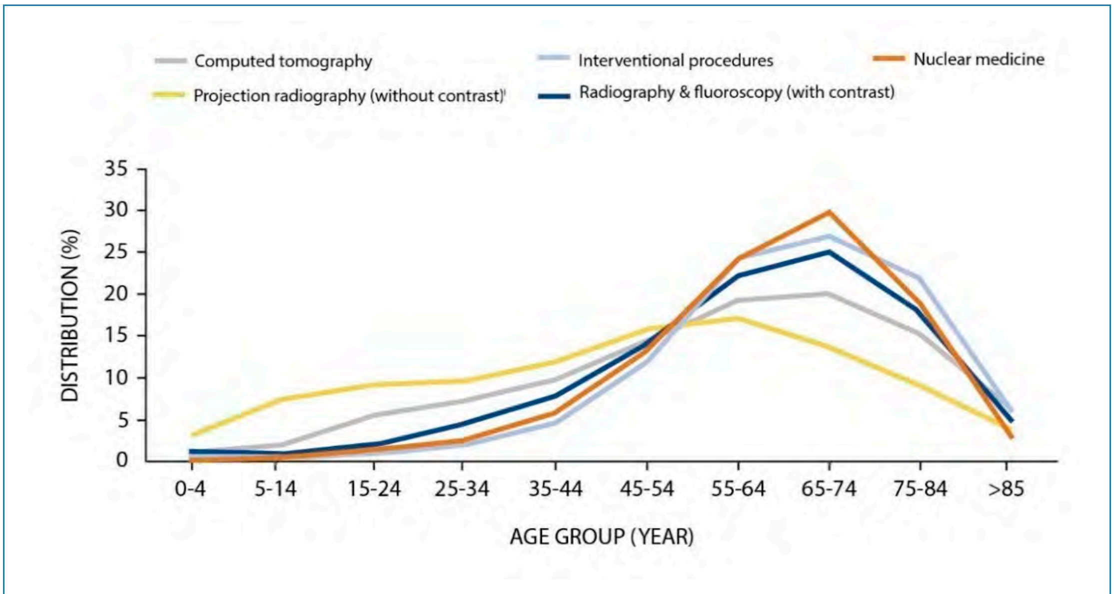
69. The uncertainty in the global estimate of medical exposure arises from a number of sources. Some countries conducted a survey of a limited number of nuclear medicine practices and then extrapolated the data to the whole country. This can lead to an over- or underestimation of the true number of procedures, depending on how representative the sample sites are of the whole country. Further, there are often a number of different radiopharmaceuticals available for any one procedure and the particular one used may vary from site to site and from patient to patient, depending on their clinical history. Additionally, while computed tomography is now used in almost all PET procedures, this is not the case with SPECT. Although the number of SPECT/CT installations has increased markedly in the past decade, the computed tomography component is usually used in less than 55% of cases. It is common practice to perform the SPECT study first, and then perform the computed tomography only if the study is abnormal and the anatomical localization of the abnormality cannot be clearly identified from the SPECT images. This level of detail is often not available in national surveys but needs to be considered for future surveys.

VII. DISTRIBUTIONS BY AGE AND SEX

70. The UNSCEAR Global Survey provided detailed data on the distribution of procedures by age and sex for a number of countries. Data was provided by ten countries for projection radiography (without contrast), and for radiography and fluoroscopy (with contrast). Data for computed tomography was provided by eleven countries, for interventional radiology by eight countries, for nuclear medicine by 13 countries, and for radiation therapy by nine countries. With the exception of Thailand, all data on the age and sex distribution of procedures came from HCL I countries. Detailed discussions of the age and sex distributions are presented in appendices B to E .

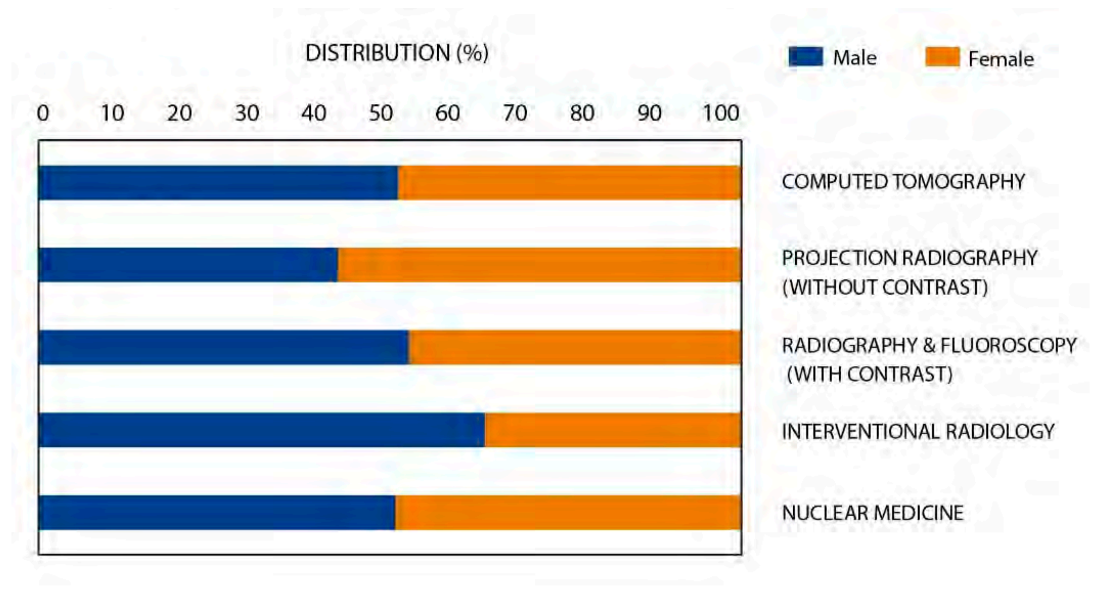
71. The distributions of projection radiography (without contrast), radiography and fluoroscopy (with contrast), computed tomography, interventional radiology and nuclear medicine procedures by patient age are presented in figure III. Computed tomography, radiography and fluoroscopy (with contrast), interventional radiology and nuclear medicine show very similar age profiles, with the bulk of procedures occurring in patients aged 55 years and older. Projection radiography (without contrast) shows a markedly flatter profile, with many procedures performed on children and young adults. The distribution for computed tomography also shows elevated rates between ages 15 and 44 in comparison with radiography and fluoroscopy, interventional radiology and nuclear medicine.

Figure III. Comparison of age distributions for examinations/procedures by modality categories, averaged across countries reported data to UNSCEAR Global Survey



72. The proportions of examinations/procedures by patient sex are presented in figure IV. The male-female ratio is close to even for computed tomography and nuclear medicine procedures. Fluoroscopic examinations show a slight preponderance of males, while interventional procedures show a strong tendency to males with a ratio close to 2:1. The preponderance to males in interventional radiology is seen for many procedure types but particularly for percutaneous coronary angioplasty (PTCA). By contrast, projection radiography is weighted towards females, mainly due to the contribution from mammography examinations. Only a few countries were able to provide data on age and sex distributions of examinations/procedures. It is desirable to have such data also from lower middle-income and low-income countries where the age structure of the population, clinical presentations, equipment, staffing and practice may differ from the results presented in this annex.

Figure IV. Distributions of patient sex received radiological examinations by modality categories, averaged across countries reported data to UNSCEAR Global Survey



VIII. TRENDS IN MEDICAL EXPOSURE

73. The results of this current evaluation are compared with matching data from the UNSCEAR 2008 Report [U9] in table 19. Comparisons for selected procedures within conventional radiology (excluding dental) are also shown to highlight major changes.

74. The estimated number of procedures in conventional radiology (excluding dental) is lower in the present assessment by about 10%, and there is a large reduction, approximately 60%, in the assessed collective effective dose. There are some differences in methodology that contribute to the lower number of estimated procedures. The previous assessment included counts of individual radiographic projections in some cases, whereas the present assessment attempts to estimate the number of procedures, some of which may include multiple projections. The present assessment also uses modelling to ascribe procedures to countries that did not submit data, instead of applying population-weighted averages from the current survey to all countries within each health-care level.

75. As discussed in more detail in appendix B typical effective doses for radiography procedures have generally decreased during the past decade, although there continues to be wide variation in reported values. Significant reductions in procedure frequencies are seen for studies of the gastrointestinal system using fluoroscopy and contrast. These procedures contributed 640,000 man Sv to the collective dose in the previous assessment. In the present assessment, the number of procedures and the collective dose have fallen by approximately 90%. The frequencies of radiographic and fluoroscopic examinations of the biliary and urinary systems have also fallen considerably and their contribution to the collective dose has decreased. A recent evaluation of medical exposure in the United States [N2] also found notable reductions in fluoroscopic gastrointestinal examinations, which in that case were ascribed to a shift to fibre-optic endoscopy and colonography.

Table 19. Comparison of annual number of examinations/procedures and annual collective dose from medical exposure with UNSCEAR 2008 Report [U9]

Modality category	*UNSCEAR 2008 Report [U9]*		*Current evaluation*	
	Number of examinations / procedures (millions) [a]	*Collective dose (1 000 man Sv)* [a]	*Number of examinations/ procedures (millions)* [a]	*Collective dose (1 000 man Sv)* [a]
Conventional radiology (excluding dental)	2 900[b]	2 350	2 626	955
Chest (thorax)	930	93	955	97
Chest photofluorography	440	340	64[c]	19[c]
Mammography (clinical)	50	19	120	27
Mammography (screening)	80	22	110	29
Gastrointestinal	135	640	18	65
Biliary system	40	76	2	11
Urography	45	120	8.6	19
Others	240	390	120	140
Dental	480	11	1 100	10
Computed tomography	220	1 540	403	2 556
Interventional radiology	3.6[d]	41	23.6	334
Diagnostic nuclear medicine	33	202	39.9	297
Radionuclide therapy	0.88		1.4	
Radiation therapy[e]	5.1		6.2	

[a] Values are rounded; however extended precision has been preserved to illustrate differences.
[b] UNSCEAR 2008 Report [U9] counted individual projections rather than whole examinations in some cases.
[c] Data reported by the Russian Federation, however, this category was not included in the UNSCEAR Global Survey.
[d] Data for interventional radiology were not reported separately in UNSCEAR 2008 Report [U9]. The value reported here is according to the definition of interventional radiology used in this annex.
[e] Radiation therapy was counted as courses of treatment, not individual treatment fractions.

76. Chest photofluorography contributed approximately 340,000 man Sv to the collective dose in the previous UNSCEAR 2008 Report [U9]. There is no directly equivalent category for this procedure in the present assessment, however specific data were reported by the Russian Federation. In other cases, these procedures may have been reported under the chest category. A comparison of the chest (thorax) category is included in table 19. The number of chest procedures and the assessed collective dose has increased, but only marginally. As discussed by Balonov et al. [B6], the use of fluorography has declined in the Russian Federation (see also appendix B), although it was reported to account for 44% of the total collective effective dose in Ukraine during the period 2009–2012 [S22].

77. The current evaluation shows a significant increase in the use of mammography. As discussed in section VI.A, a revised set of relative frequencies with a very low mammography component was used in ascribing procedures and doses to countries in HCL II, III and IV that did not submit data to the UNSCEAR Global Survey. The total for mammography examinations reported in table 19 are thus largely due to procedures in HCL I countries, both those included in survey submissions and those ascribed for countries that did not submit data. As discussed in appendix B, the survey data showed a

consistently large increase in the frequency of mammography examinations compared to the previous UNSCEAR 2008 Report [U9].

78. In dental radiology, the assessed number of procedures has doubled although the overall collective dose is similar. This increase may be due to an increased level of reporting for the UNSCEAR Global Survey. It should be noted that dental cone beam computed tomography (CBCT) has been counted and analysed within the computed tomography category, as presented in appendix B.

79. In computed tomography, the number of procedures and the collective dose have risen markedly. The number of procedures has increased by about 80% and the collective dose has increased by around 70%. As discussed in appendix B, an increase is observed for most countries submitting data to the UNSCEAR Global Survey; however, the procedure frequencies per 1,000 population assessed for HCL II, III and IV countries in this evaluation have increased by factors of 4 (7 to 31), 3 (3 to 11) and 1.2 (3 to 3.7), respectively. While there is evidence of some reduction in the average dose per procedure, use of computed tomography continues to grow.

80. In interventional radiology, the number of procedures has increased by a factor of 6 and the collective dose has increased by a factor of 8 compared to the previous assessment [U9]. This reflects both an increasing deployment of interventional radiology and an expansion in the range of procedure types with higher doses per procedure, on average. The large apparent change is also due in part to gaps in reporting; the previous assessment did not include cerebral and vascular procedures on the basis that these were largely diagnostic and not therapeutic. Although interventional procedures are less frequent than radiography or computed tomography examinations, the effective dose per procedure is relatively high. As a result, interventional procedures make an important contribution to the total collective dose. Coronary angioplasty remains the most frequent interventional procedure.

81. In nuclear medicine, the assessed number of procedures has increased by 20% and the collective dose has increased by 50%, indicating a growth in higher dose procedures. The greatest change in the past decade has been the steady increase in the number of PET procedures, which now represent 17% of all nuclear medicine procedures. With a typical effective dose of 15 mSv per procedure (including both radiopharmaceutical and computed tomography dose), increasing use of PET will lead to a rise in the average dose per procedure. The use of PET is likely to increase further with the initiation of new radiopharmaceuticals currently under clinical development and the growing role of PET in cancer care. Throughout the world, PET/CT systems have now largely replaced stand-alone PET systems. SPECT/CT systems have been available since about 2005, but information in the literature on their distribution is very limited. The previous rapid rise in the number of cardiac studies, particularly in the United States, appears to have moderated and reversed slightly.

82. Table 20 summarizes the trends in medical exposure for diagnosis and intervention since 1988. The values include the total annual number of examinations and collective effective doses from diagnostic and dental radiology, nuclear medicine and interventional radiology. However, no data for frequencies for dental radiology were given in the UNSCEAR 1993 Report [U5], which explains the slight decrease (figure V). The annual total number of examinations has increased from 1.7 billion in 1988 to 4.2 billion in the current evaluation. This increase is due partly to the increase in the global population, but the frequency of examination has also increased from 355 to 574 procedures per 1,000 population (figure VI). However, compared with the previous UNSCEAR evaluation [U9], the increase is minor. The estimated annual collective effective dose to the world population from medical radiological examinations has increased from 1,890,000 man Sv in 1988 to 4,150,000 man Sv in the current evaluation (figure VII). The annual per caput effective dose increased from 0.37 mSv in 1988 to 0.65 mSv in 2008 and has fallen slightly since, to 0.57 mSv (figure VIII).

Table 20. Comparison of UNSCEAR global medical exposure evaluations

Evaluation	*Annual number of examinations (millions)* [a]	*Annual frequency of examinations per 1 000 population* [a]	*Annual collective effective dose (1 000 man Sv)* [a,b]	*Annual effective dose per caput (mSv)* [a, b]
UNSCEAR 1988 Report [U4]	1 740	355	1 890	0.37
UNSCEAR 1993 Report [U5]	1 620	305	1 780	0.33
UNSCEAR 2000 Report [U6]	2 460	426	2 460	0.43
UNSCEAR 2008 Report [U9]	3 660	561	4 210	0.65
Current evaluation	4 190	574	4 150[b]	0.57

[a] Values are rounded.

[b] For the effective dose determination, ICRP 60 [I9] tissue weighting factors were applied.

83. Overall, the current evaluation shows only a slight change from the UNSCEAR 2008 Report [U9] and a slight reduction in the effective dose per caput. This contrasts with the previous two UNSCEAR reports [U6, U9], which showed notable increases, not only in the total number of examinations but also in the frequencies of examinations per 1,000 population and the annual effective dose per caput. As discussed above, this evaluation shows the influence of technological changes and changes in medical practice as previously more common procedures were supplanted by different techniques or phased out entirely. The use of computed tomography has continued to grow and the contribution from interventional radiology has increased rapidly. It appears likely that these two trends will continue and, thus, the effective dose per caput may be expected to rise again in the future as access to these techniques using ionizing radiation spreads to lower middle- and low-income countries.

84. Figure IX shows that the frequency of radionuclide therapy has increased by 40% since the UNSCEAR 2008 Report [U9], continuing a trend of increasing use seen in previous UNSCEAR reports. In the past decade, a number of new therapies have been introduced clinically and are now available in many countries. These include ^{90}Y-microspheres for the treatment of liver tumours, ^{177}Lu-octreotide for neuroendocrine tumours and ^{177}Lu labelled onto prostate-specific membrane antigen (^{177}Lu-PSMA) for prostate cancer. Statistics on the use of these newer therapies are often limited so the frequencies estimated in this evaluation are likely to be an underestimate. Considerable research is under way into “theranostics”, in which the same pharmaceutical is used for both diagnosis and treatment. This is likely to lead to the establishment of these new procedures in routine clinical practice in many countries in coming years.

Figure V. Trend in global annual number of medical radiological examinations/procedures

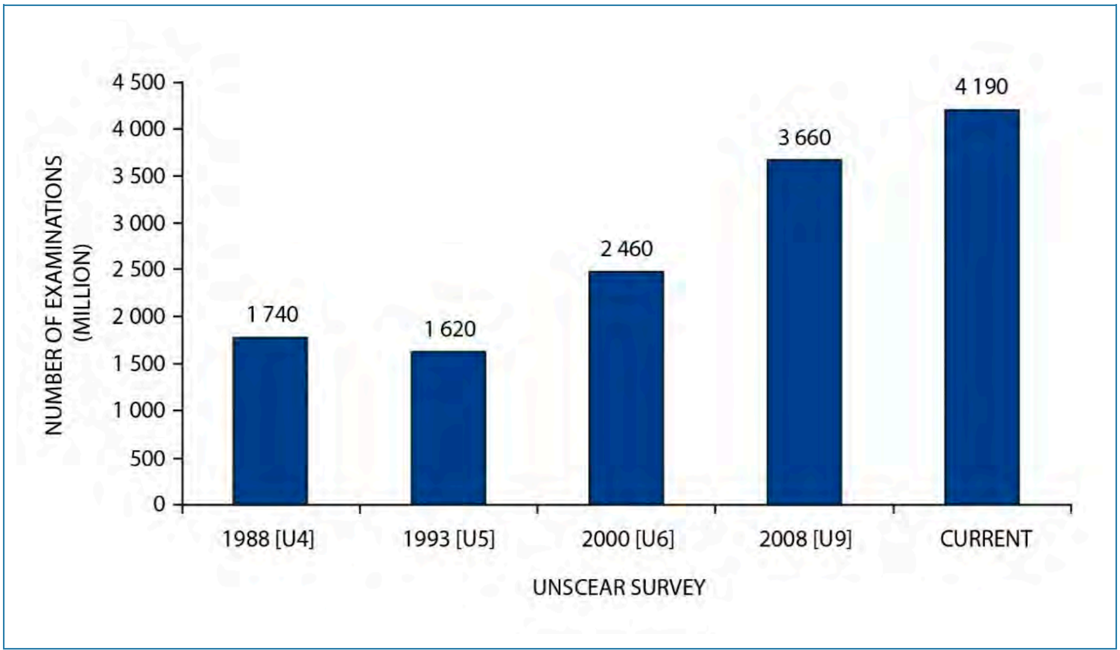


Figure VI. Trend in global annual frequency per 1,000 population of medical radiological examinations

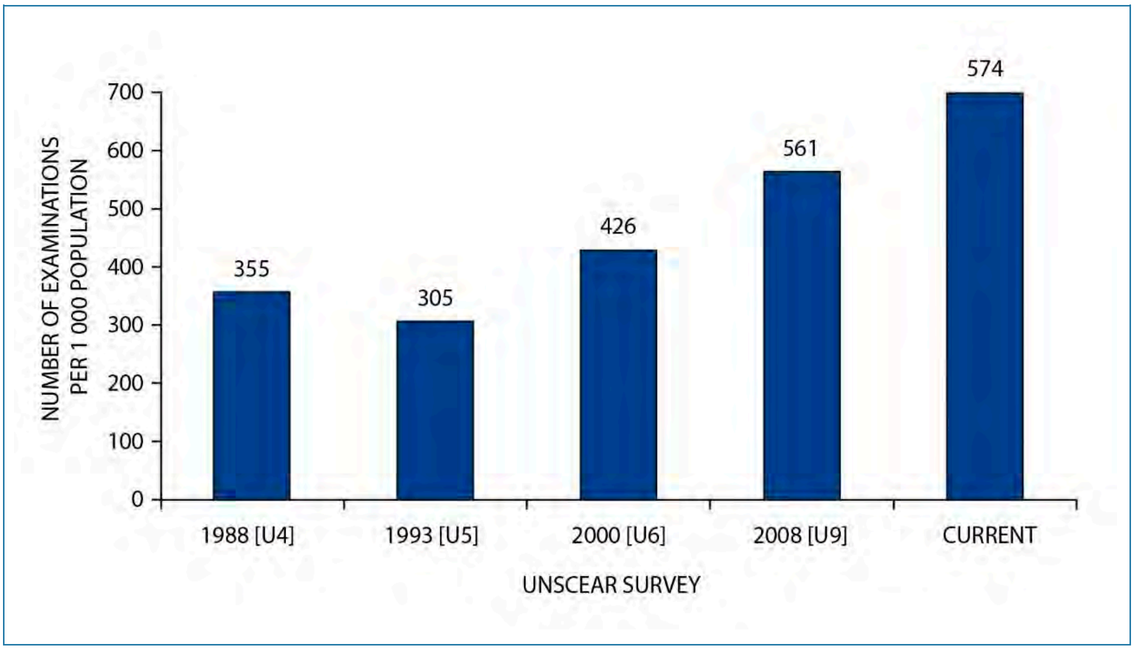


Figure VII. Trend in global annual collective effective dose from medical radiological examinations

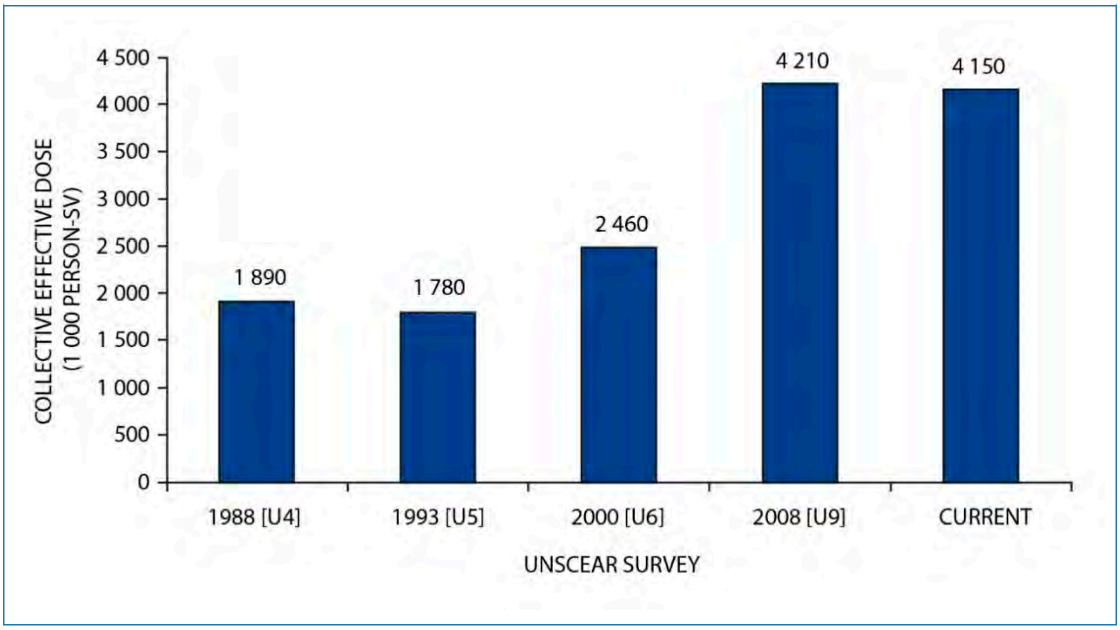


Figure VIII. Trend in global annual effective dose per caput from medical radiological examinations

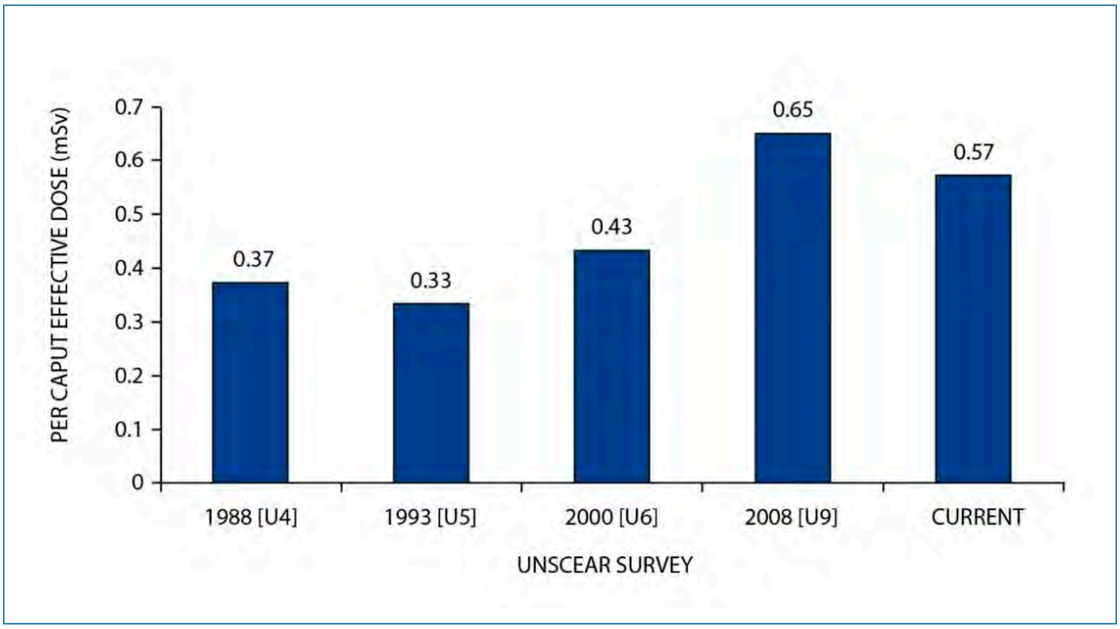


Figure IX. Trend in global annual frequency of radionuclide therapy treatments

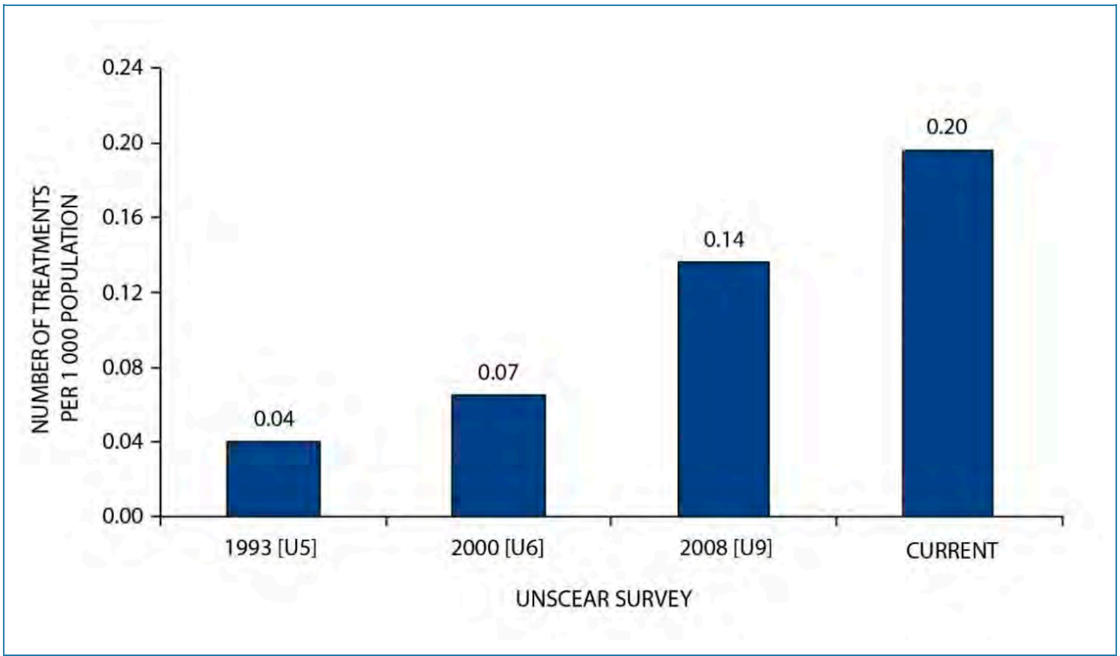
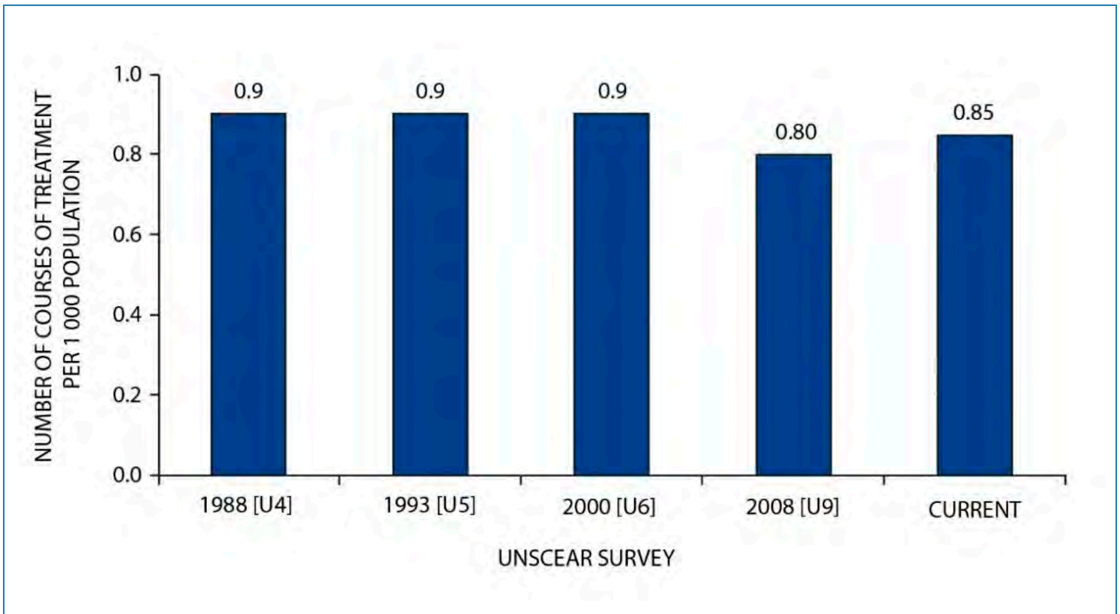


Figure X. Trend in global annual frequency of courses of radiation therapy treatment (excluding radionuclide therapy)



85. The annual number of courses of radiation therapy treatment (excluding radionuclide therapy) is estimated to have increased from 5.1 to 6.2 million since the UNSCEAR 2008 Report [U9]. However, the long-term trend in the frequency of radiation therapy treatment courses shows little change (figure X). There is a trend towards greater sparing of normal tissues and improved conformity with the target volume. This trend is made possible by the increase in technological sophistication of treatment delivery: specifically, the use of image guidance and of delivery techniques such as intensity-modulated radiation therapy (IMRT), volumetric modulated arc therapy (VMAT), particle beams and stereotactic techniques [K7].

86. The trends in improved geometric targeting have been accompanied by a trend towards higher tumour dose, or higher dose per fraction combined with a smaller number of fractions. These changes recognize the reduced doses delivered to normal tissues enabling an escalation of tumour dose, thus achieving greater tumour control without an increase in normal tissue toxicity.

IX. IMPLICATION FOR FUTURE ANALYSES

87. The compilation of a global assessment of medical exposure is a complex task. Data must be sourced from a wide array of locations, checked for consistency, and integrated into an overall summary. The recommendations below are intended to facilitate the process; allowing for improved data collection, speed and robustness of future assessments by the Committee.

88. As national surveys of medical exposure require adequate planning, with significant time and resources, the Committee recommends the use of its UNSCEAR Global Survey questionnaires (especially the essential data sets) to collect such information on a regular basis. Also, the Committee intends to update its assessments more often through a focus on essential data, which includes annual total numbers of examinations/procedures within each broad type of radiological discipline: conventional radiology, dental radiology, computed tomography, interventional radiology, nuclear medicine and radiation therapy.

89. National surveys of medical exposure should include, whenever possible, information on age and sex distribution of patients by the major types of medical examinations. In particular, estimations of collective dose to paediatric patients are of special interest. The Committee recommends that frequencies of radiological examinations be reported per 1,000 population. The population data and the typical doses for examinations used to derive the collective dose should be clearly stated, as should the period to which the data refer. This will facilitate the compilation of global summaries and comparative analysis of data between countries. For projection radiology, in particular for frequency data, it should always be made clear whether dental examinations are included or not.

90. The collection and collation of national data on medical exposure is not a simple process; however, the publication of more data on collective doses and trends in medical exposure from lower middle-income and low-income countries is desirable, as imaging patterns and technology may change quite rapidly in these countries.

91. Regular assessment of typical effective doses for medical examinations is important in order to track any optimization of technique due to factors such as the uptake of new technologies, improved training for operators and the availability of expert advice. Changes in practice and levels of exposure likely occur in a gradual fashion over time. Regular published assessments of typical doses would facilitate the tracing of trends.

92. Initiatives for future evaluations by the Committee should focus on motivating submission, of even partial data sets of key information (essential data), from countries not represented in this evaluation. Further, action should target countries with large populations (and so potentially significant contributors to global practice) and also those with developing levels of health care. It might be useful to focus data collection efforts on examinations and procedures that contribute most to the population dose, such as the TOP 20 methodology developed the EC DDM 1 project [E3].

93. The success of the EC DDM 2 project [E5] in facilitating data collection for the assessment of population dose in Europe could form the basis for similar regionally-organized initiatives, also involving the training of national contact persons in population dose assessment and organized data collection. These could help promote national surveys elsewhere, such as in Africa, Asia and Latin America, and so increase participation in future UNSCEAR Global Surveys.

94. There is generally a huge variation in the typical effective dose per radiological examination used in different countries, which subsequently affects the variations in estimated collective doses. Part of this variation is due to the use of different methods of estimation, including different conversion factors (effective dose per dosimetric quantity). The applicability, accuracy and consistency of the various approaches should be addressed for future studies. The conversion factors used to estimate effective dose should be reported in the surveys.

95. The impacts of technological changes in computed tomography—increasing numbers of simultaneously acquired slices, the introduction and use of dose saving features, and evolving diagnostic applications—are quite complex. There are both decreasing and increasing trends in the mean effective dose per examination, which have significant implications for the overall estimated collective effective dose from medical exposure.

96. Revised categories for interventional radiology procedures should be considered for future collection and reporting of medical exposure data. Cardiac procedures are studied more than any other interventional radiology procedure. This is justified due to their high frequency and radiation dose; however, a focus on these procedures may mean that interventional radiology procedures performed outside traditional radiology and cardiology departments are omitted from reporting due to the lack of an appropriate category, e.g., vascular procedures or vertebroplasties. Moreover, any system of categorization and analysis needs to allow for the fact that the distinction between diagnosis and intervention is becoming increasingly blurred. Procedures frequently begin as diagnostic in intent but will progress to intervention as dictated by the needs of the particular case (for instance, a diagnostic coronary angiography procedure that is followed by a PTCA). The combination of many examinations in a single group makes it difficult to assess exposure and to interpret trends (e.g., PTCA and cardiac ablation may be reported under a single "cardiac" category although patient exposure differs substantially). Careful evaluation of categories to be included in future surveys will be needed.

97. Continuing advances in imaging technology and interventional techniques allow the treatment of more complex medical conditions; however, these increasingly complex procedures may involve higher patient exposure and a greater likelihood of exceeding thresholds for tissue reactions. While data on the frequency of tissue reactions have not typically been within the scope of assessments of medical exposure, future surveys could include the possibility of reporting skin doses in interventional radiology procedures.

98. National surveys of nuclear medicine procedures need to include the dose from the computed tomography component of PET/CT and SPECT/CT examinations. When including the computed tomography component for SPECT, it is important to recognize that *(a)* not all SPECT examinations will require SPECT/CT; *(b)* some examinations will require more than one SPECT/CT; and *(c)* for certain examinations, particularly skeletal imaging, the SPECT/CT could cover any part of the body. In

some cases, full diagnostic computed tomography will be performed, and future surveys will need to consider whether to count and analyse such procedures as a component of nuclear medicine studies or to include them with regular diagnostic computed tomography examinations.

99. Future evaluation of nuclear medicine will need to expand the recorded frequency data to allow for a number of possible radiopharmaceuticals for one clinical procedure to be considered in order to more accurately determine the collective dose. This particularly applies to gastroenterology, renal, brain and oncology procedures where several different radiopharmaceuticals may be used, depending on the clinical indication for the study.

100. Only one publication [K10] reported on the frequencies of therapeutic nuclear medicine procedures. As this is an area of increasing application, statistics on the number of patients being treated with the growing range of radiopharmaceuticals is needed.

101. Future evaluations of radiation therapy practice will need to clarify the data requested, including the number of courses of treatment, the conditions for which patients are treated (including benign conditions), as well as the most common treatment modalities, doses and numbers of treatment fractions delivered.

102. The global assessment of medical exposure has focused on the frequencies of examinations/procedures and estimates of dose per procedure/examination. This approach assesses the overall collective exposure but does not provide information on the distribution of doses from medical exposure to individual patients. Only a few peer reviewed papers discuss cumulative doses due to multiple examinations performed on the same patient, although the issue of the number of patients receiving cumulative doses greater than 100 mSv has been raised recently [B31, R6, R7]. Collection of data on cumulative doses to patients, similar to the collection of data on occupational exposure, is important for improved analyses of trends and for the implications for patient management.

103. The impact of the use of either ICRP 60 [I9] or ICRP 103 [I11] tissue weighting factors should be comprehensively analysed and future global assessments should be directed towards using the ICRP 103 tissue weighting factors. An analysis is needed to study any changes introduced into global medical exposure estimates due to this change compared with other factors. In the current evaluation, there was a minor impact for conventional radiology (excluding dental), computed tomography and interventional radiology (+0.9%, −1.5% and −0.5%, respectively), a 15% reduction for diagnostic nuclear medicine, and an 88% increase for dental radiology. However, the overall impact on the collective effective dose was, with a reduction of 1.6%, rather small.

X. SUMMARY AND CONCLUSIONS

104. Medical exposure remains by far the largest human-made source of exposure of the general population to ionizing radiation. From the present assessment, it was concluded that about 4.2 billion medical radiological examinations are performed annually. The total annual collective effective dose to the world population of 7.3 billion people is estimated to be 4.2 million man Sv. The uncertainty in the estimate of the number of examinations is assessed as ±30% and the uncertainty in the collective effective dose is also assessed as ±30%. Further, the Committee estimated 6.2 million courses of radiation therapy treatment performed each year, about 5.8 million by external beams and 0.4 million by brachytherapy. In addition, 1.4 million radionuclide therapy treatments are estimated to be performed annually.

105. Conventional radiology (excluding dental) accounts for about 63% of all medical radiological examinations and 23% of the collective dose. Dental radiology accounts for about 26% of the examinations but only 0.2% of the overall collective dose. Computed tomography makes the largest contribution (62.6%) to the overall collective dose but accounts for only about 10% of all examinations. Interventional radiology accounts for only 0.6% of medical radiological examinations but contributes 8% of the overall collective dose. Diagnostic nuclear medicine procedures account for 1% of all medical radiological examinations and 7.2% of the overall collective dose.

106. The estimated annual effective dose per caput from medical radiological examinations has fallen slightly compared to the Committee's previous assessment in 2008 [U9] (from 0.65 to 0.57 mSv). The difference is, however, within the bounds of the estimated uncertainty. This trend stands in contrast to the trends observed in the previous two UNSCEAR reports [U6, U9], which showed notable increases.

107. The use of computed tomography has continued to expand and has replaced some of the older radiography and fluoroscopy examinations. However, there has been a major reported reduction in radiography and fluoroscopy examinations of the gastrointestinal tract, and also reduction in fluoroscopy examinations of the biliary and urinary systems and of the chest region. The contribution of interventional radiology has increased dramatically and now accounts for 8% of the collective dose (compared to 2% in the previous assessment), despite only accounting for 0.6% of the total number of examinations. Nuclear medicine continues to account for around 1% of all examinations and its contribution to the collective dose has risen from 5% to about 7%. The number of radionuclide therapy treatments is estimated to have increased by 60% since the UNSCEAR 2008 Report [U9], while the number of courses of radiation therapy has increased by 22%.

108. The age distributions of patients undergoing computed tomography, interventional radiology and nuclear medicine examinations are quite similar, with the bulk of examinations occurring in patients aged 55 years and older. Conventional projection radiography shows a markedly flatter profile, with many examinations performed on children and young adults. The distribution of examinations between the sexes is generally even, although interventional radiology procedures, especially in cardiology, show a higher proportion of males. Projection radiography is weighted towards females, mainly due to the contribution from mammography examinations.

109. The use of radiation for diagnosis and therapy continues to be strongly weighted to high-income and upper middle-income countries. These countries account for around 70% of all medical radiological examinations and 75% of the overall collective dose. This disparity is even more marked in nuclear medicine where high-income and upper middle-income countries account for over 90% of the

procedures and more than 95% of the collective dose. Access to radiation therapy is similarly concentrated, with around 95% of all treatment courses occurring in high-income and upper middle-income countries.

110. The results of this global assessment of medical exposure were derived, for the first time, from a continuous model using data from the UNSCEAR Global Survey to generate predictions for countries that did not provide data, rather than by extrapolation of averaged data within health-care level categories. It is important to recognize that both the modelling and extrapolation approaches require representative data to reflect the broad patterns of use and exposure to derive a robust overall global assessment. Thus, the Committee wishes to highlight the importance of regular collection and publication of medical exposure data and seeks support to initiate data collection programmes for lower middle-income and low-income countries for its future evaluations.

111. Systematic collection, analysis and interpretation of relevant health data is essential for designing, implementing and evaluating health policies and actions. In particular, data collection within each country and inclusion of such data in global surveys such as the UNSCEAR assessments offers several benefits to participating countries. By knowing about health parameters such as frequency of medical examinations and procedures involving the use of ionizing radiation, as well as associated doses per procedure, the participating countries can inform the development of policies and strategies for the optimization of health-care delivery and improve practice. In addition, disparities in health-care delivery involving use of ionizing radiation in regions of a country can be identified and evaluated alongside other relevant health indicators. Population doses due to medical exposure can be determined and tracked in the context of temporal trends in regions and around the globe. Furthermore, results from surveys such as the UNSCEAR Global Survey can serve as reference material for researchers, students and government advisory bodies.

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TUR	Turkey	S. Turkes Yilmaz	
UKR	Ukraine	V. Chumak	O. Solodiannikova, L. Stadnyk
ARE	United Arab Emirates	J. AlSuwaidi	F. Riaz
GBR	United Kingdom	A. Bexon	
USA	United States	M. Mahesh	A. Ansari, V. Holahan
URY	Uruguay	F. Soca	

[a] The International Organization for Standardization Country Code 3166 was used in some tables and figures [I22].

APPENDIX A. METHODOLOGY FOR GLOBAL ASSESSMENT OF MEDICAL EXPOSURE

I. INTRODUCTION

A1. The Committee has regularly provided information on medical exposure since its first report in 1958 [U3]. Since its UNSCEAR 1988 Report [U4], it has attempted to estimate global exposure rather than simply presenting country-specific data. In addition, the Committee decided to prepare a survey questionnaire, in cooperation with the World Health Organization (WHO), and to distribute it to all Member States of the United Nations. The survey aimed to acquire data on medical exposure in addition to those appearing in the published literature. The survey approach and the cooperation with WHO has continued to the current evaluation.

A2. The Committee, since its UNSCEAR 1988 Report [U4], has used the health-care level (HCL) model to estimate the annual number of medical radiological examinations performed using ionizing radiation, according to the number of physicians per population [M7]. Extrapolation to derive a global estimate was performed by determining both the population-weighted average frequencies for procedures and the population-weighted average dose per procedure within each health-care level and then applying these population-weighted averages to the whole population within each health-care level. This approach worked well when the world population was relatively evenly distributed between health-care levels and when sufficient representative data could be obtained for each health-care level. In this evaluation, however, 53% of the total population is in countries categorized as HCL I and very few UNSCEAR Global Survey data have been received from countries at other health-care levels. Therefore, alternative approaches were explored, as described in detail in this appendix (section II).

II. FRAMEWORK FOR ANALYSIS

A3. This evaluation continues the application of approaches used by UNSCEAR in previous reports [U6, U9] in order to provide continuity in results, and also *(a)* takes account of updated dosimetric recommendations from the International Commission on Radiological Protection (ICRP) [I11] and *(b)* explores improved methods for modelling global medical exposure to establish new baselines for examining trends in medical exposure in future evaluations. An essential part of the assessment is the requirement to provide estimates of the medical exposure of the global population.

A. Dose assessment

A4. Medical exposure in diagnostic and interventional radiology is routinely characterized in terms of the physical dose quantities used for monitoring performance in radiology [I1, I16]. These quantities are:

- Entrance surface dose (ESD in mGy);
- Dose-area product (DAP, Gy cm²) for conventional X-ray procedures;
- Volume-weighted computed tomography dose index ($CTDI_{vol}$, mGy);
- Dose-length product (DLP, mGy cm) for computed tomography (CT) [I17].

Exposure in nuclear medicine and radiation therapy is characterized in terms of administered activity of the radiopharmaceutical (MBq) and prescribed doses (Gy) to target volumes, respectively [U9]. Whereas the above dose quantities provide the basis for ensuring the effective delivery of medical exposure, associated radiation risks for diagnostic procedures are determined by mean doses to organs and tissues via specific risk models. However, such analyses of risk are not in the scope of this evaluation.

A5. Diagnostic medical exposure can also be summarized for the purposes of broad comparison in terms of effective dose, *E*, although this radiation protection quantity was developed specifically by International Commission on Radiological Protection (ICRP) as part of its system for the control of sources of exposure to ionizing radiation through the application of dose limits, constraints and reference levels for workers and members of the public [I11]. The concept usefully allows the summation of radiation exposure, whether whole- or partial-body, from internal and external radiation exposure, and provides a single measure of the dose to a reference person (averaged for age and sex) that is roughly proportional to the total "radiation detriment" from stochastic effects associated with the exposure [W1]. The effective dose, *E*, is calculated as a weighted sum of the mean absorbed doses (or, strictly, the mean equivalent doses) to those tissues and organs in the body that are prone to radiation-induced cancer or heritable effects, using detriment-related tissue weighting factors specified by the ICRP [I11]. The tissue weighting factors are simple adjustments based on nominal risk coefficients (relating *E* to radiation detriment), averaged over all ages and both sexes, calculated for an ICRP "world population" with Western and Asian components. The sum of the effective doses from a particular source of exposure to individuals within a population results in the collective effective dose (*S*), which provides a measure of population dose normally for radiation protection purposes [I11]. Dividing S by a population size gives the associated per caput dose, which represents the average dose to every member of that population—irrespective of their particular circumstances of exposure.

A6. Whereas *E* is a risk-adjusted dosimetric quantity, its intended purpose is for use as a radiation protection quantity; it is not intended as a measure of risk for specific populations or individuals and should not be used for epidemiological purposes. However, *E* can be applied with caution in relation to medical radiology in order to compare doses between different diagnostic and interventional procedures or with those from other sources of ionizing radiation when populations are similar with regard to age and sex distribution [U6].

A7. In accordance with the above discussion, the effective dose is used with caution here, as in previous UNSCEAR reports [U5, U6, U9], for the pragmatic evaluation of population doses (as collective effective doses) and average doses per person (per caput doses) in relation to medical radiological exposures. The intended purpose is to provide broad, convenient measures of practice solely for the assessment of trends and comparison between different sources of exposure for the world population and not the estimation of any risks. In using reported values of *E* in such an analysis, however, it should be noted that evolution in the recommendations from the ICRP concerning the calculation of *E* (in relation to both tissue weighting factors and also reference anthropomorphic phantoms) can lead to significant variation in estimates made under different sets of recommendations for a given type of examination that may amount to some tens of per cent [J6, S14]. The influence on derived values of *E* arising from changes in tissue weighting factor between recommendations from ICRP Publications 103 [I11] and 60 [I9] is illustrated in tables A1 and A2 in relation to some common X-ray examinations [W1] and nuclear medicine radiopharmaceuticals [I10], respectively. In addition, the ratios presented in table A3 [S14] illustrate the influence on values of both E-103 [I11] and E-60 [I9] derived for some common computed tomography procedures in the United Kingdom that arise from choice of anthropomorphic reference phantom: the recently-recommended ICRP computational voxel adult male and female [I12] or the Medical Internal Radiation Dosimetry (MIRD) hermaphrodite mathematic phantom originally developed by Oak Ridge National Laboratory [C15]. Tables A1–A3 demonstrate that such recent evolution in the ICRP recommendations leads to patterns of change in calculated values of *E* that differ between types of examination, leading to both increases (ratios >1) and decreases (ratios <1). These variations serve to further highlight the broad nature of any comparisons of values of *E*.

Table A1. Ratio of effective doses calculated using tissue weighting factors in ICRP Publications 103 (E-103) and 60 (E-60) for typical X-ray examinations in the United Kingdom [W1]

CT: Computed tomography

Complete examination	*Ratio E-103 / E-60*
Head (two projections)	1.36
Cervical spine (one projection)	1.00
Chest (one projection)	1.00
Thoracic spine (two projections)	1.03
Lumbar spine (two projections)	0.91
Abdomen (one projection)	0.91
Pelvis (one projection)	0.62
Intravenous urography (five projections)	0.91
Barium swallow	1.07
Barium follow-through	0.87
Barium enema	0.73
CT-head	0.84
CT-chest	1.14
CT-abdomen	1.09
CT-abdomen and pelvis	0.98
CT-chest, abdomen and pelvis	1.09

A8. Under ideal circumstances, this review of global medical exposure would assess values of effective dose in terms of both E-103 and E-60. Unfortunately, it is likely that the Committee's present review of doses from medical exposure includes the collection of values of *E* that have been derived following different ICRP recommendations. These data have often been reported without a clear description of their underlying basis, such that corrections to rationalize all data to the latest ICRP recommendations are not practical. Accordingly, it will be assumed that all reported values of *E* relate primarily to E-60 [I9], with any variations in the basis for their computation representing sources of potential uncertainty. However, the differing changes observed between particular types of examination (tables A1 to A3) will, to some extent, tend to balance out when considering a mix of examinations in assessing population dose such that the influence of these uncertainties will be reduced.

Table A2. Ratio of effective doses calculated using tissue weighting factors in ICRP Publications 103 (E-103) and 60 (E-60) for a range of common nuclear medicine procedures on the basis of E-60 as calculated in ICRP Publication 128 and E-103 [A6, A7, H5, S14, W1]

CT: Computed tomography; FDG: Fluoro-2-D-deoxyglucose; HDP: Hydroxydiphosphonate; MAA: Macroaggregated albumin; MAG3: Mercaptoacetyltriglycine; MIBI: Methoxy isobutyl isonitrile

Examination	*Radiopharmaceutical*	*Ratio E-103 / E-60*
Perfusion lung scan	^{99m}Tc-MAA	1.27
Bone scan	^{99m}Tc-HDP	0.70
Renal scan	^{99m}Tc-MAG3	0.57
Myocardial perfusion scan (rest)	^{99m}Tc-MIBI	0.73
Myocardial perfusion scan	^{201}Tl-chloride	0.73
Tumour scan	^{18}F-FDG	0.90

Table A3. Ratio of effective doses calculated for the ICRP computational voxel adult (as mean result for male and female) and a modified MIRD-type hermaphrodite mathematical phantom (HPA18+) using tissue weighting factors both in ICRP Publications 103 (E-103) and 60 (E-60) for a range of typical CT examinations in the United Kingdom [W1]

HPA18+ is a modified adult MIRD-type hermaphrodite mathematical phantom [S14]

Examination	*Ratio E (ICRP voxel reference adult) / E (HPA18+MIRD)*	
	E-103	*E-60*
Head	0.93	0.80
Chest	1.41	1.39
Abdomen	1.27	1.15
Abdomen and pelvis	1.23	1.18
Chest, abdomen and pelvis	1.25	1.20

B. Sources of data

A9. A comprehensive evaluation of annual global medical practice requires information concerning every radiological procedure performed in the world during a particular year. Under such ideal circumstances and for the example of diagnostic radiology (similar arguments apply broadly to the other modality categories of medical practice involving exposure to ionizing radiation), the total number of X-ray examinations performed annually in the world is given by:

$$N = \sum_{i,j} N_{i,j} \qquad (A.1)$$

where $N_{i,j}$ is the annual number of examinations of type i carried out in country j and the summation includes all countries and types of examination.

Similarly, the population dose from diagnostic radiology S (man Sv) is given by:

$$S = \sum_{i,j} \left(N_{i,j} \times \frac{E_{i,j}}{1{,}000} \right) \tag{A.2}$$

where $E_{i,j}$ is the typical effective dose (mSv) for examination i in country j, and the global per caput effective dose (mSv) (for world population of size P) is given by:

$$E_{\text{per caput}} = \left(\frac{S}{P} \times 1{,}000 \right) \tag{A.3}$$

1. UNSCEAR Global Survey data

A10. As an integral part of its work, the Committee seeks to collect, via the UNSCEAR Global Survey incorporating a detailed questionnaire,[1] all available national information concerning annual numbers (N_j) and typical doses (E_j) for each type of diagnostic examination, together with additional supporting information on national medical imaging practice. For therapeutic exposure, typical doses are requested more simply in terms of administered activity (MBq) or prescribed doses (Gy).

A11. The questionnaires used in the recent UNSCEAR Global Survey consist of four parts:

- *Part 1*: Essential information and data on annual total numbers of examinations and procedures within each broad type of radiological discipline (such as diagnostic radiology including all X-rays, all dental examinations, all interventional radiology and all computed tomography examinations separately), together with total numbers for broad types of equipment and staffing;
- *Part 2*: Detailed information on diagnostic and therapeutic equipment and staffing;
- *Part 3*: Numbers of diagnostic radiological examinations, nuclear medicine procedures (both diagnostic and therapeutic) and radiation therapy treatments;
- *Part 4*: Information of dosimetric data including estimates of effective dose per examination or procedure.

A12. The UNSCEAR Global Survey was launched in 2014. To encourage increased participation and secure the collection of available data, particularly from countries that could supply only less detailed information, a simplified version of the questionnaire was distributed in 2017. This questionnaire requested key indicators of practice, including annual totals for national numbers of examinations of diagnostic and interventional radiology and information on subcategories such as conventional radiology, dental radiology and computed tomography separately, together with totals for broad types of radiological equipment and staffing information. Similar key summary was sought in relation to nuclear medicine procedures and radiation therapy treatments. For further details, see also the electronic attachments B1 to E1.

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[1] Available at the country specific webpage on www.survey.unscear.org.

2. Literature review data

A13. The national data available from the UNSCEAR Global Survey have been supplemented by other information, including reports from national institutes/authorities. The availability of such national data has been facilitated in Europe by the European Basic Safety Standards Directive [E4] that requires European Union Member States to periodically monitor population doses. Initiatives on this topic in some countries have led to the publication of national data supporting assessments of population dose, including those in Australia [H6], Europe [E5], the United Kingdom [H5] and the United States [N1, N2].

A14. This evaluation is also supported by useful information reported in the published literature in relation to various surveys of medical practice. Ideally, these studies should be both robustly conducted and regionally based. Smaller-scale surveys can be of interest if they provide coherent novel results from countries for which data are otherwise not available. Dose data reported for particular types of examination in terms of typical values of physical dose metrics (e.g., ESD, DAP, DLP) were converted to *E* using a set of standard dose coefficients included in the user manual for the UNSCEAR Global Survey [U11].

A15. The ongoing development of initiatives in monitoring patient exposure, including automated dose assessment and data management systems that support dose registries and databases, will also facilitate the future collection of data concerning frequency and dose at the national level [L1, R3, R9].

III. APPROACHES FOR GLOBAL ASSESSMENT

A16. A number of approaches have been explored and several models were applied in performing the present global assessment of medical exposure. In this section, the HCL model applied in previous UNSCEAR reports on medical exposure [U4, U5, U6, U9], a model based on an alternative classification scheme, and also continuous mathematical models are tested and discussed.

A17. In the inevitable absence of the comprehensive information required for a complete analysis, it becomes necessary to undertake extrapolation so that results for the available sample of data can be scaled using an appropriate model in order to derive an assessment of global medical exposure. The challenge posed by the limited information available from the UNSCEAR Global Survey is illustrated in table A4, which shows the size (as a percentage of the global population) of the data sample provided in relation to X-ray, nuclear medicine and radiation therapy procedures for previous evaluations and in the current evaluation period (2009-2018). Whereas, for example, X-ray data were available in relation to 63% of the world population for the 1988 evaluation [U4], the sample size decreased during successive evaluations to only 11% for the 2008 evaluation [U9]; the corresponding sample size in this evaluation is 43% of the world population, although this figure tends to hide the often limited scope of the data available. Corresponding sample sizes in relation to nuclear medicine (diagnostic and therapy) are 49% and 46%, respectively and 64% of the world population for radiation therapy.

Table A4. Percentage of world population included through national data concerning diagnostic radiology, nuclear medicine and radiation therapy collected for UNSCEAR periodic evaluations

Report	*Population in sample (%)*[a]				*World population (millions)*[a]
	X-ray (medical/dental)	*Nuclear medicine*		*Radiation therapy (teletherapy/ brachytherapy)*	
		Diagnostic	*Therapy*		
UNSCEAR 1988 [U4]	63	56	2.8	31	5 000
UNSCEAR 1993 [U5]	60	58	46	46	5 300
UNSCEAR 2000 [U6]	48	51	45	49	5 800
UNSCEAR 2008 [U9]	11	13	10	31	6 500
Current evaluation	43	49	46	64	7 300

[a] Values are rounded.

A18. Another challenge in making a global assessment on the basis of limited data is the wide variation between different countries in practice, in relation to the numbers of examinations and their typical doses. The frequencies of all medical (including dental) radiological examinations reported in the present sample of countries range from <0.1 to over 2,000 per 1,000 population (representing a factor of over 20,000), which highlights the importance of the particular model used when managing potential uncertainties in scaling up the results from the survey sample to global practice.

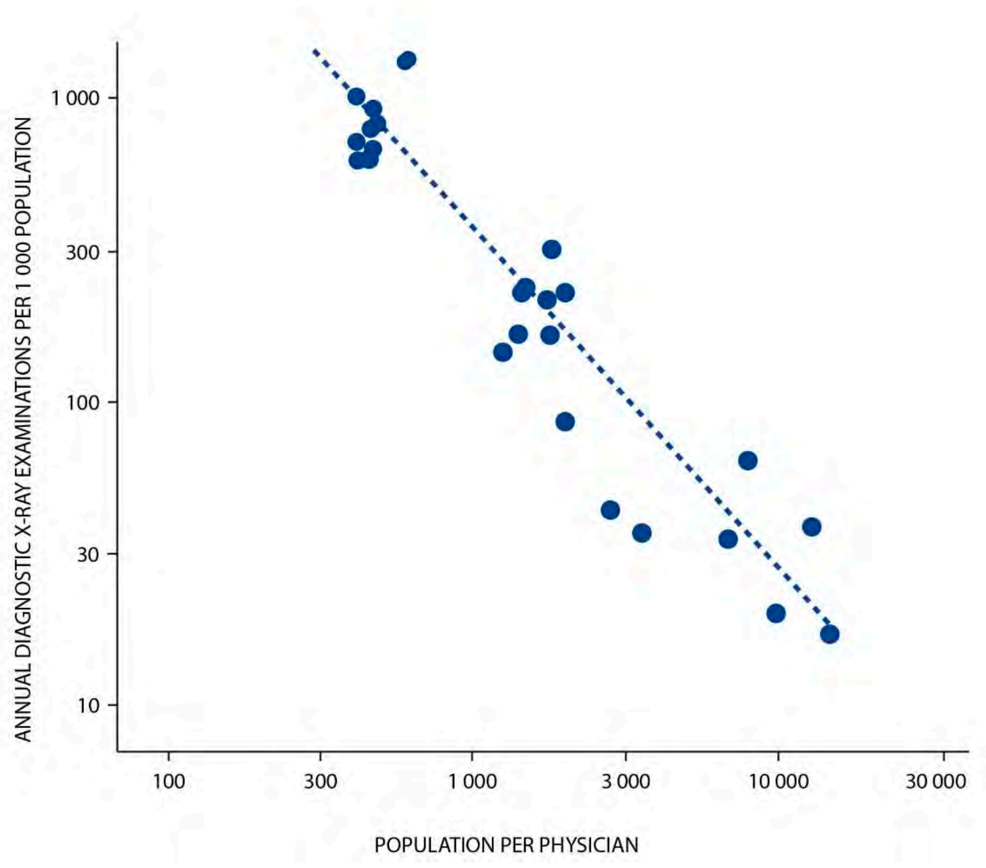
A19. In developing a model for the global assessment of medical exposure for the UNSCEAR 1988 Report [U4], Mettler et al. [M7] explored the relationships between the national use of radiation in medicine and other national data that might be more readily available from a wider range of countries. Correlations between the national annual frequency of diagnostic radiological examinations per 1,000 population and health-care expenditure per caput or number of hospital beds were reported to be "poor" and "less than optimal", respectively, whereas a correlation with population per physician was "high".

A20. Mettler et al. [M7] assigned countries to four health-care levels in order to estimate the worldwide medical population exposure as follows:

- HCL I with more than one physician for 1,000 population;
- HCL II with one physician for 1,000–2,999 population;
- HCL III with one physician for 3,000–10,000 population;
- HCL IV with less than one physician for over 10,000 population.

A21. Following the HCL model, all countries are stratified according to the number of physicians per population on the assumption that this is linked to the medical radiological practice per caput (figure A-I). In this way, relatively similar national data within each HCL category can be pooled to provide population-weighted average values that can be scaled for total populations within the same category or for the whole world. This approach of averaging and extrapolating data within one category of medical care should lead to smaller uncertainties compared with a simple global average. Population sizes for each of the four health-care levels are summarized in table A5. Whereas the world population had grown significantly (by nearly 30%) between the Committee's reviews for 1988 and 2008, HCL I countries continued to account for around a quarter of the global population. In contrast, the global proportion assigned to HCL II countries rose from a third (in 1988) to a half in 2008, with reductions for HCLs III and IV countries to proportions of 16% and 12%, respectively, over this period. In the current evaluation, world population has increased by 13% since 2008, with a more significant increase in the proportion in HCL I countries (24 to 53%) and a corresponding reduction for HCL II (49 to 31%). Proportions of global population within HCL III and HCL IV are also reduced from their levels in 2008 (16 to 9% and 11 to 7%, respectively). One contributing factor in this significantly different pattern is the change in classification for Brazil and China from HCL II in 2008 to HCL I in 2015. This occurrence highlights a limitation in the non-continuous nature of the HCL model.

Figure A-I. Correlation of annual frequency of radiological examinations and physician density [M7]



A22. Limitations in the broad HCL classification system have already been discussed in UNSCEAR 2000 Report [U6] where some flexibility in the practical application of the model was applied. For example, some countries with relatively large numbers of physicians were classified as HCL II or HCL III rather than HCL I [U6].

Table A5. Distribution of world population by health-care level

HCL: Health-care level

Report	*Distribution of world population in millions (%)* [a]				
	HCL I	*HCL II*	*HCL III*	*HCL IV*	*World*
UNSCEAR 1988 [U4]	1 300 (26%)	1 750 (35%)	1 220 (24%)	730 (15%)	5 000 (100%)
UNSCEAR 1993 [U5]	1 350 (25%)	2 630 (50%)	850 (16%)	460 (9%)	5 290 (100%)
UNSCEAR 2000 [U6]	1 530 (26%)	3 070 (53%)	640 (11%)	565 (10%)	5 800 (100%)
UNSCEAR 2008 [U9]	1 540 (24%)	3 150 (49%)	1 010 (16%)	740 (11%)	6 440 (100%)
Current evaluation	3 910 (53%)	2 250 (31%)	620 (9%)	520 (7%)	7 300 (100%)

[a] Values are rounded.

A23. The HCL model can be applied, for example, to the sample national data concerning diagnostic radiology collected by the Committee. If $N_{i,j}$ is the annual number of examinations of type i in country j (of population P_j), the frequency of examination i per 1,000 population in country j is:

$$F_{i,j} = \frac{N_{i,j}}{P_j} \times 1{,}000 \tag{A.4}$$

A24. The weighted average frequency of examination i per 1,000 population in HCL level k (with population $P_{\mathrm{HCL(k)}}$) is then given by:

$$F_{i,HCL(k)} = \sum_j \left(F_{i,j} \times \frac{P_j}{P_{HCL(k)}} \right) = \sum_j \left(\frac{N_{i,j}}{P_j} \times 1{,}000 \times \frac{P_j}{P_{HCL(k)}} \right) =$$

$$\Sigma_j \left(\frac{N_{i,j}}{P_{HCL(k)}} \times 1{,}000 \right) \tag{A.5}$$

Similarly, the weighted average typical effective dose (mSv) for examination i in HCL level k is given by:

$$E_{i,HCL(k)} = \Sigma_j \left(E_{i,j} \times \frac{P_j}{P_{HCL(k)}} \right) \tag{A.6}$$

where $E_{i,j}$ (mSv) is the typical effective dose for examination i in country j.

The population dose (man Sv) from all examinations in HCL level k is then:

$$S_{HCL(k)} = \Sigma_i \left(F_{i,HCL(k)} \times \frac{E_{i,HCL(k)}}{1{,}000} \times \frac{P_{HCL(k)}}{1{,}000} \right) \tag{A.7}$$

The global population dose (man Sv) from all examinations is given by:

$$S_{world} = \Sigma_{k=I-IV} S_{HCL(k)} \tag{A.8}$$

A25. Absolute numbers of examinations (within each HCL category or for the world) are determined from their frequencies and associated populations (equation (A.4)), and per caput doses from knowledge of population doses and size of populations (equation (A.3)).

A26. Successful application of the HCL model requires (considering the often incomplete national data collected) establishment of a consistent set of data, for each HCL category and for the world, in which the sum of the frequencies for each type of examination is equal to the total frequency for all examinations. Thus, the HCL model does not intend to provide estimates of examination numbers, population dose or per caput effective dose for individual countries. Rather, it provides a robust assessment of global estimate of medical exposure using ionizing radiation.

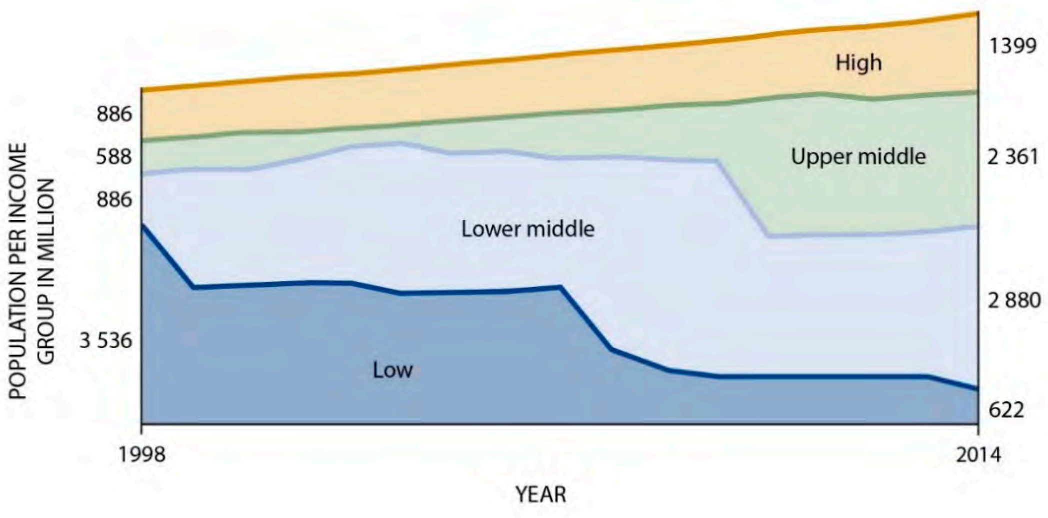
A27. The above analysis should also be viewed in the light of the relative populations in each HCL category and their overall contributions to global population dose. Whereas HCL I included about a quarter of the world population in 2008 (table A5), it accounted for around 73% of the global dose from medical X-rays [U9]. Corresponding data for HCL II were around one half and one quarter, respectively, with HCLs III and IV each providing only 1% towards the global dose (yet accounting for over one quarter of the global population). The present analysis suggests an increasing dominance of HCL I, with inclusion of about half of the global population. Whereas it is important to have robust data from HCLs II-IV in order to report on the range of practice around the world, such data would appear to be less critical in terms of the assessment of global medical exposure.

A. Classification by income levels

A28. A possible alternative to classification by health-care levels is to use the World Bank income classifications for countries [F3]. The World Bank income classification is based on gross national income per caput (current USD) and has also four levels: high, upper middle, lower middle, and low. Figure A-II shows the distribution of the global population among these levels (16, 36, 39 and 9%, respectively), which is more even than the distribution among health-care levels (53, 31, 9 and 7%, respectively).

Figure A-II. Population in millions by each income group [F3]

Latest year of data availability during each fiscal year



B. Application to present assessment

A29. Table A6 presents estimates of the annual number of conventional radiology (excluding dental) examinations derived using extrapolations of the population-weighted average frequencies in the assessed data, by the HCL model and by a separate extrapolation of population-weighted average frequencies categorized by income level. Also shown are the number of countries for which there were data, compared with the total number of countries in each category, and the proportion of the total population in each category covered by the data. These extrapolations yield estimates of 2.39 and 2.47 billion examinations per annum, respectively. It should be noted that for the extrapolation by income levels, the data for the upper middle-income and lower middle-income groups were combined because the population-weighted average frequency in the lower middle-income classification was actually higher than that in the upper middle-income classification. The population-weighted average frequency within the lower middle-income group alone was 370 examinations per 1,000 population and using this value in the extrapolation gives 1,070 million examinations for this category, increasing the overall projected total by 270 million.

Table A6. Estimates of the global number of conventional radiology (excluding dental) examinations per annum by extrapolation of population-weighted average frequencies to all countries in each category from assessed data by health-care level and by income level

Based on data from 65 countries (UNSCEAR Global Survey and additional sources) for the period 2009–2018

Category	*Population-weighted average examinations per 1 000 population* [a]	*Countries included/all countries* [b]	*Proportion of population in assessed data (%)*	*Total population (millions)*	*Extrapolated examinations (millions)* [a]
Extrapolation by health-care level					
I	466	60/105	86	3 908	1 823
II	202	1/31	0.1	2 256	455
III	172	3/31	18	622	107
IV	1.9	1/27	4	526	1
Total	**326**	**65/194**	**48**	**7 312**	**2 386**
Extrapolation by income level					
High	867	43/57	96	1 149	997
Upper middle	267 [c]	15/58	80	2 619	700
Lower middle	267 [c]	5/45	8	2 882	771
Low	7	2/34	7	662	4.5
Total	**338**	**65/194**	**48**	**7 312**	**2 472**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Member States of WHO.

[c] Data for upper middle-income and lower middle-income have been combined. The population-weighted average number of procedures for upper middle-income was 256 per 1,000 population and for lower middle-income was 370 per 1,000 population.

A30. Table A7 presents estimates of the annual number of dental radiology examinations derived using extrapolations of the population-weighted average frequencies in the assessed data, categorized by the HCL model and income level. Also shown are the number of countries for which there were data, compared with the total number of countries in each category, and the proportion of the total population in each category covered by the data.

A31. These extrapolations both yield estimates of 1.19 billion examinations per annum; however, this concordance is dependent on a number of assumptions. There were no data for HCL III and HCL IV; therefore, average frequencies of 20 per 1,000 population and 10 per 1,000 population, respectively, were assumed in the extrapolation by health-care level. These choices are essentially arbitrary but follow a pattern of reducing frequencies at lower health-care levels. The population-weighted average frequency for lower middle-income countries in the assessed data was actually higher (340 per 1,000) than for upper middle-income countries (88 per 1,000). As in the similar case for conventional radiology (excluding dental), the two categories were combined to give an overall population-weighted average of 94 per 1,000 population. There were also no data for low-income countries and an average frequency of 10 per 1,000 population was assumed in the extrapolation by income level. If the actual population-weighted average for lower middle-income countries were used, the overall total would increase by around 50%, but the increase would be based on the data from only two countries. Thus, the nominal agreement between the two extrapolations shown in table A7 is highly dependent on the assumptions made in the absence of data.

Table A7. Estimates of the global number of dental radiology examinations per annum by extrapolation of population-weighted average frequencies to all countries in each category from assessed data by health-care level and by income level

Based on data from 49 countries (UNSCEAR Global Survey and additional sources) for the period 2009–2018

Category	*Population-weighted average examinations per 1 000 population* [a]	*Countries included/all countries* [b]	*Proportion of population in assessed data (%)*	*Total population (millions)*	*Extrapolated examinations (millions)* [a]
Extrapolation by health-care level					
I	270	48/105	76	3 908	1 057
II	49	1/31	0.1	2 256	111
III	20[c]	0/31	0	622	12.4
IV	10[d]	0/27	0	526	5.3
Total	**162**	**49/194**	**41**	**7 312**	**1 186**
Extrapolation by income level					
High	578	38/57	95	1 149	665
Upper middle	94[e]	9/58	71	2 619	247
Lower middle	94[e]	2/45	2	2 882	272
Low	10[f]	0/34	0	662	6.6
Total	**163**	**49/194**	**41**	**7 312**	**1 191**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.
[b] Member States of WHO.
[c] Assumed frequency of 20 per 1,000 population applied to HCL III.
[d] Assumed frequency of 10 per 1,000 population applied to HCL IV.
[e] Data for upper middle-income and lower middle-income have been combined. The population-weighted average number of examinations for upper middle-income was 88 per 1,000 and for lower middle-income was 340 per 1,000.
[f] Assumed frequency of 10 per 1,000 population applied to the low-income category.

A32. Table A8 presents estimates of the annual number of computed tomography examinations derived using extrapolations of the population-weighted average frequencies in the assessed data, categorized by health-care level and income level. Also presented are the number of countries for which there were data, compared with the total number of countries in each category, and the proportion of the total population in each category covered by the data.

A33. Extrapolation applying the average frequencies across each health-care level yields an estimated annual total of 378 million computed tomography examinations. No data were received from HCL II countries; therefore, for the extrapolation, a frequency of 20 CT examinations per 1,000 population were assumed for HCL II. As in the similar case for dental radiology, this is a largely arbitrary choice, though it is broadly consistent with a geometric progression across the health-care levels. This assumed value accounts for 12% of the extrapolated total of CT examinations for the period 2009-2018. Extrapolation by income levels yields a lower estimate of 346 million examinations per annum. High-income countries average 160 examinations per 1,000 population per annum, upper middle-income countries 46 per 1,000, and lower middle-income countries 15 per 1,000. Examination frequency in the single low-income country included in the assessment was 0.2 per 1,000.

Table A8. Estimates of the global number of computed tomography examinations per annum by extrapolation of population-weighted average frequencies to all countries in each category from assessed data by health-care level and by income level

Based on data from 69 countries (UNSCEAR Global Survey and additional sources) for the period 2009–2018

Category	*Population-weighted average examinations per 1 000 population* [a]	*Countries included/all countries* [b]	*Proportion of population in assessed data (%)*	*Total population (millions)*	*Extrapolated examinations (millions)* [a]
Extrapolation by health-care level					
I	84	63/105	84	3 908	330
II	20 [c]	0/31	0	2 256	45
III	5.1	3/31	16	622	3.2
IV	0.6	3/27	19	526	0.34
Total	**52**	**69/194**	**48**	**7 312**	**378**
Extrapolation by income level					
High	160	44/57	98	1 149	184
Upper middle	46	15/58	76	2 619	120
Lower middle	15	9/45	10	2 882	42
Low	0.2	1/34	8	662	0.14
Total	**47**	**69/194**	**48**	**7 312**	**346**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Member States of WHO.

[c] Assumed frequency of 20 per 1,000 population applied to HCL II.

A34. Table A9 presents estimates of the annual number of interventional radiology procedures derived using extrapolations of the population-weighted average frequencies in the assessed data, categorized by health-care level and by income level. Also shown are the number of countries for which there were data, compared with the total number of countries in each category, and the proportion of the total population in each category covered by the data.

A35. Extrapolation applying the average frequencies across each health-care level yields an estimated annual total of 21.9 million procedures. No data were received from HCL II or HCL IV countries. For the extrapolation, a frequency of one procedure per 1,000 population was assumed for HCL II and the frequency for HCL III was applied to HCL IV also. Approximately 90% of the extrapolated total comes from HCL I countries, where the coverage of the assessed data is 81% of the population. Extrapolation by income levels yields a lower estimate of 18.6 million procedures per annum. High-income countries average 13 procedures per 1,000 population per annum, upper middle-income countries 1.4 per 1,000 and lower middle-income countries 0.13 per 1,000 population. In the extrapolation, the observed frequency of procedures per 1,000 population used for lower middle-income countries was also applied for low-income countries.

Table A9. Estimates of the global number of interventional radiology procedures per annum by extrapolation of population-weighted average frequencies to all countries in each category from assessed data by health-care level and by income level

Based on data from 57 countries (UNSCEAR Global Survey and additional sources) for the period 2009–2018

Category	*Population-weighted average procedures per 1 000 population* [a]	*Countries included/all countries* [b]	*Proportion of population in assessed data (%)*	*Total population (millions)*	*Extrapolated procedures (millions)* [a]
Extrapolation by health-care level					
I	5.0	55/105	83	3 908	19.5
II	1.0[c]	0/31	0	2 256	2.3
III	0.13	2/31	14	622	0.08
IV	0.13[d]	0/27	0	526	0.07
Total	**3.0**	**57/194**	**46**	**7 312**	**21.9**
Extrapolation by income level					
High	13	39/57	93	1 149	14.5
Upper middle	1.4	12/58	78	2 619	3.6
Lower middle	0.13	6/45	8	2 882	0.39
Low	0.13[e]	0/34	0	662	0.09
Total	**2.5**	**57/194**	**46**	**7 312**	**18.6**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.
[b] Member States of WHO.
[c] Assumed frequency of 1 per 1,000 population applied to HCL II.
[d] Frequency for HCL III was applied.
[e] Frequency for lower middle-income level was applied.

A36. Table A10 presents estimates of the annual number of nuclear medicine procedures derived using extrapolations of the population-weighted average frequencies in the assessed data, categorized by health-care level and by income level. Also shown are the number of countries for which there were data, compared with the total number of countries in each category, and the proportion of the total population in each category covered by the data. Extrapolation by applying the average frequencies across each health-care level yields an estimated annual total of 42 million procedures. Extrapolation by income levels yields a similar estimate of 39 million procedures per annum.

Table A10. Estimates of the global number of diagnostic nuclear medicine procedures per annum by extrapolation of population-weighted average frequencies to all countries in each category from assessed data by health-care level and by income level

Based on data from 68 countries (UNSCEAR Global Survey and additional sources) for the period 2009–2018

Category	*Population-weighted average procedures per 1 000 population* [a]	*Countries included/all countries* [b]	*Proportion of population in assessed data (%)*	*Total population (millions)*	*Extrapolated procedures (millions)* [a]
Extrapolation by health-care level					
I	10.3	61/105	84	3 908	40.3
II	0.63	3/31	19	2 256	1.42
III	0.09	1/31	6	622	0.057
IV	0.04	3/27	12	526	0.02
Total	**5.7**	**68/194**	**52**	**7 312**	**41.8**
Extrapolation by income level					
High	26	41/57	96	1 149	29.0
Upper middle	2.6	16/58	79	2 619	6.8
Lower middle	1.0	10/45	21	2 882	2.7
Low	0.03	1/34	3	662	0.02
Total	**5.3**	**68/194**	**52**	**7 312**	**39.0**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.
[b] Member States of WHO.

A37. Table A11 presents estimates of the annual number of radionuclide therapy treatments derived using extrapolations of the population-weighted average frequencies in the assessed data, categorized by health-care level and by income level. Also shown are the number of countries for which there were data, compared with the total number of countries in each category, and the proportion of the total population in each category covered by the data. No data were received from HCL IV or low-income countries. Thus, for the purposes of making the extrapolations, the frequency for HCL III countries was applied to HCL IV countries and for low-income countries. Extrapolation by applying the average frequencies across each health-care level yields an estimated annual total of 1.5 million radionuclide therapy treatments. Extrapolation by income levels yields a similar estimate of 1.45 million treatments per annum.

A38. Table A12 presents estimates of the annual number of radiation therapy treatment courses derived using extrapolations of the population-weighted average frequencies in the assessed data, categorized by health-care level (HCL model) and by income level. Also shown are the number of countries for which data were compared with the total number of countries in each category and the proportion of the total population in each category covered by the data.

A39. Extrapolation applying the population-weighted average frequencies across each health-care level yields an estimated total of 6.22 million radiation therapy treatment courses annually. As no data were available from HCL IV countries, the same frequency as for HCL III was assumed for the extrapolation. Radiation therapy treatment courses at HCL III and HCL IV countries make only a small contribution to the global total number of treatment courses. The UNSCEAR Global Survey covered over 75% of the population in each of the HCL I and HCL II levels. Extrapolation by income levels yields a slightly lower estimate of 5.88 million treatment courses per annum. High-income countries average 2,748 treatment courses per million population per annum, upper middle-income countries 923 per million, and lower middle-income countries 105 per million and low-income only 7 per million.

Table A11. Estimates of the global number of radionuclide therapy treatments per annum by extrapolation of population-weighted average frequencies to all countries in each category from assessed data by health-care level and by income level

Based on data from 41 countries (UNSCEAR Global Survey) for the period 2009–2018

Category	*Population-weighted average treatments per 100 000 population* [a]	*Countries included/all countries* [b]	*Proportion of population in assessed data (%)*	*Total population (millions)*	*Extrapolated treatments (millions)* [a]
Extrapolation by health-care level					
I	29.9	36/105	75	3 908	1.17
II	13.3	4/31	20	2 256	0.30
III	3.9	1/31	6	622	0.02
IV	3.9[c]	0/27	0	526	0.02
Total	**20.7**	**41/194**	**47**	**7 312**	**1.51**
Extrapolation by income level					
High	31.6	24/57	74	1 149	0.36
Upper middle	30.4	12/58	78	2 619	0.80
Lower middle	9.1	5/45	19	2 882	0.26
Low	3.9[c]	0/34	0	662	0.03
Total	**19.8**	**68/194**	**47**	**7 312**	**1.45**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.
[b] Member States of WHO.
[c] Frequency for HCL III was applied.

Table A12. Estimates of the global number of radiation therapy treatment courses per annum by extrapolation of population-weighted average frequencies to all countries in each category from assessed data by health-care level and by income level

Based on data from 44 countries (UNSCEAR Global Survey and additional sources) for the period 2009–2018

Category	*Population-weighted average treatment courses per million population* [a]	*Countries included/all countries* [b]	*Proportion of population in assessed data (%)*	*Total population (millions)*	*Extrapolated treatment courses (millions)* [a]
Extrapolation by health-care level					
I	1 501	37/105	76	3 908	5.87
II	128	5/31	78	2 256	0.288
III	56	2/31	10	622	0.035
IV	56[c]	0/27	0	526	0.030
Total	**979**	**44/194**	**66**	**7 312**	**6.22**

Category	Population-weighted average treatment courses per million population [a]	Countries included/all countries [b]	Proportion of population in assessed data (%)	Total population (millions)	Extrapolated treatment courses (millions) [a]
Extrapolation by income level					
High	2 748	26/57	86	1 149	3.16
Upper middle	923	11/58	75	2 619	2.42
Lower middle	105	6/45	64	2 883	0.304
Low	7	1/34	4	662	0.0046
Total	**805**	**44/194**	**66**	**7 312**	**5.88**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Member States of WHO.

[c] Frequency for HCL III was applied.

C. Continuous models

A40. Experience gained from testing the data received for the UNSCEAR Global Survey has highlighted significant limitations in the HCL model previously established to provide assessments of global medical exposure. This model uses four health-care levels and relies on an assumed homogeneity of data within each health-care level. Drawbacks with this approach include the following:

– It relies on having a sufficient sample of national data within each health-care level in order to provide robust estimates of population-weighted mean values (for frequency and dose) that are representative for the level;

– It is non-continuous in nature and thus sensitive to movement of countries between health-care levels , with a risk for over- or underestimation of results if a large country moves from one level to another;

– There has been a pragmatic need in previous reviews to deal with apparent outliers to the general trend (between national numbers of examinations and physicians), with necessary ad hoc reclassification of health-care level for some countries;

– Uncertainties, as now required for the Committee's global evaluations, are difficult to assess.

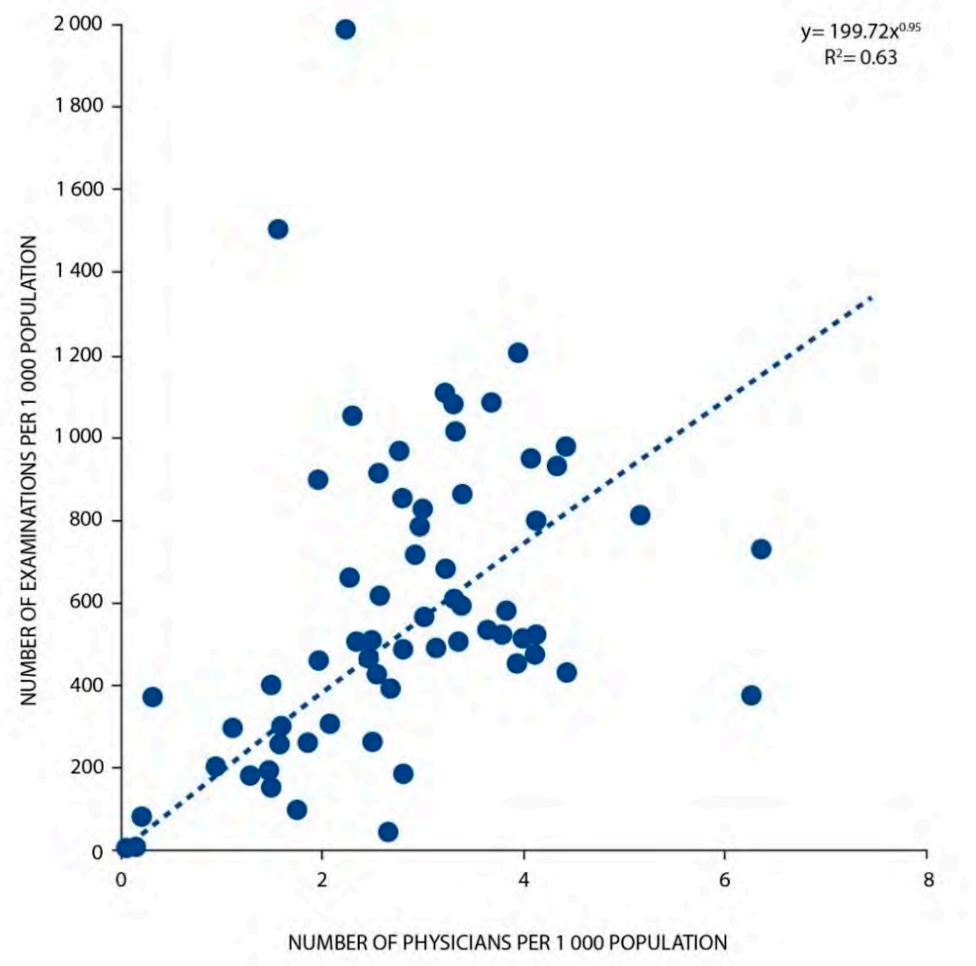
A41. To address the deficiencies identified above, the present assessment has used continuous models to extrapolate the UNSCEAR Global Survey data to the global population. To estimate the global population exposure, the frequencies of different medical radiation examinations must first be estimated. Since only a few countries provided detailed data at the level of examinations/procedures, broader modality categories of examinations were considered for the global estimation. These were: conventional radiology (excluding dental radiography), dental radiography, computed tomography, interventional radiology, and nuclear medicine. The frequency estimates for each modality category were then multiplied by typical dose values to obtain a collective effective dose per category. Although not relevant for the global population dose estimation, the global frequency of radionuclide therapy and of radiation therapy were also estimated.

A42. For example, in figure A-III, annual frequencies of conventional radiology (excluding dental) examinations per 1,000 population are plotted against the number of physicians per 1,000 population. The dashed line shows a least squares fit for a continuous model, a power function ($F = a \cdot X^b$), where F is the procedure frequency, X is the physician density, and a and b are the model parameters. The coefficient of determination (R^2 value) is 0.63, indicating that 63% of the variation in the annual number of conventional radiology (excluding dental) examinations per 1,000 population is predictable from the variation in the number of physicians per 1,000 population.

A43. Figure A-III also highlights the relative lack of data in relation to HCLs II-IV. Sixty of 65 countries included in the assessment with data regarding overall numbers for conventional radiology (excluding dental) are in HCL I, one country in HCL II, three in HCL III, and one in HCL IV. As a proportion of the total population in the assessed data, countries classified as HCL I represent 96%, whereas only 4% are categorized as HCL II-IV (3% in HCL III and 1% in HCL IV). This is important in relation to application of the global HCL model.

Figure A-III. Relationship between density of physicians and annual frequency of conventional radiology examinations (excluding dental)

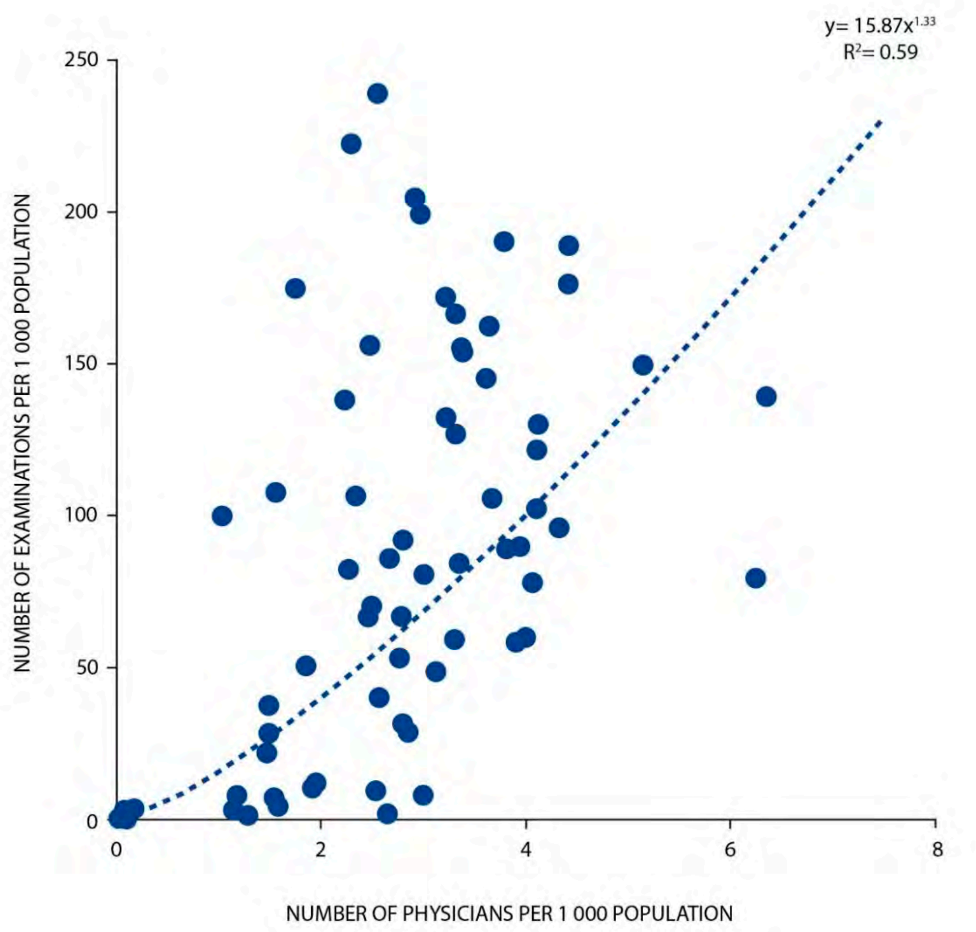
Result of a non-linear regression (power function) based on 65 countries (dots, UNSCEAR Global Survey and additional sources)



A44. Computed tomography examinations increasingly contribute to the population dose as their dose per procedure is relatively high and their frequency continues to rise. Sixty-seven countries are included in the frequency data for computed tomography. Figure A-IV shows the annual frequencies of computed tomography examinations per 1,000 population from the UNSCEAR Global Survey versus number of physicians per 1,000 population. Again, the scattering of the data points is pronounced, and the fitted model is a continuous power function (coefficient of determination 0.59).

Figure A-IV. Relationship between density of physicians and annual frequency of CT examinations

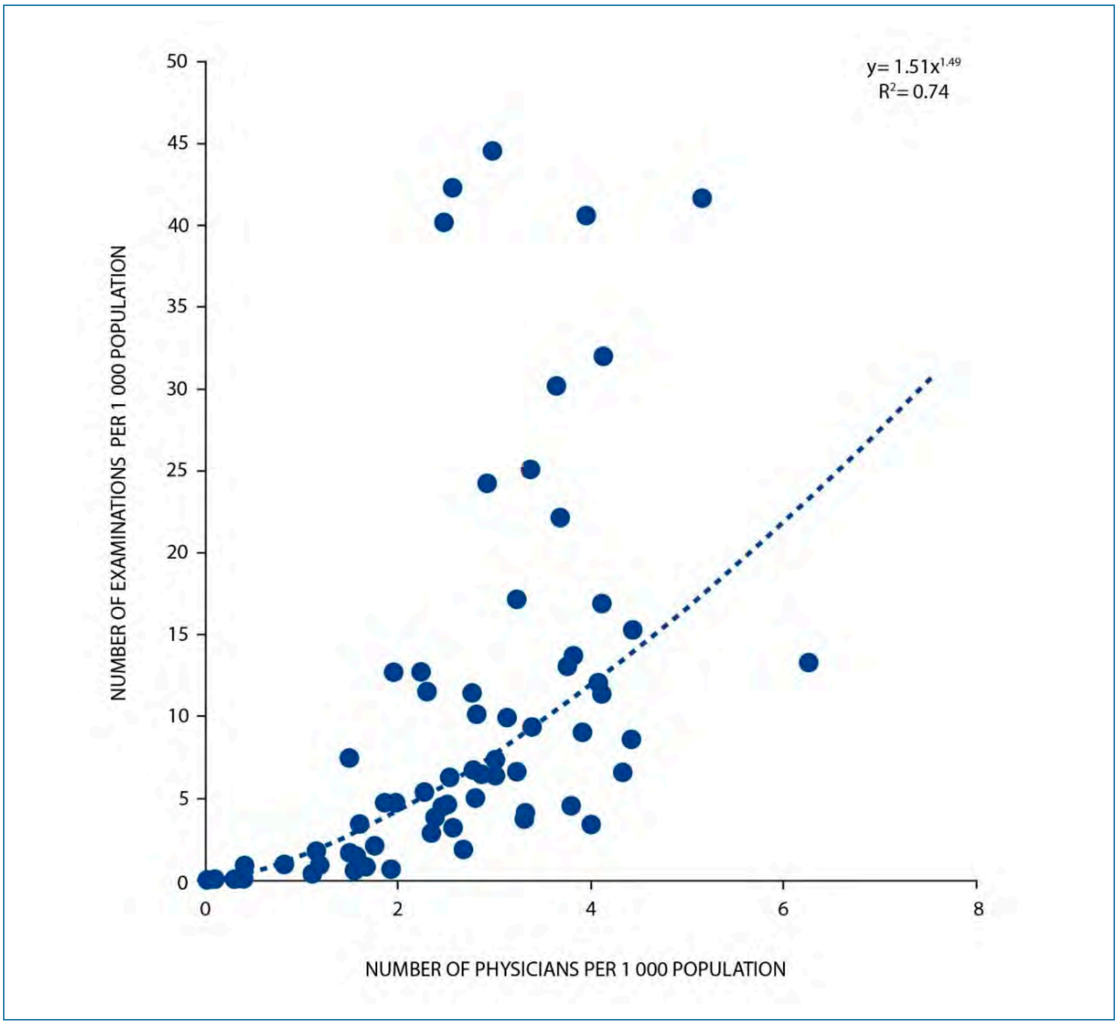
Result of a non-linear regression (power function) based on data from 67 countries (dots, UNSCEAR Global Survey and additional sources)



A45. Whereas diagnostic radiology represents the most significant contributor, with 95% in 2008, of the global collective dose from all diagnostic medical exposure [U9], the UNSCEAR Global Survey also seeks to assess worldwide practice in nuclear medicine (accounting for the remaining 5% of global population dose) and radiation therapy. Scatter plots of procedures versus physician density for diagnostic nuclear medicine (data from 69 countries) and radiation therapy (data from 45 countries) are illustrated in figures A-V and A-VI, respectively. Overall, patterns are generally similar to that observed in relation to diagnostic radiology and computed tomography (figures A-III and A-IV), with coefficients of determination (R^2 values) of 0.74 (nuclear medicine) and 0.67 (radiation therapy), for fitted power function models.

Figure A-V. Relationship between number of physicians per 1,000 population and annual number of nuclear medicine examinations per 1,000 population

Result of a non-linear regression (power function) based on 69 countries (dots, UNSCEAR Global Survey and additional sources)

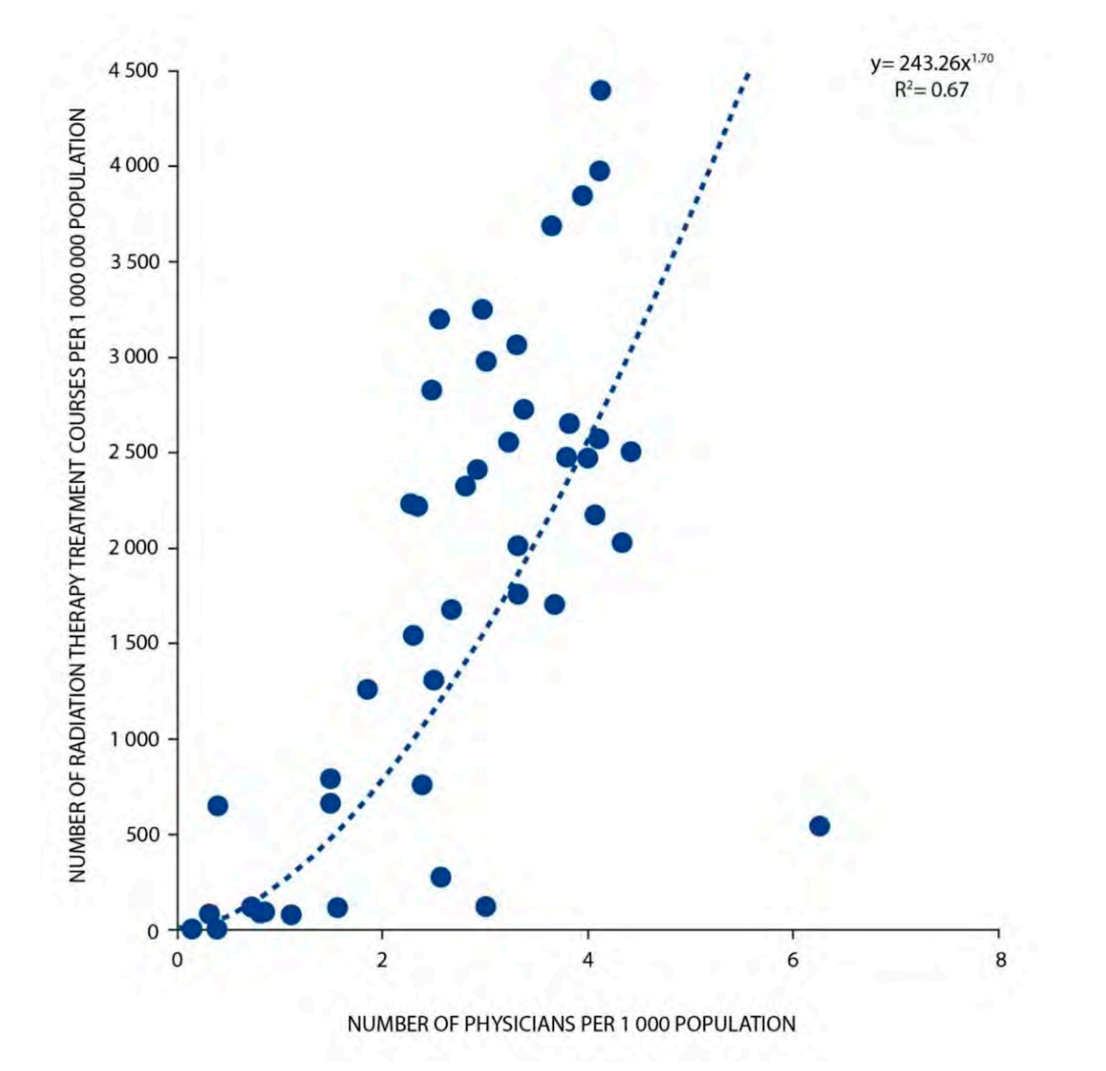


A46. Publicly available data on health-care systems and economical capacities of countries (e.g., [U10, W7, W10] data from 2015 or the nearest available) have been used to test whether alternative variables are more appropriate than physician density (per 1,000 population) alone, namely:

- Life expectancy (years);
- Proportion of population aged 0–14 years (%);
- Proportion of population aged 65+ years (%);
- Skilled health professionals (per 10,000 population);
- Medical physicists (per million population);
- Health expenditure proportion (%);
- Human development index;
- Gross domestic product per caput (USD);
- Gross national income per caput (USD);
- Medical devices (conventional X-ray machines and computed tomography scanners, nuclear medicine systems, radiation therapy units) per 1,000 population.

Figure A-VI. Relationship between density of physicians and annual frequency of radiation therapy treatments

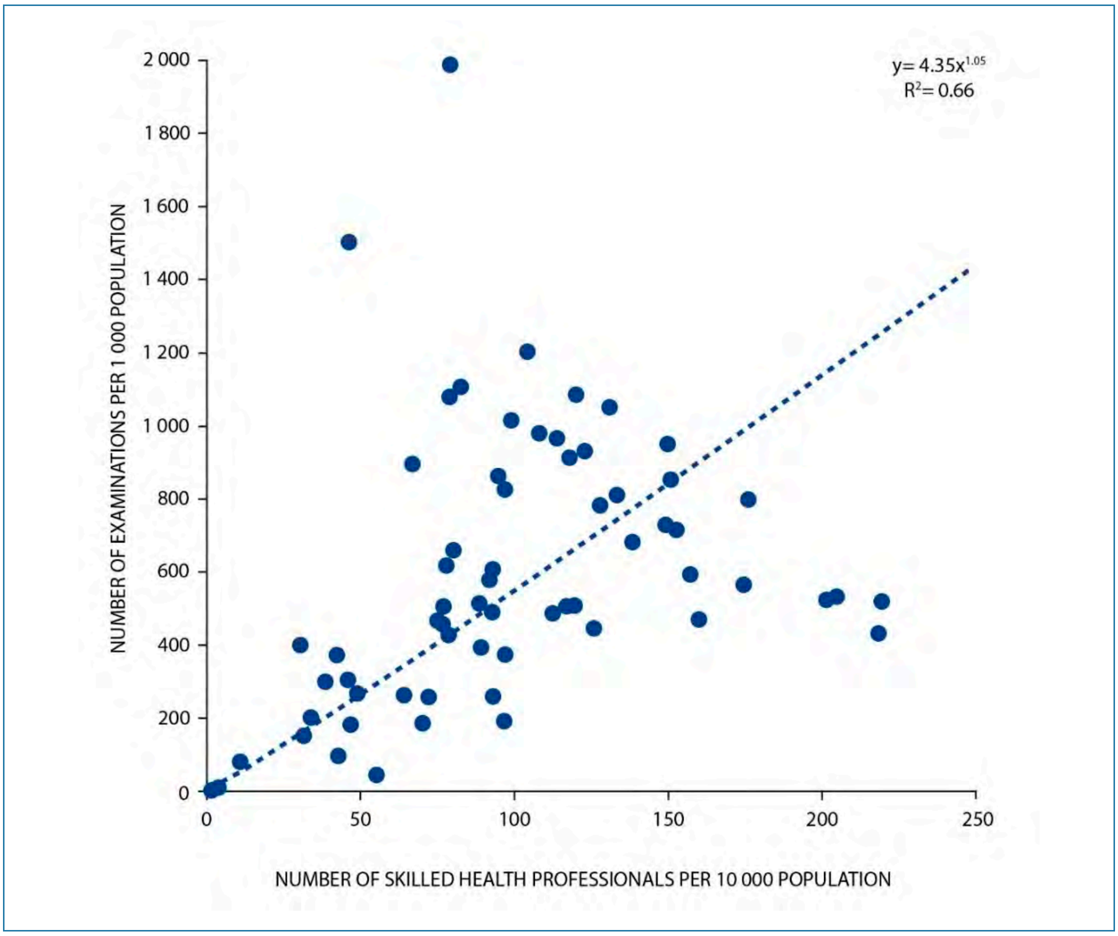
Result of a non-linear regression (power function) based on 45 countries (dots, UNSCEAR Global Survey)



A47. In order to test the suitability of any of the above parameters to substitute the established health indicator, one-variable regressions were performed. As in the regression analyses with physician density, power functions were used. Two examples of the relationship between the submitted data of procedure frequencies and alternative key indicators are presented in figure A-VII, which shows the density of skilled health professionals versus annual frequency of conventional radiology examinations (excluding dental); and figure A-VIII, which shows the density of computed tomography devices versus annual frequency of computed tomography examinations. The coefficients of determination show higher values compared to regressions using physician density alone.

Figure A-VII. Relationship between density of skilled health professionals and annual frequency of conventional radiological examinations (excluding dental)

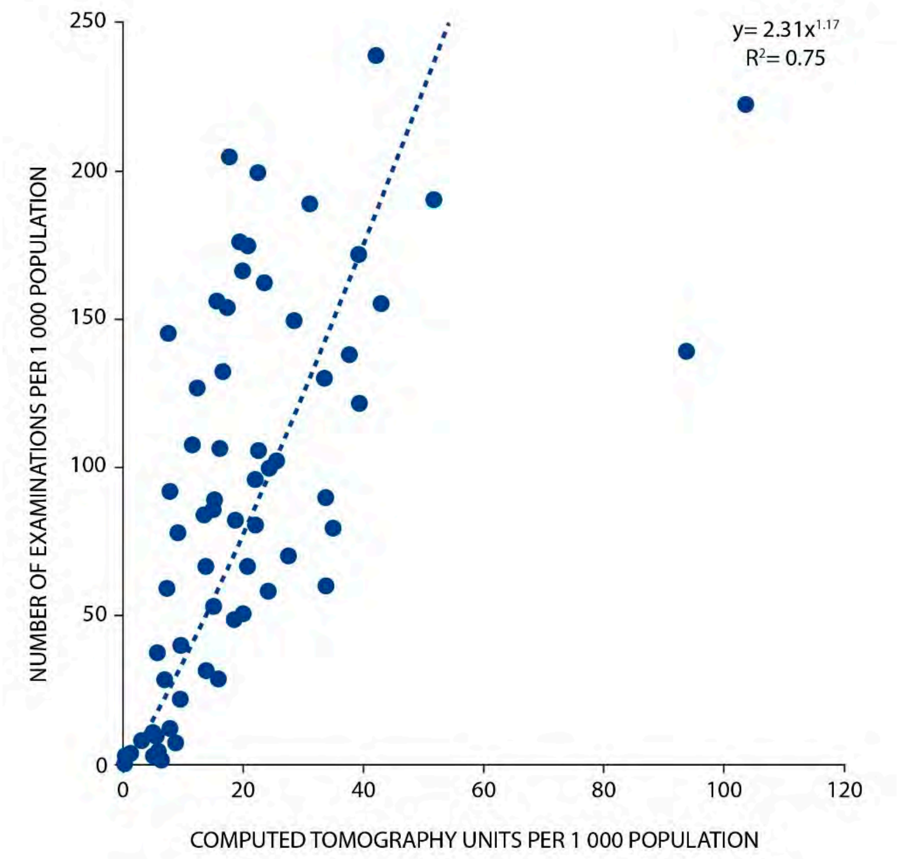
Result of a non-linear regression (power function) based on 65 countries (dots, UNSCEAR Global Survey and additional data)



A48. Correlations between the variables listed above were examined using covariance matrix plots to find variables that correlate so strongly with each other that one of them did not need further consideration. To make the modelling process as effective as possible, only the variables associated with the greatest amount of variance in the observed frequency data were used. The next step was to analyse how these data were related to the outcome parameters in the UNSCEAR Global Survey (e.g., frequencies of the different modality categories considered).

Figure A-VIII. Relationship between density of computed tomography devices and annual frequency of computed tomography examinations

Result of a non-linear regression (power function) based on data from 67 countries (dots, UNSCEAR Global Survey and additional data)



A49. Input variables were also restricted to those for which a large number of values were available globally. This was the case for all population-related data, but not for all parameters relating to medical devices or staff (e.g., number of nuclear medicine devices). The lower limit was set at 100 in order to achieve a high coverage of the world population in extrapolations using the resulting models.

A50. An exploratory analysis of model candidates was performed, including a correlation analysis. With the help of recursive feature elimination [K17], up to five candidate variables for inclusion in a model were identified. To keep the resulting model rational for non-specialists, single-variable non-linear regression and multiple-linear regression techniques were used to select appropriate models for conventional radiology (excluding dental), dental radiology, computed tomography, nuclear medicine and interventional radiology procedures, and for radionuclide and radiation therapy treatments.

A51. Further statistical modelling of the procedure frequency data was undertaken using the R and STATA software packages [S26]. Fitting a model to all the available data leaves no data against which to assess the predictive capability of the model. Therefore, the available data were randomly split into separate creation and validation sets. The performance of a model generated from the creation dataset was assessed against the validation dataset, using the mean squared error as the metric. Models were generated in a stepwise fashion with addition or elimination of predictor variables (depending on the specific method) and tested against the validation dataset, building an assessment of the variation in test statistics (mean squared error) with the number of variables in the model. In this manner, the model with the fewest variables but adequate predictive power could be chosen. Having assessed the suitability of general model forms by this method, a final fit of the preferred model to the full dataset was used to generate predictions of procedure frequencies for countries that did not provide data to the UNSCEAR Global Survey.

A52. The results of the modelling often indicated that variables other than physician density provided greater predictive power for the data under consideration. Among these were the human development index, the density of relevant medical devices (e.g., computed tomography scanner density when modelling computed tomography examination frequency), and the proportion of the population in particular age brackets. However, data on some of these indicators were not sufficiently widely available to be useful in making predictions for all countries worldwide. In general, models using a simple power function of the physician density were assessed as providing the best balancing of predictive power and general applicability.

A53. As an additional check on the modelling described above, exploratory analyses for conventional radiology (excluding dental) and computed tomography were conducted using an artificial neural network approach. Artificial neural networks are well-suited for a very broad class of non-linear approximation [B1, D11], where the appropriate forms of the transfer functions relating the predictor variables and the response variables are unknown. Neural network models were developed using the Neural Network Toolbox in MATLAB 8.2 (The Math Works Inc.) [D4]. With these tools, a simple script can be constructed to load the relevant data from an input file, train and validate the neural network model, and save the model architecture and performance in an output file [E2]. The results of these exploratory analyses gave very similar predictions for the overall number of conventional radiology (excluding dental) and computed tomography procedures to the simpler approaches described above, providing increased confidence in the suitability of the simplified approach.

A54. The models selected for use in the UNSCEAR global assessment take the form of power functions of the physician density (physicians per 1,000 population). This choice was motivated by the *(a)* simplicity of the model, *(b)* satisfactory predictive power, and *(c)* availability of the data as WHO publishes these values regularly [W7] and its close relation to the health-care level classification used in previous UNSCEAR assessments. The general form of the models is:

$$F_i = a \times (d_i)^b \qquad \text{(A.9)}$$

where F_i is the procedure frequency in country i, d_i is the physician density in country i, and a and b are the model parameters. Two variants are considered: the first with the modelling performed in the absolute data space, and the second with the parameters a and b determined by linear regression using log-transformed data (figures A-III to A-VI). These two approaches yield different results as the first gives equal weight to the absolute differences between the data and the model, while the second gives equal weight to the relative differences.

A55. A third, more sophisticated, modelling approach using negative binomial regression [H10] was examined to test the robustness of the results from the simpler models. Negative binomial regression is a generalization of Poisson regression, in which the variance is allowed to differ from the mean. This loosening is used to deal with over dispersion in the model, where the extra variance is presumed to be due to factors not considered in the model. The functional form of the model is:

$$ln(N_i) = \beta_0 + \beta_1 \times x_{1,i} + \cdots + \beta_n \times x_{n,i} + \ln(P_i) \qquad (A.10)$$

where N_i is the count of procedures in country i, $\{x_{1,i} \ldots x_{n,i}\}$ are the values of predictor variables $\{x_1 \ldots x_n\}$ for country i, $\{\beta_0 \ldots \beta_n\}$ are the parameters of the model and P_i is the population of country i, the natural logarithm of which is treated as an offset in the model. The covariates included in the final model varied across the seven broad modality categories, depending on which were found, through a bootstrap process, to predict the most variance in each particular case.

A56. Summary results for the three continuous models described above (power-law in absolute space, power-law in log space, and negative binomial regression) are shown in table A13. The total numbers of examinations were derived by combining the submitted data from the survey with the predictions of the selected model for countries that did not provide data to the analysis. Additional data, including categorization of the different model results by health-care level and income level, are available in electronic attachment A-2. The mean squared error for all models is calculated by comparison to the absolute values in the assessed data. The model selected for the global evaluation is the power-law fit in absolute data space. Although the mean squared error for this model is not always the lowest of the models considered, this model has been chosen because of its simplicity, involving only a single predictor variable (physician density), its satisfactory predictive power, and the wide availability of the data for the predictor variable. Aside from these considerations, the predictions from all models are quite similar.

A57. For conventional radiography (excluding dental), survey data from 43 countries were included in the evaluation. After inclusion of data from the EC DDM 2 project [E5] and from other sources, data from 65 countries, covering 48% of the total world population, contributed to the assessment. The model estimates range from 2.1 to 2.6 billion procedures per annum (table A13). With the selected power-law model fitted in the absolute data space, the total number of conventional radiography (excluding dental) procedures across the world is assessed at 2.6 billion per annum.

Table A13. Predictions of three continuous models tested for estimation of examination/procedure frequencies for the global assessment by modality categories

Modelling information	*Model*		
	Power-law *(absolute space)* [a]	Power-law *(log space)*	*Negative binomial regression* [c]
Conventional radiology (excluding dental)			
Mean squared error [b]	111 000	128 000	100 000
Radiography examinations in assessed data (millions)	1 587	1 587	1 587
Additional radiography examinations from model (millions)	1 039	551	843
Total conventional radiology examinations (millions)	2 626	2 138	2 430
Countries with no prediction (missing data)	1	1	14
Proportion of total population included (%)	99.8	99.8	99.3

Modelling information	*Power-law (absolute space)* [a]	*Power-law (log space)*	*Negative binomial regression* [c]
Dental radiology			
Mean squared error [b]	50 000	59 000	33 000
Dental radiography examinations in assessed data (millions)	809	809	809
Additional dental radiography examinations from model (millions)	292	246	192
Total dental radiography examinations (millions)	1 101	1 055	1 001
Countries with no prediction (missing data)	1	1	15
Proportion of total population included (%)	99.8	99.8	99.2
Computed tomography			
Mean squared error [b]	2 940	3 090	3 180
Computed tomography examinations in assessed data (millions)	278	278	278
Additional computed tomography examinations from model (millions)	125	87	36
Total computed tomography examinations (millions)	403	365	314
Countries with no prediction (missing data)	1	1	9
Proportion of total population included (%)	99.8	99.8	99.4
Interventional radiology			
Mean squared error [b]	45	54	39
Interventional radiology procedures in assessed data (millions)	16.5	16.5	16.5
Additional interventional radiology procedures from model (millions)	7.1	2.3	1.0
Total interventional radiology procedures (millions)	23.6	18.8	17.5
Countries with no prediction (missing data)	1	1	9
Proportion of total population included (%)	99.8	99.8	99.4
Nuclear medicine (diagnostic)			
Mean squared error [b]	104	111	84
Nuclear medicine procedures in assessed data (millions)	34.1	34.1	34.1
Additional nuclear medicine procedures from model (millions)	5.8	4.5	3.1
Total nuclear medicine procedures (millions)	39.9	38.6	37.2
Countries with no prediction (missing data)	1	1	15
Proportion of total population included (%)	99.8	99.8	99.3

Modelling information	*Power-law (absolute space)* [a]	*Power-law (log space)*	*Negative binomial regression* [d]
Radionuclide therapy			
Mean squared error [b]	200	228	252
Radionuclide therapy treatments in assessed data (millions)	0.936	0.936	0.936
Additional radionuclide therapy treatments from model (millions)	0.496	0.305	0.539
Total radionuclide therapy treatments (millions)	1.432	1.241	1.475
Countries with no prediction (missing data)	1	1	1
Proportion of total population included (%)	99.8	99.8	99.8
Radiation therapy			
Mean squared error [b]	585 000	697 000	622 000
Radiation therapy treatment courses in assessed data (millions)	4.7	4.7	4.7
Additional radiation therapy treatment courses from model (millions)	1.5	1.1	0.8
Total radiation therapy treatment courses (millions)	6.2	5.8	5.5
Countries with no prediction (missing data)	1	1	57
Proportion of total population included (%)	99.8	99.8	95.7

a Selected model for the global assessment.

b Mean squared error for all models is calculated by comparison to the absolute value.

c Using 5 parameters.

d Using 1 parameter.

A58. For dental radiography, survey data from 36 countries were included in the assessment. After inclusion of data from the EC DDM 2 project [E5] and from other sources, data from 49 countries, covering 41% of the total world population, contributed to the assessment. The estimated results range from 1.0 to 1.1 billion examinations per annum. The negative binomial regression model is clearly a better fit to the assessed data. The spread of results is quite narrow, however, and the choice of model has only a slight impact on the overall result. The selected power-law model fitted in the absolute data space gives a global annual estimate of dental radiography examinations of 1.1 billion.

A59. The UNSCEAR Global Survey data for computed tomography were received from 43 countries. Additional data on examination frequencies were obtained from the EC DDM 2 project [E5] and from data reported to the OECD [O3]. Further data for HCL III and HCL IV countries were taken from previous UNSCEAR reports [U6, U9]. The assessment included data from 69 countries, covering 48% of the total world population. The estimated results range from 314 to 403 million examinations per annum. The selected power-law model fitted in the absolute data space gives a total estimate for computed tomography examinations worldwide of 403 million per annum.

A60. For interventional radiology, data were received from 39 countries. After inclusion of data from the EC DDM 2 project [E5] and from previous UNSCEAR reports [U6, U9], a total of 57 countries, covering 46% of the total world population, contributed to the assessment. The estimated results range from 17.5 to 23.6 million procedures per annum. The selected power-law model fitted in the absolute data space gives a total estimate for interventional radiology procedures across the world of around 24 million per annum.

A61. The assessment for diagnostic nuclear medicine procedures included survey data from 46 countries. With the addition of data from the EC DDM 2 project [E5] and from previous UNSCEAR reports [U6, U9], data from 68 countries, covering 52% of the total world population, contributed to the assessment. The estimated results range from 37.2 to 39.9 million procedures per annum. The selected power-law model fitted in the absolute data space gives a total estimate for diagnostic nuclear medicine procedures across the world of around 40 million per annum.

A62. For radionuclide therapy treatments, survey data were received from 41 countries, covering 47% of the total world population. The estimated results range from 1.2 to 1.5 million treatments per annum. The selected power-law model fitted in the absolute data space gives a total estimate for radionuclide therapy treatments across the world of 1.4 million per annum.

A63. The assessment for radiation therapy treatment courses included data from 44 countries, covering 66% of the total world population. The estimates range from 5.5 to 6.2 million procedures per annum. The selected power-law model fitted in the absolute data space gives a total estimate for the number of radiation therapy treatment courses across the world of 6.2 million per annum.

A64. The modelling results are consistent with the extrapolation results shown earlier. This consistency supports the overall totals adopted from the modelling. In some cases, e.g., for dental radiography and for computed tomography, the consistency of the categorical extrapolations with the modelling results is dependent on assumptions made in the absence of data. This demonstrates the advantages of the modelling approach over extrapolation by categories when there are no or only few data for some categories. The modelling results for HCL IV and for low-income countries are notably higher than the extrapolation results, suggesting that there may be some overestimation. However, the extrapolation results at these levels are dependent on data from only one or two countries and, thus, must be considered very unreliable. In any event, the assessed number at these levels is a very minor component of the overall analysis.

A65. In summary, the Committee selected a continuous model for examination frequencies in the seven general modality categories based on power-law fits in the absolute data space with physician density as the only predictor variable. The total numbers of examinations per modality category reported in the current evaluation were derived by combining the submitted data from the survey with the predictions of the selected model for countries that did not provide data to this analysis.

IV. ANALYSIS OF UNCERTAINTIES

A66. Previous UNSCEAR reports [U6, U9] have not quantified the effect of limitations in the model used to evaluate global practice for medical exposure. However, the Committee recognizes the importance of including estimates of likely uncertainties in relation to its global assessments of numbers of examinations and population doses. Accordingly, an appropriate methodology was developed for the purpose of addressing uncertainties in relation not only to the national data but also to the model used for their extrapolation to global practice.

A67. A framework for the assessment of uncertainty in relation to estimates of collective dose was developed and is presented in detail in the electronic attachment A-1. Sources of uncertainty in the estimation of medical exposure and a standard methodology for their assessment were applied in this appendix. This methodology could also be applied at a national level before countries submit their data for UNSCEAR surveys of global practices.

A68. Hart and Wall [H4], assessed the per caput effective dose from X-rays to the United Kingdom population in 1997/1998 at 0.33 mSv and estimated the related uncertainties as 9% (±0.03 mSv). Such methods for uncertainty analysis were also discussed in detail by the EC DDM 2 project [E5] and formed the basis for the uncertainty estimate of ±6% quoted in relation to the per caput effective dose of 1.06 mSv assessed for the European population from X-ray procedures [E5]. Zontar et al. [Z1] also assessed the uncertainty in a national estimate of collective effective dose in Slovenia as ±11% (1 standard deviation). Such additional information would support the provision of robust estimates of uncertainty in relation to estimates of worldwide medical exposure.

A69. Given that complete information on a country's population dose, S_j (man Sv), with country-specific estimates of uncertainty, u_j, would be available for every country j in the world, an estimate of uncertainty, U_{world}, in the global population dose could easily be assessed following the rules of propagation of uncertainties (see also electronic attachment A-1):

$$U_{world} = \sqrt{\sum_j u_j{}^2} \qquad \text{(A.11)}$$

A70. Applying the HCL model to assess the global population dose, the uncertainty U_{world} can be estimated as follows. The uncertainty $u_{i,HCL(k)}$ in the weighted average frequency of examination i per 1,000 population in HCL k, $F_{i,HCL(k)}$ (see equation (A.5)), is

$$u_{i,HCL(k)} = \sqrt{\sum_j \left(\frac{u_{i,j}}{P_{HCL(k)}}\right)^2} \times 1{,}000 \qquad \text{(A.12)}$$

where $u_{i,j}$ is the absolute uncertainty in the annual number of examinations of type i in country j, $N_{i,j}$ and $P_{HCL(k)}$ is the population in HCL k.

A71. The uncertainty $v_{i,HCL(k)}$ (mSv) in the weighted average typical effective dose for examination i in HCL k, $E_{i,HCL(k)}$ mSv (see equation (A.6)), is given by

$$v_{i,HCL(k)} = \sqrt{\sum_j \left(v_{i,j} \times \frac{P_j}{P_{HCL(k)}}\right)^2} \qquad \text{(A.13)}$$

where $v_{i,j}$ (mSv) is the absolute uncertainty in the typical effective dose for examination i in country j, $E_{i,j}$ (mSv), P_j is the population in country j and $P_{HCL(k)}$ is the population in HCL k.

A72. The uncertainty, $w_{HCL(k)}$ (man Sv) in the population dose from all examinations in HCL k, $S_{HCL(k)}$ man Sv (see equation (A.7)), is then:

$$w_{HCL(k)} = \sqrt{\sum_i \left(\frac{u_{i,HCL(k)}}{F_{i,HCL(k)}}\right)^2 + \left(\frac{v_{i,HCL(k)}}{E_{i,HCL(k)}}\right)^2} \times \frac{P_{HCL}}{1{,}000{,}000} \qquad \text{(A.14)}$$

A73. Ignoring the uncertainty associated with the HCL model, the uncertainty, V_{world} (man Sv) associated with the estimate of the global population dose from all examinations, S_{world} (man Sv), derived by the HCL model can be estimated by:

$$V_{world} = \sqrt{\sum_{k=I}^{IV} \left(w_{HCL(k)}\right)^2} \qquad \text{(A.15)}$$

If the uncertainty, U_{model}, associated with the HCL model is also taken into account, the uncertainty in the global population dose, U_{world} (man Sv), is given by:

$$U_{world} = \sqrt{(U_{model})^2 + \left(\frac{V_{world}}{S_{world}}\right)^2} \times S_{world} \quad (A.16)$$

A74. Assuming that the countries that contributed data to this survey also provided information on the relative uncertainty, $u_{rel,j}$, of their frequency data, one can estimate the absolute uncertainty for the total number of examinations from all submitting countries, U_{survey}, as follows:

$$U_{survey} = \sqrt{\sum_j u_j{}^2} \quad (A.17)$$

where u_j is the absolute uncertainty assessed from the relative uncertainty and the examination frequency for each country.

A75. To estimate the uncertainty in the total number of examinations and the global annual collective effective dose using the selected continuous model, the following approach was adopted: for the uncertainty in the total number of examinations for countries that submitted data, equation (A.17) was first applied to the five modality categories as outlined above, i.e. for conventional radiology without dental examinations (A), dental radiology (B), computed tomography (C), interventional radiology (D) and nuclear medicine (E), giving the uncertainties $U_{survey(i)}$ (i=A, …, E). With these, the uncertainty in the total number of examinations in the survey data, U_{survey}, can be estimated:

$$U_{survey} = \sqrt{\sum_{j=A,\ldots,E} U_{survey(j)}{}^2} \quad (A.18)$$

A76. Second, the uncertainty in the total number of examinations from the modelling for all modality categories was estimated, using the square root of the mean squared error from the modelling results as the estimated absolute error in the calculated examination frequency. If $U_{model(i)}$ (I=A, … , E) is the uncertainties for the five modality categories, then the uncertainty of the total number of examinations in the modelling data, U_{model}, can be estimated as follows:

$$U_{model} = \sqrt{\sum_{j=A,\ldots,E} U_{model(j)}{}^2} \quad (A.19)$$

A77. Finally, the uncertainty in the global estimate of the number of examinations, U_{global}, is

$$U_{global} = \sqrt{U_{survey}{}^2 + U_{model}{}^2} \quad (A.20)$$

A78. Estimates of uncertainties in dose metrics were provided by some countries in their submissions to the UNSCEAR Global Survey. The survey included options to provide data on the variation in the relevant practical dose quantity as well as the resulting effective dose and also included the option of recording the size of the sample used to derive this data. Countries commonly reported the mean dose and the sample standard deviation as the indication of the level of variation. While the standard error calculated by dividing the sample standard deviation by the square root of the sample size is a formal estimate of the standard uncertainty in the mean dose for a particular examination or procedure, this quantity only represents the precision to which the mean dose is determined and does not necessarily reflect the uncertainties introduced by applying the mean dose as an estimate of the dose for all such examinations. As discussed in the electronic attachment A-1, following the approach proposed in the EC DDM 1 project [E3], uncertainties (one standard deviation) in the dose per examination can be taken to vary from about ±7% (for a large sample size and well-matched conversion coefficients) to around ±25% (for a small sample size and poorly-matched conversion coefficients). In the extreme, when local data is unavailable and data from another country is used as an estimate, an uncertainty of ±50% is recommended.

A79. As described in the annex, for countries that did not provide data to the UNSCEAR Global Survey, a frequency-weighted dose per examination or procedure in a given modality category was ascribed and the collective effective dose was estimated by multiplying the estimated total number of examinations or procedures in the modality category by the frequency-weighted dose. For all such cases the uncertainty in the dose was taken to be ±50%, as recommended for the "Foreign data only" category in the electronic attachment A-1. For countries that did provide data to the UNSCEAR Global Survey, the stated uncertainties were used where provided. If the only data provided were the sample standard deviation and the sample size, estimated uncertainties ranging between 10% and 50% were applied, depending on the stated sample size and the relative sample standard deviation. The uncertainties in the overall estimates of collective effective dose were not very sensitive to the uncertainties assigned to the data for each country. This is due to a combination of the averaging effect of deriving the uncertainty in a sum over many parts and the fact that the uncertainties in the estimates of the number of examinations or procedures were generally larger and tended to dominate the overall uncertainty estimated.

A80. The relative uncertainty of the collective dose for each procedure category, $U_{rel,D(i)}$, is calculated by the relative uncertainty of the frequency, $u_{rel,fr(i)}$, and the relative uncertainty of the dose, $u_{rel,D(i)}$, per procedure estimate (i=A, …, E), where $u_{rel,D(i)}$ was estimated by the standard error of the mean of the doses per procedure category from the survey:

$$U_{rel,D(i)} = \sqrt{u_{rel,fr(i)}{}^2 + u_{rel,D(i)}{}^2} \; (i = A, \ldots, E) \tag{A.21}$$

giving the absolute uncertainties, $U_{D(i)}$, of collective dose per procedure category by multiplying $U_{rel,D(i)}$ with the collective dose of each category (i=A, …, E).

A81. The absolute uncertainty of the global collective dose, U_{col_D}, is then

$$U_{col\_D} = \sqrt{\sum_{j=A,\ldots,E} U_{D(j)}{}^2} \tag{A.22}$$

A82. In summary, standard uncertainties for the total number of examinations in each category of medical radiological exposure were derived by combining the estimated standard uncertainties for examination counts included in country submissions to the UNSCEAR Global Survey with the standard uncertainties in the predictions of the selected continuous models, which were based on the square root of the mean squared error from the modelling. Uncertainties in the average doses per procedure were derived from the UNSCEAR Global Survey data when provided and were otherwise assumed to be ±50%. These were combined with the standard uncertainties for the numbers of examinations to derive the overall standard uncertainty in the collective effective dose for each modality category. Finally, the uncertainties in the modality categories were combined to obtain an uncertainty estimate for the global total collective effective dose. Taking twice the standard uncertainty as an estimate of the overall uncertainty, the ranges for the total number of examinations and the total collective effective dose are estimated as ±30%. Table A14 summarizes the uncertainties derived for the global estimates of frequencies and collective effective doses by modality categories.

Table A14. Relative uncertainties for the global estimates of frequencies and collective effective doses by modality

Values are rounded to the nearest 1%. Uncertainties are expressed as 2-standard deviations

Modality category	*Uncertainties of frequency estimates (%)*	*Uncertainties of collective effective doses estimates (%)*
Conventional radiology (excluding dental)	36	42
Dental radiology	58	68
Computed tomography	40	44
Interventional radiology	80	88
Nuclear medicine	72	76
Radionuclide therapy[a]	32	Not applicable
Radiation therapy[a]	26	Not applicable
Total	**28**	**30**

[a] Not included in the total.

V. SUMMARY

A83. The Committee previously used a categorical HCL model to derive data on examination frequencies and doses and to then extrapolate the data into a global evaluation of medical radiological exposure. In the present assessment, however, 53% of the total population is in countries classified as HCL I and very few survey data were received from countries in other HCL levels. Therefore, an alternative approach was adopted, constructing mathematical models of the observed variation in examination frequencies and using these models to predict the expected practice in countries that did not supply data. In this assessment, continuous models of examination frequencies within seven broad modality categories have been developed to generate projections for countries that did not provide data for the UNSCEAR Global Survey. The modality categories used in this assessment were conventional radiology (encompassing projection radiography, radiography and fluoroscopy but excluding dental radiology), dental radiology, computed tomography, interventional radiology, nuclear medicine, radionuclide therapy, and radiation therapy.

A84. A continuous model, which takes the form of a power function of the physician density (physicians per 1,000 population) in each country, was selected. This choice was made because of the availability of the data, as WHO regularly publishes such values provided by its Member States, and the close relation of the model to the HCL classification used in previous UNSCEAR reports [U6, U9]. More sophisticated modelling involving multiple parameters was also performed, yielding similar results and, thus, supporting the predictions of the single-parameter model. The results from the single-parameter power function were selected for the evaluation due to their uncomplicated interpretation, the satisfactory predictive power of the model, and the wide availability of the data. The new continuous modelling approach has advantages over the former categorical approach when there are no or only few data for some modality categories. The total numbers of examinations reported in the current assessment were derived by combining the submitted data from the UNSCEAR Global Survey with the predictions of the selected continuous model for countries that did not provide data to the survey.

A85. In this assessment, an alternative to the HCL classification, the World Bank income classification, was used to present the results of the extrapolation. The World Bank classification is based on gross national income per caput (current USD) and has also four levels: high, upper middle, lower middle and low. An advantage of using the World Bank classification is the possibility of comparing medical exposure with other health indicators as WHO uses the same classification in their health statistics.

A86. A framework for evaluating the uncertainties in the UNSCEAR global assessment has been outlined and applied. The estimated uncertainty in the total number of medical radiological examinations is ±30% and the estimated uncertainty in the total collective effective dose is also ±30%.

APPENDIX B. LEVELS AND TRENDS OF EXPOSURE IN DIAGNOSTIC RADIOLOGY

I. INTRODUCTION

B1. Diagnostic radiology consists of two main imaging modalities *(a)* conventional radiology including projection radiography (without contrast media) and radiography/fluoroscopy (mostly with contrast media); and *(b)* computed tomography. For each of these modalities, 16–19 subgroups or types of examinations have been defined in the user manual for the UNSCEAR Global Survey [U11] for data reporting and collection, with "other (please specify)" used as the last category in each modality. The subgroups are generally similar to the broader modality categories defined by the European Commission Dose Data Med projects (EC DDM) [E3, E5]. As shown in the literature reviews below, there have not been uniform classification systems, or systems consistent with the UNSCEAR Global Survey, when collecting data and publishing the results of examination frequency or population dose studies. These differences in classification create some difficulties when comparing published data with submissions to the UNSCEAR Global Survey, or when comparing published country data.

B2. Medical exposure in any country or region depends on many factors such as:

- Availability of radiological imaging facilities and appropriately trained staff (e.g., radiologists, radiographers, medical physicists);
- Types of radiological examinations requested by the referring physicians;
- Types of radiological systems (e.g., proportion of screen-film systems, computed radiology and full digital radiology systems, image-intensifier and flat-panel detectors) and their capabilities (e.g., over- or under-couch, continuous fluoroscopy versus pulsed fluoroscopy, tube current modulation versus fixed tube current, iterative reconstruction) and, thus, the exposure parameters required during the procedures;
- Level of optimization applied in imaging protocols (e.g., consideration of patient size);
- Protocols chosen for the particular examinations/procedures (e.g., adult versus paediatric);
- Patient demographics (e.g., size and weight, proportions of adult and paediatric patients);
- Methodology chosen for estimating the collective effective dose in general and the related uncertainties in estimating frequencies of examinations/procedures and typical effective doses per examination/procedure (e.g., sample sizes, national survey versus reimbursement systems);
- Tissue weighting factors used for the calculation of the effective dose according to the recommendations of the International Commission on Radiological Protection (ICRP 60 [I9] or ICRP 103 [I11]);
- Types of radiological examinations/procedures considered for a modality; differing interpretations are probable for conventional fluoroscopy and interventional radiology (e.g., fluoroscopy or diagnostic interventional procedure followed by a therapeutic procedure or only therapeutic interventional procedures).

B3. It is clear from above that, among other factors, both the imaging technology and the local choices for imaging practice can affect the trends in the numbers of examinations and patient dose levels. The impact of technology is discussed more in connection with the trends (section B.VII).

B4. The following analysis with summaries for diagnostic radiology procedures is based on the results of the UNSCEAR Global Survey and a comprehensive review of the published literature during the past decade. The results of the survey provide up-to-date information on examination frequencies, typical effective doses and staffing and equipment levels in several countries, supplemented with information on the age and sex distributions of examination frequencies in some countries. However, the results of the survey are not complete enough to estimate or summarize the collective effective doses to population or effective doses per caput for these countries. The results of the literature review provide relatively recent data for comparison with the current survey data, including published information on collective effective doses in some countries. The results of both the survey and the literature review enable identification of the diagnostic radiology examinations that make the highest contribution to the frequencies, typical effective dose and collective effective doses, and also some analysis of the recent trends in frequencies and doses and in the related technology.

B5. The results presented in this appendix reflect mainly the situation in the countries that submitted data to the UNSCEAR Global Survey (see also electronic attachment B-1) and published national surveys. The results have been used *(a)* for specific prediction models for the global assessment (more details in appendix A and electronic attachment A-3), and *(b)* for comparison and trend analyses presented here.

II. RECAPITULATION OF PREVIOUS UNSCEAR REPORTS

B6. According to the UNSCEAR 2008 Report [U9], using the health-care level (HCL) model, approximately 3.6 billion diagnostic radiology X-ray examinations (including dental examinations) were undertaken annually worldwide in the period 1997–2007. The 24% of the population living in HCL I countries receive approximately two thirds of these examinations.

B7. The annual frequency of diagnostic medical examinations (excluding dental radiology) in HCL I countries was estimated to have increased from 820 per 1,000 population in 1970–1979 [U6] to 1,332 per 1,000 population in 1997–2007 [U9]. Comparative values for HCL II countries exhibited an even greater relative increase, from 26 per 1,000 in 1970–1979 to 332 per 1,000 in 1997–2007. Most of the increase for HCL I and II countries occurred in 1997–2007. The estimated annual frequency of diagnostic medical examinations in HCL III and HCL IV countries had remained fairly constant over this period although, since data for these countries were limited, considerable uncertainty was associated with this estimate. Globally, for HCL I to HCL IV countries there were, on average, just over 488 diagnostic medical examinations and 74 dental examinations per 1,000 population.

B8. Also according to the UNSCEAR 2008 Report [U9], there were wide variations in diagnostic medical examinations between different HCL countries. For example, diagnostic medical examinations were over 66 times more frequent in HCL I countries than in HCL III and HCL IV countries. The change in annual frequency of diagnostic medical examinations reflected changes in population demographics, as most medical exposure applied to older “patients”.

B9. In the UNSCEAR 2008 Report [U9], computed tomography accounted for 7.9% of the total number of diagnostic medical examinations in HCL I countries, and just over 2% in HCL II countries.

For diagnostic dental examinations, the annual frequency had remained relatively constant for HCL I countries, at 275 per 1,000 population, compared with 320 per 1,000 population in the 1970–1979 survey. Over this period, there had been a substantial increase in the annual frequency of diagnostic dental examinations in HCL II countries, rising from 0.8 per 1,000 population in 1980–1984 to 16 per 1,000 population in 1997–2007.

B10. In the UNSCEAR 2008 Report [U9], the annual collective effective dose to the population from diagnostic medical radiological examinations was estimated to be *(a)* 2,900,000 man Sv for HCL I countries; *(b)* 1,000,000 man Sv for HCL II countries; *(c)* 33,000 man Sv for HCL III countries; and *(d)* 24,000 man Sv for HCL IV countries. The total annual collective effective dose to the global population from diagnostic medical examinations was estimated to be 4,000,000 man Sv. Since the UNSCEAR 2000 Report [U6], there had been a rise of approximately 1,700,000 man Sv. This increase resulted partly from an increase in the annual frequency of diagnostic medical radiological examinations, an increase in the per caput effective dose per examination (from 0.4 to 0.62 mSv) and an increase in the global population (from 5,800 million to 6,446 million).

B11. The UNSCEAR 2008 Report [U9] estimated an average value of the annual per caput effective dose across the global population as 0.62 mSv, with 1.9 mSv, 0.32 mSv and 0.03 mSv in HCL I, HCL II and HCL III/IV countries, respectively. The contribution of computed tomography scanning to the total collective effective dose due to medical examinations was 47% in HCL I countries and 15% in HCL II countries, respectively. Globally, on average, the contribution of computed tomography to the total collective effective dose due to diagnostic medical radiology was 43%, having increased from 34% in the UNSCEAR 2000 Report [U6]. In contrast, exposure from dental examinations accounted for less than 1% of the total collective effective dose.

B12. More specifically, the typical effective doses for chest radiography and mammography decreased significantly, while that for computed tomography decreased only slightly since the previous UNSCEAR reports [U6, U9]. The introduction of new imaging techniques, including computed tomography and digital imaging was anticipated to increase the population dose globally in the future.

III. FREQUENCIES OF RADIOLOGICAL EXAMINATIONS

B13. This section presents information on the frequencies and distributions of diagnostic radiological examination resulting from the submissions to the UNSCEAR Global Survey (2009-2018) and from the review of published literature.

A. UNSCEAR Global Survey data

B14. In the current UNSCEAR Global Survey, essential information (selected main groups of examination frequencies, numbers of professionals and diagnostic radiological systems and devices) from 51 countries with more detailed information (frequency and dose data) from 30–33 countries have been received for diagnostic radiology. However, only 11 countries have submitted information on age and sex distributions with incomplete dose information.

B15. The total frequencies per 1,000 population for diagnostic radiology (projection radiography including dental procedures, radiography and fluoroscopy and computed tomography) obtained from the UNSCEAR Global Survey is shown in figure B-I. Detailed frequency information obtained from the UNSCEAR Global Survey for projection radiography including dental examinations, radiography and fluoroscopy and computed tomography are summarized in tables B1 to B3.

B16. There are great variations of the diagnostic radiology frequencies per 1,000 population between the countries involved. The frequency of diagnostic radiology examinations makes by far the highest contribution (97.8%) to the total frequency of medical imaging per 1,000 population: the mean frequency of diagnostic radiology procedures was 1,038 per 1,000 population, with the range from 311 to 2,414 procedures per 1,000 population.

B17. In projection radiography, dental examinations make the highest contribution to the total frequency of this group (28.7%), while also chest-thorax (20.2%) and limbs and joints (18.2%) also make high contributions; all the other types of projection radiography examinations contribute less than 6% of the total; the contribution of mammography is 3.1% and screening mammography 5.3%. In radiography and fluoroscopy, coronary angiography makes the highest contribution (16.3%) to the total of this modality, followed by examinations of gastrointestinal tract (barium studies) (14.0%) and urogenital tract (5.4%); miscellaneous examinations ("others": 38.6%) are excluded because in many countries, this category includes examinations from the other categories not reported separately. In computed tomography, head examinations (skull and facial bones and soft tissue and brain altogether) make the highest contribution (26.3%) followed by chest (thorax: 12.2%) and abdomen (11.9%). Compared with the total frequency per 1,000 population for all three diagnostic radiology modalities, on average, all radiography and fluoroscopy (without dental) is 61.6%, dental is 23.2% and computed tomography is 12.9%.

Figure B-I. Total frequency per 1,000 population for diagnostic radiology (projection radiography, radiography and fluoroscopy, and CT) by countries reported to UNSCEAR Global Survey

Only countries having submitted data for all three modalities are included

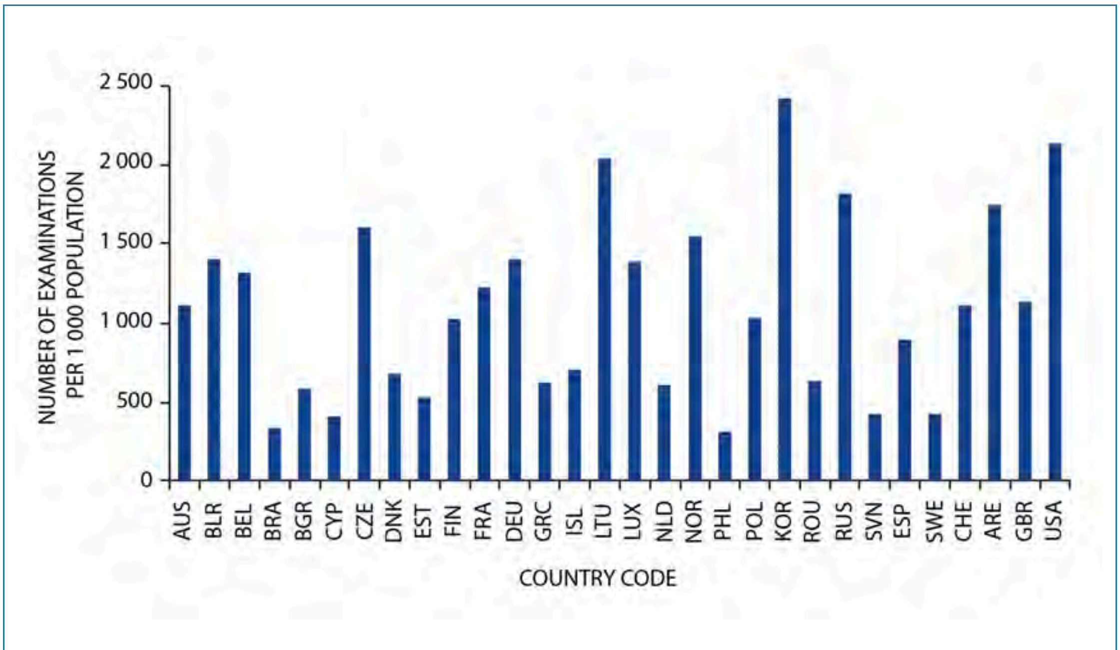


Table B1a. Annual frequencies per 1,000 population for different projection radiography examinations reported to UNSCEAR Global Survey

Country	Examination frequency per 1 000 population [a,b]								
	Total projection radiography [c]	*Head (skull and facial bones)*	*Head (soft tissue)*	*Neck (cervical spine)*	*Neck (soft tissue)*	*Chest-thorax*	*Chest (thoracic spine)*	*Chest (shoulder girdle and ribs)*	*Mammo-graphy*	*Mammography (screening)*
Australia	928	16	1.7	26		116	4.3	36	24	41
Belarus	1 311	36		17		758	19	17	13	
Belgium	1 083	4.8		12	1.6	192	8.9	48	92	41
Brazil	284	9.3	0.04	6.6		47	2.7	9.8	13	39
Bulgaria	502	19		20		169	9.2		10	21
Cyprus	314			18		172	9.1		0.5	18
Czech Republic	1 450	51		39		233	25	49	10	36
Denmark	507	1.3		4.1	0.03	117	7	24	21	51
Estonia	350	15		6.5			0.2	25	30	58
Finland	936	22	0.02	0.02		187	4	26	18	63
France	1 083	15		15		151	5.8	33	78	
Germany	1 232	36		31		170	15	41	26	33
Greece	538	18				162			60	
Iceland	502	6.6	0.01	4.3	0.01	153	5.3	28	8	54
Iran (Islamic Republic of)	407	20		27		80	20			
Japan	1 571								45	
Lithuania	1 872	26				225	77		6.1	35
Luxembourg	1 087	6.3	0.02	20	0.05	65	14	10	28	34
Netherlands	511	22		7.8		121	7.4	27	22	59
Norway	1 364			8.9		130	5.2		64	
Philippines	279	14	0.5	5.4	0.2	198	1.3	3.4	0.3	0.04
Poland	936	26		35		223	16		7.5	29

Country	*Examination frequency per 1 000 population* [a,b]									
	Total projection radiography [c]	*Head (skull and facial bones)*	*Head (soft tissue)*	*Neck (cervical spine)*	*Neck (soft tissue)*	*Chest-thorax*	*Chest (thoracic spine)*	*Chest (shoulder girdle and ribs)*	*Mammo-graphy*	*Mammography (screening)*
Republic of Korea [d]	4 933	75	46	203	7.6	963	24	309	46	296
Romania	517	15		19		118	12		21	
Russian Federation	1 306	57		22		219	15		22	38
Slovenia	361					188	17		46	
Spain	795			36		267	28		69	20
Sweden	291	0.5		3.1		61	2		17	140
Switzerland	969	3.3		8.4		143	5.6		22	16
United Arab Emirates	1 624	33	7.4	48	12	869	16	29	15	6.9
United Kingdom	1 027	2.1	0.08	5.6	0.3	158	3.2	16	11	40
United States	1 866	4.2		15		342	7.8	37	122	

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

[c] Values as reported; may not equal sum of all categories.

[d] Values reported are projections per 1,000 population; not examinations per 1,000 population. Examinations often include more than one projection.

Table B1b. Annual frequencies per 1,000 population for different projection radiography examinations reported to UNSCEAR Global Survey

Country	Examination frequency per 1 000 population [a,b]										
	Lumbar spine	*Lumbo-sacral joint only*	*Abdomen*	*Pelvis and hips (bone)*	*Pelvis (soft tissue)*	*Limbs and joints*	*Whole spine (trunk)*	*Skeletal survey (head and trunk)*	*Dental intraoral*	*Dental panoramic*	*Others*
Australia	20	2.1	12	72		188	0.2	1.2	302	59	8.3
Belarus	30		12	26		152			185	44	
Belgium	22		23	76	0.8	227	3.8		254	63	14
Brazil	1.8	10	4.8	9.5	0.07	62	0.05	0.02	65	3.2	
Bulgaria	23		15	23	7.5	104			62	19	0.9
Cyprus	26		26	17					5.8	22	
Czech Republic	42	11	31	61		282	1.8		420	117	41
Denmark	16	2.3	3.2	46		173	1.6	34	0.8		4.1
Estonia	22		6.8	14		80	0.02		34	59	
Finland	23	0.4	5.5	34		173	1.4	0.02	297	69	13
France	40		22	77		202	8.8	1.2	385	39	10
Germany	56		19	64		257	0.1		339	140	4.1
Greece	34			19		78			128	37	1.8
Iceland	13	1	11	40		178	0.8			0.3	
Iran (Islamic Republic of)	18		18	38							187
Japan									411	120	995
Lithuania	161		26	71	58				832	357	
Luxembourg	34	4.4	13	66		243	6.6		362	94	88
Netherlands	22		13	40		149	1.5	5.3	13	1.5	
Norway	19		8.5	53					1 048	27	
Philippines	2.1	0.9	12	8.9		31	1.1	0.2	0.2		
Poland	56		12	22		224			224	60	

Country	*Examination frequency per 1 000 population* [a,b]										
	Lumbar spine	*Lumbo-sacral joint only*	*Abdomen*	*Pelvis and hips (bone)*	*Pelvis (soft tissue)*	*Limbs and joints*	*Whole spine (trunk)*	*Skeletal survey (head and trunk)*	*Dental intraoral*	*Dental panoramic*	*Others*
Republic of Korea	374	65	219	132		1 524	48		386	181	35
Romania	32	1.1	11	19		90			92	67	19
Russian Federation	26		8.2	22		144		38	191		503
Slovenia	54		20	37							
Spain	48		42	50					211	22	
Sweden	9		1.8	34						22	
Switzerland	17		9	42					404	71	227
United Arab Emirates	81	16	62	26	2.7	243	6	1	107	43	
United Kingdom	8.5	0.3	15	34		119	1.1	0.3	539	74	
United States	35		38	63		178			916	64	44

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

Table B2a. Annual frequencies per 1,000 population for radiography and fluoroscopy examinations with contrast media reported to UNSCEAR Global Survey

ERCP: Endoscopic retrograde cholangiopancreatography; IVU: Intravenous urography

Country	*Examination frequency per 1 000 population* [a,b]							
	Total [c]	*Gastrointestinal*		*Biliary tract*			*Urogenital tract*	
		Barium studies	*Defecography*	*Cholangiography*	*ERCP*	*Cholecystography*	*IVU*	*Kidney, bladder and urethra*
Australia	30.8	4.3	0.1	0.05	0.4	0.3	0.6	1.2
Belarus	19.3	9					4	
Belgium	33.1	1	4.4	0.1	1	0.2	0.3	1.6
Brazil	0.9	0.02						0.1
Bulgaria	24.6	6.5	1.9	0.1	0.3	0.1	1.3	1.1
Cyprus	9.6	4.4					3.2	
Czech Republic	45.6	2.4		0.4	1.8		0.6	1.2
Denmark	11.5	1.5	0.02	0.1	0.1			1.2
Estonia	11.1	2.6	0.2	1		0.2		0.6
Finland	9.6	1.2	0.2		0.8		0.02	0.3
France	11.1	2.5					0.5	2.4
Germany	41.1	2.6		0.6			7.4	
Greece	4.9	0.7		0.07	0.1		0.2	1
Iceland	18.1	4.6	0.1	0.1	3.1		1.3	1.2
Lithuania	64.9							
Luxembourg	94	2.5		0.1	0.05	0.6	0.7	2.9
Netherlands	12.3			0.02	1.5			0.7
Norway	9.6	2.8						1.1
Philippines	1	0.5	0.01	0.2		0.07	0.04	0.09
Poland	10.5	1.6				0.1	2.1	
Republic of Korea	46.4	25	0.2	0.2	0.01		2.5	1.6

Country	*Examination frequency per 1 000 population* [a,b]							
	Total [c]	*Gastrointestinal*		*Biliary tract*			*Urogenital tract*	
		Barium studies	*Defecography*	*Cholangiography*	*ERCP*	*Cholecystography*	*IVU*	*Kidney, bladder and urethra*
Romania	32.1	6			0.07		1.2	
Russian Federation	13.1	7.2					0.9	0.2
Slovenia	6.1	1					1.3	
Spain	10.7	5.3					2.8	
Sweden	8.3	2.5					1.7	
Switzerland	17.8	0.8					1	
United Arab Emirates	10	3.7			0.3		2	1.1
United Kingdom	10.6	2.7	0.2	0.2	0.8	0.02	0.2	0.4
United States	24	10					2	

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

[c] Values as reported; may not equal sum of all categories.

Table B2b. Annual frequency per 1,000 population for radiography and fluoroscopy examinations with contrast media reported to UNSCEAR Global Survey

Country	*Examination frequency per 1 000 population* [a,b]								
	Myelography	*Arthrography*	*Angiography*						*Others*
			Cerebral	*Cardiac*	*Thoracic*	*Abdominal*	*Pelvic*	*Peripheral*	
Australia	0.1	1.6	0.2	11	0.4	0.5	0.3	1.2	9
Belarus									6.3
Belgium			0.6	6.6	1	0.9		0.5	15
Brazil	0.08	0.12	0.2	0.04	0.04	0.1	0.07	0.03	
Bulgaria		2	0.3	6.2					4.9
Cyprus				1.9					
Czech Republic	0.03	0.07		5.3				0.04	34
Denmark	0.01		0.8	5.6	0.4	0.6	0.3	0.8	0.07
Estonia			0.2	3.8				2.5	
Finland	0.01	0.1	0.4	4.6	0.02	0.1		0.9	1
France				3.9					1.9
Germany			0.6	19		0.9	2		7.9
Greece			0.03	1.8				0.1	
Iceland	0.06		0.2	5.7	0.07	0.2	0.03	1.1	0.3
Lithuania									
Luxembourg	0.09	10.2	0.2	4.3		0.05	0.2	0.2	71.9
Netherlands	0.1	0.71	0.01	1.3	0.2	1.2	0.1	2.8	3.7
Norway					5.7				
Philippines									
Poland			0.3	6	0.08	0.03		0.4	0.02
Republic of Korea	4.1	0.7	1.3	3.4	0.4	1.2	0.1	0.68	5.4
Romania			0.1	1.5		0.1	0.06	0.2	23

Country	*Examination frequency per 1 000 population* [a,b]								
	Myelography	*Arthrography*	*Angiography*						*Others*
			Cerebral	*Cardiac*	*Thoracic*	*Abdominal*	*Pelvic*	*Peripheral*	
Russian Federation				3.6					1.1
Slovenia				3.8					
Spain				2.6					
Sweden				4.2					
Switzerland				6.4					9.5
United Arab Emirates		0.6	0.2	1.8	0.06	0.2		0.1	
United Kingdom	0.03	0.4	0.1	2.3	0.09	0.03	0.05	0.07	3.1
United States				7.7					4.2

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

Table B3a. Annual frequency per 1,000 population for different computed tomography examinations reported to UNSCEAR Global Survey

CT: Computed tomography

Country	*Examination frequency per 1 000 population* [a,b]									
	Total [c]	*CT-head (skull and facial bones)*	*CT-head (soft tissue and brain)*	*CT-neck (cervical spine)*	*CT-neck (soft tissue)*	*CT-chest (thoracic spine)*	*CT-chest (thorax)*	*CT-abdomen (lumbar spine)*	*CT-abdomen (abdomen)*	*CT-abdomen (liver, pancreas, kidneys)*
Australia	157	19	21	7.8	2.8	0.9	17	19	1.1	0.02
Bangladesh	155									
Belarus	78	16					7.3		6.8	
Belgium	201	50			5.6		26		42	
Brazil	51	2.4	17		1	0.6	6.9	3.2	8.9	
Bulgaria	58		2.2	7.4			8.5		13	
Canada	153									
Chile	115									
Cyprus	86	15		3.6		12			14	
Czech Republic	105	4.1	32	2.3	1.8	0.4	16	4	12	10
Denmark	161	5.1	23	2.3	5.4	0.5	46	1.2	41	22
Estonia	166	44		3.4	3.6	1	25	5.4	7.1	0.8
Finland	80	0.4	29	1.8	2.2	0.1	9.9	0.7	10	2.5
France	130	32			3		26	16	6.2	
Germany	129	40		4.8	2.3		25	11	22	3.6
Greece	79		16	2.3	1.3	0.7	19	4.8	32	
Hungary	229									
Iceland	182	12	36	3.7	6	1.1	48	5.8	45	11
Iran (Islamic Republic of)	29									
Japan	221									
Lithuania	96	7.7	18	9.6		7.7	15	18	11	

Country	*Examination frequency per 1 000 population* [a,b]									
	Total [c]	*CT-head (skull and facial bones)*	*CT-head (soft tissue and brain)*	*CT-neck (cervical spine)*	*CT-neck (soft tissue)*	*CT-chest (thoracic spine)*	*CT-chest (thorax)*	*CT-abdomen (lumbar spine)*	*CT-abdomen (abdomen)*	*CT-abdomen (liver, pancreas, kidneys)*
Luxembourg	204		47	14			33	30	49	
Malaysia	61[d]									
Netherlands	85	5.7	17				23			
North Macedonia	31									
Norway	173		32		6.6		22		32	
Philippines	31	10	13	0.3	0.4	0.2	3.1	0.2	2.9	0.6
Poland	83	33	2.2	2.1	0.9	0.6	13	4.2	16	0.07
Republic of Korea	163	6.7	32	4.5	4.5	4.5	38	4.5	38	16
Romania	84		31	3.4		0.51	9.3	2.3	8.7	
Russian Federation	58	21		1.4		1	12	2.4	8.4	1.5
San Marino	136									
Saudi Arabia	40									
Slovenia	54	24		1.4		3.2	6.3		8.8	
Spain	88		22	7.5		0.3	14	12	16	
Sweden	124	4.8	36	4.6		1.1	24	2.5	43	
Switzerland	120	3.5	22				28		31	5.7
United Arab Emirates	106	14	28	3.4	0.9	2.1	7.8	4.2	9.2	14
United Kingdom	91	26	21	1.5	0.7	0.3	3	0.5	1.9	2.2
United States	238	22	47				39			62

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

[c] Values as reported; may not equal sum of all categories.

[d] Not included in the modelling due to late submission.

Table B3b. Annual frequency per 1,000 population for different computed tomography examinations reported to UNSCEAR Global Survey

CT: Computed tomography

Country	*Examination frequency per 1 000 population* [a,b]								
	CT-pelvis (pelvic bones)	*CT-pelvis (pelvic soft tissue and vascular)*	*CT-pelvis (pelvimetry)*	*CT-full spine (neck, chest, abdomen)*	*CT-trunk (chest, abdomen, pelvis)*	*CT-limbs*	*CT-dental*	*CBCT-dental*	*CBCT-others*
Australia	1.7	27	0.02	1.3	12	8.9		0.1	
Bangladesh									
Belarus									
Belgium					18	19		0.8	0.8
Brazil	7.4			2.1		1.4			
Bulgaria	4.9			0.6			1		
Canada									
Chile									
Cyprus	7.4			8.9	24			0.5	
Czech Republic		1.4		2.6	6.4	4.5	0.1		
Denmark	1.6			0.07	0.8	5.9	0.01		
Estonia	0.3	0.5			7.7	2.1	0.05	4	
Finland	0.7	1.2		0.09	11	2.5		2.6	2.6
France		32	0.8		4.9	9.5			
Germany	6.7			4.5		6.7			
Greece	0.6					0.5	0.8	0.8	
Hungary									
Iceland	5			0.04	2.6	6.6	0.04		
Iran (Islamic Republic of)									
Japan									
Lithuania		7.7							

Country	*Examination frequency per 1 000 population* [a,b]								
	CT-pelvis (pelvic bones)	*CT-pelvis (pelvic soft tissue and vascular)*	*CT-pelvis (pelvimetry)*	*CT-full spine (neck, chest, abdomen)*	*CT-trunk (chest, abdomen, pelvis)*	*CT-limbs*	*CT-dental*	*CBCT-dental*	*CBCT-others*
Luxembourg					4.3	12	4.4		
Madagascar									
Netherlands	1.4			5.1		3.2			
North Macedonia									
Norway		22		4.3					
Philippines	0.06	0.1	0.01	0.04	0.1	0.1			
Poland						1.4		5.7	
Republic of Korea				0.5		8.6		6.3	
Romania		5				1			
Russian Federation	2.6						2.3		
San Marino									
Saudi Arabia									
Slovenia	0.5								
Spain	9.2				7.3		0.2	0.09	
Sweden	1.7	4						2	
Switzerland	6.7								
United Arab Emirates	1.7	1.8	0.9	2.6	10	4.2	0.2	1	
United Kingdom	1.1	4.9		0.9	12	1.6		1.2	0.07
United States				20	0.9	5.2		16	

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

B. Literature review data

B18. The frequency per 1,000 population of diagnostic radiological examinations and population dose from such procedures were reported in 28 peer-reviewed articles, corresponding to 22 countries (one country reported only regional values) and one region of several countries (Europe). These articles are summarized in table B4. Diagnostic radiology and interventional radiology procedures were grouped together as X-ray procedures in table B4 because not all publications made a clear distinction between radiography and fluoroscopy and interventional procedures.

B19. An exact comparison of data is difficult due to the difference in the studies; however, high-income countries like Germany, Republic of Korea, Switzerland and the United States seem to have the highest frequencies of X-ray examinations (over 1,200 per 1,000 population). In contrast, low-income countries like Kenya and North Macedonia are lower with typically less than 200 per 1,000 population.

B20. In most countries, the population dose from medical exposure is higher than the global average, while the population dose from medical exposure in some countries now are the greatest human-made contributor to the population dose (e.g., in Australia [H6] and the United States [N1]).

B21. The contributions of computed tomography examinations to the total frequencies (medical radiological examinations) vary substantially: the mean contribution is 9% with the range from 0.7 to 25.5% (about 36-fold variation), compared with 12.9% with the range from 3.2 to 30% (about ninefold variation) in the current survey. The contributions of computed tomography examinations to total frequencies are typically much lower than their contribution to the total collective effective dose: namely, on average 52.5%, range from 5.3 to 79% (about 15-fold variation). Dental examinations are typically 10–40% of the total frequency of diagnostic examinations, with a mean value of 23.5% (compared with 23.2% in the current survey) but contribute less than 1% to the total collective effective dose. Conventional fluoroscopy is typically a few per cent of the total frequency of diagnostic examinations, with a mean value of 2.8%, but the mean contribution to the total collective effective dose is 9.7% (1.1–28.6%). Interventional radiology is typically less than 1% of the total frequency but the mean contribution to the total per caput effective dose is 8.2% (0.5–23%).

B22. Under the EC DDM 2 project [B20, E5], population dose was estimated in 36 European countries (28 European Union Member States and eight other European countries) between 2007 and 2010 for all diagnostic examinations/procedures (diagnostic radiology, interventional radiology and nuclear medicine) and the results were used to obtain the European averages shown in table B4. However, only five countries (Bulgaria, Finland, Germany, Switzerland and United Kingdom) performed a comprehensive evaluation including all diagnostic examinations/procedures, while all other countries based the medical exposure estimation on the TOP 20 methodology as introduced in the EC DDM 1 project [E3], which focuses on the 20 examinations contributing most to the collective effective dose and typically underestimates by 20–30%.

Table B4. Evaluation of medical exposure for diagnostic and interventional radiology and nuclear medicine procedures published since the UNSCEAR 2008 Report [U9]

Country	*Year (period)*	*Annual number per 1 000 population (frequency) of diagnostic examinations and interventional procedures* [a,b]			*Population dose of diagnostic and interventional procedures per caput effective dose (mSv)* [a,b]			*Reference*
		X-ray	*Nuclear medicine*	*Total* [c]	*X-ray*	*Nuclear medicine*	*Total* [c]	
Australia	2010	370	20.2	390[d]	1.59	0.11[e]	1.70	[H6]
Bulgaria	2010	513	2.6	516	0.41	0.009	0.42	[E5]
Finland	2008	1 197	5.6	1 202	0.45	0.03	0.48	[B19, E5]
France	2007	1 151	18.5	1 170	1.16	0.13	1.3	[E10]
	2012			1 247			1.6	[D10]
	2010			0.6[f]			0.2[f]	[E11]
Germany	2009	1 437	35.7	1 472	1.67	0.08	1.75	[E5]
Ireland	2010–2013				0.49	0.05	0.55	[O1]
Italy[g]	2006						1.07	[C12]
Kenya	2011	82			0.05			[K13]
Republic of Korea	2013	4 579[h]	12.7	4 592[h]	1.39[h]	0.15	1.54[h]	[L3]
Luxembourg	2002			1 366	1.83	0.15	1.98	[S12]
Macedonia (The former Yugoslav Republic of)	2010	142			0.25[d]			[G3]
Norway	2002	742			1.09			[B25]
Portugal	2010	830[d]			0.96[d]	0.08	1.04[d]	[T3]
Romania	2012	274	0.85	275	0.371	0.0025	0.3735	[G5]
Russian Federation	2015	1 397[i]	2.8	1 400[i]	0.51[i]	0.009	0.52[i]	[B6]
Slovenia[j]	2011	2 098 (980)			0.65 (0.60)			[Z1]
Sudan	2010	326			0.18			[S24]
Switzerland	2003				1.2			[A8]
	2008	1 667	9.4	1 677	1.18	0.047	1.23	[E5]
	2013	1 219			1.4			[L2]

Country	Year (period)	Annual number per 1 000 population (frequency) of diagnostic examinations and interventional procedures [a,b]			Population dose of diagnostic and interventional procedures per caput effective dose (mSv) [a,b]			Reference
		X-ray	Nuclear medicine	Total [c]	X-ray	Nuclear medicine	Total [c]	
Taiwan, China	2008	733	13.6	746	0.64	0.10	0.74	[C6]
United Kingdom	2008	746	8.5	755	0.39	0.025	0.42	[E5]
Ukraine[j]	2009–2012	1 218 (1 000)			1.06 (0.95)			[S22]
United States	2006	1 221[k]	64	1 285	2.2[k]	0.8	3	[N1]
	2016	1 102[i]	42	1 144[i]	1.8	0.4	2.2	[N2]
Europe (36 countries)	2007–2010				1.05	0.05	1.10	[B20]

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

[c] Values as reported; may not equal sum of all categories.

[d] TOP 20 examinations only.

[e] Excluding contribution from PET examinations; 0.12 mSv if PET is included.

[f] Paediatric examinations only.

[g] Emilia-Romagna región.

[h] Excluding interventional procedures; calculation with ICRP 103 tissue weighting factors [I11].

[i] I:Excluding dental examinations.

[j] J:Extrapolated number, TOP 20 value in parenthesis.

[k] K: Excluding dental bitewing and full-mouth procedures (500 million images across whole population, per caput effective dose about 0.01 mSv).

B23. As with the differences between modality categories (projection radiography with and without dental, radiography and fluoroscopy and computed tomography), the most frequent individual types of procedures can be different from the procedures that make the highest contribution to the collective effective dose. In Norway, Borretzen et al. [B25] showed that radiography of the thorax (two projections) is often the most frequent procedure undertaken in projection radiography while it provides a low contribution to the collective effective dose. General radiology of the pelvis/hips has similar characteristics while the difference is less notable. Contributions to the collective effective dose by dental radiography (excluding dental cone beam computed tomography) are also very small or almost insignificant (typically less than 1%), while their frequency can be among the highest. Computed tomography examinations in general, and computed tomography of abdomen, thorax and pelvis in particular, provide high collective effective dose contributions in spite of the relatively low procedure frequency [B25].

B24. Other published data from several countries are in general agreement with the example from Norway. In Taiwan, China a study by Chen et al. [C6] indicated that conventional chest X-rays contributed most to total frequency (33%) followed by dental (periapical) X-rays (8.6%), while thorax and abdomen computed tomography contributed most to the total collective effective dose (29.4 and 15%, respectively). In France, Étard et al. [E10] studied conventional radiography and concluded that chest and limbs examinations were the most frequent (29.8 and 26.3%, respectively), while the collective dose was due mainly to abdominal and pelvic examinations (41.5 and 29.8%, respectively). However, in low-income countries, trends can be different. Korir et al. [K13] showed that in Kenya the largest contributors to the total collective dose, in decreasing order, were conventional radiography, computed tomography, fluoroscopy, interventional radiology and mammography.

IV. TYPICAL EFFECTIVE DOSES PER PROCEDURE

A. UNSCEAR Global Survey data

B25. The typical (mean) effective dose for each radiological imaging procedure is needed to calculate the population dose (collective effective dose to population or per caput effective dose), in addition to the frequency of the procedure and the population number. While the typical effective dose for a representative number of procedures can be determined by rather sophisticated methods (e.g., based on Monte Carlo calculations), the most common approach is to convert its value from the representative typical (mean) value of dosimetric quantities (mainly dose area product (DAP) or dose length product (DLP)) with the help of a conversion factor based on a large number of published studies. In the current UNSCEAR Global Survey, consistent values of conversion factors have been applied as shown below, mostly taken from the user manual for the UNSCEAR Global Survey [U11]. Due to this practice, only the typical effective dose will be reported and not the typical values of dosimetric quantities.

B26. From the 51 countries submitting data for diagnostic radiology examinations (projection radiography, radiography and fluoroscopy and computed tomography) in the survey, only some of them (1–28 countries depending on the type of examination) have submitted either the typical effective dose directly or the typical value of the dosimetric quantity (DAP: in projection radiography and radiography and fluoroscopy, and DLP: in computed tomography) for the calculation of typical effective dose using a conversion factor. Many countries, however, have submitted frequencies but no data for doses (neither effective doses nor DAP or DLP values) for many examinations. For most countries, dose data were not complete for some types of diagnostic radiology examinations.

B27. Table B5 summarizes the typical (mean) effective doses submitted by countries to UNSCEAR Global Survey for the different projection radiography examinations, including both the effective doses directly submitted and the values calculated from the submitted DAP values by a conversion factor. The conversion factors used in the calculation are shown in table B6. DAP with a conversion factor has been used to calculate the typical effective dose whenever the DAP has been submitted. The mean value of typical effective dose, for each type of projection radiography examination, is shown in table B7.

Table B5a. Typical mean effective doses (mSv) for projection radiography examinations

The effective doses were calculated from reported DAP values, using conversion factors, or were directly reported values (in italics)

Country	*Mean effective doses (mSv) per examination*[a,b]								
	Head (skull and facial bones)	*Head (soft tissue)*	*Neck (cervical spine)*	*Neck (soft tissue)*	*Chest-thorax*	*Chest (thoracic spine)*	*Chest (shoulder girdle and ribs)*	*Mammography*	*Mammography (screening)*
Australia	0.06		0.07	*0.01*	0.1	0.15		*1.60*	*1.60*
Belarus	*0.07*		*0.08*		*0.21*	*0.79*	*0.09*	*0.35*	
Belgium					0.17			*0.30*	
Brazil	*0.15*	*0.15*	*0.10*		*0.11*	*0.85*		*0.66*	*0.60*
Bulgaria	0.06		*0.27*		0.05	0.24		*0.18*	*0.18*
Czech Republic			0.12		0.03	0.32		*0.16*	*0.31*
Denmark					0.05				
Estonia			0.02		0.01	0.03	0.03		
France	*0.08*		*0.30*		*0.06*	*0.40*	*0.02*	*0.40*	
Germany	*0.03*		*0.30*	*1*	*0.15*	*0.45*	*0.06*	*0.30*	*0.25*
Greece	*0.04*		*0.02*		*0.13*			*0.16*	
Iceland	0.02		0.13		0.05	0.58	0.05	*2.50*	*2.30*
Lithuania	0.12				0.04	0.29			
Luxembourg	0.09		0.18		0.07	0.45	0.14		
Malaysia	0.10		0.17		0.04	0.51			
Norway			0.18		0.08	0.49		*0.15*	
Poland	*0.10*		*0.10*		*0.10*	*0.80*		*0.60*	*0.60*
Republic of Korea									
Romania	0.07		0.07		0.08	0.17		*0.23*	
Russian Federation	*0.10*		*0.14*		*0.30*	*0.70*		*0.25*	*0.20*
Saudi Arabia	0.04		0.15		0.08	0.20			
Slovenia			0.13		0.05	0.36		*0.41*	

Country	*Mean effective doses (mSv) per examination* [a,b]								
	Head (skull and facial bones)	*Head (soft tissue)*	*Neck (cervical spine)*	*Neck (soft tissue)*	*Chest-thorax*	*Chest (thoracic spine)*	*Chest (shoulder girdle and ribs)*	*Mammography*	*Mammography (screening)*
Spain	0.06		0.07		0.06	0.48		*0.27*	*0.26*
Sweden	0.04		0.1		0.03	0.60			
Switzerland	*0.08*		*0.10*		*0.06*	*0.60*		*0.30*	*0.30*
United Arab Emirates			0.03		0.01				
United Kingdom	0.15		0.12		0.08	0.40			

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

Table B5b. Typical mean effective doses (mSv) for projection radiography examinations

The effective doses were calculated from reported DAP values, using conversion factors, or were directly reported values (in italics)

Country	*Mean effective doses (mSv) per examination* [a,b]									
	Lumbar spine	*Lumbo-sacral joint only*	*Abdomen*	*Pelvis and hips (bone)*	*Pelvis (soft tissue)*	*Limbs and joints*	*Whole spine (trunk)*	*Skeletal survey (head and trunk)*	*Dental intraoral*	*Dental panoramic*
Australia	0.62		0.56	0.36						
Belarus	*1.65*		*0.71*	*0.48*		*0.019*			*0.006*	*0.07*
Belgium	2.49		0.57	0.65						
Brazil	*0.92*		*0.30*							
Bulgaria	0.53	0.15	0.49	0.47	*1.50*	*0.03*				*0.02*
Czech Republic	0.86		0.38	0.45						
Denmark	0.90			0.39						
Estonia	0.14	0.15	0.1	0.09		0.005				
France	*1.90*		*1.60*	*0.800*		*0.002*	*1.60*	*0.50*	*0.004*	*0.03*
Germany	*1.20*		*0.55*	*0.40*		*0.08*	*1.50*		*0.003*	*0.02*
Greece	*1.32*			*0.33*		*0.001*			*0.003*	*0.02*
Iceland	1.8	0.06	1.10	0.64		0.02				
Lithuania	0.62		0.34	0.58						
Luxembourg	1.14			0.46						
Malaysia	0.18	0.86	0.34	0.61						
Norway	1.37		1.27	0.55						
Poland	*1.30*		*0.80*	*0.60*		*0.01*				*0.01*
Republic of Korea			*0.44*							*0.02*
Romania	0.32	0.33	0.35	0.42		0.046			*0.004*	*0.02*
Russian Federation	*1.40*		*0.80*	*0.74*		*0.01*			*0.01*	
Saudi Arabia			0.17	0.33						

Country	*Mean effective doses (mSv) per examination* [a,b]									
	Lumbar spine	*Lumbo-sacral joint only*	*Abdomen*	*Pelvis and hips (bone)*	*Pelvis (soft tissue)*	*Limbs and joints*	*Whole spine (trunk)*	*Skeletal survey (head and trunk)*	*Dental intraoral*	*Dental panoramic*
Slovenia	0.68		0.44	0.57						
Spain	0.80		0.52	0.58					*0.01*	*0.008*
Sweden	0.85		0.92	0.48						
Switzerland	*1.50*		*0.80*	*0.80*						
United Arab Emirates	0.03		0.04	0.005		0.004				
United Kingdom	0.72	0.45	1.13	0.53						

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

Table B6. Conversion factors used in effective doses calculation from DAP values for projection radiography examinations

Examination type	*Conversion factor (mSv/(Gy cm²))*	*Selection of the conversion factor*
Head (skull and facial bones)	0.14	Selected to yield the mean effective dose (mean of submitted typical values) from the mean value of submitted DAP values
Head (soft tissue)	0.14	Taken to be the same as for head (skull and facial bones)
Neck (cervical spine)	0.28	Selected to yield the mean effective dose (mean of submitted typical values) from the mean value of submitted DAP values
Neck (soft tissue)	0.28	Taken to be the same as for neck (cervical spine)
Chest-thorax	0.18	Table 4 in [U11] (for high kV)
Chest (thoracic spine)	0.19	Table 4 in [U11]
Chest (shoulder girdle and ribs)	0.19	Taken to be the same as for chest (thoracic spine)
Mammography		No calculation, the reported value for mean effective dose was used
Mammography (screening)		No calculation, the reported value for mean effective dose was used
Lumbar spine	0.21	Table 4 in [U11]
Lumbo-sacral joint only	0.21	Taken to be the same as for lumbar spine
Abdomen	0.26	Table 4 in [U11]
Pelvis and hips (bone)	0.29	Table 4 in [U11]
Pelvis (soft tissue)	0.29	Taken to be the same as for pelvis and hips (bone)
Limbs and joints	0.16	Selected to yield the mean effective dose (mean of submitted typical values) from the mean value of submitted DAP values
Whole spine (trunk)		No calculation, the reported value for mean effective dose was used
Skeletal survey (head and trunk)		No calculation, the reported value for mean effective dose was used
Dental intraoral		No calculation, the reported value for mean effective dose was used
Dental panoramic		No calculation, the reported value for mean effective dose was used

B28. Table B7 shows that the highest typical effective doses are for whole spine (trunk), pelvis (soft tissue) and lumbar spine, all of these more than 1 mSv; however, the values for the first two are based on only 1–2 submitted values. Standard deviations are typically quite high, reflecting a high level of variability in doses between countries. Dental intraoral has with 0.006 mSv the lowest typical effective dose per examination.

Table B7. Mean values of typical effective doses for projection radiography examinations reported to UNSCEAR Global Survey

Examination type	*Typical effective dose (mSv)*	*Standard deviation*	*Number of countries included*
Head (skull and facial bones)	0.08	0.04	18
Head (soft tissue)	0.15	0	1
Neck (cervical spine)	0.13	0.08	23
Neck (soft tissue)	0.51	0.7	2
Chest-thorax	0.08	0.07	26
Chest (thoracic spine)	0.45	0.22	22
Chest (shoulder girdle and ribs)	0.06	0.05	6
Mammography	0.52	0.61	17
Mammography (screening)	0.66	0.72	10
Lumbar spine	1.01	0.60	25
Lumbo-sacral joint only	0.33	0.29	6
Abdomen	0.61	0.38	24
Pelvis and hips (bone)	0.49	0.19	25
Pelvis (soft tissue)	1.50	0	1
Limbs and joints	0.02	0.02	10
Whole spine (trunk)	1.55	0.07	2
Skeletal survey (head and trunk)	0.50	0	1
Dental intraoral	0.01	0.003	6
Dental panoramic	0.02	0.02	8

B29. Table B8 summarizes the typical (mean) effective doses submitted to UNSCEAR Global Survey for different radiography and fluoroscopy examinations, including both the effective doses submitted and the values calculated from the DAP values by a conversion factor. The conversion factors used in the calculation are shown in table B9. The DAP values when available with respective conversion factors have been used to calculate the typical effective dose.

Table B8. Typical mean effective doses (mSv) for radiography and fluoroscopy examinations

The effective doses were calculated from reported DAP values, using conversion factors, or were directly reported values (in italics)

ERCP: Endoscopic retrograde cholangiopancreatography; IVU: Intravenous urography

Country	*Mean effective doses (mSv) per examination* [a,b]														
	Gastrointestinal tract		*Biliary tract*			*Urogenital tract*		*Myelo-graphy*	*Arthro-graphy*	*Angiography*					
	Barium study	*Defeco-graphy*	*Cholangio-graphy*	*ERCP*	*Cholecysto-graphy*	*IVU*	*Kidney, bladder and urethra*			*Cerebral*	*Cardiac*	*Thoracic*	*Abdominal*	*Pelvic*	*Peripheral*
Australia	2.3						2.3				7.9				
Belgium				3.2											
Bulgaria	2.5	3.8	15.4	4.2	2.3	4.9	0.5	*9.2*	4.1	9.1	9				
Czech Republic						1.6					8.2				
Estonia	0.4	18.4	8.6				0.1			9.8	15.9				3.2
Finland											4.4				
France	*10.2*					*1.9*	*2.1*				9				
Germany	*8*		*9*	*7*		*3*	*4*				*6.3*	*8.5*	*9*	*7*	
Greece											8.5				
Iceland				4.4							1.1				
Lithuania	4.4											*0.2*			
Malaysia	0.5					0.8					4.3				
Norway							2.3				7.6				
Poland	*5.1*				0.6	*8.2*									
Republic of Korea				13.9						5.8					
Romania	1.2			0.5		0.9				3.2	5.5		*7*	*8.1*	*1.9*
Russian Federation	*3.2*						*1.4*	*1.8*				*5.8*			
Saudi Arabia	1.9														

Country	Mean effective doses (mSv) per examination [a,b]														
	Gastrointestinal tract		Biliary tract			Urogenital tract		Myelo-graphy	Arthro-graphy	Angiography					
	Barium study	Defeco-graphy	Cholangio-graphy	ERCP	Cholecysto-graphy	IVU	Kidney, bladder and urethra			Cerebral	Cardiac	Thoracic	Abdominal	Pelvic	Peripheral
Slovenia	1.4					0.9					4.8				
Spain	7					2					6.2				
Sweden	1					0.6					2.5				
Switzerland	4					2.2					10				
United Arab Emirates	3.9		0.06				0.3								
United Kingdom	1.4	4.2	1	1.1		2.1			0.1	6.5	5				4.6

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

Table B9. Conversion factors used for effective doses calculation from dose area product values for radiography and fluoroscopy examinations

DAP: Dose-area product; ERCP: Endoscopic retrograde cholangiopancreatography; IVU: Intravenous urography

Examination type	*Conversion factor (mSv/(Gy cm²))*	*Selection of the conversion factor*
Gastrointestinal tract (barium studies)	0.20	Table 4 [U11] (barium meal)
Gastrointestinal tract (defecography)	0.28	Chosen to yield the effective dose from DAP value using their values submitted by Bulgaria
Biliary tract (cholangiography)	0.25	Chosen to yield the effective dose from DAP value using their values submitted by Bulgaria
Biliary tract (ERCP)	0.26	Table 5 [U11]
Biliary tract (cholecystography)		No calculation, the reported value for mean effective dose was used
Urogenital tract (IVU)	0.18	Table 4 [U11]
Urogenital tract (kidney, bladder and urethra)	0.18	Table 5 [U11]
Myelography		No calculation, the reported value for mean effective dose was used
Arthrography	0.10	Table 5 [U11] (arthrograms)
Cerebral angiography	0.087	Table 5 [U11]
Cardiac angiography	0.20	Table 5 [U11]
Thoracic angiography		No calculation, the reported value for mean effective dose was used
Abdominal angiography		No calculation, the reported value for mean effective dose was used
Pelvic angiography		No calculation, the reported value for mean effective dose was used
Peripheral angiography	0.10	Table 5 [U11] (peripheral phlebography/venography)
Lymphangiography		No calculation possible, no DAP values submitted

B30. Table B10 shows typical effective doses (mean values) for radiography and fluoroscopy examinations. More details are also presented in electronic attachment B-1. The highest typical effective doses are for gastrointestinal tract (defecography), biliary tract (cholangiography, abdominal, pelvic, cerebral and cardiac angiographies), all of these are more than 6 mSv. Urogenital tract (kidney, bladder and urethra) examinations have the lowest typical effective dose, 1.3 mSv. For some types of examinations, the mean value is based on only one or two submissions. As for projection radiography, it should also be noted that the standard deviations are typically very high, reflecting large variations between countries. For lymphangiography, no dose data have been submitted from any country, so it has not been possible to present a mean value.

Table B10. Typical effective doses (mean values) for radiography and fluoroscopy examinations

ERCP: Endoscopic retrograde cholangiopancreatography; IVU: Intravenous urography

Examination type	*Typical effective dose (mSv)*	*Standard deviation*	*Number of countries included*
Gastrointestinal tract (barium studies)	3.4	2.8	15
Gastrointestinal tract (defecography)	8.8	8.3	3
Biliary tract (cholangiography)	8.5	5.9	5
Biliary tract (ERCP)	4.9	4.5	7
Biliary tract (cholecystography)	1.5	1.2	2
Urogenital tract (IVU)	2.4	2.2	13
Urogenital tract (kidney, bladder and urethra)	1.6	1.3	8
Myelography	5.5	5.2	2
Arthrography	2.1	2.8	2
Cerebral angiography	6.9	3.1	4
Cardiac angiography	7.0	3.4	18
Thoracic angiography	4.8	4.3	3
Abdominal angiography	8.0	1.4	2
Pelvic angiography	7.5	0.8	2
Peripheral angiography	3.2	1.4	3

B31. Table B11 summarizes the typical (mean) effective doses submitted to UNSCEAR Global Survey by countries for the different computed tomography examinations, including both the effective doses directly submitted and the values calculated from the submitted DLP values by a conversion factor. The conversion factors used in the calculation are shown in table B12. The typical effective dose was calculated from the DLP with a conversion factor whenever the DLP had been submitted, i.e. also in the case when both DLP and typical effective dose had been submitted. The mean value of typical effective doses for each type of computed tomography examination is shown in table B13 (see also electronic attachment B-1).

Table B11a. Typical mean effective doses for computed tomography examinations

The effective doses were calculated from reported DAP values, using conversion factors, or were directly reported values (in italics)
CT: Computed tomography

Country	*Mean effective doses (mSv) per examination*[a,b]								
	CT-head (skull and facial bones)	*CT-head (soft tissue and brain)*	*CT-neck (cervical spine)*	*CT-neck (soft tissue)*	*CT-chest (thoracic spine)*	*CT-chest (thorax)*	*CT-abdomen (lumbar spine)*	*CT-abdomen (abdomen)*	*CT-abdomen (liver, pancreas, kidneys)*
Australia	1.4	1.5	3.6	2.5	6.7	4.8	8.1	8.1	11.1
Belarus	*1*							*6.3*	
Belgium	1.7		*2.3*			3.7	7.9	7	
Brazil	2.7	2.8	4.7		13.4	8.9	13.9	11	
Bulgaria	1.8	0.8	2.8			4.3	5.8	5.8	8.5
Czech Republic	1.9	0.7				5.2	6.6	9.1	
Denmark		1.8				7		8.3	
Estonia	0.6	2	2.2	0.9	7.2	5.2	9.4	9.6	5.7
Finland		1.4				4.4		7	
France	*1.4*			*3.3*		*7.8*	*11*	*13.8*	
Germany	*1.9*	1.7	*1.9*	*3.1*	*6.6*	*7.3*	*3.1*	*16*	*14*
Greece			*3.9*	*3.7*		*9.1*	*10.5*	*14*	
Iceland	0.09	2	2.6	1.9		4.1	6.7	9.7	5.6
Lithuania		1.9	2.4		8.3	9.7	7.8	16.7	
Luxembourg		1.8				4.3	7.1	6.7	
Malaysia	2.1	1.7	2.8		7.3	10	13	9.6	9.1
Norway		1.8		3		4.7		9.5	
Philippines	1.1	1.4	3.9	3.9	14.3	10	17.1	31.4	9.9
Poland	1.8	3.6	2.9	4.6	8.7	10.1	8.9	22.3	
Republic of Korea	1.8							6.3	

Country	*Mean effective doses (mSv) per examination* [a,b]								
	CT-head (skull and facial bones)	*CT-head (soft tissue and brain)*	*CT-neck (cervical spine)*	*CT-neck (soft tissue)*	*CT-chest (thoracic spine)*	*CT-chest (thorax)*	*CT-abdomen (lumbar spine)*	*CT-abdomen (abdomen)*	*CT-abdomen (liver, pancreas, kidneys)*
Romania		2.3	3.9		6.8	6.9	10.5	6.5	
Russian Federation	1.7	4.1	2.4		4.5	*5.3*	*5.3*	7.5	21
Saudi Arabia	0.3	2.4	8.4	3.2	9.3	7.8	14.1	22.2	20.3
Slovenia	*2.9*		*3*		*9.9*	*6.7*			
Spain		1.7	2.4		9.1	6.9	11.1	10.5	
Sudan		*2.4*			*9.2*	10.7		20.4	7.9
Sweden		1.7	1.3			3.5		6.2	
Switzerland	1.9	0.9	2.4		5	3.5		8.1	8.1
Turkey		1.4				3.5		2.7	
United Arab Emirates	1.3			1.1	1.2	3.8		6	2.5
United Kingdom		1.9	3.1			7		12	10.1

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

Table B11b. Typical mean effective doses for computed tomography examinations

The effective doses were calculated from reported DAP values, using conversion factors, or were directly reported values (in italics)
CBCT: Cone beam computed tomography; CT: Computed tomography

Country	*Mean effective doses (mSv) per examination* [a,b]							
	CT-pelvis (pelvic bones)	*CT-pelvis (pelvic soft tissue and vascular)*	*CT-pelvis (pelvimetry)*	*CT-full spine (neck, chest, abdomen)*	*CT-trunk (chest, abdomen, pelvis)*	*CT-limbs*	*CT-dental*	*CBCT-dental*
Australia	6.1	6.3		16.7	11.3			
Belarus								
Belgium								
Brazil	13.2							
Bulgaria	*11.2*			*15*				
Czech Republic	7.4				15.8			
Denmark					19.1			
Estonia	4.8	5.7		11.6		0.4	0.25	
Finland					9.4			
France		*14.5*	*0.5*		*16.3*	*5.7*		
Germany	*5.3*	*5.3*		*12.1*	*17.6*	*4.8*	*2*	*0.2*
Greece	*7.7*				25.4			
Iceland	7.1							
Lithuania		9.3						
Luxembourg								
Malaysia	8.2	19.8						
Norway		7.3		*5.6*				
Philippines	9.8	17.9		25.8	30.8	0.7		
Poland	8.4	22.1						*0.06*
Republic of Korea								
Romania		4.9			10.7	0.4		

Country	*Mean effective doses (mSv) per examination [a,b]*							
	CT-pelvis (pelvic bones)	*CT-pelvis (pelvic soft tissue and vascular)*	*CT-pelvis (pelvimetry)*	*CT-full spine (neck, chest, abdomen)*	*CT-trunk (chest, abdomen, pelvis)*	*CT-limbs*	*CT-dental*	*CBCT-dental*
Russian Federation	8.1						*0.10*	
Saudi Arabia	14.6				25.9	0.5		
Slovenia	*9.8*							
Spain	11.6				13		0.49	0.06
Sudan			10.1					
Sweden		9.7						
Switzerland	8.1	8.1						
Turkey			4.4					
United Arab Emirates					8.7			
United Kingdom					13.5			

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

Table B12. Conversion factors used for effective dose calculations from dose length product values for computed tomography examinations

CBCT: Cone beam computed tomography; CT: Computed tomography

Examination type	*Conversion factor (mSv/(mGy cm))*	*Selection of the conversion factor*
CT-head (skull and facial bones)	0.0021	Table 7 [U11] (Head)
CT-head (soft tissue and brain)	0.0021	Table 7 [U11] (Head)
CT-neck (cervical spine)	0.0059	Table 7 [U11] (Neck)
CT-neck (soft tissue)	0.0059	Table 7 [U11] (Neck)
CT-chest (thoracic spine)	0.014	Table 7 [U11] (Chest)
CT-chest (thorax)	0.014	Table 7 [U11] (Chest)
CT-abdomen (lumbar spine)	0.015	Table 7 [U11] (Abdomen and pelvis)
CT-abdomen (abdomen)	0.015	Table 7 [U11] (Abdomen and pelvis)
CT-abdomen (liver, pancreas, kidneys)	0.015	Table 7 [U11] (Abdomen and pelvis)
CT-pelvis (pelvic bones)	0.015	Table 7 [U11] (Pelvis)
CT-pelvis (pelvic soft tissue and vascular)	0.015	Table 7 [U11] (Pelvis)
CT-pelvis (pelvimetry)	0.015	Table 7 [U11] (Pelvis)
CT-full spine (neck, chest and abdomen)	0.015	Table 7 [U11] (Trunk)
CT-trunk (chest, abdomen and pelvis)	0.015	Table 7 [U11] (Trunk)
CT-limbs	0.001	Selected based on the Romanian data so that the use of the conversion factor and the reported DAP value results in the reported effective dose
CT-dental	0.0021	Selected based on the Spanish data so that the use of the conversion factor and the reported DAP value results in the reported effective dose
CBCT-dental	0.002	Selected based on the Spanish data so that the use of the conversion factor and the reported DAP value results in the reported effective dose
CBCT-others		No calculation possible, no submitted dose values

B32. It can be seen in table B13 that the highest typical mean effective doses are for computed tomography examinations of trunk (chest, abdomen and pelvis) and full spine (neck, chest and abdomen), and for the two types of computed tomography examinations of abdomen, all of these are more than 11 mSv. As could be expected, the dental computed tomography examinations have the lowest effective dose (0.3 mSv or less).

Table B13. Mean values of typical effective doses for computed tomography examinations

CBCT: Cone beam computed tomography; CT: Computed tomography

Examination	*Typical effective dose (mSv)*	*Standard deviation*	*Number of countries included*
CT-head (skull and facial bones)	1.5	0.7	19
CT-head (soft tissue and brain)	1.9	0.8	23
CT-neck (cervical spine)	3.1	1.5	20
CT-neck (soft tissue)	2.8	1.2	11
CT-chest (thoracic spine)	8	3.2	16
CT-chest (thorax)	6.4	2.4	29
CT-abdomen (lumbar spine)	9.4	3.5	19
CT-abdomen (abdomen)	11.2	6.2	31
CT-abdomen (liver, pancreas, kidneys)	10.3	5.6	12
CT-pelvis (pelvic bones)	8.8	2.7	16
CT-pelvis (pelvic soft tissue and vascular)	10.9	6.1	12
CT-pelvis (pelvimetry)	5	4.8	3
CT-full spine (neck, chest, abdomen)	14.5	6.7	6
CT-trunk (chest, abdomen, pelvis)	16.7	6.9	13
CT-limbs	2.1	2.5	6
CT-dental	0.7	0.9	4
CBCT-dental	0.1	0.1	2

B. Literature review data

B33. As for the results of the UNSCEAR Global Survey, only the typical (mean) effective doses have been considered and not the typical (mean) values of dosimetric quantities. Typical effective doses for a large number of types of procedures for all modalities using the TOP 20 methodology was recently reported by Vilar-Palop et al. [V6]. The study was based on a comprehensive literature review from 2005 onwards through the Medline, Embase and Cochrane Library Plus databases, including studies backed by scientific or governmental organizations. Twenty-seven articles and five web references were included in the study. Other variables included year and type of study (survey or descriptive), country, method and sample used for the measurement. Mean effective dose, minimum, maximum and standard deviation were calculated. Of these 20 procedures, a total of 378 dose values were reported, 280 (74%) with calculations based on ICRP 60 [I9] and 98 (26%) based on ICRP 103 [I11]. The results shown in table B14 were compared with data from the EC DDM 2 project [E5].

Table B14. Comparison of mean effective dose for selected examinations according to different sets of ICRP tissue weighting factors (ICRP 60 [I9] and ICRP 103 [I11]), and published values [E5, M10]

E: Effective dose; IVU: Intravenous urography; LSJ: Lumbosacral junction; PTCA: Percutaneous transluminal coronary angioplasty

Category	*Examination*	*ICRP 60 [I9]*			*ICRP 103 [I11]*			*Published E (mSv)*	
		Mean E (mSv)	*Min-max E (mSv)*	*Standard deviation*	*Mean E (mSv)*	*Min-max E (mSv)*	*Standard deviation*	*Mettler et al. [M10]*	*EC DDM 2 [E5]*
Plain radiography	Chest/thorax	0.07	0.01–0.14	0.04	0.05	0.01–0.07	0.02	0.02	0.10
	Cervical spine	0.08	0.02–0.18	0.06	0.05	0.01–0.11	0.05	0.20	0.19
	Thoracic spine	0.60	0.23–1.22	0.43	0.50	0.10–1.20	0.40	1.00	0.64
	Lumbar spine (incl. LSJ)	1.20	0.20–1.90	0.60	0.80	0.20–1.50	0.7	1.50	1.20
	Mammography	0.33	0.26–0.46	0.11	0.64			0.40	0.27
	Abdomen	0.92	0.21–2.10	0.60	0.50	0.14–0.75	0.25	0.70	0.90
	Pelvis and hip	0.90	0.45–1.82	0.47	0.37	0.09–0.66	0.24	0.60	0.71
Fluoroscopy	Barium meal	3.60	1.50–4.93	1.50	4.50			6.00	6.20
	Barium enema	5.80	3.00–8.25	2.40	2.90	2.20–3.50	0.90	8.00	8.50
	Barium follow-through	3.50	1.20–7.70	3.70	1.30	1.20–1.30	0.10	5.00	7.30
	IVU	3.50	2.30–6.50	2.00	2.10			3.00	2.90
	Cardiac angiography	9.30	3.30–22.30	6.40	3.10			7.00	7.70
Computed tomography	Head	1.80	1.40–2.60	0.40	1.70	0.90–2.60	0.50	2.00	1.90
	Neck	3.20	1.80–6.00	1.30	3.00	1.70–5.80	1.90	3.00	2.50
	Chest	6.70	4.40–11.80	2.10	7.00	4.60–10.10	1.70	7.00	6.60
	Spine	10.30	4.00–16.70	5.30	7.00	1.00–12.00	0.00	6.00	7.70
	Abdomen	8.10	5.10–11.70	2.00	6.80	5.60–8.00	1.20	8.00	11.30
	Pelvis	8.30	4.00–11.90	2.40	7.40	5.70–9.90	2.20	6.00	7.30
	Trunk	12.20	6.70–15.80	3.30	12.30	10.00–16.00	2.00		14.80
Interventional radiology	PTCA	19.50	7.40–48.60	15.10	7.20			15.00	15.20

[a] Zero values are indicated when available; otherwise, cells have been kept empty.

B34. The values of the effective doses calculated using ICRP 103 [I11] weights are lower than those calculated using ICRP 60 [I9] weights for almost all procedures. The only exception is mammography, and this is due to the increase in the weighting factor of the breast tissue (which has more than doubled, from 0.05 in ICRP 60 to 0.12 in ICRP 103).

B35. Table B15 presents a comparison of mean effective doses of main paediatric examinations with mean effective doses for adults conducted by Vilar-Palop et al. [V6]. Differences between children's age groups and adults vary greatly with examination types. For plain radiography examinations in children, for some age groups it resulted in higher dose than those for adults. For fluoroscopy procedures in children, the effective doses are consistently lower than those for adults. For computed tomography examinations in children, effective doses for head, abdomen and pelvis are very similar to those for adults, while those for chest and trunk are lower than those for adults.

Table B15. Description of mean effective doses for paediatric patients according to age group and comparison with adult effective doses (according to ICRP 60) [V6]

IVU: Intravenous urography; LSJ: Lumbosacral junction

Category	*Examination*	*Effective dose (mSv)* [a,b]				
		<1 year	*1–5 years*	*6–10 years*	*11–15 years*	*Adults*
Plain radiography	Chest/thorax	0.05	0.05	0.05	0.06	0.07
	Cervical spine	0.02	0.03	0.05	0.10	0.08
	Thoracic spine	0.39	0.42	0.77	1.18	0.60
	Lumbar spine (incl. LSJ)	0.4	0.5	0.6	0.8	1.2
	Abdomen	0.07	0.09	0.15	0.27	0.9
	Pelvis and hip	0.08	0.10	0.15	0.21	0.90
Fluoroscopy	Barium meal	0.7	0.6	0.9	1	3.6
	Barium enema	2.3	2.3	2.3	2.3	5.8
	Barium follow-through	1.2	1.2	1.2	1.2	3.5
	IVU	0.5	0.5	0.7	1	3.5
Computed tomography	Head	1.7	1.6	1.8	1.6	1.8
	Chest	3.9	2.8	4.2	6.8	6.7
	Abdomen	7.9	7.9			8.1
	Pelvis	7.9	7.9			8.3
	Trunk	3.9	3	5.6	8.3	12.2

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

B36. The differences between the mean effective dose values using ICRP 60 [I9] and ICRP 103 [I11] tissue weighting factors, according to Vilar-Palop et al. [V6] are shown in table B16. In table B17, corresponding differences are presented for paediatric computed tomography examinations [B26].

Table B16. Comparison of mean effective doses calculated using tissue weighting factors from ICRP 60 [I9] and ICRP 103 [I11] for adult patients [V6]

E: Effective dose; LSJ: Lumbosacral junction; PTCA: Percutaneous transluminal coronary angioplasty

Category	*Examination*	*Mean E-60 (mSv)*	*Mean E-103 (mSv)*	*Ratio E-103/ E-60*
Plain radiography	Chest/thorax	0.07	0.05	0.71
	Cervical spine	0.08	0.05	0.63
	Thoracic spine	0.6	0.5	0.83
	Lumbar spine (incl. LSJ)	1.2	0.8	0.67
	Mammography	0.3	0.6	1.94
	Abdomen	0.92	0.5	0.54
	Pelvis and hip	0.9	0.4	0.41
Fluoroscopy	Barium meal	3.6	4.5	1.25
	Barium enema	5.8	2.9	0.50
	Barium follow-through	3.5	1.3	0.37
	Intravenous urography	3.5	2.1	0.60
	Cardiac angiography	9.3	3.1	0.33
Computed tomography	Head	1.8	1.7	0.94
	Neck	3.2	3	0.94
	Chest	6.7	7	1.04
	Spine	10.3	7	0.68
	Abdomen	8.1	6.8	0.84
	Pelvis	8.3	7.4	0.89
	Trunk	12.2	12.3	1.01
Interventional radiology	PTCA	19.5	7.2	0.37

Table B17. Comparison of mean effective dose calculated using tissue weighting factors from ICRP 60 [I9] and ICRP 103 [I11] for paediatric computed tomography examinations [B26]

Computed tomography examination	*Mean effective dose E-60 (mSv)*	*Mean effective dose E-103 (mSv)*	*Effective dose ratio E-103/E-60*
Brain	2	1.7	0.85
Chest	4	3.6	0.90
Abdomen/pelvis	5.1	3.9	0.76

B37. Many recent population dose studies have made use of the data published in the EC DDM 1 project [E3]. This study was based on data from 10 European countries that reported mean typical effective doses in three levels (high, mean and low) following the TOP 20 methodology as presented in table B18. In the subsequent EC DDM 2 project [E5], mean values for the TOP 20 methodology based on data from 36 European countries and also for the 10 earlier EC DDM 1 countries were reported. These data are compared in table B19 with earlier estimated dose data for HCL I countries [U9].

Table B18. Comparison of mean effective dose between the European Commission Dose Data projects and UNSCEAR HCL I countries

HCL: Health-care level; IVU: Intravenous urography; LSJ: Lumbosacral junction; PTCA: Percutaneous transluminal coronary angioplasty

Modality category	*Examination*	*EC DDM 1 [E3]*			*EC DDM 2 [E5]*				*UNSCEAR HCL I [U9]*
		Low	*Mean*	*High*	*DDM 1 countries 10*	*DDM 2 countries 36*			
		Effective dose (mSv)	*Effective dose (mSv)*	*Effective dose (mSv)*	*Mean effective dose (mSv)*	*Mean effective dose (mSv)*	*Range*	*Max/min*	*Mean effective dose (mSv)*
Plain radiography	Chest/thorax	0.01	0.10	0.25	0.1	0.1	0.014–0.25	18.6	0.1
	Cervical spine	0.04	0.27	0.70	0.1	0.2	0.02–0.7	41.2	0.2
	Thoracic spine	0.40	1.00	2.00	0.5	0.6	0.14–2.0	14.2	0.8
	Lumbar spine (incl. LSJ)	0.50	1.90	2.80	1.3	1.2	0.29–3.15	10.9	2.2
	Mammography	0.25	0.33	0.40	0.2	0.3	0.02–0.6	35.3	0.4
	Abdomen	0.50	1.50	1.80	0.9	0.9	0.11–2.9	27.9	0.8
	Pelvis and hip	0.45	0.90	1.35	0.6	0.7	0.21–2	9.7	1.1
Fluoroscopy	Barium meal	2.60	7.70	15.00	7.2	6.2	0.8–15	18.8	
	Barium enema	6.40	8.60	12.50	8.1	8.5	2.2–25.2	11.5	7.4
	Barium follow-through	4.40	10.00	24.50	5.7	7.2	0.63–24.5	38.9	
	IVU	2.60	4.00	3.50	2.9	2.9	0.43–5.63	13	2.6
	Cardiac angiography	5.30	9.10	11.25	7.2	7.7	3.25–11.25	3.5	11.2
Computed tomography	Head	1.60	2.00	2.40	1.7	1.9	0.28–3.98	14.3	2.4
	Neck	2.40	2.50	2.80	2.8	2.5	0.42–5.38	13	
	Chest	6.60	8.00	8.20	5.5	6.6	2.03–20.4	10	7.8
	Spine	3.60	5.30	6.00	8.3	7.7	2.38–16.3	6.9	5
	Abdomen	10.20	12.00	13.50	10	11.3	2.61–28.7	11	12.4
	Pelvis	8.70	8.70	8.80	6.3	7.3	0.8–14.5	18.1	9.4
	Trunk	10.40	14.00	24.40	20.2	14.8	2.35–50.5	21.5	
Interventional radiology	PTCA	13.15	14.00	17.00	12.9	15.2	4–29	7.3	11.9

B38. The published mean effective dose values from the above studies are compared with the applicable values obtained in UNSCEAR Global Survey in table B19 (projection radiography), table B20 (radiography and fluoroscopy) and table B21 (computed tomography).

Table B19. Comparison of mean effective doses for projection radiography

Data from literature and obtained from UNSCEAR Global Survey (both calculated and submitted values); LSJ: Lumbosacral junction

Examination	*Mean effective dose (mSv)*			
	Current evaluation	*E-60 [V6]*	*E-103 [V6]*	*EC DDM 2 [E5]*
Chest/thorax	0.09	0.07	0.05	0.10
Cervical spine	0.13	0.08	0.05	0.19
Thoracic spine	0.45	0.6	0.5	0.64
Lumbar spine (incl. LSJ)	1.04	1.2	0.8	1.20
Mammography	0.52	0.33	0.64	0.27
Abdomen	0.62	0.92	0.5	0.90
Pelvis and hip	0.49	0.9	0.37	0.71

Table B20. Comparison of mean effective doses (mSv) for radiography and fluoroscopy

Data from literature and obtained from UNSCEAR Global Survey (both calculated and submitted values)

Procedure	*Mean effective dose (mSv)*			
	Current evaluation	*E-60 [V6]*	*E-103 [V6]*	*EC DDM 2 [E5]*
Barium meal	4	3.6	4.5	6.2
Intravenous urography	2.6	3.5	2.1	2.9
Cardiac angiography	7	9.3	8.1	7.7

Table B21. Comparison of the mean effective doses for computed tomography

Data from literature and obtained from UNSCEAR Global Survey (both calculated and submitted values)

Computed tomography examination	*Mean effective dose (mSv)*			
	Current evaluation	*E-60 [V6]*	*E-103 [V6]*	*EC DDM 2 [E5]*
Head	1.7	1.8	1.7	1.9
Neck	2.9	3.2	3	2.5
Chest	7.2	6.7	7	6.6
Spine	14.5	10.3	7	7.7
Abdomen	10.7	8.1	6.8	11.3
Pelvis	8.4	8.3	7.4	7.3
Trunk	15.9	12.2	12.3	14.8

B39. As computed tomography examinations on the average make the highest contribution to the population dose, typical (mean) doses from such examinations deserve high attention. Some recent studies dealing with the typical effective dose of computed tomography examinations are presented in tables B22 to B26. Dougeni et al. [D7] reviewed published literature (after 2000) with the objective of collecting substantial information on effective dose during the most common computed tomography examinations in adult and paediatric patients. This extensive review enables a thorough understanding of the range of effective doses possible in computed tomography examinations. The authors demonstrated immense dose variations, up to 32-fold (table B23), indicating a large potential for dose optimization. Tables B23 and B24 summarize the review by Dougeni et al. [D7].

Table B22. Ranges of effective dose for adult computed tomography examinations [D7]

Computed tomography examination	*Effective dose (mSv)*		
	Minimum	*Maximum*	*Ratio (Max./Min.)*
Head	0.4	7.9	19.8
Chest	1.9	26	13.7
Abdomen	2.4	55.2	23
Pelvis	1.9	36.5	19.2
Lumbar spine	0.8	11.6	14.5
Coronary angiography	1	31.8	31.8
Pulmonary angiography	1.4	19.9	14.2

Table B23. Ranges of effective doses for paediatric computed tomography examinations [D7]

Computed tomography examination	*Effective dose (mSv) per age group*					*Number of references*
	<1 year	*1 year*	*5 years*	*10 years*	*15 years*	
Paediatric head	0.8–14.5	0.3–5.6	0.5–4	0.6–2.8	1–2.2	3–8
Paediatric chest	0.9–23.1	1–7	1.3–21.1	1.8–6.9	1.3–6.4	4–14
Paediatric abdomen	1.9–19	2.3–11.7	2.8–19.3	3.7–19.9	3.3–4.4	3–8
Paediatric abdomen-pelvis	13.1	8.5–19	3–10.4	4.4–14.4	3.1–16.1	1–2
Paediatric pelvis	1.5–8.4	6.7	6	6.4	4.7	1–2
Paediatric chest-abdomen-pelvis	13		1.3–17.2			1–2
Paediatric angiography		1.5–4	1–28	2.6	3	1–3
Paediatric cystic fibrosis			1.5–29.3			1

Table B24. Mean effective dose values for adults computed tomography examinations [D7]

Computed tomography examination		*Mean effective dose (mSv)*	*Range*	*Number of references*
Head		2	0.4–7.9	22
Chest		7.4	1.9–26	21
High resolution		2.7	0.4–5.7	4
Abdomen		10.8	2.4–55.2	23
Thoracic spine			8.2–29.8	1
Cervical		2.2	0.3–4.1	4
Pelvis		8.5	1.9–36.5	12
Chest-abdomen-pelvis		11	8.1–16.6	2
Lumbar spine		6.2	0.8–11.6	10
Computed tomography coronary angiography	Prospective	3.6	0.6–31.8	23
	Retrospective	13.5		
	Calcium scoring	1.8		
Pulmonary angiography		7.6	1.4–19.9	8
Appendix		4.6	4.5–13.3	3
Pancreas		8.4	5.1–14.6	2
Liver-spleen-pancreas		10.1	7.2–13	3
Kidneys		9.4	7.9–11	2

B40. A study by Shrimpton et al. [S14] presented the trend in the United Kingdom in effective dose of computed tomography examinations in three successive patient dose surveys (table B25). The levels of DLP represent typical values for the United Kingdom, derived as mean values of the distributions of mean doses (including tube-current modulation, where applied) from the computed tomography centres participating in the national survey. The coefficients of E/DLP (mSv/(mGy cm)) for examinations on adult patients were calculated as mean values over a range of computed tomography scanner models operating at medium applied potentials (principally 120 kV). The values of E/DLP shown for paediatric head examinations are based on those published previously by Deak et al. [D3] on the basis of E-103 [I11] using a hermaphrodite mathematical phantoms.

B41. Whereas the typical *E* for head examinations on children aged 0–1 year appears to have fallen by over 10% between the two UK surveys (2003 and 2011), estimates for most examinations common to both national reviews have increased in range from 20% (in relation to adult head) to over 400% (for high-resolution examinations of the chest). Such significant increases in *E* are explained in part by underlying increases of 30–160% in the typical values of DLP, and partly from the application between surveys of different sets of coefficients when estimating *E* from values of DLP.

Table B25. Typical effective dose (mSv) estimated for adult and paediatric patients undergoing common computed tomography examinations in the United Kingdom in 2011 together with mean data from previous national surveys for 1989 and 2003 [S14]

DLP: dose-length product; E_{60}: effective dose using ICRP 60 tissue weighting factors; E_{103}: effective dose using ICRP 103 tissue weighting factors H_E: effective dose equivalent

Examination		*1989* [a,b]		*2003* [a,b]			*2011* [b,c]		
		H_E *(mSv)*	E_{60} *(mSv)*	*E/DLP* [d,e] *(mSv/(mGy cm))*	*DLP* [d,f] *(mGy cm)*	E_{60} *(mSv)*	*E/DLP* [d,g] *(mSv/(mGy cm))*	*DLP* [d,f] *(mGy cm)*	E_{103} *(mSv)*
Head		3.5	1.8	0.0021	690	1.5	0.0020	890	1.8
Cervical spine		1.9	2.9	(0.0059)			0.0057	525	3
Chest		9.1	8.3	0.014	400	5.8	0.027	500	14
Chest (high resolution) all				0.014	88	1.2	0.027	230	6.2
Chest (high resolution) axial							0.027	110	3
Chest (high resolution) helical							0.027	360	9.7
CT- angiography				(0.015)			0.024	800	19
CT- pulmonary angiography				(0.015)			0.027	360	9.7
Abdomen		8.8	7.2	0.015	350	5.3	0.024	670	16
Abdomen and pelvis				0.015	470	7.1	0.020	645	13
Virtual colonoscopy				(0.015)			0.020	780	16
Enteroclysis				(0.015)			0.020	580	12
Kidney-ureters-bladder				(0.015)			0.018	355	6.4
Urogenital tract				(0.015)			0.018	960	17
Paediatric head	0–1 year			0.011	230	2.5	0.0069 [h]	315	2.2
	>1–5 years			0.0040	380	1.5	0.0044 [h]	530	2.5
	>5 years			0.0032	510	1.6	0.0027 [h]	750	2

[a] Effective doses refer to the hermaphrodite mathematic MIRD phantom; originally developed at Oak Ridge National Laboratory [C15].
[b] Empty cell indicates no data available.
[c] Effective doses for adults refer to average data for ICRP adult computational reference phantoms [I12].
[d] Values for head and neck relate to measurements of DLP in a small (16 cm diameter) standard CT dosimetry phantom, whereas values for all other procedures relate to a large (32 cm diameter) phantom.
[e] Values in parentheses reflect the general coefficients that would have been applied if these examinations had been included in the 2003 review.
[f] Mean values from distributions of typical doses observed for sample in national survey.
[g] Mean examination-specific coefficients for adult patients.
[h] Values taken from Deak et al. [D3].

B42. The typical effective dose of a computed tomography examination for a given anatomical region can vary much depending on the indication of the examination. A study by Smith-Bindman et al. [S17] indicated two–sevenfold differences and a study by Teeuwisse et al. [T2] three–sixfold differences depending on the type of the computed tomography examination and indication. A few more examples of published typical effective dose values for computed tomography examinations are shown in table B26.

Table B26. Examples of typical effective doses for diagnostic radiology examinations

CT: Computed tomography; CBCT: Cone beam CT; MSCT: Multi-slice CT

<table>
<tr><th>Examination</th><th>Effective dose (mSv)</th><th>Conversion factor used</th><th>Reference</th></tr>
<tr><td rowspan="3">Cardiac CT angiography</td><td>2.7</td><td>0.014 mSv/(mGy·cm)</td><td rowspan="2">[S23]</td></tr>
<tr><td>5.1</td><td>0.026 mSv/(mGy·cm)</td></tr>
<tr><td>9.6</td><td>0.026 mSv/(mGy·cm)[a]</td><td>[C2]</td></tr>
<tr><td>CT by swallowing</td><td>3.9</td><td>0.0066 mSv/(mGy·cm)</td><td>[K12]</td></tr>
<tr><td>C-arm flat panel CT</td><td>0.30±0.08</td><td>0.030–0.035 mSv/(mGy·cm)</td><td>[B3]</td></tr>
<tr><td>Head radiography (sinus and middle ear)</td><td>0.02</td><td></td><td rowspan="5">[D5]</td></tr>
<tr><td>Non-dental CBCT</td><td>0.09 to 0.10</td><td></td></tr>
<tr><td>MSCT for sinus</td><td>0.21 to 0.33</td><td></td></tr>
<tr><td>CBCT for middle ear</td><td>0.19 to 0.4</td><td></td></tr>
<tr><td>MSCT for middle ear</td><td>1.95 to 2.33</td><td></td></tr>
<tr><td>Intraoral radiography</td><td></td><td>0.06–0.07 mSv/(Gy·cm²)</td><td rowspan="2">[H7]</td></tr>
<tr><td>Panoramic radiography</td><td></td><td>0.08 mSv/(Gy·cm²)</td></tr>
</table>

[a] ICRP 103 tissue weighting factors [I11].

V. DISTRIBUTIONS BY AGE AND SEX

A. UNSCEAR Global Survey data

B43. To the UNSCEAR Global Survey, 11 countries submitted data on the distribution of examination frequencies according to the age and sex of patients, mainly in five-year intervals according to the survey template. In general, for population dose evaluations, also in most of the published studies, paediatric examinations are almost always included in the total number of examinations and not evaluated separately although the typical effective doses in paediatric examinations can differ significantly.

B44. The age distributions of examination frequencies for each modality are roughly similar among different countries but the ratios of older to younger patients differ between countries. In particular, in the Philippines, a significantly higher share of the projection radiography examinations is carried out for younger patients than in other countries. In France, the percentage of young adults (about 20 to 40 years) in radiography and fluoroscopy examinations are significantly higher than in other countries. In Brazil and Philippines, a higher percentage of computed tomography examinations seems to be in the younger age groups (i.e. fewer computed tomography examinations of very old patients). Figures B-II to B-IV summarize age distributions of examination frequencies from the UNSCEAR Global Survey.

B45. The difference in the age distributions of frequencies between males and females is not very significant except for projection radiography, where a higher portion of examinations is performed for females aged between 40 and 70 years, mainly due to mammography examinations. For radiography and fluoroscopy with contrast media, examinations of younger adults (<40–60 years) for females are more numerous, while in the older age groups between about 50–80 years, examinations for males outnumber those for females. Figures B-V and B-VI show that the ratio male/female is much higher in Belgium than in Brazil. For computed tomography, the distributions between Brazil and Czech Republic have roughly similar shapes although in Brazil the examinations for females over about 40 years seem to be more numerous, while the reverse is true for the Czech Republic (figure B-VII). Further, the peak in Brazil is on lower age groups (around 60) than in Czech Republic (around 70).

B46. The age and sex distributions of frequencies from the UNSCEAR Global Survey indicate overall similar shapes of the distributions as in few published studies. However, the detailed data from this survey enabled up-to-date verification of typical distributions and the indications of differences.

Figure B-II. Percentage of examinations in each age group from total number of examinations in projection radiography; for 10 countries reporting detailed data to UNSCEAR Global Survey

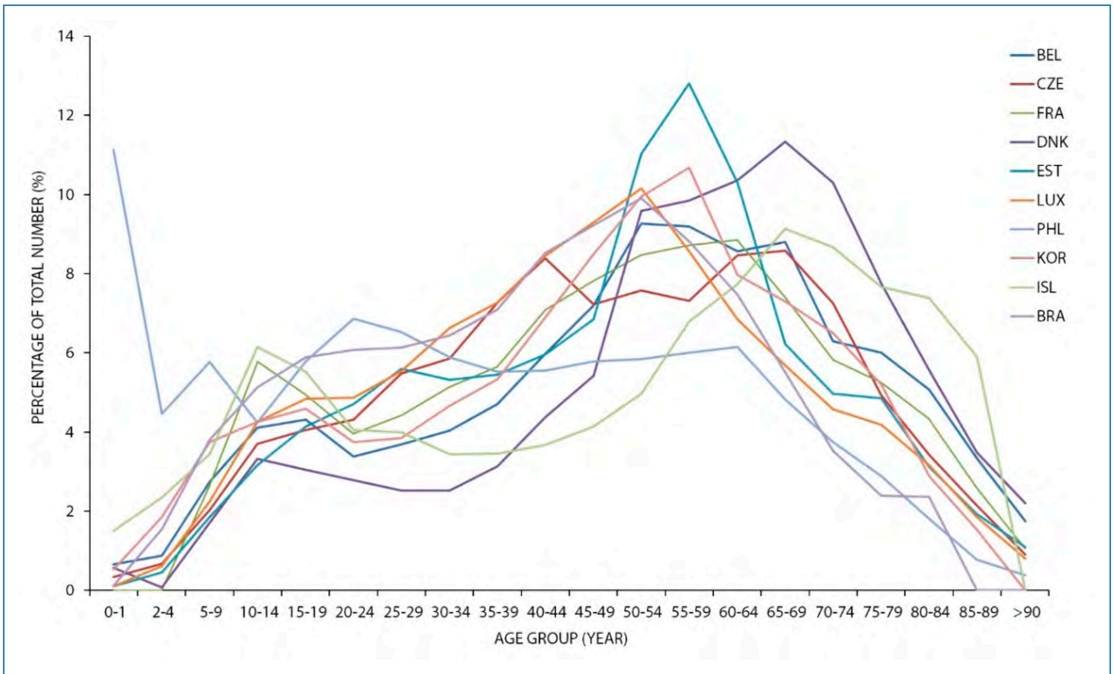


Figure B-III. Percentage of examinations in each age group from total number of examinations in radiography and fluoroscopy; for 10 countries reporting detailed data to UNSCEAR Global Survey

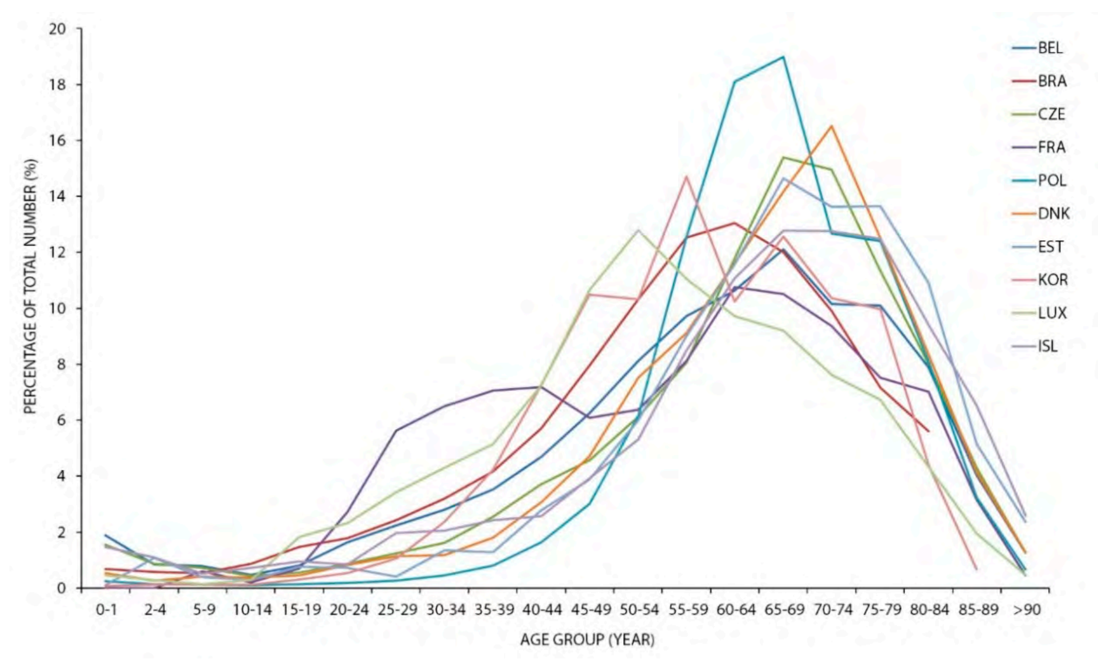


Figure B-IV. Percentage of examinations in each age group from total number of examinations in computed tomography; for 11 countries submitting detailed data to UNSCEAR Global Survey

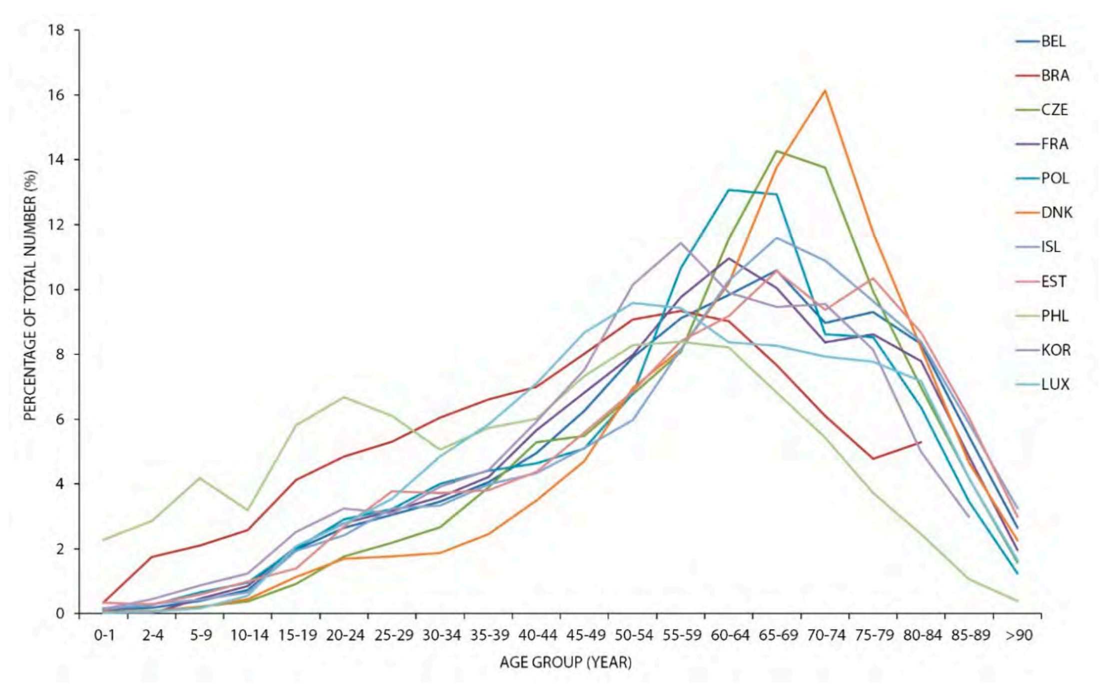


Figure B-V. Age and sex distribution for patients received projection radiography examinations in Belgium and Brazil

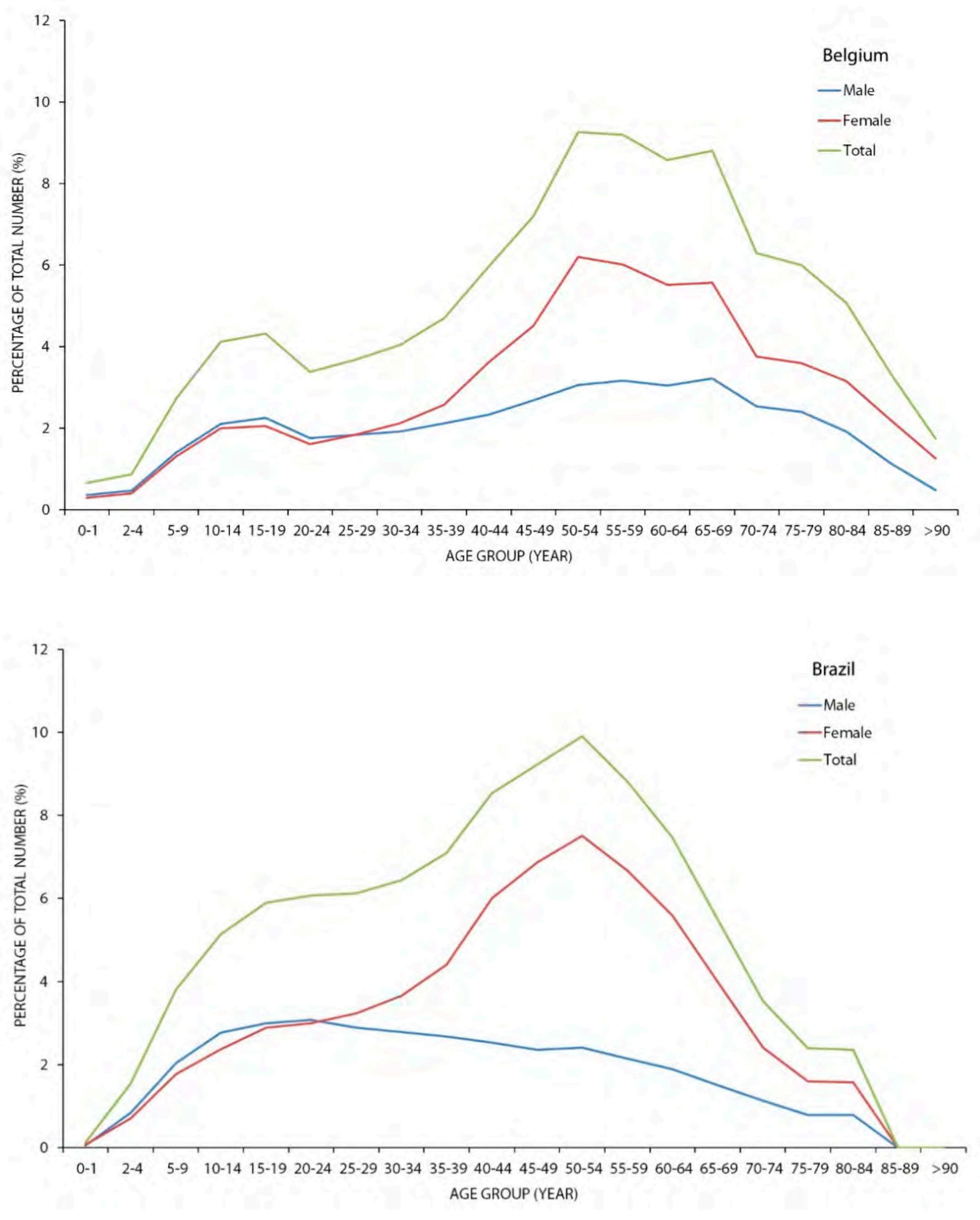


Figure B-VI. Age and sex distribution for patients received radiography and fluoroscopy (with contrast media) examinations in Belgium and Brazil

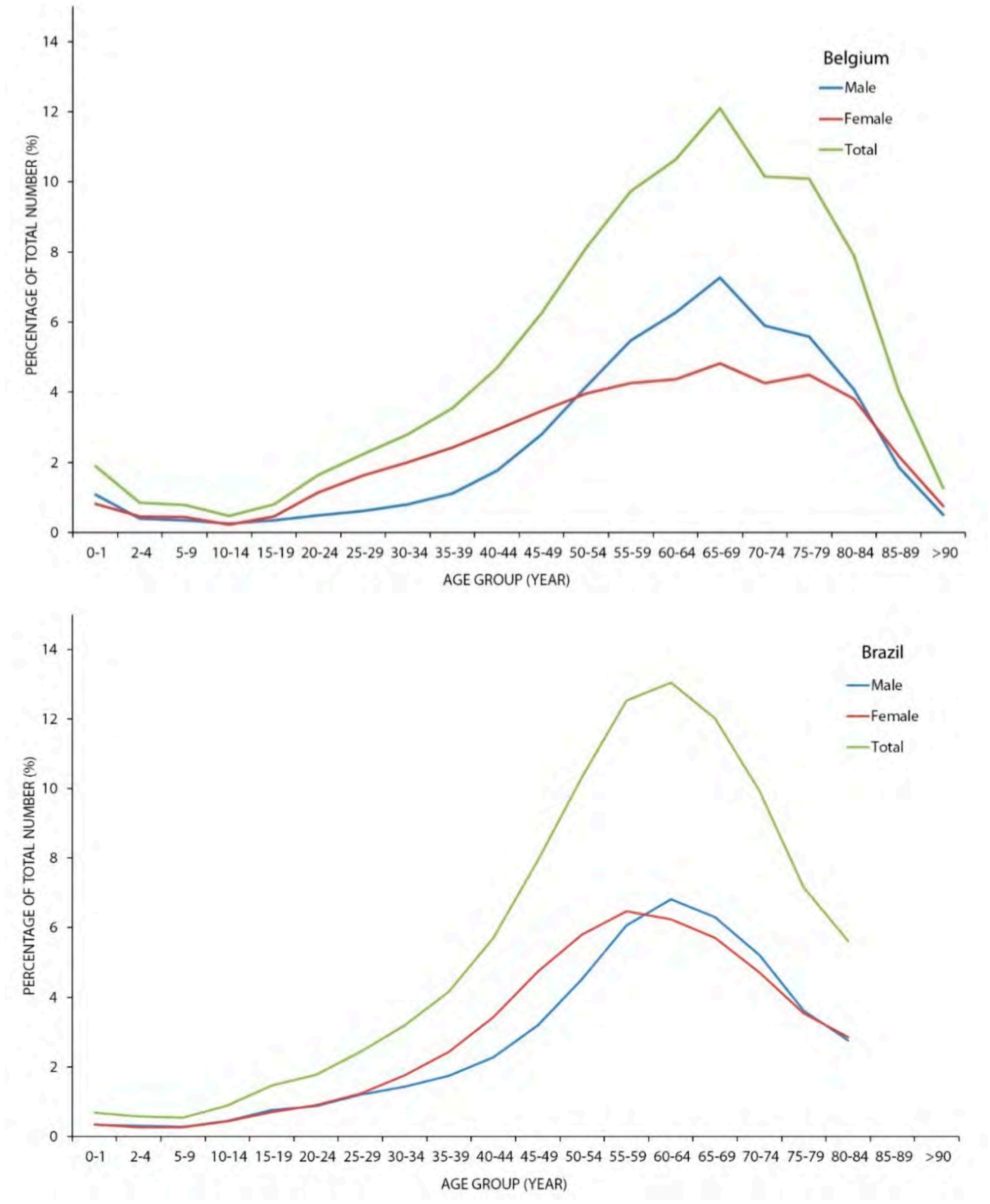
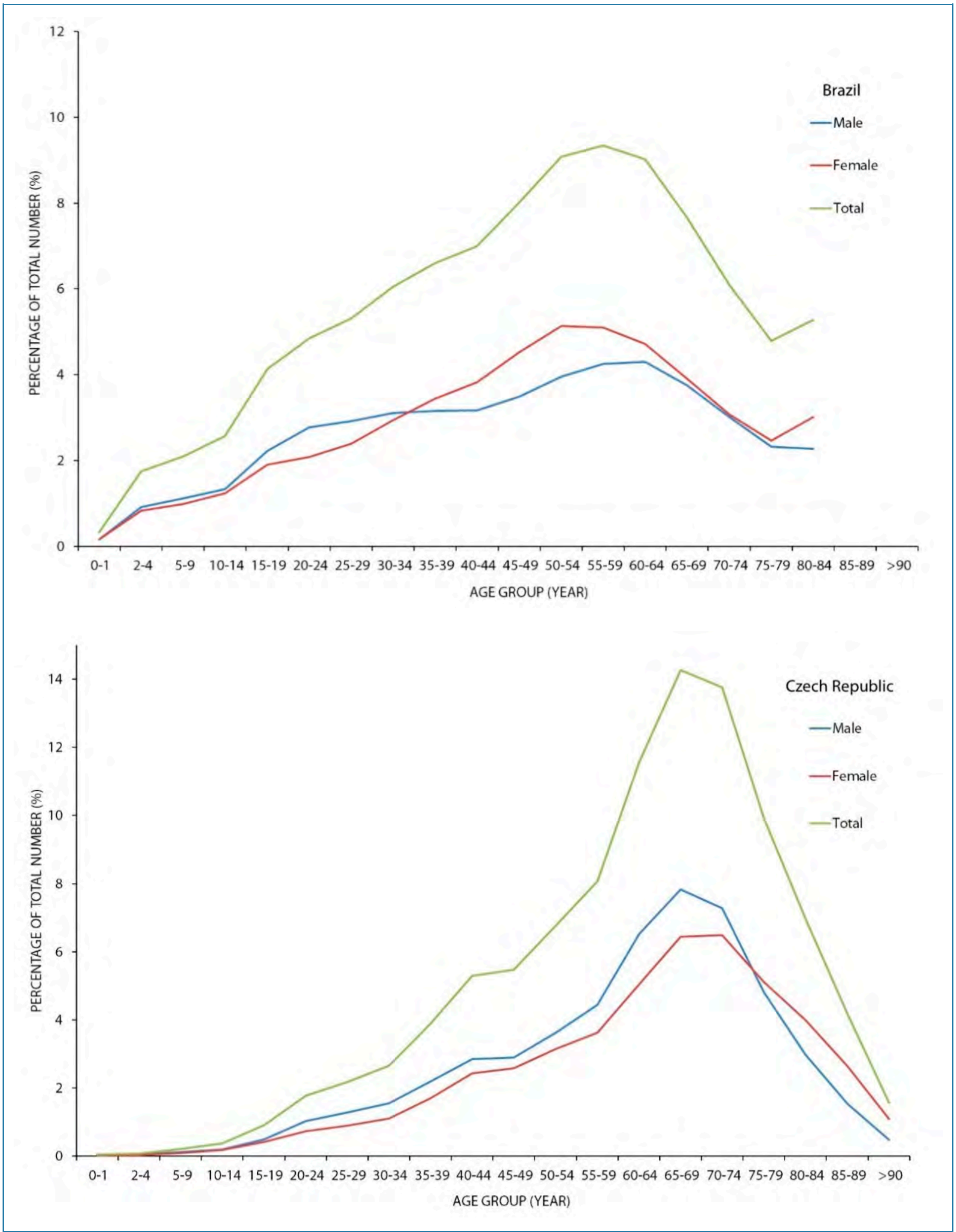


Figure B-VII. Age and sex distribution for patients received computed tomography examinations in Brazil and Czech Republic



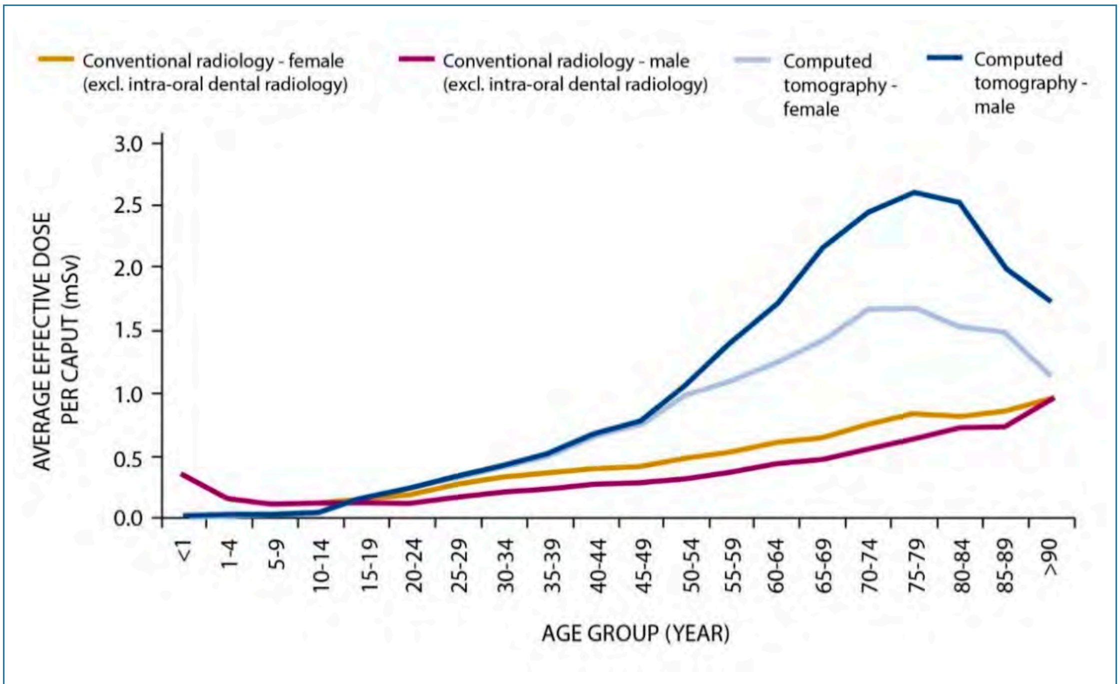
B. Literature review data

B47. Data on frequencies and collective or per caput effective doses as a function of age and sex have not been extensively published. In particular, published data on dose distributions and all paediatric data are sparse. Therefore, the few reported examples are important for this evaluation even though these might not be representative for all cases.

B48. In France, on average, the effective dose to women and men from diagnostic procedures using ionizing radiation was similar, 1.3 mSv per year per caput in 2007 [E10] and 1.6 mSv in 2012 [D10] (table B4), including all ages. In 2007, the distribution of effective dose according to age and sex showed that the average effective dose per caput increased with age and was higher for men; the proportion of exposure due to conventional radiology and to computed tomography differed between women and men (figure B-VIII). The effective dose due to computed tomography was much higher for men aged over 55 due to a higher number of computed tomography examinations performed, especially abdominal and pelvic computed tomography, which contributed significantly to the collective dose.

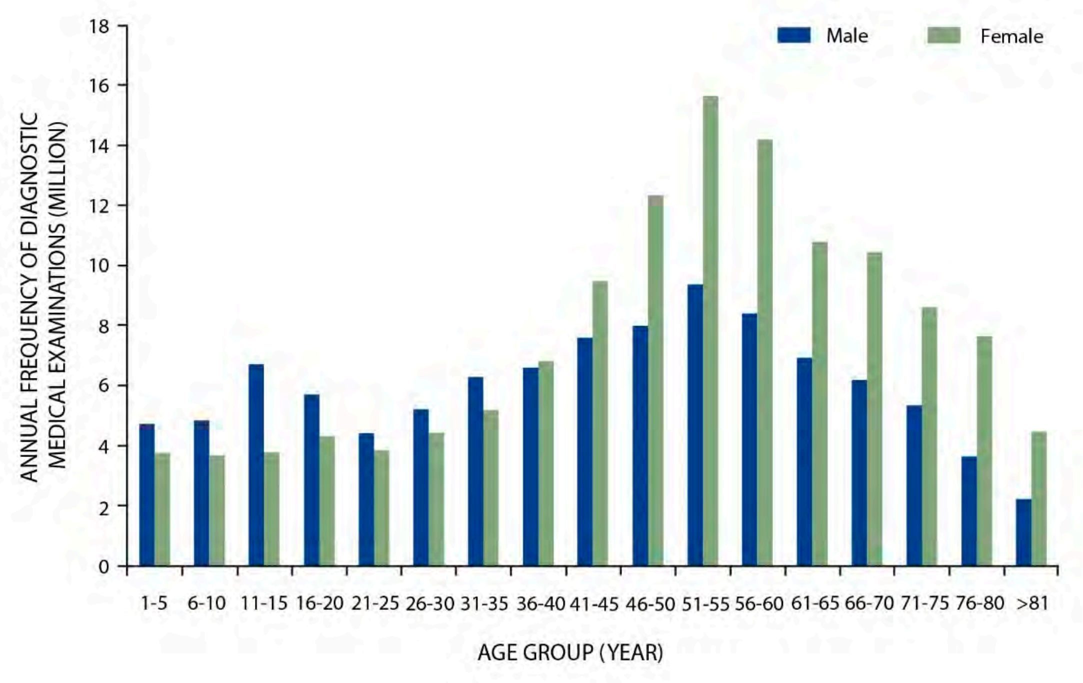
B49. A similar age distribution of frequencies was observed in France in the latest published survey of 2012 [D10]. In 2012, about 44% of the French population had benefited from at least one diagnostic examination using ionizing radiation. This percentage rose from 18% among children less than five years to approximately 60% among adults aged around 70 years. Women were more likely to receive a radiological examination: 49% of the female population underwent at least one examination, whereas only 39% of the male population did. A significant peak could also be observed for children and adolescents aged 10–19 years, who were roughly 10% more likely to undergo a radiological examination than young adults aged 20–29 years.

Figure B-VIII. Distribution of average effective dose per caput from conventional radiology and computed tomography examinations by age and sex in France [E10]



B50. A study in the Republic of Korea [L3] analysed national statistical data gathered during 2006–2013 for seven types of radiography (general radiography, computed tomography, mammography, fluoroscopy, angiography, dental and nuclear medicine; interventional procedures were excluded) for age groups classified by five-year intervals from 1 to 80 years (figure B-IX). The highest frequency of examinations was in the 51–55-year age group for both males (10.8%) and females (9.2%) with a decreasing trend thereafter. The difference in frequencies between male and female patients aged over 41 years can partly be explained by the longer life expectancy of women.

Figure B-IX. Distribution of annual frequency of diagnostic medical examinations by age group and sex in the Republic of Korea in 2013 [L3]



B51. Studies in France on radiation exposure from diagnostic medical procedures of the French paediatric population are of particular interest, because of the general scarcity of paediatric data and because the French studies have been a very comprehensive and systematic effort. The first study from 2010 paediatric data [E11] has recently been repeated for 2015 paediatric data [I20]. All diagnostic imaging procedures using ionizing radiation (conventional radiology, dental radiology and diagnostic interventional radiology, computed tomography and nuclear medicine), performed in 2015 on children aged under 16 years at the time of the procedure, were considered.

B52. The frequency of procedures for children according to the imaging modality and age group in 2015 in France is shown in table B27. About 604 diagnostic procedures were carried out per 1,000 children aged under 16 years, which is relatively stable (+1.5%) compared to the value from 2010. Children aged 11 to 15 years were the most frequently exposed, with 993 procedures per 1,000 children, whereas children aged 1 to 5 years were the least frequently exposed, with 250 procedures per 1,000 children. Conventional radiology and dental radiology accounted for 56 and 41%, respectively, computed tomography for just over 2%, and nuclear medicine and diagnostic interventional radiology for less than 1%. This distribution was substantially equivalent to the distribution in 2010. Girls were exposed slightly more often than boys, for all age groups combined (+1.8%) [I20].

B53. The annual mean effective dose was 135 µSv per child, 25% less compared to that in 2010. Conventional radiology contributed about 53% to this dose or 72 µSv per child, which was a 53 µSv reduction compared with 2010. Computed tomography scans accounted for about 40% of the total dose or 55 µSv per child, which was a slight increase of 7 µSv since 2010. Dental radiology, nuclear medicine and diagnostic interventional radiology together contributed less than 7% or 9 µSv, which was a 2 µSv increase since 2010. The annual mean effective doses of girls and boys were identical.

Table B27. Number of diagnostic examinations per 1,000 paediatric patients according to imaging modalities by sex and age in France [I20]

Modality category	*Number of diagnostic examinations per 1 000 patients (%)*				
	<1 year	*1–5 years*	*6–10 years*	*11–15 years*	*All ages*
Conventional radiology	521 (95.8)	214 (85.5)	288 (48.9)	490 (49.3)	339 (56.2)
Boys	562 (95.1)	224 (85.2)	272 (48.4)	501 (51.6)	343 (57.6)
Girls	476 (96.8)	204 (85.9)	305 (49.5)	478 (47)	336 (54.7)
Dental radiology	0.5 (0.1)	26.7 (10.7)	289 (49.1)	478 (48.1)	249 (41.2)
Boys	0.3 (0.1)	28.8 (11)	278 (49.6)	444 (45.7)	235 (39.6)
Girls	0.6 (0.1)	24.6 (10.4)	300 (48.6)	514 (50.5)	262 (42.8)
Computed tomography	17 (3.2)	7.6 (3.1)	11 (1.8)	24 (2.4)	14 (2.3)
Boys	22 (3.7)	8.2 (3.1)	11 (1.9)	25 (2.5)	15 (2.5)
Girls	12 (2.5)	7 (3)	11 (1.7)	23 (2.2)	13 (2.2)
Nuclear medicine	3.4 (0.6)	1.7 (0.6)	0.8 (0.1)	1.8 (0.2)	1.5 (0.3)
Boys	5.1 (0.9)	1.5 (0.6)	0.8 (0.1)	1.6 (0.2)	1.5 (0.3)
Girls	1.6 (0.3)	1.9 (0.8)	0.9 (0.1)	1.9 (0.2)	1.6 (0.3)
Interventional radiology	1.5 (0.3)	0.2 (0.1)	0.1 (0)	0.1 (0)	0.2 (0)
Boys	1.8 (0.3)	0.3 (0.1)	0.1 (0)	0.1 (0)	0.2 (0)
Girls	1.3 (0.3)	0.1 (0)	0.2 (0)	0.2 (0)	0.2 (0)
All modality categories	543 (100)	250 (100)	588 (100)	993 (100)	604 (100)
Boys	592 (100)	262 (100)	562 (100)	971 (100)	595 (100)
Girls	492 (100)	238 (100)	616 (100)	1 017 (100)	613 (100)

VI. STAFF AND DEVICES

A. UNSCEAR Global Survey data

B54. The numbers of various professionals per million of population submitted to the UNSCEAR Global Survey are presented in table B28, and the numbers of various types of diagnostic radiology systems and devices per million of population in tables B29 to B31.

B55. The data on the numbers of professionals and diagnostic radiological systems and devices generally show large variations between countries. From the total number of diagnostic systems, on average, still more than half (about 56%) are analogue systems. The majority of computed tomography scanners (not including computed tomography scanners used in nuclear medicine and radiation therapy) are multi-slice scanners and, on average, less than 5% are single-slice scanners (excluding dental and cone-beam scanners).

Table B28. Number of professionals per million population working in diagnostic radiology reported to UNSCEAR Global Survey

Country	*Number of professionals per million population* [a]					
	Radiologists	*Dentists*	*Other physicians* [b]	*Medical physicists*	*Radiation technologists*	*Nurses*
Australia	71	874		4.2	470	
Bangladesh		40				
Belgium	136	24	166	4.5		
Brazil	47	408		0.8	4	7.9
Bulgaria	122	1 088	136	2.7	136	
Belarus	125	571	104	15	259	34
Canada	69	592		2.2	51	
Chile	58	1 198				
Cyprus	98	875	11	22	287	
Czech Republic	136	708	38	1.5	241	49
Denmark	105	807		4.4		
Estonia	154	955	163	8.4	293	
Finland	114	802	54	9.1		
France	128	629		1.1		
Germany	81	874				
Greece	313	1 269		8.4	346	92
Hungary	102	611	2 088		66	166
Iceland	96	1 211				

Country	*Number of professionals per million population* [a]					
	Radiolo-gists	*Dentists*	*Other physicians* [b]	*Medical physicists*	*Radiation technologists*	*Nurses*
Iran (Islamic Republic of)	32	206				
Italy		1 009				
Japan	50	823				
Lithuania	126	682	0	14	294	157
Luxembourg	109	862	140	7	421	349
Malaysia	7	221		5.5		
Netherlands		535				
North Macedonia		843				
Norway	154	1 006			709	
Poland	96	1 043			212	
Republic of Korea	65	336	258		417	106
Romania	88	727		1.5		98
Russian Federation	111	250		1.9	218	
San Marino	367	1 072	551	0	459	674
Saudi Arabia		439				
Slovenia	100	656		2	244	
Spain	95	668		5.6	187	31
Sweden	260	780		15		550
Switzerland	102	501	310	3	380	4 751
Thailand	28	251		0.7	27	2.4
United Arab Emirates	306	557	259	20	710	27
United Kingdom	70	616		96	375	13
United States	85	606	10		240	35
Uruguay						

[a] Zero values are indicated when available; otherwise, cells have been kept empty.

[b] Other physicians conducting radiological examinations.

Table B29. Number of diagnostic radiology systems per million population reported to UNSCEAR Global Survey

Country	*Number of diagnostic radiology systems per million population* [a] *(% digital system)*						
	Total [b]	*Radio-graphy*	*Fluoro-scopy*	*Mammo-graphy*	*Dental*	*Angio-graphy*	*Densi-tometry*
Argentina	295	167		19	89	8.3	12
Australia	951	113	76	27	640		21
Belgium	1 502	342	2.6	45	1 064	16	31
Bangladesh	38				3.1		

Country	*Number of diagnostic radiology systems per million population*[a] *(% digital system)*						
	Total[b]	*Radio-graphy*	*Fluoro-scopy*	*Mammo-graphy*	*Dental*	*Angio-graphy*	*Densi-tometry*
Brazil	388	110	7.2	27	230	4.1	11
Bulgaria	141 (16)	92 (30)	92 (27)	28 (29)	93 (55)	8.7 (100)	6.4
Belarus	193 (33)	30 (45)	57 (19)	5.3 (80)	38 (21)	3.5 (100)	0.9 (100)
Canada	1 777				1 424		
Chile	115						
China	45	35 (11)		1.3 (19)	4.9	1	
Cyprus	769 (10)	117 (9)	48 (11)	42 (25)	483 (0)	7.4 (86)	38 (100)
Czech Republic	1 016 (51)	110 (60)	37	12 (81)	653 (43)	12 (100)	9.7
Denmark	1 387	967	78	17	1 171	4.4	18
Estonia	900 (74)	109 (69)	11 (93)	12 (88)	661 (71)	8.4 (100)	7.6 (100)
Finland	1 385	172	5.3	30	1107	17	11
France				35 (83)			
Germany	1 626				1 179		
Greece	1 000 (10)	84 (4)	2.3 (8)	59 (26)	699 (0)	11 (100)	55 (100)
Hungary	530				428		
Iceland	1 383	157	61	15	1 115	23 (100)	12
Indonesia	32 (64)	0			22		
Iran (Islamic Republic)	77	58		7.6		2.6	
Iraq	81				16		
Italy	1 816				660		
Japan					630		
Lithuania	734	131	35	15	565	8	7.6
Luxembourg	1 422 (7)	104 (53)	63 (8)	12 (100)	1 220	18 (100)	1.8 (100)
Malaysia	92	73 (23)	5.8 (14)	7.6 (32)	5.1 (3.9)	5.1 (77)	3.7
Niger	4.4				4.1		
Netherlands	129						
Norway	928	70	78	15	662	18	10
Philippines	65 (43)	32 (30)	10 (40)	4.4 (36)	5.6 (36)	0.4 (0)	0.4 (0)
Poland	515	91	28	15	345	9.8	8.1
Republic of Korea	564	564	187	63	662		136
Romania	231	59	36	12	109	4.6	10
Russian Federation	250	148 (21)	14 (38)	19 (29)	38 (28)	3.2 (100)	1.5 (100)
Saudi Arabia	142						
San Marino[c]	1 378	765 532	6 124	218 942	919	919	96 151

Country	*Number of diagnostic radiology systems per million population[a] (% digital system)*						
	Total[b]	*Radio-graphy*	*Fluoro-scopy*	*Mammo-graphy*	*Dental*	*Angio-graphy*	*Densi-tometry*
Slovenia	395	78 (27)	40 (83)	19 (53)	212 (62)	8.3 (65)	22
Spain	972	76	23	14	828	5.4	5.3
Sudan	19			0.3 (60)			
Sweden	1 500	59	52	18	1 200	12	8.5
Switzerland	2 222	496	207	29 (100)	1 428		24
Thailand	276	97 (66)	28 (100)	6.9 (100)	124	3.6 (100)	3.5 (100)
United Arab Emirates	1 205	283 (77)	69 (81)	40 (74)	530 (84)	28 (63)	34 (78)
United Kingdom					544 (20)		
United States	2 058	52	25	47	1 757	8.9	36
Uruguay	217	71	21	23	175	6.4	2.3

[a] Zero values are indicated when available; otherwise, cells have been kept empty.
[b] Values as reported; may not equal sum of all categories.
[c] Only digital systems.

Table B30. Image processing systems per million population reported to UNSCEAR Global Survey

Country	*Number of image processing systems per million population[a]*		
	Chemical development systems	*Computed radiography digital systems*	*Total (Contribution of digital system (%))*
Bulgaria	71	86	157 (55)
Belarus	150	81	231 (35)
China	27	4.3	31.3 (14)
Cyprus	525	53	578 (10)
Czech Republic	188	237	425 (56)
Estonia		54	54 (100)
Luxembourg	0	14	14 (100)
Malaysia	17.7	0.5	18.2 (3)
Philippines	0.2	0.2	0.4 (57)
Russian Federation	61	1.6	62.6 (2.5)
San Marino		1 378	1 378 (100)
Slovenia	98	61	159 (38)
Spain	4.3	43	47.3 (91)
United Arab Emirates	5.3	95	103.3 (95)
United States		27	27 (100)

[a] Zero values are indicated when available; otherwise, cells have been kept empty.

Table B31. Computed tomography scanners per million population reported to UNSCEAR Global Survey

CT: Computed tomography (excluding scanners used in nuclear medicine or radiation therapy departments)

Country	*Scanners per million population* [a]					
	Total [b]	*Single-slice CT*	*Multi-slice CT*	*Dual source CT*	*Dental CT*	*Cone beam CT*
Argentina	21.2					
Australia	43.3					
Bangladesh	2.8					
Belgium	22.6	0	22.6	2.1	17.3	2.9
Brazil	20.9				0.6	
Bulgaria	32.7	0.7	32.1	0.1	1.1	0.4
Belarus	9.1		8.2	0.8		0.4
Canada	15.3	0.24	12.2	3.8		
Chile	17.3					
China	5.8					
Cyprus	33.6	0	30.5	0	0	3.2
Czech Republic	38.5	0	21.9	0.5	15.1	1
Denmark	23.3		23.3		17.5	1.2
Estonia	19.8		13.7	3.8	15.2	
Finland	22.1	1.8	20.2			2
France	16.2	0	16.2			
Germany	33.3					
Greece	38.1	10.4	23.2	1.3	3.2	
Hungary	12.2					
Iceland	49.5		49.5			11.7
Indonesia	8.4		0			
Iran (Islamic Republic of)	7	3.6				
Iraq	6.2					
Italy	33.2					
Japan	103.2		76.9		128.8	
Lithuania	21.8	0.7	20.4	1.4	0.4	25.6
Luxembourg	17.6	0	12.3	3.5	0	1.8
Malaysia	8.5					
Niger	0.2					
Netherlands	13.6					
Norway	32.1				13	

Country	*Scanners per million population* [a]					
	Total [b]	*Single-slice CT*	*Multi-slice CT*	*Dual source CT*	*Dental CT*	*Cone beam CT*
Poland	18.7					
Republic of Korea	37				171.8	0.3
Romania	15.4	0.8	12.8	1.1	0.7	
Russian Federation	12.3	0.5	10.9	0	5.2	
Saudi Arabia	9.5					
San Marino	91.9		30.6			61.2
Slovenia	15.1	0	12.2	2	6.8	
Spain	16.9	0	15.9		1	0.1
Sudan	1.1		1.1			
Sweden	21		23.5	3	17	1.5
Switzerland	38.7					57.3
Thailand	22.7		10.9	0.2	9.5	2.1
United Arab Emirates	25.6	0.5	7.8	0.4	1.7	0.9
United Kingdom	7.7				14.5	
United States	41.9	0	41.9			
Uruguay	17.4					

[a] Zero values are indicated when available; otherwise, cells have been kept empty.
[b] Values as reported; may not equal sum of all categories.

B. Literature review data

B56. A survey involving 93 countries on the global perspective of the medical physics workforce performed for the International Organization for Medical Physics (IOMP) reported by Tsapaki et al. [T9] a total of 29,179 medical physicists, of whom 8,702 were females (30%) and 20,477 males (70%). The geographical distribution of medical physicists is presented in table B32, indicating a need for more medical physicists, especially in Latin America, the Caribbean and Africa.

Table B32. Global medical physicist workforce for various geographical regions compared to population size in 2017 [T9]

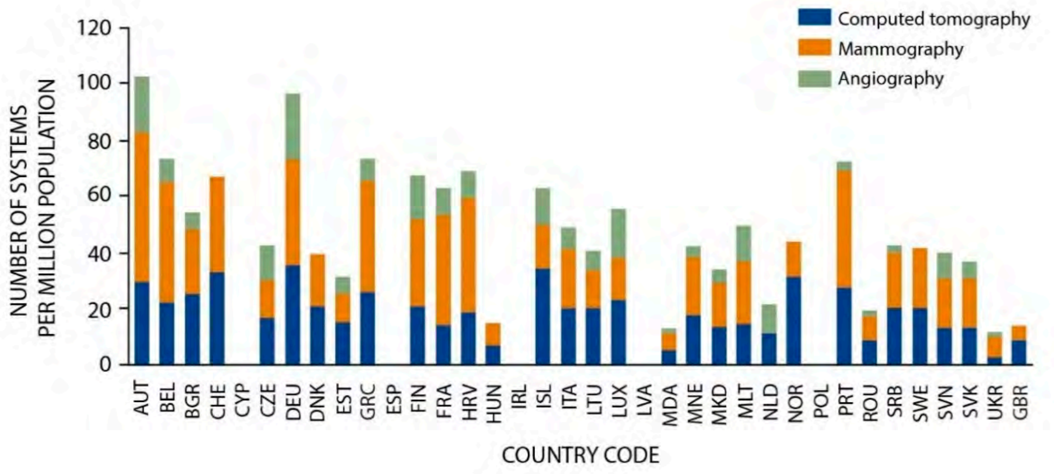
Geographical region	*Total*	*Population* [a]	*Medical physicists per million population*
Africa	697	1 287 920 518	0.5
Asia (with Middle East)/Oceania	7 589	4 586 394 306	1.7
Europe	10 062	742 264 801	13.5
Latin America/Caribbean	1 256	652 012 001	1.9
North America	9 575	363 844 490	26.3

[a] World population in 2017 [W11].

B57. The numbers of devices were surveyed in the EC DDM 2 project [E5]. The numbers of computed tomography, mammography and angiography devices are shown in figure B-X.

Figure B-X. Number of specific imaging devices per million population in European countries [E5]

Countries with no numbers did not reply to the questionnaire



B58. The European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry regularly published age and density data (number of systems in use per million population) of computed tomography and angiography equipment (besides magnetic resonance imaging and molecular positron emission tomography equipment). Figure B-XI shows the density profiles for computed tomography systems in 2015 [C11]. The report also highlighted the dramatic deterioration in the age of the installed base of medical imaging systems, for example about 3,000 units, approximately a quarter of the computed tomography systems installed in Europe, were technically incompatible with radiation dose-saving software upgrades [C11].

Figure B-XI. Density of computed tomography equipment in Europe in 2015 (number of systems in use per million population) [C11]

VII. TRENDS

B59. By 2009, the average annual per caput effective dose from medicine worldwide (about 0.6 mSv of the total 3.0 mSv was received from all sources) had approximately doubled in the previous 10–15 years [M10, U9]. Since then, in the countries involved in the UNSCEAR Global Survey and literature review, the trend of increasing collective effective dose, or per caput effective dose, has continued on average while the increase is less notable than during the previous decade. The increase is due mainly to continued increasing use of high dose procedures, particularly in computed tomography, but also to some interventional radiology and nuclear medicine in some large countries (the United States in particular). For computed tomography, it has been shown that the observed rise in use cannot be attributed primarily to the growth and ageing of the population [B17]. On the other hand, despite the increased use of computed tomography, the increase of collective effective dose from computed tomography has been slowed down in some cases due to the significant development of dose-saving technology. At the same time, the frequencies and the per caput effective dose of some conventional radiography or fluoroscopy procedures have been decreasing. For diagnostic radiology examinations, these general findings are supported by the results of the UNSCEAR Global Survey and several published reports as shown below.

A. UNSCEAR Global Survey data

B60. The frequencies per 1,000 population from the current survey have been compared with the data from the UNSCEAR 2008 Report [U9] in tables B33 and B34, where the percentage changes between the two data sets have been reported for all countries that submitted data to both UNSCEAR surveys. The mean changes and the population-weighted mean changes are presented in the tables. Similarly, the typical (mean) effective doses from the current survey have been compared with the data from the UNSCEAR 2008 Report [U9] in tables B35 and B36.

B61. Table B33 indicates that, except for mammography, pelvis and dental examinations, the frequencies of projection radiography examinations have decreased on average in the past decade. The average decrease is most noticeable for head and neck, chest (thoracic spine) and lumbar spine examinations. Except for coronary angiography, radiography and fluoroscopy examinations have also decreased on average in the past decade. The average decrease is most remarkable for gastrointestinal tract (barium studies) and biliary tract (cholecystography). Table B34 also shows that the frequencies of computed tomography examinations on average have continued to increase in the past decade. The overall effect is that the total frequency of examinations of diagnostic radiology and interventional radiology has remained nearly the same, while the increase for dental examinations is around 100%.

B62. Tables B35 and B36 suggest that the typical (mean) effective doses have generally decreased during the past decade, although the notable increases in a few large countries (e.g., Australia, Belgium, Germany, and the United Kingdom) for some projection radiography examinations, or the shortage of data in other cases (e.g., screening mammography, dental panoramic and computed tomography pelvis examinations), results in increased average doses for some types of projection radiography and computed tomography examinations. For radiography and fluoroscopy examinations, a decrease in typical effective dose is more evident as the data for almost all countries showed a decreasing trend.

B63. The data published in the UNSCEAR 2008 Report [U9] do not enable comparison of the contributions of frequencies to the total frequency on a country level between the 2008 data and the present data. However, the summary data for HCL I can be compared as shown in table B37. While this comparison suffers from the non-equivalence of the countries included in both data sets, the results highly suggest that the contributions of all radiography and fluoroscopy (without dental) to the total has somewhat decreased while that of dental, computed tomography and interventional radiology examinations, and also coronary angiography, have increased dramatically.

Table B33. Comparison of frequency data for projection radiography examinations between UNSCEAR 2008 Report [U9] and UNSCEAR Global Survey for countries reported to both evaluations

Changes are expressed in percentage of frequencies per 1,000 population. Mean values and population-weighted mean values have been calculated for countries reported them; due to some exceptionally high values, also median values have been calculated

Country	*Projection radiography changes[a] (%)*											
	Head (skull, facial bones and soft tissue)	*Neck (cervical spine)*	*Chest-thorax*	*Chest (thoracic spine)*	*Mammo-graphy*	*Mammo-graphy (screening)*	*Lumbar spine*	*Abdomen*	*Pelvis and hips (bone and soft tissue)*	*Limbs and joints*	*Dental intraoral*	*Dental panoramic*
Australia	−7	0.9	−36	−81	46	5	−52	4.5	54	18		
Belgium	−85	−83	−5	−77	0.5	481	−72	−51	−13	−16		
Bulgaria	−1.8	91	69	−5.4	109	193	22	51	103	33	94	1 139
Czech Republic	26	56	114	970	−58		−8.7	106	98	84	106	227
Finland	−71	−100	−17	−33	0.3	68	−22	−48	−1	−18	−5.8	21
France	−60		66						11	−11	51	5.8
Germany	−22	−44		−38			18	−38	−24			
Greece	−53		−48		238		−53		−35	−43		1 770
Iceland	−69	−64	−6.1	−38		6.2	−55	−21	364	−5.2		
Japan					208						−15	28
Lithuania			78			40						
Luxembourg	−70	−30		−23	11	25	−39	−35	0.9	0.5	51	98
Netherlands			−28		35	32					−96	−80
Norway		−55	−17	−40	−85			−14	−28		172	123
Republic of Korea	31	128	121	−35			180	139	175			
Romania	−45	18	95	28	397		34	229	54	13	511	9 158
Russian Federation	38	−24	154	−26	268	2 253	−15	49	33	620	129	
Slovenia			−32	−67	55		−56	−2.3	−67			
Spain		−40	−43	−15	108	−34	14	97	126		148	−17

Country	*Projection radiography changes[a] (%)*											
	Head (skull, facial bones and soft tissue)	*Neck (cervical spine)*	*Chest-thorax*	*Chest (thoracic spine)*	*Mammo-graphy*	*Mammo-graphy (screening)*	*Lumbar spine*	*Abdomen*	*Pelvis and hips (bone and soft tissue)*	*Limbs and joints*	*Dental intraoral*	*Dental panoramic*
Sweden	−94	−85	−68	−88	−42	139	−77	−74	−28			
Switzerland	−85	−84	−39	−75	−38		−77	−27	0.6			
United Kingdom	−89	−61	13	−33	65	78	−39	−26	16	−7.9	238	46
Mean change (%)	**−41**	**−24**	**17**	**19**	**77**	**274**	**−17**	**20**	**44**	**56**	**105**	**973**
Population-weighted mean change (%)	**−20**	**−18**	**88**	**−12**	**166**	**1 015**	**6**	**150**	**41**	**246**	**102**	**55**
Median change (%)	**−56**	**−42**	**−17**	**−35**	**46**	**54**	**−39**	**−14**	**11**	**−2**	**94**	**72**

[a] Empty cell indicates no data available.

Table B34. Comparison of frequency data for radiography and fluoroscopy, computed tomography and total frequencies between UNSCEAR 2008 Report [U9] and UNSCEAR Global Survey for selected countries reported to both evaluations

Changes are expressed in percentage of frequency per 1,000 population. Mean values and population-weighted mean values have been calculated for countries reported them; due to some exceptionally high values, also median values have been calculated

IVU: Intravenous urography

Country	*Radiography and fluoroscopy changes (%)* [a]				*Computed tomography changes (%)* [a]			*Total changes (%)* [a]		
	Barium studies	*Biliary tract (cholecysto-graphy)*	*Urogenital tract (IVU, kidney, bladder, urethra)*	*Cardiac angio-graphy*	*Chest (thorax, thoracic spine)*	*Abdomen (lumbar spine, abdomen, liver, pancreas, kidneys)*	*Pelvis (pelvic bones, pelvic soft tissue and vascular)*	*Without dental*	*Only dental*	*With dental*
Australia		143	−0.3	588						
Belgium	−68	−76	−0.8	246	−60	−35		−30		−8.4
Bulgaria	−59	−77	−0.4					35	141	44
Czech Republic	−72		−0.7	−41	275	250	−69	93	124	−49
Finland	−60		−0.8	44		13	777	−2.3	−1.7	−54
France					159	44		5.2	45	−1.9
Germany	−76		−0.5	23	37	33	48	−11	−17	−25
Greece	−95			−44	20	102	−97			
Iceland	−46		−0.7	−21	395	198	532	14		
Japan								−87	−7.9	
Lithuania									1 065	
Luxembourg	−68	66	−0.8	24	148	199		7.3	17	10
Netherlands					72			13	−95	−27
Norway	−67		−0.8		106	82	99	−42	167	32
Republic of Korea					950	883		378		
Romania	−87		−0.9	66	−5.6			−2.1	904	26
Russian Federation	−56		−0.8	1 392	1 696	784		49	116	55

Country	*Radiography and fluoroscopy changes (%)* [a]				*Computed tomography changes (%)* [a]			*Total changes (%)* [a]		
	Barium studies	*Biliary tract (cholecysto-graphy)*	*Urogenital tract (IVU, kidney, bladder, urethra)*	*Cardiac angio-graphy*	*Chest (thorax, thoracic spine)*	*Abdomen (lumbar spine, abdomen, liver, pancreas, kidneys)*	*Pelvis (pelvic bones, pelvic soft tissue and vascular)*	*Without dental*	*Only dental*	*With dental*
Slovenia				322	−37	−41				
Spain	−71			102	147	103	172	−23	109	−7.5
Sweden	−84				131	215	101	−29		
Switzerland	−78			140	145	66	−59	−55		−73
United Kingdom	−73	−98	−0.9	−15	−0.9	−7.6		4.7		61
Mean change (%)	**−73**	**−8**	**−0.7**	**202**	**246**	**181**	**167**	**18**	**197**	**−1**
Population-weighted mean change (%)	**−124**	**−41**	**−0.7**	**104**	**195**	**338**	**87**	**22**	**96**	**17**
Median change (%)	**−72**	**−76**	**−0.8**	**55**	**130**	**92**	**99**	**1**	**109**	**−5**

[a] Empty cell indicates no data available.

Table B35. Comparison of typical mean effective doses (mSv) for selected main projection radiography examination between data from UNSCEAR 2008 Report [U9] and UNSCEAR Global Survey

Changes are expressed as a percentage of the effective dose from the UNSCEAR 2008 Report [U9]

Country	*Projection radiography changes (%)* [a]											
	Head (skull and facial bones and soft tissue)	*Neck (cervical spine)*	*Chest-thorax*	*Chest (thoracic spine)*	*Mammo-graphy*	*Mammo-graphy (screening)*	*Lumbar spine*	*Abdomen*	*Pelvis and hips (bone and soft tissue)*	*Limbs and joints*	*Dental intraoral*	*Dental panoramic*
Australia	82	169	94	-40		300	68	−44	−38			
Belgium			126				414	−43				
Bulgaria			33									
Czech Republic		-65	−63	−62	−87		−37	−65	−68			
France	18								33	−90	−60	150
Germany	−25	233	173	50	−40		100	−8.3	−20	60	−70	
Norway		−0.4	−39	−31	15		−21	−65	−8.2			
Republic of Korea								76				
Romania	−61	−50	−64	−85	−56		−81	−86	−84	16		
Russian Federation	−29	−38	25		−17	33	−16	−11	−60	−90	−50	
Spain	−10	−65	−48	−20	−32	−63	−24	−35	−28			
Sweden			−54				−39		4.7			
Switzerland	−80	−33	−14	−68			−39	−62	−50			
United Kingdom	157	73		−42			−28	61	6.7			
Mean (%)	**6.5**	**25**	**15**	**−37**	**−36**	**90**	**27**	**−26**	**−28**	**−26**	**−60**	**150**
Population-weighted mean (%)	**29**	**42**	**45**	**−14**	**−30**	**42**	**14.8**	**−1.7**	**−26**	**−44**	**−58**	**150**

[a] Empty cell indicates no data available.

Table B36. Comparison of typical (mean) effective doses for selected radiography and fluoroscopy examinations and for computed tomography examinations between data from UNSCEAR 2008 Report [U9] and UNSCEAR Global Survey

Changes are expressed as a percentage of the effective dose from the UNSCEAR 2008 Report [U9]

IVU: Intravenous urography

Country	*Radiography and fluoroscopy changes (%)* [a]			*Computed tomography changes (%)* [a]		
	Barium studies	*Urogenital tract (IVU, kidney, bladder and urethra)*	*Cardiac angiography*	*Chest (thorax, thoracic spine)*	*Abdomen (lumbar spine, abdomen, liver, pancreas, kidneys)*	*Pelvis (pelvic bones, pelvic soft tissue and vascular)*
Australia				−51.8	−59.5	
Belgium				−11.1	−37.9	
Czech Republic		−43.4		−40.8	2.6	−13.2
France				55.2	58.3	
Germany	33.3			−5.2	1.4	
Greece				26.4	100	
Iceland			−80.7			
Norway			−18.3	−59.2	−25	
Republic of Korea					−4.3	
Romania	−84.3	−86.7				
Spain	−10.4			3.9	23.5	60.4
Sweden	−88.7	−77.8		−46.7	−37.9	
Switzerland	−70.4	−58.5	−41.2	−65.	−42.1	
United Kingdom	-74.1	3.5	−28.3	−12	20.3	
Mean (%)	**−48.6**	**−52.6**	**−42.1**	**−18.7**	**−0.05**	**23.6**
Population-weighted mean (%)	**−24.3**	**−28**	**−27.5**	**−0.6**	**11.7**	**46.9**

[a] Empty cell indicates no data available.

Table B37. Comparison of frequency contributions between UNSCEAR Global Survey and UNSCEAR 2008 Report [U9]

Data are HCL I and the world for selected imaging modalities; HCL: Health-care level

Modality category	*Contribution to total frequencies (%)*				
	Current evaluation	*UNSCEAR 2008 [U9]*		*Difference*	
		HCL I	*World*	*HCL I*	*World*
All radiography and fluoroscopy (without dental examinations)	62.5	74.3	80.7	−18.9	−29.1
Dental radiology	23.5	17	13.4	27.7	43
Computed tomography	13.1	8	6.3	39.1	52.1
Interventional radiology	0.9	0.2	0.1	76.6	88.3
Cardiac angiography	0.5	0.1	0.5	80.4	2.2

B. Literature review data

B64. The EC DDM 2 project [E5] provided the possibility to compare trends in medical exposure in Europe because in the earlier EC DDM 1 project [E3], collective effective doses were also surveyed for 10 European countries. Table B38 compares the trend for frequencies for the TOP 20 methodology. It can be seen that for several groups of plain radiography and fluoroscopy, the average frequency for EC DDM 1 countries in 2015 [E5] is lower than the average for all 36 countries, while for coronary angiography, PTCA and most computed tomography groups, the reverse is true. In the EC DDM 1 countries, the average frequencies for several groups of plain radiography and fluoroscopy have decreased significantly from the results of an earlier study in 2008 [E3], while the frequencies for the coronary angiography, PTCA and the computed tomography category have increased significantly, in some cases more than doubled (for CT trunk about threefold increase). Comparison of the results of the EC DDM 2 project with the UNSCEAR 2008 Report [U9] shows that frequencies for most conventional examinations in the survey are lower than in the UNSCEAR data for HCL I countries, while the frequencies for some more complex examinations (e.g., coronary angiography and PTCA) are higher. These differences reflect the fact that the UNSCEAR 2008 Report [U9] are global and generally older than the data of the EC DDM 2 project.

B65. Because the examinations with increased frequencies (coronary angiography, PTCA and all CT) represent the high-dose procedures, the net effect is that the population dose seems to have increased in the EC DDM 1 countries (table B39), where the corresponding trend in per caput effective dose is presented. As only data from France, Germany, Switzerland and United Kingdom were based on complete reported overall frequencies and data from other countries were based on a rough estimation (TOP 20 methodology), no strict conclusions about the trends can be drawn. However, there seems to be an upward trend which could be anticipated from the increased frequencies, in particular for computed tomography examinations, because the typical effective dose for these countries has not significantly decreased.

Table B38. Comparison of averaged frequencies per 1,000 population obtained from EC DDM 2 [E5], EC DDM 1 [E3] projects and UNSCEAR 2008 Report [U9]

CT: Computed tomography; LSJ: Lumbosacral junction; PTCA Percutaneous transluminal coronary angioplasty

Examination	*Frequency per 1 000 population* [a,b]			
	Average 36 EC DDM 2 countries [E5]	*Average 10 EC DDM 1 countries [E5]*	*Average 10 EC DDM 1 countries [E3]*	*Average UNSCEAR HCL I countries [U9]*
Chest/thorax	194	151	177	168
Cervical spine	26	17	26	32
Thoracic spine	17.5	9.8	15	16
Lumbar spine (incl. LSJ)	39.5	33.6	38.2	31
Mammography	63.3	69	58.2	43
Abdomen	22.5	18.4	21.4	45
Pelvis and hip	48.7	59.4	59.3	40
Barium meal	3.8	1.5	3.6	
Barium enema	2.6	1.6	4.7	9.3
Barium follow-through	1.2	0.7	1.1	
Intravenous urography	2.8	2.3	7	8.5
Coronary angiography	4.2	5.6	5.4	1.5
CT-head	26.9	31.9	26.3	40
CT-neck	3.9	6.2	2.9	
CT-chest	12.6	17.3	8.9	24
CT-spine	8.4	12.7	10.5	11
CT-abdomen	18.1	28.9	14.4	30
CT-pelvis	4.1	4.8	3.5	19
CT-trunk	9	5.3	1.8	
PTCA	2	2.8	1.2	0.9

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Empty cell indicates no data available.

B66. Besides the EC DDM 1 and EC DDM 2 projects, data on trends in frequencies/population doses have been reported separately by several other countries. In Finland, by 2008, the collective effective dose from X-ray examinations had remained stable over the past decade [B19]. About 50% of the collective effective dose from X-ray examinations was caused by computed tomography in 2005 (in 1997 only 20%) and in 2008 it increased to 58%. In the fluoroscopy category, the barium meal examination was a rare procedure and only the barium swallow examination from the suggested TOP 20 procedures is among the most frequent contrast enhanced radiography procedures in Finland. Instead, more frequent procedures were contrast enhanced fluoroscopy of biliary and pancreatic ducts. However, their contribution to the total TOP 20 collective effective dose is only 1%. The only interventional procedure among the TOP 20 procedures is PTCA while in Finland other procedures, such as nerve root block, have made a remarkable contribution to the dose.

Table B39. Comparison of overall effective doses per caput from EC DDM 1 [E3] and EC DDM 2 [E5]

Values presented for the 10 countries that participated in both projects

Country	*Effective doses per caput (mSv)*		
	EC DDM 1 [E3]	*EC DDM 2 [E5]*	*Ratio EC DDM 2 / EC DDM 1*
Belgium	1.77	1.96	1.11
Denmark	0.46	0.89	1.92
France	0.70	1.25	1.78
Germany	1.66	1.67	1.01
Luxembourg	1.82	1.79	0.98
Netherlands	0.45	0.63	1.39
Norway	1.10	1.25	1.14
Sweden	0.68	0.77	1.14
Switzerland	1.00	1.18	1.18
United Kingdom	0.38	0.39	1.04
Mean	**1.00**	**1.18**	**1.27**

B67. In France, the average number of diagnostic examinations using ionizing radiation was constant between 2002 and 2007 and equal to 1.2 examinations per year per person [E10]. The use of conventional radiology decreased over that period (0.77 examination per year per person in 2002 versus 0.74 in 2007) while use of computed tomography increased (0.10 examination per year per person versus 0.12) as did the use of nuclear medicine (0.013 examination per year per person versus 0.018). Computed tomography was used more in 2007, and a higher percentage of computed tomography was for chest (21% in 2007 versus 12% in 2002) and abdomen-pelvic computed tomography (31% versus 18%) while frequency of head and neck computed tomography decreased (28% versus 37%). This trend led to a significant increase in average effective dose per person between 2002 and 2007: 0.83 mSv per year per person in 2002 to 1.3 mSv per year per person in 2007. This change represents an increment of 57% of the total dose of ionizing radiation delivered to the French population for medical diagnostic purposes. The latest published survey from France [D10] indicated an increase of almost 4% over a decade for all modalities together. This was mainly due to a major rise in dental radiology (40% over the same period) and to a lesser extent to computed tomography (34%). The average individual effective dose increased by 20% between 2007 and 2012, from 1.3 mSv to 1.6 mSv. This increase is much less noteworthy than that of the previous period (57% between 2002 and 2007) and can be mostly explained by an increase of 10% in the number of computed tomography examinations per person between 2007 and 2012; and by a better knowledge of clinical practices and delivered doses, particularly for computed tomography.

B68. In France, a recent study on paediatric medical exposure [I20] indicated very few changes in the frequency of diagnostic procedures in 2015 compared to 2010. The annual mean effective dose, calculated for the whole population as for the exposed population, was significantly lower than in the previous study. The fact that this reduction in children's mean exposure was observed, even though the number of imaging procedures was stable, indicates that the reduction is linked to the decrease in the mean effective dose per procedure. Several explanations related to better techniques and practices could be associated with this reduction too, such as the use of digital image receptors in conventional radiology and iterative reconstruction algorithms in computed tomography, improved awareness of optimization and justification among professionals, increased involvement of medical physicists in radiology and the use of best practice guidelines as requested by European regulations [E4].

B69. In Germany, almost constantly, 1.7 X-ray procedures per person and year were performed in 2007–2014. The frequency of most conventional X-ray examinations decreased during this period (e.g., radiographies of head by 15%, of thorax and spine by 20%, and X-ray examinations of digestive and urogenital tracts by 30%). On the other hand, dental X-ray examinations increased from 0.6 to 0.7 per person. The frequency of computed tomography examinations increased by about 40% from 2007 to 2014. In 2007, computed tomography contributed 6% to frequency and 56% to collective effective dose, while in 2014, the contributions were 8 and 64%, respectively. The doses per computed tomography procedure were only slightly reduced despite various dose reduction approaches established in preceding years. Therefore, the rising computed tomography frequency caused an increase in the total mean dose per person by about 15% between 2007 and 2014 [N3].

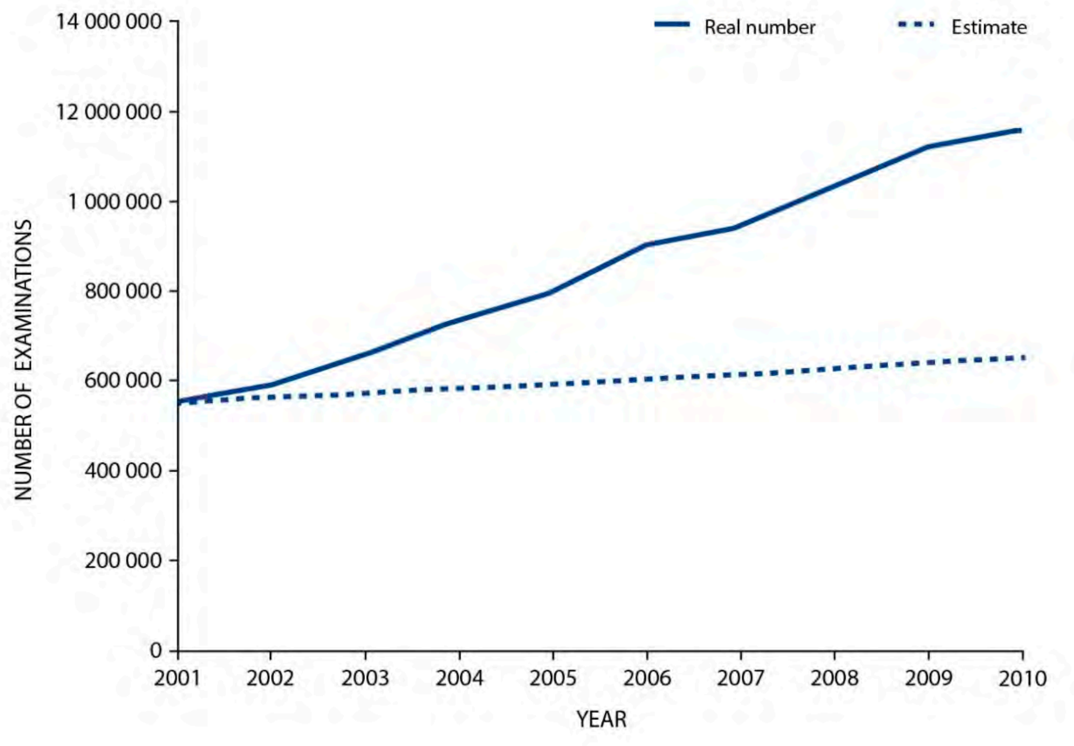
B70. In the Netherlands, besides analysing the trends in per caput effective dose, the trends in population statistics are compared to the trend in the number of computed tomography scans for the period 2001–2011 [B17]. The increase of per caput effective dose is mainly due to both radiology and computed tomography examinations. In 2011, computed tomography with 0.45 mSv and diagnostic radiology with 0.40 mSv made both together 89% of the per caput effective dose (0.95 mSv) [B17]. Further, the collective dose from medical exposure increased by 30% between 2001 and 2011. Routinely collected data on computed tomography examinations in the Netherlands [R8] have been combined with population size and age information available from Statistics Netherlands to show that the observed rise in the use of computed tomography cannot be primarily attributed to the growth and ageing of the Dutch population (figure B-XII). This is a key finding, because population ageing is often assumed to be one of the driving forces behind the increasing (collective) medical radiation exposure. Plausible explanations for the increasing use of computed tomography may include its increased availability and associated technology push, its expanding technical capabilities (e.g., for cardiac imaging), and changes in the attitude of both medical staff and patients towards the deployment of computed tomography for imaging. The latter may involve computed tomography educated medical staff becoming more prone to perform scans, fear of litigation among medical staff leading to precautionary computed tomography.

B71. In Switzerland, a survey showed that the annual effective dose of 1.2 mSv per caput in 2008 increased by 0.2 mSv from its 1998 value [S3]. The frequency of computed tomography examinations continued to increase from 2008 to 2013, leading to a 17% increase in the average annual effective dose per person [L2].

B72. In the United States from 1950 to 2006, the frequency of diagnostic radiological examinations increased almost tenfold [M10] but since then by 2016 the value remained essentially the same even though the population had increased by about 24 million. Using the ICRP Publication 60 [I9] tissue weighting factors, the annual per caput effective dose from diagnostic and interventional medical procedures was estimated to have been 2.9 mSv in 2006 and 2.3 mSv in 2016 [M11, N2]. The largest contributions to the per caput effective dose came primarily from computed tomography and nuclear medicine [M9, M11, N1, N2].

Figure B-XII. Observed and estimated trends in numbers of computed tomography examinations for Dutch population

Estimated trend follows from number of examinations in 2001, change in population size, and change in age distribution of population [B17]



B73. In Australia, trend analysis (1999–2004–2010) indicated increasing trend of per caput effective dose, mainly caused by an increase in computed tomography examinations by about 7.2% per year [H6]. Trends in the collective effective dose were not directly proportional to frequency and so cannot be estimated on the basis of frequency alone. Studies on the trends of paediatric computed tomography in Australia [B27, B28] have shown significant increase in paediatric computed tomography imaging frequency (average annual increase of 5.1%) until about 2000. Since then, the increase in paediatric computed tomography frequency has slowed overall or in some cases even declined.

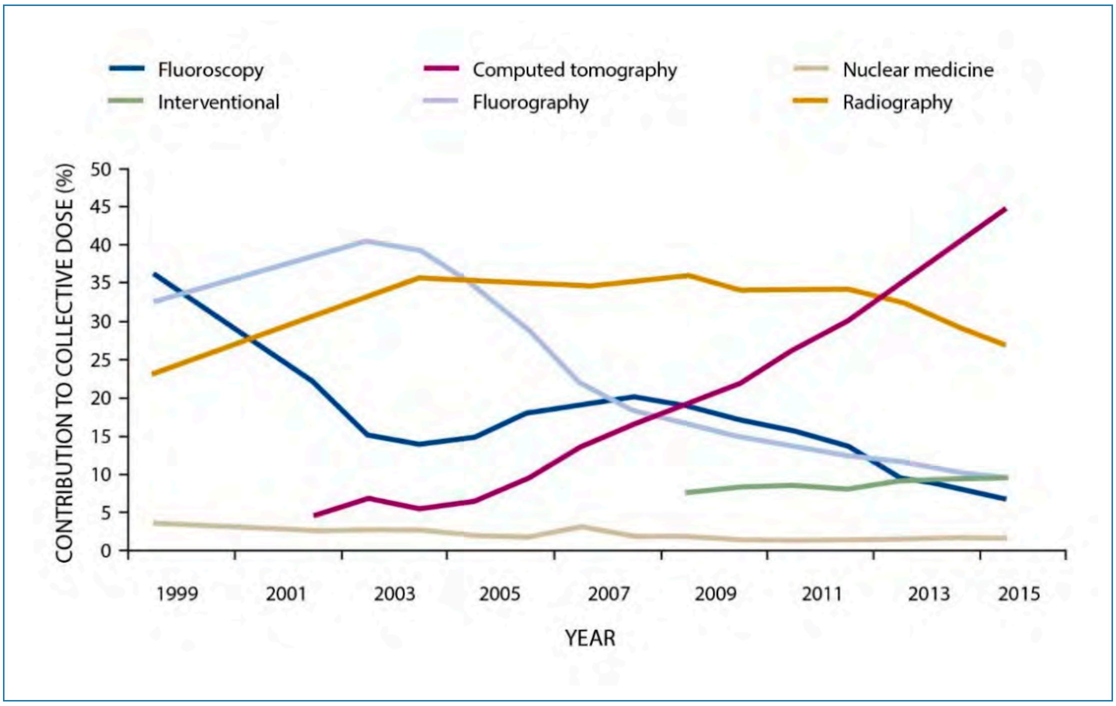
B74. In Taiwan, China from 2000 to 2013, the average annual growth rate of computed tomography examinations was 7.6% [Y1]. The number of computed tomography examinations in 2013 was 2.6 times that in 2000. The population effective dose was 0.30 mSv per caput in 2000 and increased to 0.74 mSv per caput in 2013, with an annual growth rate of 7.2%.

B75. In Kenya, the total number of examinations and the collective effective dose are increasing annually, indicating a significant change in the medical imaging pattern, where new types of procedures are conducted using high dose imaging modalities [K13]. The annual number of X-ray examinations per 1,000 population was estimated to be 82. This per caput estimate is 156% larger than that for 1986 (32 examinations per 1,000 population). There was a strong indication that access to diagnostic radiological services in Kenya would continue to increase. The national annual number of computed tomography examinations increased by 60% from 2007 to 2011, which demonstrated the impact of multi-slice or multi-detector scanners (MSCT) since it was introduced in the country.

B76. In the Republic of Korea, the number of diagnostic radiological devices increased by 22% from 2008 to 2012 [L3]. From 2006 to 2013, the frequency of examinations demonstrated a rapid growth of 54.4% (average 6.5% per year), while annual collective effective dose and annual per caput effective dose increased from 0.89 mSv per caput effective dose in 2006 to 1.54 mSv in 2013 [L3].

B77. In the Russian Federation, the collective effective dose from medical exposure has decreased by a factor of two since the end of 1990 and has stabilized in 2015 at a level of about 77,000 man Sv (0.52 mSv per caput). This process is accompanied by an increase in the number of examinations – about 35% in the past decade. A decrease in the collective effective dose by 4% per year on average was mainly due to the replacement of analogue X-ray units by digital units and a reduction of the number of high-dose fluoroscopies [B6]. The numbers of computed tomography units and examinations in the Russian Federation doubled between 2010 and 2015, reaching 8.5 million examinations. However, it still represented only 2.9% of the total number of diagnostic examinations and 44.9% in the collective effective dose in the country. The trends of contributions of different imaging modalities in the collective dose in the Russian Federation are shown in figure B-XIII.

Figure B-XIII. Contribution of various types of imaging modalities to collective dose from medical exposure in the Russian Federation between 1999 and 2015 [B6]



B78. As for international trends in paediatric computed tomography examinations, a large epidemiological study, "Epidemiological study to quantify risks for paediatric computerized tomography and to optimise doses" (EPI-CT) [I6], investigated the relationship between the exposure to ionizing radiation from computed tomography scans in childhood and adolescence and possibly attributable late health effects. While the study did not provide information on population doses, the knowledge gained on current and past paediatric computed tomography examination practice will help to propose strategies for further dose reduction.

1. Impact of technology

B79. The development of imaging technology plays an important role in the trends of imaging practices, numbers of examinations and patient dose levels. Development means the introduction of new imaging technologies by manufacturers, including improved detectors and imaging principles, and associated equipment and software. There is an extensive variation in the availability of new technologies worldwide and, in many low-income and very low-income countries, the level of technology is still largely non-digital, based on older techniques and often lacking appropriate provisions for patient dose monitoring (such as DAP meters) [R5]. There are also variations in the selection of the imaging modality for a given clinical investigation, or in the types of equipment available within a chosen modality (different manufacturers or different models of the same manufacturer). While trends in imaging practices and patient dose levels are affected by the availability of new technologies and by the variations of modalities and equipment, these will not be considered here.

B80. During the past decade, major technological developments in computed tomography have been impacting population dose from medical exposure. This is because in many countries, at least in high-income countries, computed tomography makes the highest, up to 70–80%, contribution to the collective effective dose from all medical X-ray procedures. On the other hand, the major changes in the development of X-ray examinations, such as the replacement of the conventional film-screen systems by digital techniques, the replacement of computed radiography techniques by direct digital techniques, and the development of new detectors with higher detective quantum efficiency, have been introduced and largely implemented already during the preceding periods and thus discussed in previous UNSCEAR reports [U6, U9]. Therefore, the discussion below is limited to conventional and cardiac applications of computed tomography.

B81. While there is no doubt about the impact of technology development in several cases, a recent extensive study on computed tomography examinations indicated that the high variations of patient doses across countries are primarily attributable to local choices regarding technical parameters, rather than patient, institution or machine characteristics [S19].

(a) *"Conventional" computed tomography*

B82. In computed tomography, the development of technology during the past 10–15 years has had a pronounced effect both on the number of computed tomography examinations and on patient dose levels. The single-slice (or single-detector) scanners have been largely replaced by computed tomography scanners with a marked increase in the number of detector rows, i.e., multi-slice or MSCT. The improved efficiency of modern MSCT scanners has contributed to the increase in the number of computed tomography examinations while also broadening the use of new computed tomography applications. As a few examples, a pronounced increase of the number of computed tomography examinations after 2000 was reported to coincide with the introduction of MSCT in Denmark [H2] and the United States [M9]. Faster computed tomography scanners have increased the use of computed tomography for paediatric examinations by reducing the requirement of sedation to prevent children from moving during examination and by enabling less need for oral contrast administration, reduced amount of intravenous contrast medium, and improved image quality [D8]. Computed tomography technology has developed strongly towards better dose management with significant reduction of patient doses, by introduction of automated tube current modulation and iterative image reconstruction.

B83. Effective doses (*E*, mSv) were assessed in several countries with regard to the publication year and scanner technology (i.e. single-slice versus multi-slice) [P4]. Among studies, the considerable variation in reported values was attributed to variations in both examination protocol and scanner design. The effective doses of computed tomography examinations for head, chest and abdomen prior to 1995 were significantly higher than for later studies whereas between 1996 and 2009, effective dose remained virtually unchanged [P4]. Significant dose reduction in more recent studies was attributed to the implementation of dose management procedures, X-ray beam filtration and collimation, tube current modulation and adaptation for patient body habitus, peak kilovoltage optimization, improved detection system efficiency, and noise reduction algorithms [P4].

B84. In a study by Chen and Moir [C5], average effective dose per computed tomography examination in Canada from MSCT scans was shown to be 13–36% higher than from single-slice scans. A study by Kim et al. [K8] showed differences in effective dose and organ dose between single-slice and multi-slice scans with a ratio of effective doses of 2.4 higher doses from MSCT for high-resolution lung scan, 1.1 for head scan and 2.2 for abdomen scan. However, for chest scans the effective dose using MSCT was 20% lower due to the application of dose-saving techniques.

B85. While the MSCT technology of early 2010s has led to increasing patient doses compared with earlier technologies of late 1990s, the associated development of dose-saving features, such as iterative reconstruction, has converted this dose trend downwards for most types of computed tomography examinations. Studies and reviews on radiation exposure from computed tomography indicated a potential for dose reduction by applying innovative dose-saving techniques in combination with optimized protocols [K1, M3, N6].

B86. According to a study by Schegerer et al. [S8], the data provided for about 11% of all computed tomography scanners operated in Germany in the years 2013 and 2014, the effective dose was 4.6/5.9 mSv per examination. The $CTDI_{vol}$ values, and consequently the effective doses, were considerably reduced by about 15% compared with computed tomography practice before 2010. Modern computed tomography technology, such as tube current modulation and iterative reconstruction reduced the effective dose considerably by 6 and 13%, respectively. Considering examinations where iterative reconstruction was not used, tube current modulation reduced $CTDI_{vol}$ and effective dose considerably by 7 and 6%, respectively, and a marked dose reduction up to 35% was obtained for some examinations. When using iterative reconstruction, $CTDI_{vol}$ and effective dose were considerably reduced by 15 and 13%, respectively, compared with scans reconstructed with the conventional filtered back projection algorithm. In the German study, the mean effective dose for scanners produced by different manufacturers differed by 25% at maximum. These differences may be due to technical differences (e.g., filtering, detector efficiency, the amount of tissue irradiated without being reconstructed (over ranging), effectiveness of dose-saving measures) or to differences in optimization protocols [S8].

B87. A specific development within the computed tomography technology has been the introduction of dual-energy computed tomography, which can also have an impact on patient dose levels. For the computed tomography examinations of adults there is phantom and clinical evidence that this technique is not associated with increased radiation dose to patient [H9]. For paediatric computed tomography examinations, the use of dual-energy computed tomography resulted in radiation doses comparable to or even less than that from single-energy computed tomography scans while maintaining contrast and contrast-to-noise ratio [S15].

B88. Besides the number of computed tomography examinations and patient dose, the development of computed tomography technology had an impact on the pattern of computed tomography procedures. As for the imaged anatomical regions, a trend towards an increasing proportional contribution of abdomen/pelvis and chest scans with a simultaneous decrease of head scans over time has been observed [D8, E10, M8, M10, S7]. Although differences in living conditions and population distributions may result in different computed tomography patterns worldwide, the increasing proportions of abdomen/pelvis and chest scans may have resulted from the introduction of faster and more efficient computed tomography scanners [F5].

(b) *Cardiac computed tomography*

B89. In cardiac radiology, the development of computed tomography scanning technology has progressed with significant dose savings. A review by Efstathopoulos et al. [E6] reported patient effective doses associated with coronary artery calcium scoring (20 studies) and computed tomography coronary angiography (61 studies). Patient effective doses from computed tomography cardiac examinations varied among institutions due to examination protocol and computed tomography scanner type variations. The conventional retrospectively electrocardiogram (ECG) -gated helical scan protocol does not use radiation as efficiently as the prospectively ECG-triggered scan techniques. Published results indicate that the use of prospective ECG triggering is more effective in minimizing patient exposure compared with dose modulated retrospective ECG gating.

B90. Prospective acquisition was shown to allow for major dose savings compared to retrospective acquisition (mean effective dose 4.5 mSv with prospective acquisition versus 27.5 mSv with retrospective acquisition) [B12], and mean effective dose 6.0 mSv for prospective computed tomography angiography (CTA) and 8.4 mSv for retrospective computed tomography angiography [O4]. In a recent German study [S8], the dose was significantly reduced by 55% with prospective triggering compared to retrospectively gated computed tomography coronary angiographies (CTCA). Further evidence of the benefits of prospective acquisition techniques is provided by a recent large international study by Stocker et al. [S23] in which 61 hospitals from 32 countries prospectively enrolled 4,502 patients undergoing cardiac CTA during one calendar month in 2017 were analysed. The median DLP of coronary CTA was 195 mGy cm (range 110–338 mGy cm), corresponding to effective doses of 2.7 or 5.1 mSv, estimated using the thoracic or the recently published cardiac DLP to effective dose conversion factor of 0.014 or 0.026 mSv/(mGy cm), respectively. The authors compared the results with a similar survey conducted in 2007. A significant 78% reduction in DLP for CTA was observed in 2017 ($P < 0.001$), without an increase of frequency in non-diagnostic coronary CTAs (1.7% in 2007 versus 1.9% in 2017 surveys, $P=0.55$). Among the major factors contributing to this dose reduction is the availability of dose efficient scan protocols with a reduced tube potential, prospective ECG-triggering and iterative image reconstruction. However, a large 37-fold inter-site variability in median radiation dose was observed, which underlines the need for further site-specific training and adaptation of contemporary cardiac scan protocols. In a recent study by Alhailiy et al. [A3], diagnostic reference levels for CTCA in Australia were established and shown to be lower than in most published studies, due to the implementation of dose-savings technologies such as prospective ECG-gated mode and iterative reconstruction algorithms.

VIII. SUMMARY

B91. The current UNSCEAR Global Survey, with data contributed by over 50 countries, together with a comprehensive review of the literature published in the past decade, has amassed key data on frequency and dose for diagnostic radiological examinations. This includes information on the age and sex distributions of patients, professional staffing levels, and numbers of imaging devices. For the evaluation of collective effective doses or per caput effective doses, the findings are based mainly on the literature review since the survey participation has not been sufficient for direct and accurate estimations of the population dose from medical exposure. A general observation is that the countries that have published information on medical exposure in the past years are mainly the same countries that have submitted data to this survey. It seems that these countries have established mechanisms enabling them to collect information on the frequency of radiological examinations, to record dose data and to provide updates on a regular basis.

B92. Frequencies of diagnostic radiology examinations per 1,000 population vary considerably between countries, according to data in the literature and in the UNSCEAR Global Survey. The mean frequency of diagnostic radiology procedures in the countries in the survey is 1,038 examinations per 1,000 population, constituting by far the highest contribution (97.8%) to the total frequency of medical radiological procedures per 1,000 population. On average, projection radiography (without dental procedures) accounts for 59.8%, radiography and fluoroscopy 2.0%, dental procedures 25.2% and computed tomography 13.0% of all diagnostic radiology procedures. The data from the survey and the literature review indicate a slight increase in the overall frequency of X-ray procedures in general (combining diagnostic radiology and interventional radiology) and nuclear medicine frequencies (see for more details appendix D); however, for some types of examinations and in some countries there are also decreasing trends. The average increase in diagnostic radiology examinations is most remarkable for chest (thorax), mammography, limbs and joints, dental panoramic examinations, coronary angiography, chest scans and abdomen scans. The average decrease is most notable for projection radiography of the thoracic spine, lumbar spine, abdomen, and gastrointestinal tract (barium studies).

B93. Data on frequencies and collective or per caput effective doses as a function of age and sex have not been widely published. The results from 11 countries in the survey indicate that the age distributions of examination frequencies for each modality are roughly similar across countries; however, the proportions of older and younger patients differ for some countries. Differences may reflect national preferences in imaging practice and/or differences in population age distributions. Differences in the age distributions of frequencies between the two sexes are not very high except for projection radiography, where a significantly higher proportion of examinations are performed for females between about 40 and 70 years, mainly due to mammography. In paediatric examinations, children older than 10 years seem to be the most frequently exposed, whereas children younger than 5 years are the least frequently exposed. About half of paediatric examinations are in conventional radiology and dental radiology while computed tomography and diagnostic interventional radiology account for just a few per cent of the total. Age and sex distributions of frequencies from the few published studies indicate roughly similar shapes as in the survey.

B94. The UNSCEAR Global Survey and the published studies indicate large variations between different countries in the typical effective doses for examinations. However, there are no great differences in any diagnostic radiology subcategories when the mean effective dose calculated from the survey data is compared with various publications. From the survey data, the highest typical effective doses in *(a)* projection radiography (>1 mSv) are for whole spine (trunk), pelvis (soft tissue) and lumbar spine; in *(b)* radiography and fluoroscopy (>6 mSv) for abdominal, pelvic, cerebral and cardiac angiographies and biliary tract (cholangiography); and in *(c)* computed tomography (>11 mSv), examinations of the trunk (chest, abdomen and pelvis), full spine (neck, chest and abdomen) and two types of computed tomography examinations of the abdomen. Within computed tomography examinations, dental computed tomography examinations have the lowest effective dose (0.3 mSv or less). Except for mammography and for examinations of the head region, for all diagnostic radiology procedures the effective dose calculated using ICRP 103 [I11] tissue weighting factors is lower than that calculated using ICRP 60 [I9] factors. The increase in effective dose for mammography is due to the increase in the weighting factor for the breast. For paediatric data, differences between age groups and with adults vary greatly between examination types; effective doses for computed tomography procedures are generally quite similar to those of adults, for fluoroscopy procedures doses seem to be consistently lower, and for plain radiography the results are mixed. The results of the UNSCEAR Global Survey together with reviewed publications suggest that typical (mean) effective doses have generally decreased during the past decade, although significant increases in a few large countries, or the shortage of data in some cases, lead to average values that indicate increased typical dose for some types of projection radiography and computed tomography examinations.

B95. The literature review indicates that X-ray procedures (diagnostic radiology and interventional procedures) make a major contribution to the total collective effective dose and effective dose per caput from all medical imaging, 92% on average. The contribution of computed tomography examinations to the total per caput effective dose is typically much more than their contribution to the total frequency: from the literature review, the mean contribution to the total per caput effective dose is 52.5% and the range from 5.3% to 79.0% (about 15-fold variation) while the contribution to total frequency is only 9.0% with the range from 0.7% to 25.5% (about 36-fold variation). Dental procedures are typically 10 to 40% of the total frequency but contribute less than 1% to the total per caput effective dose. Conventional fluoroscopy is typically a few per cent of the total frequency, but the mean contribution to the total per caput effective dose is 9.7%. Interventional radiology is typically less than 1% of the total frequency but the mean contribution to the total per caput effective dose is 8.2%.

B96. The data on the numbers of professionals and of diagnostic radiological systems and devices generally show great variation between countries. For example, recent literature indicates that the number of medical physicists is highest in Europe (34% of the total number of medical physicists), followed by North America (33%) and Asia/Oceania (24%). From the total number of diagnostic systems, on average, still more than half (about 56%) used are analogue systems. The majority of computed tomography scanners are multi-slice scanners and, on average, less than 5% are single-slice scanners (excluding dental and cone-beam scanners).

B97. The development of imaging technology plays an important role in the trends in imaging practices, numbers of examinations and patient dose levels. The major changes in imaging technology, such as the replacement of conventional film-screen systems by digital techniques, the replacement of computed radiography techniques by direct digital techniques, and the development of new detectors with higher detective quantum efficiency have had a recognized impact on imaging practices and patient dose levels, as already noted in the previous UNSCEAR report [U9]. In computed tomography, the development of technology during the past 10–15 years has had a pronounced effect both on the number of computed tomography examinations and on patient dose levels. Single-slice scanners have been largely replaced by multi-slice scanners, and the improved efficiency of modern multi-slice scanners has contributed to the increase in the number of computed tomography examinations while also broadening the use of computed tomography into new applications. Also, in cardiac radiology, the development of computed tomography scanning technology has progressed with significant dose savings: among the major factors contributing to this dose reduction is the availability of dose efficient scan protocols with a reduced tube potential, prospective ECG-triggering and iterative image reconstruction. However, there is extensive variation in the availability of these new technologies worldwide and, in many low-income and lower middle-income countries, the level of technology is still largely non-digital, based on older techniques and often lacking appropriate provisions for patient dose monitoring (such as DAP meters). It should be noted, further, that there are not major patient or equipment differences to explain the large variations in patient doses across countries, but the variation comes mainly from how the equipment is used and thus suggests room for optimization.

B98. The results of the UNSCEAR Global Survey and the literature review have shown that the earlier trend of increasing collective effective dose and per caput effective dose in medical imaging has continued in the past ten years but has been less significant than in the previous decade. The increase has been caused mainly by continued increasing use of high dose procedures, in particular computed tomography, but also some interventional procedures and nuclear medicine procedures (see also appendices C and D). For computed tomography, it has been shown that the observed rise in use cannot be primarily attributed to the growth and ageing of the population. Nevertheless, despite the increased use of computed tomography, the increase of collective effective dose from computed tomography has slowed in some cases due to the development of dose-saving technologies.

APPENDIX C. LEVELS AND TRENDS OF EXPOSURE IN INTERVENTIONAL RADIOLOGY

I. INTRODUCTION

C1. Interventional radiology has been defined internationally in a range of ways. Future surveys on medical exposure would benefit from adopting common terminology and a common methodology in relation to interventional radiological procedures. For example, the International Basic Safety Standards [I3] uses the term “image guided interventional procedures” also used by the Committee in its UNSCEAR 2008 Report [U9], which described it as "fluoroscopic guidance frequently utilized in performing many interventional techniques, including precision diagnostic and therapeutic injection procedures". The European Basic Safety Standards Directive [E4] defines “interventional radiology” as "the use of X-ray imaging techniques to facilitate the introduction and guidance of devices in the body for diagnostic or treatment purposes". The International Commission on Radiological Protection (ICRP) in its publication 120 calls it “fluoroscopically guided interventions”, which are "procedures comprising guided therapeutic and diagnostic interventions, by percutaneous or other access, usually performed under local anaesthesia and/or sedation, with fluoroscopic imaging used to localize the lesion/treatment site, monitor the procedure, and control and document the therapy" [I14]. Another definition given by the National Council on Radiation Protection and Measurements (NCRP) says that “interventional fluoroscopy” refers to "any procedure in which the use or application of a medical device is fluoroscopically guided in the body, and includes procedures that are performed for diagnostic and therapeutic purposes" [N1]. The International Electrotechnical Commission (IEC) calls a "radioscopically guided interventional procedure" "an invasive procedure, involving the introduction of a device, such as a needle or a catheter into the patient, using radioscopy as the principal means of guidance and intended to affect treatment or diagnosis of the medical condition of a patient" [I18].

C2. A consensus statement was signed by many national interventional radiology organizations in 2010 [K5]. It stated that “interventional radiology originated within diagnostic radiology as an invasive diagnostic subspecialty. It is now a therapeutic and diagnostic specialty that comprises a wide range of minimally invasive image-guided therapeutic procedures as well as invasive diagnostic imaging. The range of diseases and organs amenable to image-guided therapeutic and diagnostic procedures are extensive and constantly evolving, and include, but are not limited to, diseases and elements of the vascular, gastrointestinal, hepatobiliary, genitourinary, pulmonary, musculoskeletal and, in some countries, the central nervous system”. The scope of interventional radiology as agreed in the consensus statement [K5] was:

- Evaluation and management of patients with diseases or conditions amenable to image-guided interventions;
- Invasive diagnostic imaging with the exception of invasive cardiac imaging;
- Minimally invasive image-guided and related procedures of vascular, gastrointestinal, hepatobiliary, genitourinary, pulmonary, musculoskeletal, and, in some countries, neurological conditions amenable to these procedures;
- Diagnostic imaging as relevant to local practice.

Cardiac interventions were excluded from this consensus statement as it was signed only by interventional radiology organizations and not interventional cardiology organizations [K5].

C3. The Committee, in its UNSCEAR 2000 and 2008 Reports [U6, U9], already recognized interventional radiology as an established part of mainstream medicine and expected that it is likely to expand further with the continuing development and adoption of new procedures, particularly in countries with well-developed health-care systems. In the last decades, the advances in technology for imaging and ancillary equipment have facilitated the development of increasingly complex radiological procedures for angiography and interventional radiology which traditionally is performed under fluoroscopy guidance using angiography systems. However, the use of angiography systems for interventional radiological guided procedures causes problems when accounting for radiological examinations based on the device used. Thus, the use of the term "interventional fluoroscopy systems" as defined by IEC [I18] could be used in the future "X-ray equipment for radioscopically guided interventional procedures".

C4. According to the user manual for the UNSCEAR Global Survey [U11], interventional radiological procedures, was defined in the past as "any minimally invasive procedure performed under fluoroscopy guidance with therapeutic purpose and may involve any cerebral, cardiac, pulmonary, hepatobiliary, gastrointestinal, genitourinary, musculoskeletal and central nervous system disease". Any minimally invasive procedure performed under fluoroscopy guidance with diagnostic purpose is part of the modality category: radiography and fluoroscopy (mostly with contrast media). The latter definition was used for the analysis of data of the current survey.

C5. The literature review showed that countries report differently fluoroscopy, diagnostic and therapeutic interventions, as shown in table C1. Certain countries treat diagnostic and therapeutic procedures as one category. Distinction from diagnostic and analysis of therapeutic procedures was possible only for three out of 12 national surveys. In two surveys, only diagnostic procedures were reported, as statistical data on therapeutic procedures were not collected at national level.

Table C1. Reporting of interventional radiological procedures according to different surveys

PTCA: Percutaneous transluminal coronary angioplasty

Included procedures	*National surveys*
Only diagnostic procedures	France [D10, E11], Republic of Korea [L3]
Only therapeutic procedures	Luxembourg [S12], Portugal[a] [T3], Ukraine[a] [S22]
Diagnostic and therapeutic in one category	Australia[b] [H6], Finland [B19], Germany [N3], Ireland [O1], Kenya[b] [K13], Norway [B25], Romania [G5], Spain [S4], Taiwan, China [C6], USA [N1]
Diagnostic and therapeutic in separate categories	Slovenia [Z1], Switzerland [A8, S2, S3], UK [H5]

[a] Only PTCA based on the TOP 20 methodology [E3].
[b] With possible separation of procedures for UNSCEAR Global Survey.

C6. The number of interventional procedures performed under computed tomography guidance is increasing and, in future, the definition of interventional procedures should also take this into account. In most of the countries, computed tomography interventions are now accounted for under the "computed tomography" category.

C7. Furthermore, modern C-arm equipment can acquire multiple projections by rotating the flat panel detector around the patient. These projections are used to reconstruct tomographic images, known as cone beam computed tomography (CBCT) images. These images present multiple planes of vessels and are used in conjunction with digital subtraction angiography and fluoroscopy to increase safety and efficacy of procedures.

C8. Recognizing the continuous development of techniques, skills, methods and processes that lead to an increasing number of interventional procedures, and also the various definitions of interventional radiology worldwide, the following updated definition is proposed for future surveys even though it is not applied to the current evaluation: “an interventional procedure refers to the insertion and positioning of a device into the body under fluoroscopic and/or computed tomography guidance for diagnostic and/or therapeutic purposes. Interventional procedures include those performed in or outside of radiology departments”.

II. RECAPITULATION OF PREVIOUS UNSCEAR REPORTS

C9. In the UNSCEAR 2000 Report [U6], which covered the period 1991–1996, interventional procedures were accounted for under diagnostic radiology along with projection radiography, fluoroscopy, mammography, computed tomography, angiography and dental radiology. The worldwide contribution to procedure frequency and collective dose for interventional procedures for 1991–1996 was estimated to be 0.3 and 4%, respectively [U6]. Percutaneous transluminal coronary angioplasty (PTCA) procedures were identified to increase with considerable variation among different countries.

C10. In the UNSCEAR 2008 Report [U9], which covers the period 1997–2007, interventional radiology was again accounted for under diagnostic radiology, but this time more data on frequencies and doses for interventional radiology and cardiology were available. Data on cardiac PTCA, as the leading interventional procedure in terms of frequency and dose, are presented here, and also under the broad category “other interventional procedures”. The contribution of interventional procedures to the frequency of diagnostic medical and dental radiological examination in the UNSCEAR 2008 Report [U9] was estimated to be 0.1% worldwide (table C2).

Table C2. Frequency of interventional procedures according to UNSCEAR 2008 Report [U9]

PTCA: Percutaneous transluminal coronary angioplasty; HCL: Health-care level

Procedure	*HCL I*	*HCL II*	*HCL III–IV*	*World*
	Number of examinations per 1 000 population[a]			
PTCA	0.9	0	0	0.3
Other interventional	1.1	0	0	0.3
	Contribution to the frequency of medical and dental examination (%)[a]			
PTCA	0.10	0.03	0	0.05
Other interventional	0.10	0.01	0	0.05

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

C11. The global annual collective effective dose for interventional procedures for 1997–2007 was estimated to be about 41,000 man Sv. The collective dose by health-care levels for the same period is presented in table C3. Further, in the UNSCEAR 2008 Report [U9], it was identified that about half of the collective effective dose due to diagnostic radiology arose from three procedures: computed tomography, angiographic examinations and interventional procedures. A major increase in the number of PTCA procedures was also noted between 1997 and 2007 [U9].

Table C3. Collective dose of interventional procedures according to UNSCEAR 2008 Report [U9]

PTCA: Percutaneous transluminal coronary angioplasty; HCL: Health-care level

Procedure	*HCL I*	*HCL II*	*HCL III–IV*	*World*
	Collective effective dose (man Sv)[a]			
PTCA	17 000	3 800	0	21 000
Other interventional	19 000	1 100	0	20 000
	Contribution to the collective effective dose of medical exposure (%)[a,b]			
PTCA	0.57	0.37	0	0.53
Other interventional	0.69	0.10	0	0.56

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Excluding exposure from nuclear medicine procedures.

III. FREQUENCIES OF PROCEDURES

C12. This section presents information on trends in the frequencies of interventional procedures resulting from the submissions to the UNSCEAR Global Survey. Furthermore, the data were supplemented with information from reviews of the published literature.

A. UNSCEAR Global Survey data

C13. In the current UNSCEAR Global Survey, detailed data (frequency and dose data) from 38 countries have been received for interventional procedures. Unfortunately, the data for many countries were incomplete and did not provide a basis for accurate evaluation of the population doses, i.e., collective effective doses and per caput effective doses. Data on the frequencies of examinations (i.e., annual numbers of examinations) are more complete, but the submitted dose data kerma in air area product (KAP) values or typical effective doses were scarce. Some countries submitted total frequencies but did not provide numbers for the individual procedures while other countries provided procedure frequencies but no data on doses (see also electronic attachment C-1).

C14. The frequency data from the current UNSCEAR survey for interventional procedures are shown in figure C-I and table C4. The frequencies are recorded per 1,000 population to allow for comparison with other radiological examinations. Some countries provided data only for the total number of interventional procedures. There is a very wide variation in procedure frequencies across the world, with the highest frequencies occurring in Estonia, Hungary, Lithuania and the United States.

C15. The frequency of interventional procedures per 1,000 population has increased significantly in several European countries. Apart from the increase in the number of interventional procedures conducted worldwide, there are differences to the previous UNSCEAR 2008 Report [U9]. In the UNSCEAR Global Survey more information on interventional procedures were collected and that the method of data collection has been changed. For example, *(a)* the Russian Federation provided data on PTCA procedures with fluoroscopy data and interventional radiology procedures including only abdominal interventions; *(b)* Spain accounted data on endovascular surgeries as interventional radiology procedures; and *(c)* Germany accounted balloon angioplasty, atherectomy, rotablation, selective thrombolysis, selective embolization, balloon valvuloplasty, stent implantation and percutaneous myocardial revascularization as PTCA procedures.

Figure C-I. Frequency of interventional procedures per 1,000 population reported in UNSCEAR Global Survey

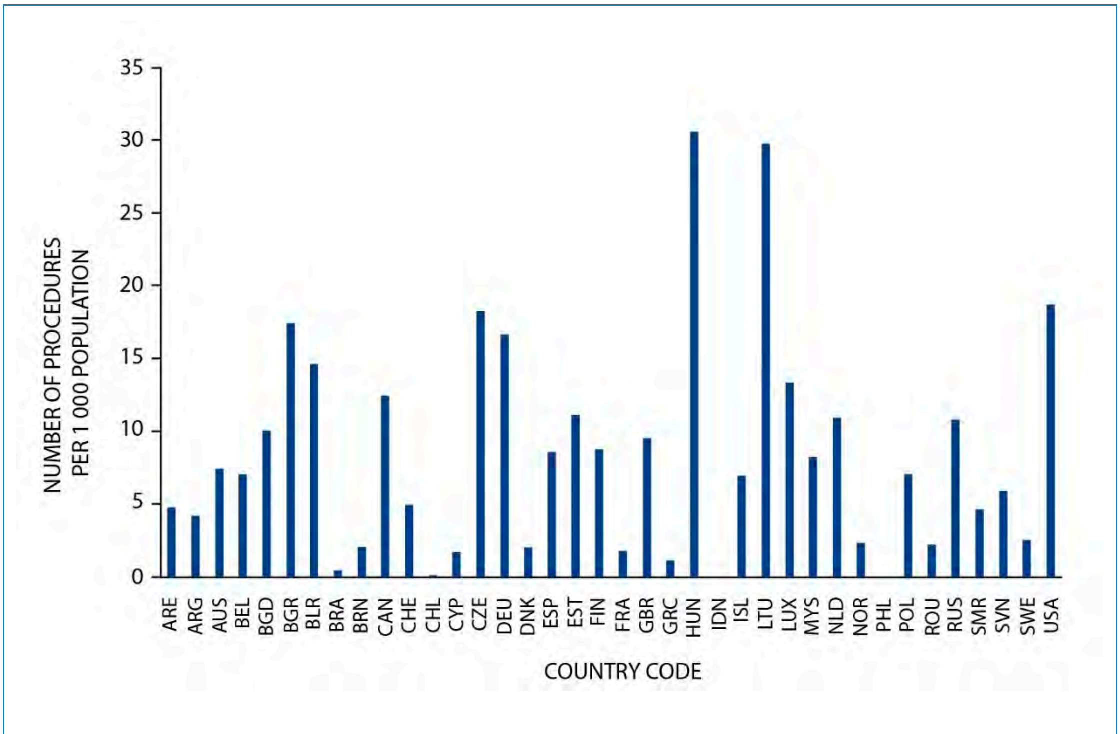


Table C4. Frequency of annual interventional procedures per 1,000 population reported to UNSCEAR Global Survey

PTCA: Percutaneous transluminal coronary angioplasty; TIPS: Transjugular intrahepatic portosystemic shunt

Country	*Frequency of procedures per 1 000 population* [a,b]										
	Head (cerebral intervention)	*PTCA*	*Chest (pacemaker)*	*Thoracic intervention (other)*	*Abdomen (biliary and urinary intervention)*	*Abdomen (TIPS)*	*Abdominal interventions (other)*	*Pelvic interventions*	*Limb interventions*	*Others* [c]	*Total*
Argentina	0.15	2.96		0.58			0.18	0.27			4.1
Australia	0.03	1.67	1.54		0.10		0.05		1.03	2.95	7.4
Bangladesh											10
Belarus											14.6
Belgium	0.11	2.30	0.04	1.02		0.02	0.10	0.004	0.06	3.32	7
Brazil											0.42
Brunei Darussalam											2
Bulgaria	0.07	3.37	0.46							13.51	17.4
Canada											12.4
Chile											0.08
Cyprus		1.69									1.7
Czech Republic		2.17	1.03	4.95	3.32	0.01				6.72	18.2
Denmark		1.96		0.03							2
Estonia	0.08	2.95							1.24	6.81	11.1
Finland		1.36	0.47			0.001				6.91	8.7
France		1.75									1.8
Germany		8.37								8.25	16.6
Greece	0.02	0.60	0.34			0.0003				0.12	1.1
Hungary										30.56	30.6
Iceland	0.06	2.05	1.36	0.17	0.15		0.11	0.36	0.25	2.40	6.9
Indonesia											0.03

Country	*Frequency of procedures per 1 000 population*[a,b]										
	Head (cerebral intervention)	*PTCA*	*Chest (pacemaker)*	*Thoracic intervention (other)*	*Abdomen (biliary and urinary intervention)*	*Abdomen (TIPS)*	*Abdominal interventions (other)*	*Pelvic interventions*	*Limb interventions*	*Others*[c]	*Total*
Lithuania		17.86								11.91	29.8
Luxembourg	0.28	3.15	1.11	1.25	4.13	0.002	0.37	0.34	1.88	0.82	13.3
Malaysia										8.24	8.2
Netherlands	0.05	8.04	0.26	0.85	0.24		0.49			0.93	10.9
Norway		2.27									2.3
Philippines				0.01	0.001		0.001			0.01	0.01
Poland	0.24	4.18	0.27	0.22	0.07	0.0001	0.001		0.62	1.38	7
Romania	0.05	0.92	0.08			0.03	0.01		0.06	1.06	2.2
Russian Federation	0.19				0.44		0.49	0.15	0.49	8.99	10.7
San Marino											4.6
Slovenia		1.85								4	5.9
Spain		1.78								6.78	8.6
Sweden		2.20								0.30	2.5
Switzerland		3.26								1.65	4.9
United Arab Emirates	0.30	1	0.13	2.09	0.21	0.030	0.19	0.10	0.62		4.7
United Kingdom	0.08	0.30	0.59	2.34	0.59	0.01	1.05	0.60	1.47	2.45	9.5
United States	0.07	2.63	1.11	1.26	0.49		0.59	0.16	1.31	11.05	18.7

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Empty cell indicates no data available.

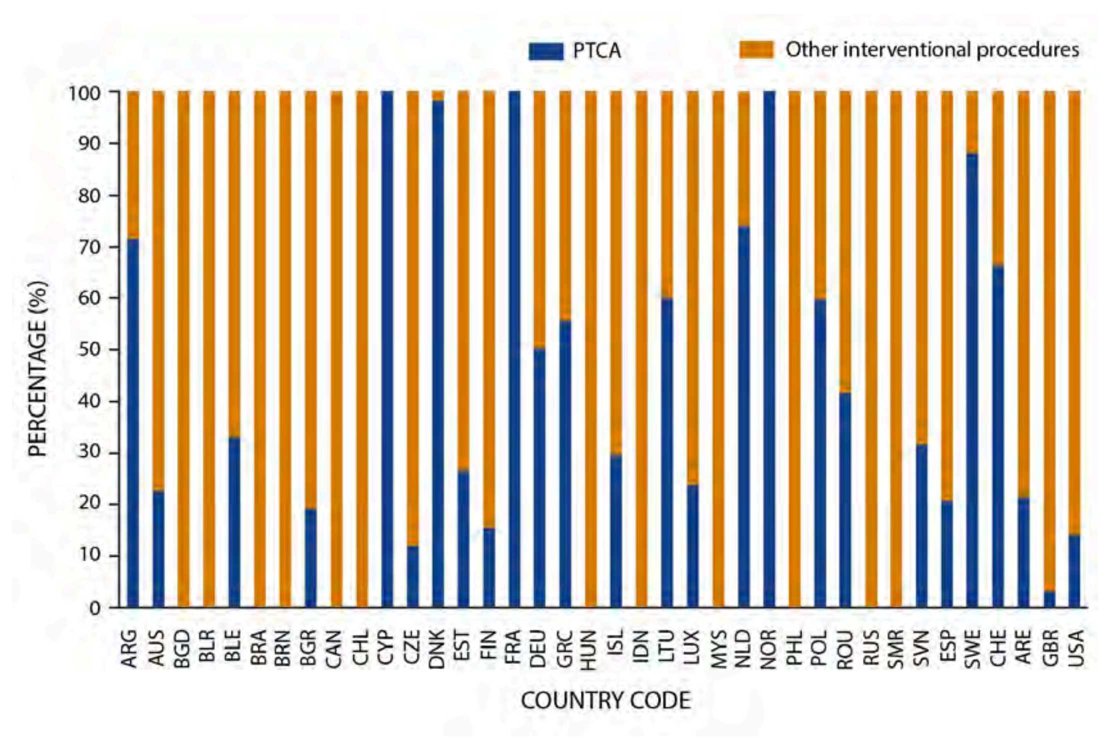
[c] Includes any procedures that were reported as “others” or did not fit any of the specific categories so that the total number of interventional procedures sum correctly.

C16. The most commonly performed interventional procedure is the PTCA procedure, followed by interventions performed at the level of the chest and abdomen/pelvic regions (biliary and urinary). In figure C-II, the contribution of PTCA to interventional procedures is displayed. The mean contribution is 48%, ranging from 3% to 100%, as some countries provided data only on PTCA procedures.

C17. Data on other examinations were reported by certain countries. Unfortunately, the scarcity of data did not allow a thorough analysis; thus, all examinations were treated as one modality category. Moreover, in some cases the total number of interventional radiology procedures did not match with the sum of the specific interventional radiology procedures. In these cases, the difference was added to the "other" procedures. The large number of "other" interventional procedures shows that an update of the list of procedures in the current survey may be needed in the future to cover development in the interventional radiology domain.

Figure C-II. Contribution of PTCA to annual frequency of interventional procedures as reported to UNSCEAR Global Survey

PTCA: Percutaneous transluminal coronary angioplasty



C18. Table C5 presents a comparison in frequency data for cerebral interventions and PTCA between UNSCEAR 2008 Report [U9] and this survey. The number of PTCA procedures seems to be rather stable or to increase between 2008 and this survey, while for cerebral interventions large differences are observed between countries. Any change in the methodology followed by individual countries for counting frequencies during this period may also contribute to large variations. Note that in the UNSCEAR 2008 Report [U9], cerebral angiography was a subcategory of interventional procedures, however, these procedures could be also considered diagnostic, which requires attention when comparing these data.

Table C5. Comparison of frequency of cerebral interventions and PTCA procedures per 1,000 population as reported to UNSCEAR Global Survey and in UNSCEAR 2008 Report [U9]

PTCA: Percutaneous transluminal coronary angioplasty

Country	Frequency per 1 000 procedures Head (cerebral intervention) [a]			Frequency per 1 000 procedures PTCA [a]		
	Current evaluation	UNSCEAR 2008 Report [b]	Change (%)	Current evaluation	UNSCEAR 2008 Report	Change (%)
Belgium				2.30	1.90	21
Bulgaria	0.07	0.66	−89			
Czech Republic				2.17	0.78	182
Finland				1.36	1.88	−28
France				1.75	1.71	2
Germany				8.37	2.30	264
Iceland				2.05	1.97	4
Lithuania				17.86	2.19	716
Luxembourg	0.28	0.07	300	3.15	1.54	105
Netherlands	0.05	1.21	−96			
Norway				2.27	0.54	320
Romania				0.92	0.73	26
Slovenia				1.85	1.80	3
Spain				1.78	0.65	174
Switzerland				3.26	1.05	210
United Kingdom	0.08	0.03	167	0.30	0.44	−32

[a] Empty cell indicates no data available.

[b] Cerebral angiography was considered as interventional procedure in UNSCEAR 2008 Report [U9].

B. Literature review data

C19. The population dose from interventional radiological procedures was reported in 22 of the reviewed articles, corresponding to 17 individual countries and one region (Europe). The population dose from interventional procedures depends on a number of factors, namely the:

- Availability of interventional radiology facilities, including appropriately trained staff;
- Type of procedure (e.g., cardiac, vascular);
- Methodology chosen for the estimation of population exposure in general (e.g., X-ray only or nuclear medicine procedures included, national survey versus reimbursement systems);
- Type of procedures considered as interventional radiological procedures (e.g., fluoroscopy or diagnostic interventional procedure followed by a therapeutic procedure or only therapeutic interventional procedures);

- Type of X-ray units and its capabilities (e.g., image-intensifier, flat panel detectors, over- or under-couch, continuous fluoroscopy, pulsed fluoroscopy, additional Cu filter for skin sparing, digital subtraction angiography, acquisition of 3-D images with C-arms) and, thus, the exposure parameters used during the interventional procedures;
- Level of optimization applied in the imaging protocols;
- Tissue weighting factors used for the calculation of the effective dose according to ICRP 60 [I9] or ICRP 103 [I11];
- Medical specialties in addition to radiologists and cardiologists performing interventional procedures (e.g., vascular surgeons).

C20. Table C6 presents the contribution, in terms of effective dose and frequency of interventional radiological procedures to population medical exposure in different countries as reported in the literature. The contribution of interventional procedures to the total number of medical radiological imaging procedures was relatively small, ranging from 0.03 to 14.2% (average 2.3%). However, the contribution to the population dose in percentage terms was higher (4 to 23%, average 8.6%), resulting in an average population dose of 0.07 mSv per caput. A wide range of reported effective doses (ranging from 0.001 mSv in Kenya to 0.14 mSv in Ireland) was observed for different countries. Although these articles were reported as national surveys that had been conducted over a large period (2002–2013) there was no correlation between per caput effective dose and the year of study.

C21. The methodology followed for the national surveys has a direct impact on the results. Two major points should be taken into account: *(a)* procedures included in a survey, and *(b)* type of procedures considered as interventional radiological procedures. In some countries, the total number of procedures includes only X-ray procedures (such as in Finland, Kenya, Romania and Switzerland); in others, it includes X-rays and nuclear medicine (such as in Australia, Ireland, Luxembourg and United States). In Norway, ultrasound and magnetic resonance imaging (MRI) examinations were included with X-ray procedures. Some countries, such as Portugal, Slovenia and Ukraine, followed the TOP 20 methodology developed by EC DDM 1 [E3]. The TOP 20 methodology includes only PTCA as interventional procedure. Although the PTCA procedure is the most frequent, the methodology considerably underestimates the total number of interventional procedures [B20]. Thus, some countries applied correction factors for improved estimations (Slovenia and Ukraine).

C22. In certain countries, the frequencies of interventional procedures and doses of both diagnostic and therapeutic procedures were accounted as one category, while other countries accounted only for therapeutic procedures or only for diagnostic procedures. The data of the latter are presented in appendix B on diagnostic radiology.

Table C6. Radiation doses and frequencies of interventional radiological procedures in different countries as reported in the literature

Based on data published between 2006 and 2017. Data on exclusively therapeutic interventional procedures are in italic

Country	*Year*	*Frequency per 1 000 population* [a,b]	*Collective dose (man Sv)* [a,b]	*Contribution to frequencies (%)*[a,b]	*Contribution to population dose (%)*[a,b]	*Per caput effective dose (mSv)* [a,b]	*Reference*
Australia	2010		*530*	*0.3*	*1.4*	*0.02*	[H6]
Finland	2008		336		14	0.06	[B19]
Ireland	2013		630	0.90	23	0.14	[O1]
Kenya	2011		*43*	*0.02*	*2.0*	*0.001*	[K13]
Luxembourg	2002				*6*	*0.12*	[S12]
Macedonia (The former Yugoslav Republic of)	2010	*0.44*		*3*	*4*		[G3]
Norway	2002	13			3	0.03	[B25]
Portugal	2010	*1.16*	*178*	*0.14*		*0.017*	[T3]
Romania	2012			0.3	2		[G5]
Slovenia	2011		*142*	*0.6*	*11*	*0.07*	[Z1]
Spain	2015		663			0.01	[S4]
Switzerland	2008			*0.4*	*6*	*0.07*	[S2]
Switzerland	2013	5		*0.4*	*6.2*	*0.09*	[L2]
Taiwan, China	2008				16.2	~0.1	[C6]
Ukraine	2012	*0.4*	*83*	*0.03*	*0.5*	*0.005*	[S22]
United Kingdom	2008		*2 037*		*8*		[H5]
United States	2008		94 000	4	14		[N1]
Europe 36 countries	2010				8	0.06	[B20]

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Empty cell indicates no data available.

C23. The EC DDM 2 project [E5] provided comprehensive information on 36 European countries regarding frequencies and radiation dose of X-ray and nuclear medicine diagnostic procedures from national surveys carried out between 2007 and 2010. On average, the total annual frequency of interventional procedures in Europe was six examinations per 1,000 population while their relative contribution to the overall collective effective dose was 9%. The mean effective dose per caput was 0.09 mSv. Typical doses for PTCA examinations in Europe ranged from 4 to 29 mSv with a mean value of 15.2 mSv. Large variation in the total number of interventional radiology examinations was observed among European countries. Interventional radiological procedures in the EC DDM 2 project included both diagnostic and therapeutic procedures. Some countries reported completed data while others followed the TOP 20 methodology [E3], which counted only the PTCA procedure as the most common interventional procedure. This may explain some of the large variations in frequency and doses of interventional procedures across Europe.

C24. Only Costa Rica focused on the estimation of the collective dose to the paediatric population deriving from interventional cardiac procedures (diagnostic and therapeutic) [U2]. The frequency of paediatric interventional radiology procedures per million population per year for the entire paediatric population (0–16 years) was 31.7 procedures. Collective dose for the children aged 0–16 years per million population was 0.16 man Sv while for the whole population this figure was 0.78 man Sv. These data are not presented in table C6, as it concerns only paediatric patients.

1. Most contributing procedures

C25. The literature review confirmed that cardiac procedures were the most frequent interventional procedures worldwide. In Australia, the two most common interventional procedures were reported by Hayton et al. [H6] with 87% for coronary angiography and 13% for PTCA. In Ireland, interventional procedures accounted for only 0.9% of examinations but contributed 23% to the collective dose. The interventional procedures category included both diagnostic and therapeutic interventional procedures, while procedures performed in operating theatres were also considered [O1]. Interventional procedures in Kenya's survey [K13] included various cardiac and non-cardiac procedures. Coronary angiography was by far the most frequent procedure with 46% of the total while other cardiac procedures, such as PTCA, percutaneous mitral valve dilatation and pacemaker contributed around 10% each (table C7). Abdominal and pelvic procedures were less frequent.

C26. In Luxembourg, interventional procedures were divided into cardiac and vascular [S12], while in Romania, the most frequent procedures were cardiac interventions (51% coronary angiography and 23% coronary angioplasty) [G5]. In Taiwan, China [C6], interventional procedures were divided into non-cardiac and cardiac procedures and showed equal contribution to the total exposure of the population. In the United States [N2], interventional procedures are divided into cardiac and non-cardiac interventional fluoroscopy procedures. The estimated total number of cardiac procedures was 4.1 million cases per year contributing to 0.6% of the total number of procedures and 6% to the collective effective dose. It is worth noting that more coronary diagnostic and percutaneous interventions are combined in a single procedure, the number of electrophysiological procedures is increasing, and a much smaller (but rapidly increasing) number of structural heart procedures exists.

Table C7. Distribution of interventional radiological procedures in Kenya in 2011 [K13]

PTCA: Percutaneous transluminal coronary angioplasty

Interventional procedure	*Distribution (%)*
Vessel angiography	7.1
Embolization	0.3
Biliary drainage	2
Cardiac angiography	45.7
Fallopian tube catheter	2.5
Inferior vena cava filter implantation	0.5
Lower limb arteriography	4.1
Nephrostomy	2.1
Pacemaker	11.1
Percutaneous mitral valve dilatation	11.8
PTCA	8.8
Pulmonary balloon valvuloplasty	2.2
Renal angiography	1.1
Vasography	0.8

C27. A study in Spain considered primarily cardiac procedures in the estimation of the annual collective dose from interventional procedures and, due to the small number of procedures other than PTCA, only PTCA data were considered. PTCA represented 96% of the interventional cardiac procedures, 3% of the procedures concerned structural heart disease and only 1% adult cardiac congenital disease [S4]. In Switzerland, a survey divided the interventional procedures into diagnostic and therapeutic [S2]. Coronary angiography was found to be most frequent, followed by PTCA procedures (34% and 18% of interventional procedures, accordingly). However, the contribution of PTCA procedures to the collective dose was 29% while for coronary angiography it was 35%.

C28. The general category “angiography/fluoroscopy” in the study by Smith-Bindman et al. [S18] in the United States included abdomen, cardiovascular and other procedures. Their corresponding contribution was 22, 69 and 11%, respectively. In conclusion, the review of the literature conducted here showed that in all countries cardiac interventional procedures were the most frequent and contributed the most to the collective dose from interventional procedures.

IV. DOSES FOR INTERVENTIONAL PROCEDURES

A. UNSCEAR Global Survey data

1. Typical effective doses per procedure

C29. Typical effective doses were reported to the UNSCEAR Global Survey by countries for the different interventional radiology procedures. Some countries have reported frequencies (annual numbers of interventional procedures) but no dose data (neither KAP nor effective doses) for any type of interventional procedures. For these countries, typical effective doses per interventional procedure were calculated on the basis of the following assumptions:

- KAP with a conversion factor was used to calculate the typical effective dose whenever the KAP was reported. The conversion factors are presented in table C8 for each type of procedure. Most of the conversion factors were given in the user manual for the UNSCEAR Global Survey [U11], while others were taken from the literature review;
- If no KAP was reported, but the effective dose was provided by the country, this was used directly;
- If neither KAP nor effective dose was reported, the mean KAP by other countries was adopted and the typical effective dose was calculated with a conversion factor; otherwise, the mean effective dose reported by other countries was adopted;
- For "other" interventional procedures, which is the only category when no KAP or effective dose from any country was reported, the mean effective dose from all procedures was used.

Table C9 summarizes the results of effective doses per procedure used in this evaluation.

Table C8. Conversion factors for interventional procedures used for effective dose calculations in UNSCEAR Global Survey

PTCA: Percutaneous transluminal coronary angioplasty; TIPS: Transjugular intrahepatic portosystemic shunt

Procedure	*Conversion factor (mSv/(Gy·cm²))*	*Reference*
Head (cerebral intervention)	0.10	[S6]
PTCA	0.26	[N1]
Chest (pacemaker)	0.10	[N1]
Thoracic intervention (other)	0.12	[N1]
Abdomen (biliary and urinary intervention)	0.26	[N1]
Abdomen (TIPS)	0.26	[N1]
Abdominal interventions (other)	0.12	[C14]
Pelvic interventions	0.18	[N1]
Limb interventions	0.23	[C14]

Table C9. Effective doses of interventional procedures reported to UNSCEAR Global Survey

PTCA: Percutaneous transluminal coronary angioplasty; TIPS: Transjugular intrahepatic portosystemic shunt

Country	*Effective dose per procedure (mSv)* [a,b]									
	Cerebral	*PTCA*	*Chest*		*Abdomen*			*Pelvic*	*Limbs*	*Other*
			Pace-maker	*Other*	*Biliary and urinary*	*TIPS*	*Other*			
Australia		21.6	0.6							
Belgium	13.1	38								
Bulgaria	10.7	30.2	6							
Czech Republic		19.4								
Estonia	9.1	31.1							10	
Finland		16.6								
France		19								
Germany	11	9		44			32	11	1.3	
Greece		29.1	2.5							
Iceland		5.2								
Lithuania	6	16.1			11.7				24.8	
Norway		17								
Republic of Korea	31.7								19.6	
Romania	3.2	6.7	1.7			2.4			2.3	
Russian Federation	4.5				5.8			3	1.9	
Slovenia		14.8								
Spain		28.6								
Sweden		8.1								
Switzerland		33.8								
United Kingdom		13.5	0.7	2.8	2.7	53.3		9.3	11.2	
Uruguay		16.6								
Average	**11.2**	**19.7**	**2.3**	**23.4**	**6.7**	**27.8**	**32**	**7.8**	**10.2**	**13.9**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Empty cell indicates no data available.

C30. Table C10 compares mean KAP values (and their standard deviations where provided), as reported by different countries to the UNSCEAR Global Survey for cerebral and PTCA interventions with KAP values provided in the UNSCEAR 2008 Report [U9] by the same countries. Large standard deviations, and variations in KAP values for both procedures are observed for some countries and throughout the years.

Table C10. Comparison of mean KAP values for cerebral interventions and PTCA reported to UNSCEAR Global Survey with UNSCEAR 2008 Report [U9]

PTCA: Percutaneous transluminal coronary angioplasty

Country	*Mean KAP (Gy cm²) ±standard deviation* [a]			
	Cerebral intervention		*PTCA*	
	Current evaluation	*UNSCEAR 2008 [U9]*	*Current evaluation*	*UNSCEAR 2008 [U9]*
Australia			83±11	
Belgium	131±99		146±124	
Bulgaria			116±143	
Czech Republic		52	75±37	120
Estonia	91±50		120±78	
Finland			64	
Greece			112±54	
Iceland			20±28	78
Lithuania	60±3		62±2	
Republic of Korea	317			
Romania	32		26	
Slovenia			57	
Spain		77	110±25	68
Sweden			31	
Switzerland		50	130	
United Kingdom			52±27	85
Uruguay			64	

[a] Empty cell indicates no data available.

C31. Table C11 summarizes typical effective doses of various interventional procedures used for the calculation of medical exposure in different countries as reported in literature. PTCA was the procedure largely studied. Large variations were observed; the minimum effective dose was 7.2 mSv and the maximum 86 mSv with a median value of 17 mSv. In most cases, effective doses were calculated using ICRP 60 [I9].

Table C11. Average effective doses used for calculating population doses from adult interventional procedures

PTCA: Percutaneous transluminal coronary angioplasty

Country / region	*Average effective dose (mSv)* [a]						
	Head (cerebral)	*PTCA*	*Chest (pacemaker)*	*Chest (other)*	*Abdomen (biliary/urinary)*	*Limbs*	*Reference*
Australia		17					[H6]
Italy		47	0.7				[P8]
Kenya		86	3	89[b]	10[c] 9[d] 41[e]		[K13]
Norway				11.4			[B25]
Portugal		14.5					[T3]
Romania	6.3[f]	21.7			4.8[e]	6.1	[G5]
Switzerland		17			17[c]	18[h]	[S2]
		20					[L2]
China, Taiwan[i]		7.2			32.3[g]		[C6]
United States		23	1				[N1]
Europe		15.2					[E5]

[a] Empty cell indicates no data available.
[b] Pulmonary balloon valvuloplasty.
[c] Drainage.
[d] Nephrostomy.
[e] Renal angioplasty.
[f] Carotid angioplasty.
[g] Trans arterial embolization.
[h] Lower limb dilatation.
[i] Applied ICRP 103 tissue weighting factors [I11].

C32. Table C12 presents typical KAP values and some conversion factors mSv/(Gy cm^2) that were used for the calculation of the effective dose of different interventional procedures in a limited number of hospitals and surveys. The large variation that is observed in the KAP values for all interventional procedures is attributed to patient-, technology- and operator-related factors. Conversion factors are expected to vary with patient size, X-ray energy distribution, field size and body part exposed and, thus, consideration of their application should be recognized in their use. A recent publication by Vano et al. [V3] indicated that, for old X-ray systems, a conversion coefficient of 0.21 mSv/(Gy cm^2) should be used and, for most recent systems with copper filtration, the coefficient should be 0.29 mSv/(Gy cm^2).

Table C12. Typical radiation dose air-kerma area product, effective dose and conversion factors for interventional procedures in adults

PCI: Prophylactic cranial irradiation; PTA: Percutaneous transluminal angioplasty; PTCA: Percutaneous transluminal coronary angioplasty; TIPS: Transjugular intrahepatic portosystemic shunt

Country or region	*Interventional procedure*	*KAP (Gy·cm²)* [a]	*Effective dose (mSv)* [a]	*Conversion factor E/KAP (mSv/(Gy·cm²))* [a]	*Method*	*Reference*
CARDIAC						
Belgium	PTCA	82	15.3	0.19 [b]	Multicentre study	[B21]
Croatia	PTCA	55.2			Multicentre study	[B34]
France	PCI	56.8 [a]			National study	[G2]
Iran (Islamic Republic of)	PTCA	44.5	9.6±1.2	0.22	Two centre study	[B2]
Ireland	PCI	78.3 (4.8–410.4)			All hospitals	[D1]
	Coronary angiography and PCI	91.5 (16–363.9)			All hospitals	[D1]
	Permanent pacemaker insertion	17.4 (0.45–171.9)			All hospitals	[D1]
Russian Federation	Cardiology therapeutic	84±79 (14–377)	17±16 (3–75)		Multicentre study	[S6]
Sweden	Adult cardiovascular			0.22	University hospital	[O5]
Switzerland	PCI	82 (3–283)			Multicentre study	[A8]
	Cardiac thermal ablation	128 (7–495)			Multicentre study	[A8]
	Coronary angiography and PCI	178 (27–487)			Multicentre study	[A8]
	Electrophysiology and cardiac thermo ablation	348 (8–1 442)			Multicentre study	[A8]
	PCI	57.6 [c]			Multicentre study	[S16]
	Chronic total occlusion	143 [c]			Multicentre study	[S16]
	Transcatheter aortic valve implantations	96.8 [c]			Multicentre study	[S16]
	Pacemaker implantation single chamber	2.4 [c]			Multicentre study	[S16]
	Pacemaker implantation double chamber	3.2 [c]			Multicentre study	[S16]
	Cardiac resynchronization therapy pacemaker	14 [c]			Multicentre study	[S16]
	Atrioventricular nodal re-entrant tachycardia	2.5 [c]			Multicentre study	[S16]
	Atrial flutter	6.6 [c]			Multicentre study	[S16]
	Atrial fibrillation	6.6 [c]			Multicentre study	[S16]

Country or region	*Interventional procedure*	*KAP (Gy·cm²)* [a]	*Effective dose (mSv)* [a]	*Conversion factor E/KAP (mSv/(Gy·cm²))* [a]	*Method*	*Reference*
			CEREBRAL			
Indonesia	Cerebral arteriovenous malformations embolization	211±113			One tertiary hospital	[R1]
	Coiling of cerebral aneurysm	315±147			One tertiary hospital	[R1]
	Intra-arterial thrombolysis	202±102			One tertiary hospital	[R1]
	Intra-arterial Nimodipine injection	97±87			One tertiary hospital	[R1]
	Juvenile nasopharyngeal angiofibroma embolization	129±37			One tertiary hospital	[R1]
Russian Federation	Cerebral therapeutic	145±104 (20–548)	17±12 (12–49)	0.10	Multicentre study	[S6]
Switzerland	Cerebral embolization	335 (24–1 345)			Multicentre study	[A8]
			ABDOMINAL			
Italy	Abdominal embolization[a]	143.8 (17.8–303.3)	20.3 (2–45.7)	0.14 (0.11–0.16)	One university hospital	[C14]
	Abdominal PTA[a]	144.3 (6.7–281.9)	21.3 (0.7–41.8)	0.12 (0.10–0.15)	One university hospital	[C14]
	Biliary drainage[a]	26.3 (3.2–236.3)	4 (0.5–47.4)	0.15 (0.14–0.19)	One university hospital	[C14]
	Biliary stent insertion[a]	58.2 (13.5–289.2)	8.9 (1.9–41.6)	0.15 (0.13–0.17)	One university hospital	[C14]
	Hepatic embolization[a]	177.7 (98.1–346.5)	27 (14.8–58.5)	0.15 (0.15–0.18)	One university hospital	[C14]
	Nephrostomy[a]	29.6 (28.5–47.1)	7.5 (7.2–11.6)	0.25 (0.246–0.253)	One university hospital	[C14]
	TIPS[a]	337.6 (93.3–422.2)	49.6 (13.4–70.1)	0.15 (0.147–0.166)	One university hospital	[C14]
Russian Federation	Abdominal (hepatic, pancreatic) therapeutic	233±221 (16–855)	42±40 (3–154)		Multicentre study	[S6]
Spain	Transjugular hepatic biopsy	45			Multicentre study	[R12]
	Biliary drainage	30			Multicentre study	[R12]
	Hepatic chemoembolization	303			Multicentre study	[R12]

Country or region	*Interventional procedure*	*KAP (Gy·cm²)* [a]	*Effective dose (mSv)* [a]	*Conversion factor E/KAP (mSv/(Gy·cm²))* [a]	*Method*	*Reference*
	Biliary drainage	68.9			Multicentre study	[V2]
	Hepatic chemoembolization	218.3			Multicentre study	[V2]
Switzerland	Hepatic embolization	463 (54–1 703)			Multicentre study	[A8]
	Biliary drainage and stent insertion	244 (5–1 375)			Multicentre study	[A8]
CHEST						
Indonesia	Bronchial artery embolization	133±87			One tertiary hospital	[R1]
PELVIC						
France	Iliac endovascular revascularization	21.5 (0.1–326)			Multicentre study	[M2]
Indonesia	Renal artery embolization	161±111			One tertiary hospital	[R1]
	Spinal artery embolization	184±114			One tertiary hospital	[R1]
	Uterine artery embolization	193±100			One tertiary hospital	[R1]
Russian Federation	Pelvic (renal, urogenital)	152±118 (32–562)	27±21 (6–101)		Multicentre study	[S6]
Spain	Uterine fibroid embolization	214			Multicentre study	[R12]
	Colon endoprosthesis	169			Multicentre study	[R12]
	Femoropopliteal revascularization	119			Multicentre study	[R12]
	Iliac stent	170			Multicentre study	[R12]
Switzerland	Iliac dilatation	344 (36–1 122)			Multicentre study	[A8]
PERIPHERAL						
Indonesia	Lower limb embolization	32±35			One tertiary hospital	[R1]
	Sclerotherapy	5.3±8.6			One tertiary hospital	[R1]
Italy	Peripheral PTA[b]	52 (34.3–67)	12.7 (8.3–15.7)	0.23 (0.21–0.25)	One university hospital	[C14]

[a] Empty cell indicates no data available.

[b] With extra Cu (0.21); while without Cu (0.18).

[c] Median values

C33. At least three procedures can be classified as PTCA procedures: namely, elective prophylactic cranial irradiation (PCI), coronary angiography followed by ad hoc PCI and chronic total occlusion. Variations between KAP values for PTCA procedures may be attributed to different categorization in a country or even centres. In a multicentre study, the three classifications were separately analysed and the median KAP values were found to be 62 Gy cm^2 for ad hoc PCI and 36 Gy cm^2 for elective PCI while for chronic total occlusion, the KAP values were significantly higher [S16].

C34. Omar et al. [O5] studied paediatric exposure during interventional procedures and provided conversion coefficients for E/KAP according to ICRP Publication 103 [I11]. The reported coefficients were 3.2, 2.2, 1.3, 0.8 and 0.4 mSv/Gy cm^2 corresponding to the five age groups <0.5, 0.5–2.5, 2.5–7.5, 7.5–12.5 and 12.5–18 years, respectively.

C35. Ubeda et al. [U1] provided conversion factors for diagnostic and therapeutic cardiac procedures according to patient age and weight. For the four age bands (<1, 1–5, 5–10 and 10–16 years), the median values were 1.70, 0.89, 0.58 and 0.40 mSv/Gy cm^2, respectively and for weight bands, the factors varied from 1.53 mSv/Gy cm^2 for <10 kg to 0.33 mSv/Gy cm^2 for 60 kg or more. The conversion factors for paediatric interventions decreased with age.

C36. A comprehensive review by Harbron et al. [H3] provided conversion factors according to different age or weight groups (table C13) and corresponding KAP values for paediatric cardiac interventional procedures (table C14).

Table C13. Conversion factors for cardiac catheterization [H3]

Age (years)	*Conversion factors E/KAP (mSv/(Gy cm^2))* [a]						
	[O6] [b]	*[K4]* [b]	*[S9]* [b]	*[A15]* [b]	*[D9]*	*[K6]* [c]	*[B9]* [c]
<1	2.72 (3.4 kg)	3.7/3.7	2.05/2.34		3.61/3.31	2.34/2.2/4	3.5/3.5
1	1.01 (9.2 kg)	1.9/1.9	0.82/1.16	1.8/1.4	2.19/2.17	1.27/1/4/2.7	1.6/2.6
5	0.49 (19kg)	1/1	0.42/0.64	0.9/0.7	0.91/0.87		0.8/1.3
10	0.29 (32.4 kg)	0.6/0.7	0.24/0.38		0.71/0.65		0.5/0.8
15	0.16 (56.3 kg)	0.4/0.4	0.13/0.22		0.41/0.39		0.3/0.4
30	0.13 (73.2 kg)		0.10/0.16				

[a] Empty cell indicates no data available.
[b] According to ICRP 60 [I9].
[c] According to ICRP 103 [I11].

Table C14. Typical radiation doses in air-kerma area product for paediatric cardiac interventional procedures by age and weight of patients [H3]

Parameters	*KAP (Gy cm²) for cardiac interventional procedures* [a]				*Reference*
	Patent ductus arteriosus occlusion	*Atrial septal defect/Patent foramen ovale occlusion*	*Pulmonary valvuloplasty*	*Aortic valvuloplasty*	
Age range (years)					
<1	5		4 (8)[b]	7	[G4]
1–4	7	9 (22)[b]	10	19	
5–9	13	14 (28)[b]	16	21	
10–15	33	39 (75)[b]	44	93	
>15	96 (110)[b]	89 (99)[b]	198	116	
Weight range (kg)					
<6.5	2.1				[B9]
6.5–14.5	1.4	1.8			
14.5–25.5	2.8	0.7			
25.5–43.5	4.3	1.1			
>43.5	10.8	2.8			
All weights	1.8	0.9			
0–10	1.4	2.9	1.1	1.5	[B22]
10–20	2.5	2.8	3.6	0.5	
20–30	4.1	4.7	7.5	14.7	
>30	20.9	12.7	50.9	44.5	
All weights	2.5	5	1.6	3.4	
5–12.5		5	2.4		[G7]
12.5–25	2.6	7.3	4.7		
25–45	5.6	16.2			
45–65		30.6			
>65		58.9			
All weights	3.5	10.4	4.1	11.2	

[a] Empty cell indicates no data available.

[b] Values in parentheses are taken from Verghese et al. [V5].

2. Specific observations

(a) *Skin and eye lens dose*

C37. Skin dose in terms of cumulative doses were reported to the UNSCEAR Global Survey by only two countries. Poland reported mean cumulative dose for head (cerebral) interventions of ~500 mGy, while Lithuania reported a mean cumulative dose of 790 mGy for PTCA procedures. Although data are scarce, high doses delivered to patient skin or eyes should not be ignored.

C38. Skin reactions are a well-known complication of radiation exposure. In recent decades, they have been recognized as a rare complication of interventional procedures [B8]. The frequency of major radiation injuries is estimated to be between 1:10,000 and 1:1,000,000 procedures, however, the risk is not known, mainly because it is assumed that these injuries are underreported [T8].

C39. Perry et al. [P7] investigated patient doses, using a calculation software, for 3,300 interventional and neuro-interventional procedures. For interventional procedures, 2.7% were found to exceed estimated skin dose of 5 Gy and all of them were performed in the abdominal/pelvic region. However, patient follow-up revealed no subsequent injury. For neuro-interventional procedures, 5.1% exceeded a skin dose of 5 Gy and 5 out of 49 patients reported temporary skin injuries [P7].

C40. Dose metrics, such as peak skin dose, are now available on modern machines while sophisticated software allows the presentation of real-time skin dose maps to facilitate dose management [T8]. High radiation doses used during therapeutic interventional procedures are related to tissue reactions. Brnic et al. [B34] recorded peak skin dose for PTCA procedures in four hospitals in Croatia. In 8% of selected patients, peak skin dose exceeded the 2 Gy threshold for erythema. No skin injuries were reported because a skin injury reporting system does not exist in Croatia; moreover, some skin injuries remain potentially unrecognized due to low clinical and risk awareness [B34].

C41. The International Atomic Energy Agency (IAEA) conducted a multinational study in eight countries in Asia. The peak skin dose was found to exceed 2 Gy for 20% of patients in this study [R4]. Peak skin doses for different therapeutic interventional procedures were reported in another multicentre study in the Russian Federation by Sarycheva et al. [S6]. For cerebral and cardiology procedures, peak skin dose ranged 0.1–3.8 Gy and 0.1–2.6 Gy, respectively, but never exceeded the 2 Gy threshold for abdominal and pelvic procedures. In another multinational prospective study by Tsapaki et al. [T7], peak skin dose was reported for diagnostic and therapeutic interventional procedures in 20 mainly low-income countries (nine in Eastern Europe, five in Africa and six in Asia). Peak skin dose exceeded the 2 Gy threshold for 20% of patients, 4.6% were in the range of 4 to 6 Gy, and 2% in the range of 6 to 10 Gy. No skin injuries were reported; however, they could not be ruled out [S6]. In a tertiary care facility in the United States with 7,500 interventional cardiology procedures per year, dose optimization efforts reduced the number of procedures with skin doses over 5 Gy by 80% from 2007 to 2017 [T8].

C42. Patient doses that may lead to eye lens reactions have been reported by Safari et al. [S1] for cerebral interventional procedures. The authors reported real-time eye lens doses during cerebral angiography procedures. As patient eyes may be exposed to primary radiation, in vivo measurements showed that eye lens dose may reach 2 Gy. In a study by Sanchez et al. [S5], 5 cases (16%) of the 31 therapeutic neuro-radiology procedures measured doses higher than 0.5 mGy to the left eye of the patient with a maximum dose of 2 Gy. At these levels of radiation, the possibility of radiation induced opacities or cataracts increases, especially in patients requiring several procedures. For the right eye, the dose measured was below 200 mGy, a value with a low probability to produce opacities.

C43. KAP value alerts were also suggested as dose indicators for skin reactions. For PTCA procedures, KAP values between 150 and 300 Gy cm^2 may correspond to peak skin dose of 2 Gy. In a multicentre study performed by Siiskonen et al. [S16] to establish European diagnostic reference levels, it was found that more than 30% of transcatheter aortic valve implantation and chronic total occlusion exceeded the 150 Gy cm^2 threshold and approximately 2% exceeded 500 Gy cm^2 [S16].

C44. Although uncertainty in risks for tissue reactions remains, medical practitioners should be made aware that the absorbed dose threshold may be as low as 0.5 Gy for circulatory disease to the heart or brain and also for cataract in the lens of the eye [I13]. During complex interventional procedures, doses of this order can be reached, thus, emphasis should be put on optimization of these procedures [I13].

C45. As tissue reactions may occur after interventional procedures due to high radiation dose, there is a need to better report patient exposure during interventional procedures and record patient follow-up. Future evaluation for the most complex interventional procedures should include:

– Dose to the lens of the eyes (in neuro-interventional radiology);
– Dose to the cerebrovascular system (in neuro-interventional radiology);
– Dose to the cardiovascular system (in interventional cardiology).

(b) *Influence of weighting factors of ICRP 60 and ICRP 103 to collective dose*

C46. The impact on effective doses for the different interventional procedures resulting from the changes of the ICRP tissue weighting factors [I9, I11] were reported by Hart et al. [H5] in the United Kingdom using a model developed by the National Radiological Protection Board (NRPB), resulting in a 2–3% decrease in the collective dose for conventional radiology, including dental, and for computed tomography and a 12–13% increase for interventional radiology. This was reflected in an overall 2% increase of the total collective dose due the ICRP weighting factors change (table C15).

Table C15. Impact of ICRP 60 and ICRP 103 tissue weighting factors on collective dose (man Sv) in the United Kingdom in 2008 [H5]

Category of examination	*Collective dose – E_{ICRP60}*	*Collective dose – $E_{ICRP103}$*
Radiography (including dental)	4 695	4 799
Computed tomography	16 302	16 723
Angiography (non-computed tomography)	1 213	1 187
Interventional (non-computed tomography)	2 037	1 985
Total	24 247	24 694

C47. In a recent study, Brambilla et al. [B30] estimated the effective dose and conversion factors with the KAP for PTCA using the ICRP 103 tissue weighting factors [B30]. The results were compared with those previously published in the literature (table C16). Estimates of E/KAP conversion factors based on ICRP 103 tissue weighting factors converged to a value of 0.33 mSv/Gy cm^2, which were about 30% higher than previous estimates based on ICRP 60. Also, conversion coefficients depended on individual installation variables, e.g., X-ray beam quality or protocol dependent (femoral or radial access), radiographic projections, phantom simulating the patient, the Monte Carlo code used for the simulation. Many of the new interventional systems use high filtration in the X-ray beam, and the conversion factors (mSv/Gy cm^2) may be higher than before [V3].

Table C16. Comparison of conversion coefficients calculated using ICRP 60 [I9] and ICRP 103 [I11] tissue weighting factors for coronary angiography and percutaneous coronary interventions

E/DAP_{PTCA} (mSv/(Gy cm^2))	*Tissue weighting factors*	*References*
0.13	ICRP 60 [I9]	[C13]
0.20	ICRP 60 [I9]	[C13] [a]
0.25	ICRP 60 [I9]	[B36]
0.33	ICRP 103 [I11]	[B30]

[a] Using the NRPB model with a mathematical phantom [H5].

3. Impact of technology on patient doses

C48. A study by Tsapaki et al. [T8] showed that the number of interventional procedures is steadily increasing as these procedures are usually performed on an out-patient basis with shorter recovery time, fewer complication risks for the patients and lower costs compared with open surgery. Moreover, fluoroscopy equipment with low-dose technology is expensive and not affordable for low-income countries [T8].

C49. Despite many efforts to reduce radiation dose, interventional procedures involve high patient exposure that may even lead to tissue reactions. Considerable variation in patient exposure has been reported in the literature and is related to patient factors (e.g., patient age, size, anatomy, co-morbidities), operator factors (e.g., training, experience), technology (e.g., flat panel detectors, image intensifiers, conventional or dedicated radiology table) and protocols used (e.g., fluoroscopy mode, cine mode, frame rate, beam collimation) [B35, G2, G6, H3, I14].

C50. Complexity of interventional procedures and its influence on patient irradiation has been studied for procedures performed for heart, liver and other body regions [B7, R12]. Complexity indices include consideration of anatomical characteristics (e.g., vessel tortuosity, angulation), type of treatment (stent, pre- or post-dilatation), type of injury (e.g., stenosis, obstruction), and puncture site (e.g., ipsilateral, contralateral, bilateral). The higher the complexity index, the higher the patient exposure. Using the complexity indices, procedures can be categorized as simple, medium and complex. Radiation doses for complex procedures were shown to reach up to 13 times those for simple procedures [R12]. Regarding the management of skin injury risk, technology has facilitated radiation dose reporting and analysis by software tools allowing installed on the equipment, that provides real-time skin dose or dose management tools that collect and analyse offline the skin dose distribution [T8].

C51. The most frequent interventional procedure is PTCA [U8] with a steady increase over time [N4]. However, in recent years, patients with arrhythmias, and with congenital and structural heart disease can also be treated in the catheterization laboratory. Currently, a variety of new imaging modalities that combine ionizing and non-ionizing radiation are available. Three-dimensional rotational angiography provides real-time 3D volume and cross-sectional images to visualize complex cardiac anatomy and navigation during the procedure and helps to reduce the amount of contrast media and radiation dose [K3, P5]. Electro anatomic systems enable conduct of complex electrophysiological procedures with very low radiation doses [G1]. Transoesophageal echocardiography has allowed ultrasonic image guidance for transcatheter procedures in septal and valvar structures. Special ultrasound probes allow application for neonates [P5].

C52. New techniques require the use of various complex technologies in hybrid rooms with many different professionals involved. Often, operators performing these interventional radiology procedures have no training in radiation protection [T8]. Nevertheless, training efforts for operators lead to reduction of patient radiation exposure and the risk of tissue reactions [F4, K11, S11].

V. DISTRIBUTIONS BY AGE AND SEX

A. UNSCEAR Global Survey data

C53. Few countries provided data to the UNSCEAR Global Survey on age and sex distribution. Figure C-III shows the analysis for age distribution for both sexes and all countries. The black line in the figure represents the average age distribution for all procedures. The age distributions are similar, with procedure frequencies peaking between the ages 65 and 74 years. Abdomen (TIPS) interventional procedures showed also a peak for younger ages (30 years), while thoracic interventions seem to be performed only on very young children.

C54. Eight countries provided data on age and sex distribution in interventional radiology. Table C17 presents the sex distribution for different interventional procedures. Males appeared to undergo more frequent (64%) interventional procedures than females (36%) for all interventional procedures apart from cerebral interventions, where there was almost no difference between the two sexes.

Figure C-III. Age distribution by interventional radiological procedures

PTCA: Percutaneous transluminal coronary angioplasty; TIPS: Transjugular intrahepatic portosystemic shunt

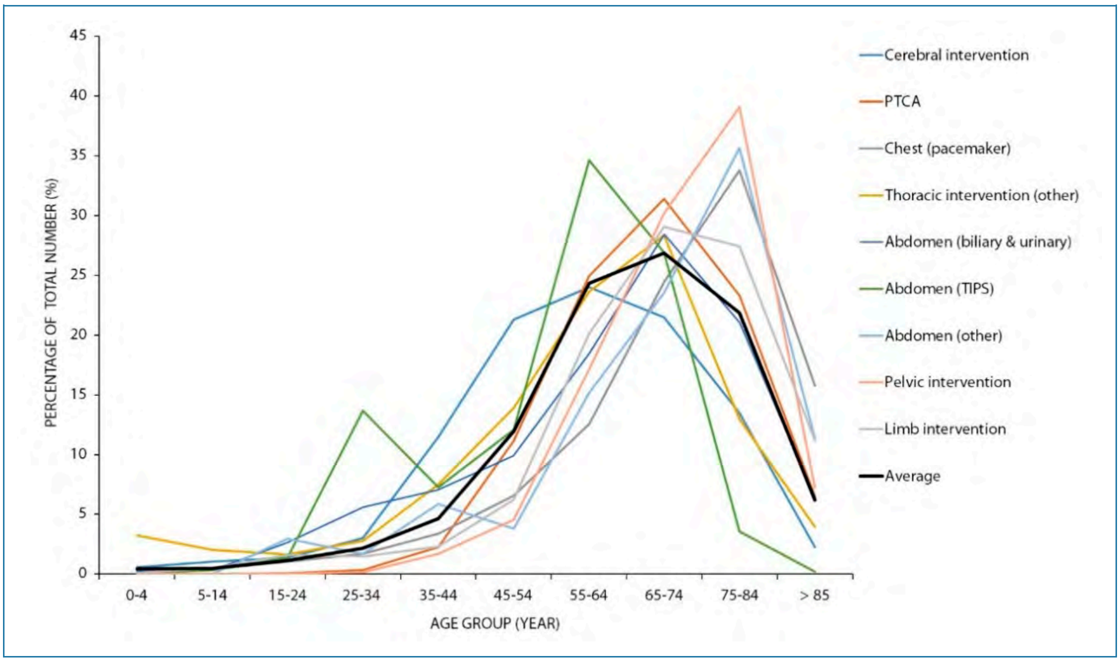


Table C17. Distribution of male and female patients undergoing interventional procedures

PTCA: Percutaneous transluminal coronary angioplasty; TIPS: Transjugular intrahepatic portosystemic shunt

Procedure	*Distribution (%)*	
	Male	*Female*
Cerebral intervention	46	54
PTCA	72	28
Chest (pacemaker)	58	42
Thoracic intervention (other)	53	47
Abdomen (biliary and urinary)	64	36
Abdomen (TIPS)	64	36
Abdomen (other)	72	28
Pelvic intervention	76	24
Limb intervention	62	38
Average	**64**	**36**

C55. Since PTCA is the interventional radiology procedure contributing most to the collective dose, a more detailed analysis was attempted. Age and sex distribution for PTCA procedures are presented in figure C-IV and table C18, respectively. PTCA procedures are most frequent between the ages of 65 and 74 years. Males undergo these procedures more frequently than females in all countries that submitted data to the UNSCEAR Global Survey.

Figure C-IV. Age distribution for PTCA procedures as reported to UNSCEAR Global Survey

PTCA: Percutaneous transluminal coronary angioplasty

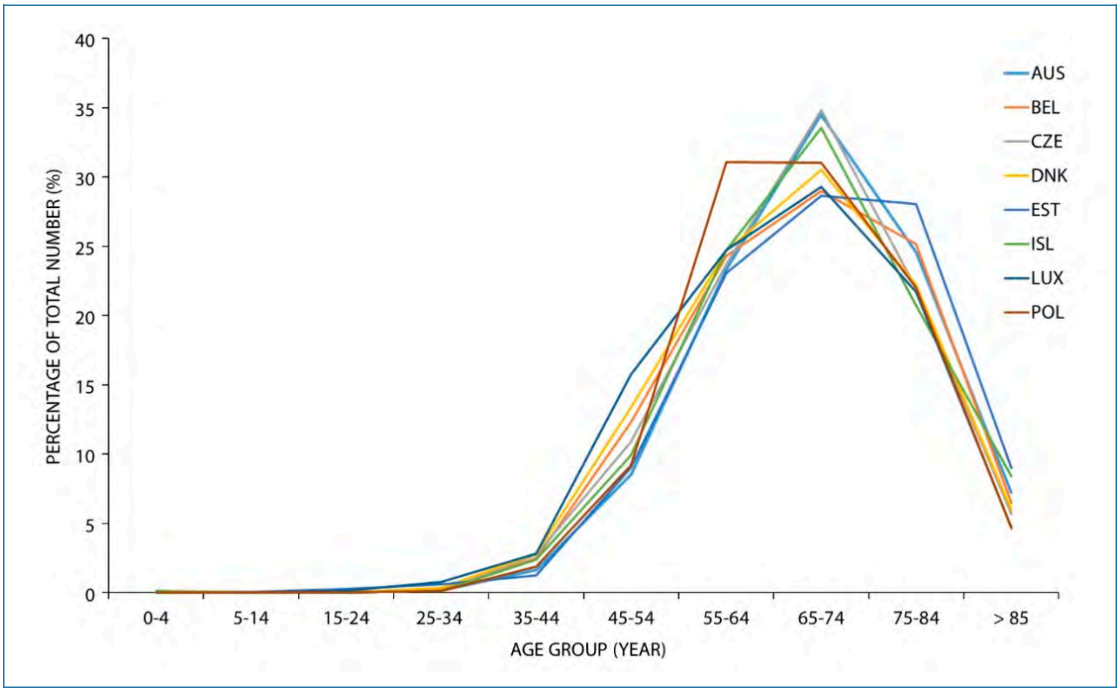


Table C18. Distribution of male and female patients undergoing PTCA procedures as reported to UNSCEAR Global Survey

PTCA: Percutaneous transluminal coronary angioplasty

Country	*Distribution (%)*	
	Male	*Female*
Australia	77	23
Belgium	73	27
Czech Republic	71	29
Denmark	75	25
Estonia	61	39
Iceland	76	24
Luxembourg	75	25
Poland	68	32

C56. Age groups were classified in the UNSCEAR 2008 Report [U9] as 0–15, 16–39 and 40 years and older. Table C19 shows a comparison of age distribution for PTCA procedures between the UNSCEAR 2008 Report [U9] data and the UNSCEAR Global Survey for five countries. No country reported significant numbers of PTCA procedures in the age group below 16 years. Table C19 also presents a comparison of sex distribution for PTCA procedures between the UNSCEAR 2008 Report [U9] and the current evaluation for the five countries. Men seemed to undergo PTCA procedures more frequently than women in the Czech Republic, Romania and Spain, while data in the UNSCEAR 2008 Report [U9] showed that the distribution of procedure frequencies for the two sexes were similar.

Table C19. Comparison of age and sex distributions for PTCA procedures between UNSCEAR Global Survey and UNSCEAR 2008 Report [U9]

PTCA: Percutaneous transluminal coronary angioplasty

Country	*Source*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–39 years*	*40+ years*	*Male*	*Female*
Czech Republic	Current evaluation	0	1	99	71	29
	UNSCEAR 2008	0	4	96	50	50
Iceland	Current evaluation	0	0	99	76	24
	UNSCEAR 2008	0	1	99	79	21
Luxembourg	Current evaluation	0	2	98	75	25
	UNSCEAR 2008	0	3	97	73	28
Romania	Current evaluation	0	2	98	60	40
	UNSCEAR 2008	0	28	71	44	56
Spain	Current evaluation	0	2	98	76	24
	UNSCEAR 2008	0	6	94	44	56

C57. Figure C-V presents the age distribution for cerebral interventions. Age distribution differs from the mean of all interventional procedures, with patients between 55 and 64 years of age undergoing cerebral interventional procedures more frequently. Table C20 shows no major differences in frequencies between the two sexes (mean values for male 46% and for female 54%).

Figure C-V. Age distribution for cerebral interventional procedures

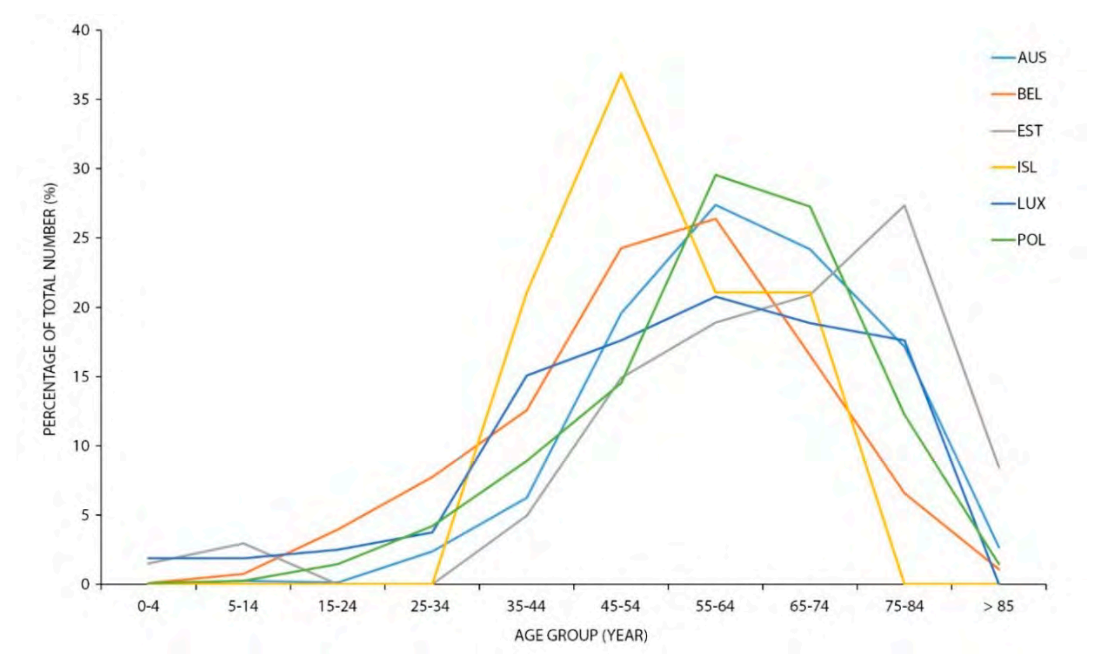


Table C20. Distribution of male and female patients undergoing head (cerebral) interventional procedures as reported to UNSCEAR Global Survey

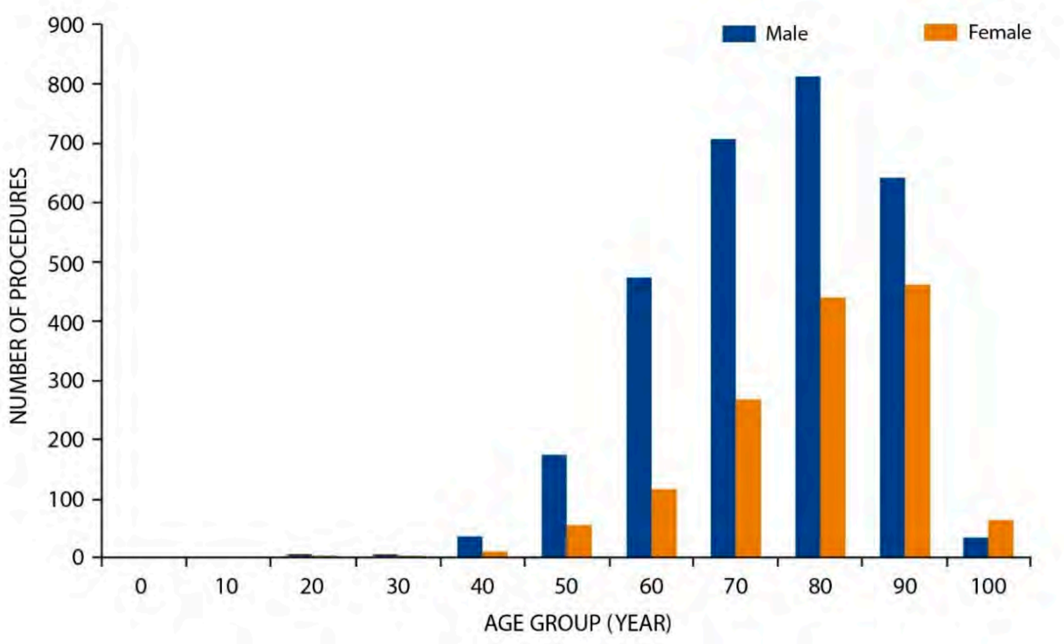
Country	*Distribution (%)*	
	Male	*Female*
Australia	39	61
Belgium	34	66
Estonia	53	47
Iceland	63	37
Luxembourg	38	62
Poland	45	55
Mean	**46**	**54**

B. Literature review data

C58. The age distribution of patients undergoing interventional procedures is rarely reported in the literature. In Italy, Peruzzo Cornetto et al. [P8] reported that 12% of the interventional cardiology procedures were performed on patients younger than 60 years of age, 56% for patients aged between 60 and 79 years and 32% for patients older than 80 years. No significant differences were found in the frequency distributions for cardiac interventional procedures when age and sex were compared.

C59. In Luxembourg, Shannoun et al. [S12] showed that the distribution of interventional procedures shifted to older patients, with about 80% of the interventions performed on patients between 50 and 80 years. Further, interventional procedures (cardiac or vascular) were more frequent for men than women [S12]. In Romania, a study by Girjoaba and Cucu [G5] reported that most patients undergoing interventional procedures were over 40 years old. For the age group 16–40, for all angiographic procedures (diagnostic and therapeutic), 20% were cerebral angiographies and 18% pelvic angiographies. In Spain [S4], twice as many men as women underwent interventional cardiac procedures, with average ages of 69 and 73 years, respectively. Only 2% of patients were between the age of 20 and 40 and 30% of patients between 40 and 60 (figure C-VI).

Figure C-VI. Age and sex distribution of interventional cardiac procedures for a sample of 4,301 procedures performed in Spain (2014–2015) [S4]



C60. In Costa Rica, a study by Ubeda et al. focused on the estimation of the collective dose to the paediatric population deriving from interventional cardiac procedures (diagnostic and therapeutic) [U2]. The distribution of the dose according to age showed that 65% of the collective dose due to interventions were performed to patients between 10 and 16 years. Nonetheless, most paediatric interventional procedures in this study were performed on children aged less than 5 years.

C61. In Kenya [K13], Korir et al. reported that 20% of the cardiac interventional procedures were performed on children; a number higher than that reported by Tsapaki et al. [T7]. The authors stated that in high-income countries 10% of the interventional procedures were performed on children while in low-income countries it was only 5%. An explanation might be that the majority of the procedures in Kenya were diagnostic ones [K13]. In the United States, although paediatric procedures were not included in the estimation for interventional procedures, it was reported that less than 1% of cardiac procedures were performed on children [N1].

C62. In a multinational study by Tsapaki et al. [T7], the annual diagnostic and therapeutic interventional procedures in 20—mostly low-income—countries (nine Eastern European, five African and six Asian) were reported for patients under the age of 15 years; however, without giving more details on patient age distribution. The percentage of children of the total annual activity varied enormously between participating hospitals (0.2–35.4%), while three of the 20 countries did not report paediatric procedures in the general hospitals chosen for the study. Of the procedures in three paediatric hospitals (two from Africa and one from Europe), 2–36% were therapeutic procedures.

C63. Rehani et al. [R4] reported information on paediatric cardiology procedures in nine Asian countries (table C21). In all countries except Sri Lanka (32%) the contribution of paediatric procedures was lower than 10%.

Table C21. Contribution of paediatric diagnostic and therapeutic interventional cardiology procedures in nine countries in Asia [R4]

Country	*Fraction of paediatric interventional procedures to all interventional procedures (%)*
Kuwait	4.8
Lebanon	0.5
Malaysia	2.7
Pakistan	9.1
Philippines	4
Qatar	2.5
Sri Lanka	32
Syria	1.5
Thailand	0.2

VI. STAFF AND DEVICES

C64. The numbers of professionals performing interventional procedures per million of population submitted to the UNSCEAR Global Survey are presented in table C22. There are three main groups of staff: interventional radiologists, interventional cardiologists and other physicians. The data on the number of professionals show large variations between countries. This has a direct impact on the number of interventional procedures performed in a country. However, the recording of professionals differs from country to country. The number of interventional radiologists in Finland includes both radiologists and cardiologists. The unusually high number of interventional cardiologists in Sweden is explained by the fact that the reported number of interventional cardiologists includes all licensed cardiologists of whom an unknown fraction is actually involved in cardiac interventional radiology. The United Kingdom counted interventional staff with general practitioners and radiologists, while in Luxembourg, interventional radiology is not an official medical specialty.

C65. Interventional procedures, according to the UNSCEAR Global Survey [U11], are performed with the same equipment as angiography examinations. Thus, the term “angiography systems” is used also for the systems used for interventional procedures. The detailed numbers of angiography systems and devices per million of population are presented in table B29 and the number of angiography systems by country is displayed as frequencies per million population in figure C-VII. Data on angiography systems from the Republic of Korea and Switzerland are included in fluoroscopy.

Figure C-VII. Number of angiography systems by country per million population as reported in UNSCEAR Global Survey

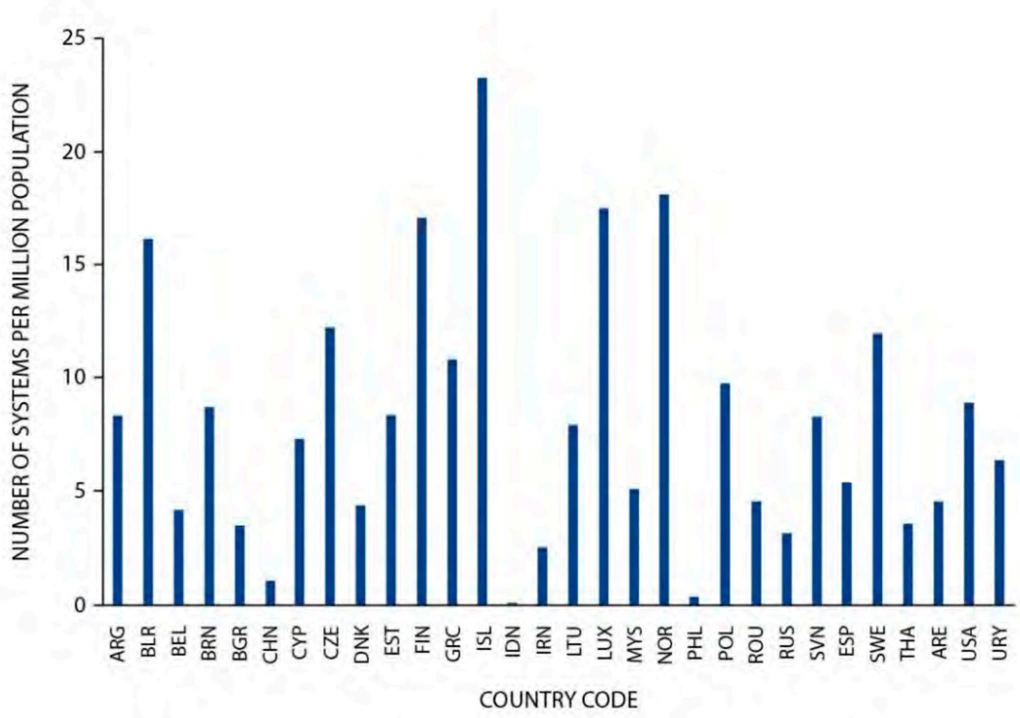


Table C22. Number of interventional staff as absolute numbers and as frequencies per million population as reported to UNSCEAR Global Survey

Country	*Interventional radiologists* [a]		*Interventional cardiologists* [a]		*Other physicians conducting interventional procedures* [a]	
	Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Argentina			487	12		
Australia	50	2	300	13	4 010	169
Belgium			504	45	1 174	105
Brazil			651	3		
Belarus	90	9	9	1	8	1
Cyprus	2	2	27	28	100	105
Czech Republic	137	13	361	34	83	8
Estonia	3	2	15	11		
Finland	244	44				
France			1 100	17		
Greece	208	19	514	47		
Hungary	306	31	49	4.9	164	16.7
Indonesia	2	0.008	7	0.03	3	0.01
Lithuania	37	13	63	22		
Luxembourg			20	35		
Malaysia			13	0.4		
Philippines	14	0.1			5	0.05
Romania	166	8	301	15	266	14
Russian Federation			847	6		
San Marino	2	61			3	92
Slovenia	20	10	30	15		
Spain	305	7	411	9		
Sweden			1 700	170		
Switzerland	250	30	170	20	500	59
Thailand	145	2	270	4		
United Arab Emirates	38	4	76	8	99	11
United Kingdom	433	7	660	10		
United States	2 967	9	3 255	10		

[a] Empty cell indicates no data available.

C66. The European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry published the density data (number of systems in use per million population) for angiography equipment in 2016 [C11]. Accordingly, angiography equipment uses X-rays in combination with a contrast agent (chemical substances used to enhance specific structures in images) in order to visualize blood vessels, particularly the coronary arteries. In this sense, angiography equipment is used for both angiography and interventional procedures. In Western Europe, the average number of X-ray angiography systems per million population decreased from 15.6 in 2013 to 13.4 in 2016 while in Central and Eastern Europe, the average number showed a slight increase [C11], which might impact the number of procedures performed in the future because of the wider access to this technology.

C67. The age profile of equipment has deteriorated slightly in Western Europe since 2013, but showed a marked improvement in Central and Eastern Europe [C11]. The X-ray angiography equipment age profile has also deteriorated in the Russian Federation, with the percentage of “six years and older” systems increasing from 32% to 40%. In China, X-ray angiography systems which are “five years old or less” have increased to 65% since 2013.

C68. Maurel et al. [M2] performed a multicentre study in France for iliac interventional procedures and found a decrease in the number of procedures performed in a radiological suite with a simultaneous increase for the procedures performed in endovascular theatre, mainly due to improvement and modernization of equipment. Advanced imaging techniques offer better image quality and allow operators to perform more complex procedures (e.g., for obese patients, steep angles). However, it is not necessarily related to lower radiation doses [M2]. In Slovenia, Zontar et al. [Z1] observed that 80% of the interventional procedures are performed in university medical centres while the rest are performed in two general hospitals and one private clinic. In Switzerland, Samara et al. [S2] studied the situation and found that more than 50% of the interventional procedures are performed in university hospitals and rarely in private institutes (8%).

VII. TRENDS

C69. Although the UNSCEAR Global Survey did not cover all interventional procedures in detail, it is noted that the number of interventional procedures performed outside the traditional radiological or cardiological suite is increasing. A clear demonstration of this trend was observed in Spain. The total number of procedures was 400,853, including vascular surgery, with a global distribution of 45% diagnostic and 55% therapeutic interventional procedures.

C70. As described in the UNSCEAR 2008 Report [U9], interventional procedures dramatically increased in frequency, principally because of the numerous benefits for the patient, the significant development in equipment and the number of trained interventionists. A steady increase was observed in PTCA procedures by, on average, 6.7% across 29 countries in Europe between 1990 and 2003 [U9].

C71. Four countries presented data on trends in exposure from interventional radiology:

(a) In Luxembourg, Shannoun et al. [S12] observed an increase of the effective dose per caput from 0.05 mSv in 1994 to 0.12 mSv in 2002 for therapeutic interventional procedures;

(b) In Norway, Borretzen et al. [B25] calculated an increase of 12% between 1993 and 2002 for interventional procedures;

(c) In Switzerland, Samara et al. [S2] reported an increase of interventional procedures between 1998 and 2008. The number of therapeutic interventional procedures per 1,000 population increased from 3.8 in 1998 to 6 per 1,000 population in 2008. The effective dose per caput also increased from 0.04 to 0.07 mSv. A very small increase in therapeutic interventional procedures was observed between 2008 and 2013 but this can be attributed to the different methodology applied [L2, S2];

(d) In the United Kingdom, Hart et al. [H5], observed an increase in interventional procedures from 0.9 to 1.4% between 1998 and 2008.

C72. A multinational study by Tsapaki et al. [T7] found the number of interventional procedures to have increased between 2004 and 2007. The rate of increase ranged between 6 and 196% (table C23). Three of the 11 countries had more than a 100% increase, another four between 50 and 91%, and the remaining four had a 6 to 24% increase. One country showed the largest rate of increase (196%) because five of the 13 catheterization laboratories for which data on workload were provided did not exist in 2004.

C73. In contrast, Smith-Bindman et al. [S18] indicated a decrease of angiography/fluoroscopy procedures in the United States between 1996 and 2010 in a retrospective analysis of electronic records of members of six large integrated health systems from different regions in the country. As the grouping of the examinations includes both angiography and fluoroscopy procedures, it cannot be concluded whether the number of therapeutic interventional procedures is, indeed, declining or the number of fluoroscopy procedures is declining.

C74. In Germany between 2007 and 2014, the mean effective dose per procedure decreased for angiography and interventional procedures, as reported by Nekolla et al. [N3]. However, the effective dose per caput remained practically constant with a mean effective dose of around 0.3 mSv per caput indicating that the number of interventions increased.

Table C23. Comparison of annual number of interventional procedures between 2004–2007 [T7]

Country	*2004*	*2007*	*Increase (%)*
Algeria	3 839	4 641	21
Armenia	496	1 062	114
Bosnia and Herzegovina	579	1 100	90
Bulgaria	5 910	7 357	24
Croatia	1 795	2 975	74
Kenya	192	337	76
Lebanon	2 050	4 627	126
Lithuania	25 781	27 440	6
Pakistan	9 613	28 475	196
Syria	4 067	4 565	12
Thailand	2 059	3 736	81

VIII. SUMMARY

C75. A detailed survey of interventional procedure practice across the world was undertaken and the submitted data has been analysed to estimate for each country the frequency of procedures and the related effective dose per procedures.

C76. The uncertainty in each of these estimations arises from a number of sources. Some countries conducted a survey of a limited number of clinics and hospitals and then extrapolated the data to the whole of the country. This can lead to an over- or underestimate of the true number depending on how representative the sample sites were of the whole country. Secondly, the reporting of interventional procedures differs from country to country, which can further lead to an over- or underestimation of the frequencies of the different examinations and procedures. Thirdly, as far as it concerns information on radiation dose per procedures, data are often not available from national surveys. Uncertainties on radiation doses depend on several factors such as technology, operator training and procedure complexity. Effective doses were estimated using conversion coefficients from ICRP 60 [I9] as conversion coefficients calculated with ICRP 103 [I11] for all interventional procedures were scarce. This needs to be taken into account for any future comparisons.

C77. Despite these limitations, the UNSCEAR Global Survey results indicate that the frequency of interventional procedures has significantly increased worldwide. Although interventional procedures are less frequent than radiography or computed tomography examinations, they generally involve high radiation doses and make a significant contribution to the collective dose (8% of the collective dose, figure II). The mean frequency of interventional procedures for the current survey is 13 procedures per 1,000 population in high-income countries, while ~2 procedures per 1,000 population were reported in the UNSCEAR 2008 Report [U9]. The collective dose was estimated at 41,000 man Sv in the UNSCEAR 2008 Report [U9], whereas in this evaluation it is estimated to be 334,000 man Sv. The age distribution of interventional procedures peaks between the ages of 65 and 74 years. Male patients undergo cardiac interventions at around two to three times the rate of female patients.

C78. Frequencies of interventional radiology procedures per 1,000 population vary considerably between countries, according to data in the literature and in the UNSCEAR Global Survey. PTCA remains the most frequent interventional procedure. However, with increasing numbers of interventional procedures performed outside hospital cardiology and radiology departments, future surveys should broaden the types of procedures included for better global estimations.

C79. Interventional radiology procedures in future surveys should include procedures with both diagnostic and therapeutic intent since procedures frequently begin as diagnostic but may move to intervention as dictated by the needs of the particular case. Moreover, the data from this survey indicated that the number of procedures performed outside radiology and cardiology departments is increasing. Radiological equipment used for interventional procedures should be identified as interventional X-ray systems. This standardization of terminology for interventional procedures in future surveys would improve both data collection and the robustness of data analysis.

C80. Finally, the high radiation doses associated with interventional procedures may lead to tissue reactions. As interventional procedures become more complex, higher radiation doses should be expected. Future surveys should include estimations of radiation dose to the skin, the lens of the eyes, and the cerebrovascular and cardiovascular systems.

APPENDIX D. LEVELS AND TRENDS OF EXPOSURE IN NUCLEAR MEDICINE

I. INTRODUCTION

D1. Nuclear medicine is primarily a functional imaging modality that uses radioactively labelled radiopharmaceuticals to localize and visualize specific body tissues, including pathological lesions. The images are obtained by detecting the gamma rays emitted by the patient, using a gamma camera, or by detecting the annihilation photons using positron emission tomography (PET). Tomographic images can be obtained from a series of images, using a gamma camera rotated around the patient, in a procedure known as single photon emission computed tomography (SPECT).

D2. Although the images provide extensive functional information, they often present poor anatomic structural information. The advantages of combining nuclear medicine images with radiological images to improve the anatomic localization of abnormalities initially led to software-based registration methods to superimpose images from multiple modalities acquired independently of each other. This was effective for rigid objects such as the skull (and thus for the brain), but less so for other parts of the body. Alternatives to software-based fusion are now available through instrumentation that combines two complementary imaging techniques within a single gantry, an approach called "hybrid imaging" combining computed tomography to SPECT/CT or PET/CT, which can acquire co-registered structural and functional information within a single procedure. These systems allow simultaneous separate imaging by the two modalities while the patient is in exactly the same position on the imaging table. The data are complementary, allowing computed tomography to accurately localize functional abnormalities and SPECT or PET to highlight areas of abnormal metabolism. The computed tomography images also facilitate accurate attenuation correction of the nuclear medicine images. More recently, hybrid systems using magnetic resonance imaging PET/MRI have become available commercially, which eliminates the additional radiation exposure from the computed tomography scan.

D3. The first SPECT/CT systems featured a four-row computed tomography detector unit with a rotation time of 23 seconds. The first combined SPECT/CT system that incorporated a fully-clinical computed tomography system was released in 2004 [B15]. Initially, this system was equipped with a two-slice computed tomography scanner but was later available with six or 16-slice computed tomography scanners. Similar systems quickly became available from all major medical imaging manufacturers and are now available with 64-slice computed tomography systems with automatic exposure control and iterative reconstruction to optimize resolution and to minimize radiation dose. A SPECT based on cadmium zinc telluride detector was introduced specifically for cardiac applications in 2009 [B15]. The main benefit of such detectors - over standard scintillator detectors -is the much higher energy resolution providing improved discrimination of scattered photons, thus improving the image contrast and potentially leading to a reduction in administered radiopharmaceutical activity. SPECT/CT systems are increasingly replacing stand-alone SPECT systems although a number of nuclear medicine procedures, particularly dynamic studies, require only the gamma camera images, so SPECT-only systems will remain clinically useful.

D4. The first prototype PET/CT became operational in 1998, incorporating a single-slice spiral computed tomography and a rotating bismuth germanate based PET system. Torso imaging using the prototype PET/CT took one hour or more [B16]. The first commercial PET/CT was announced in early 2001. Over the years, PET/CT designs have evolved following the advances in CT and PET instrumentation. The introduction of lutetium oxyorthosilicate and gadolinium silicate based PET systems, which could be operated with short coincidence time windows (4.5–6 ns) and higher lower-energy thresholds (400–450 keV) compared with 10–12 ns and 350 keV for a typical bismuth germanate based PET system, significantly improved whole-body image quality. The availability of fast scintillators with high stopping power such as lutetium oxyorthosilicate and lutetium-yttrium oxyorthosilicate enabled time-of-flight PET to become commercially viable in 2006. Time-of-flight PET has the potential to improve image quality or reduce image acquisition time. This gain is related to the object size, and the largest gain can be expected in heavy patients, which suffer most from poor image quality [B16]. The axial field of view has been also extended, typically, 16 cm to over 20 cm permitting shortened acquisition times and thus improving patient throughput or reducing the administered activity for the same acquisition time. PET systems in which the axial field of view is extended to cover the full length of the patient are currently undergoing clinical trials [C8]. Such PET systems have the potential of a 40-fold gain in sensitivity permitting whole-body PET acquisitions in 15–30 seconds, compared to 10–20 minutes. Alternatively, the administered activity could be reduced by 40% for the same acquisition time, with a corresponding reduction in patient dose.

D5. The development of combined PET/MRI systems started in the late 1990s. However, it was not until 2006 that the first simultaneous MRI and PET images of a human brain were acquired, involving a PET detector ring inside a 3 Tesla MRI system [B14]. Paediatric imaging is a key application for PET/MRI because of the lack of the additional ionizing radiation dose from the computed tomography component and also because of the advantage/convenience of a single examination providing both functional and anatomic information. The role of PET/MRI in routine clinical practice is still being established. In 2015, approximately 70 systems were reported worldwide, and it has remained primarily a research tool [B4]. Neurological applications stand to benefit greatly from PET/MRI investigations. Similarly, many cardiac studies have suggested that PET/MRI may replace PET/CT [B4].

D6. Radiopharmaceuticals labelled with ^{99m}Tc remain the mainstay of clinical nuclear medicine. About 80% of radiopharmaceuticals in clinical use are still ^{99m}Tc based, particularly for cardiac, skeletal, renal and lung imaging. The most commonly used PET radiopharmaceutical is ^{18}F-fluoro-2-D-deoxyglucose, (^{18}F-FDG), a radiolabelled analogue of glucose. FDG PET/CT has now become the main imaging modality in diagnosis, staging, restaging and prognostication of many cancers. However, the development in nuclear medicine imaging technology has been matched by the introduction of new radiopharmaceuticals into routine clinical use. Many of these are labelled peptides which have been used for both diagnosis and treatment of disease, leading to the term “theranostics” [B11].

D7. Radioiodine (^{131}I) has been used throughout the world for decades in the treatment of both hyperthyroidism and thyroid cancer. In some countries this remains the only radionuclide therapy in use; nevertheless, nuclear medicine therapy continues to evolve at an increasing rate. Radiolabelled somatostatin analogues were first reported in 1989 and, a few years later, targeted radionuclide therapy of neuroendocrine tumours with somatostatin analogues followed. The somatostatin conjugates DOTATOC and DOTATATE, labelled with ^{111}In and ^{68}Ga for SPECT and PET imaging, respectively, and with ^{90}Y and ^{177}Lu for targeted radionuclide therapy, are routinely used in many hospitals [M12]. The ^{68}Ga and ^{177}Lu combination has more recently been extended to advanced prostate cancer treatment using labelled, prostate-specific membrane antigen. Lutetium-177 has the advantage of a 208 keV gamma emission enabling quantitative SPECT/CT imaging of the distribution of the radiopharmaceutical leading to calculation of the internal dose distribution within an accuracy of ± 10%. Modern gamma cameras offer software packages for calculating patient-specific radionuclide treatment planning for routine clinical usage. Certain radionuclide therapies, such as selective internal radiation therapy using ^{90}Y-microspheres, require the radiopharmaceutical to be administered under fluoroscopic control. This will necessitate an additional radiation dose from the angiography.

D8. Radionuclides have been used for many years in the treatment of widespread bone metastases. This treatment has involved ^{89}Sr-chloride or ^{153}Sm-ethylene diamine tetramethylene phosphonate and, more recently, ^{223}Ra-dichloride. The latter radionuclide is an alpha-emitter which was initially used in the treatment of metastatic prostate cancer and, more recently, of metastatic breast cancer, with confirmed patient survival benefits. Other therapies involving alpha-emitting radionuclides are currently under development.

II. RECAPITULATION OF PREVIOUS UNSCEAR REPORTS

D9. The Committee estimated the worldwide total number of nuclear medicine procedures for 1985–1990, 1991–1996 and 1997–2007 [U5, U6, U9] to be 24, 32.5 and 32.7 million annually, corresponding to annual frequencies of 4.5, 5.6 and 5.1 per 1,000 population, respectively. The 1997–2007 global total estimate of procedures was distributed among the health-care levels of the model as follows: *(a)* 89% in HCL I countries (at a mean rate of 22 per 1,000 population); *(b)* 10% in HCL II countries (1.0 per 1,000 population); and *(c)* <1% collectively in countries of HCLs III and IV (<0.05 per 1,000 population) [U5, U6, U9].

D10. There were significant variations in the national frequencies between countries with the same health-care level. An overall decrease in the average value for HCL I countries observed in 1997–2007 was likely to be due to underreporting during that survey period. Several cases of clear increases in the numbers of procedures were seen in some countries, and some other countries (e.g., Canada and United States) that had previously reported high values did not report to the current UNSCEAR Global Survey.

D11. The global annual collective effective dose for 1997–2007 was estimated to be about 202,000 man Sv, which equated with an average per caput effective dose of 0.031 mSv [U9]. These estimates were comparable with the values for 1991–1996 (150,000 man Sv and 0.03 mSv) [U5] and 1985–1990 (160,000 man Sv and 0.03 mSv) [U6]. The distribution of collective dose among the health-care levels in 2007 was: *(a)* 92% in HCL I countries (giving a mean per caput dose of 0.12 mSv), *(b)* 8% in HCL II countries (corresponding to 0.005 mSv per caput) and *(c)* <1% in HCL III and IV countries (0.00005 mSv per caput). Globally, practice was dominated by bone, cardiovascular and thyroid procedures, with the last being particularly important in HCL III and IV countries.

D12. Overall, during 1997–2007 the use of diagnostic nuclear medicine procedures remained minor in comparison with the use of diagnostic radiological examinations. The annual numbers of nuclear medicine procedures and their associated collective doses were only 0.9 and 5.1%, respectively, of those for diagnostic radiological examinations. However, the mean dose per diagnostic procedure was larger for nuclear medicine (6.0 mSv) than for diagnostic radiology (1.3 mSv) [U9].

D13. The use of therapeutic nuclear medicine varied significantly between countries. Global annual numbers of radiopharmaceutical therapeutic treatments were broadly estimated from the limited national survey data using a global model. The uncertainties in these data were known to be significant. The worldwide total number of treatments for 1997–2007 was estimated to be about 0.87 million, corresponding to an average frequency of 0.14 treatment per 1,000 population [U9]. Radionuclide therapy during the period was less common than teletherapy (4.7 million treatments) but was similar in number to brachytherapy (0.43 million treatments).

III. FREQUENCIES OF NUCLEAR MEDICINE PROCEDURES

D14. This section presents information on trends in the frequencies of nuclear medicine procedures resulting from the submissions to the UNSCEAR Global Survey (2009-2018) also summarized in electronic attachment D-1. Furthermore, the data were supplemented with information from reviews of the published literature.

A. UNSCEAR Global Survey data

D15. Altogether, 49 countries submitted data for nuclear medicine procedures (diagnostic/ therapeutic) to the UNSCEAR Global Survey. Unfortunately, the data for many countries were incomplete and did not provide a good basis for the evaluation of population doses, i.e., collective effective doses and per caput effective doses. Data on the frequencies of examinations (i.e., annual numbers of procedures) were more complete; however, the submitted dose data (administered activity and dose length product (DLP) values, or typical effective doses) were scarce. Some countries submitted total frequencies but did not provide numbers for the individual procedures, while other countries provided procedure frequencies but no data on doses. Of the 49 country submissions, 36 provided individual procedure frequencies, 33 provided average administered activities, 8 provided DLP values for the computed tomography component of SPECT/CT procedures and 11 provided DLP values for the computed tomography component of PET/CT procedures.

D16. Table D1 shows the frequency of nuclear medicine procedures and separately for PET procedures. However, few countries submitted only the total number of procedures without differentiation between SPECT and PET procedures. Further, the table includes a comparison with the frequency of nuclear medicine procedures reported in the UNSCEAR 2008 Report [U9], although a number of countries did not provide data for the earlier survey, no comparison was possible for these countries.

D17. The frequency of nuclear medicine procedures per 1,000 population has fallen significantly in a number of European countries, while increasing significantly in others. The average change in frequency of nuclear medicine procedures since the UNSCEAR 2008 Report [U9] was +14% (excluding the very high percentage change recorded in Belarus) although the population-weighted change was only 3%. Seven of the 49 countries did not have access to PET. Table D1 also shows that PET procedures accounted for an average of 18% of nuclear medicine procedures (range 1–67%) in the countries that reported such data.

D18. Figure D-I displays the frequency of all nuclear medicine diagnostic procedures from table D1 in graphical form, which clearly highlights the very wide variation in study frequency across the world, with the highest frequencies occurring in Western Europe, Canada and the United States.

Table D1. Comparison of diagnostic nuclear medicine procedures frequency per 1,000 population reported to UNSCEAR Global Survey with UNSCEAR 2008 Report [U9]

PET: Positron emission tomography

Country	*Procedures (frequency per 1 000 population)* [a,b]			*Change compared to UNSCEAR 2008 Report (%)*	*Proportion of PET to total (%)*
	Current evaluation		*UNSCEAR 2008*		
	Total	PET			
Argentina	15.4	2.1			14
Australia	26.2	3.4	19	38	13
Bangladesh	0.1	0.007			6
Belgium	44.8	4	52.8	−15	9
Brazil	4.9	0.1			2
Bulgaria	3.7	1.3			34
Belarus	12	0	0.4	2 900	0
Canada	39.4	2.5			6
China	1.8	0.4			20
Croatia	9.9	1.8	8.6	15	18
Cyprus	5.7	0			0
Czech Republic	15.4	2.6	12.6	22	17
Denmark	30.2	8.2			27
Estonia	4.2	1	2	106	23
Finland	7.5	1.6	7.7	−3	22
France	16.8	3.6	14	20	21
Germany	31.8	1.7	46.7	−32	5
Greece	13.3	0.5	16.7	−20	4
Hungary	48.9	4.1	17.9	173	8
Iceland	4.3	0	14.1	−69	0
Iran (Islamic Republic of)	7.6	0.04			1
Italy	40				
Japan	13.6	4.5	10.2	33	33
Lebanon	4.6	2.1			45
Lithuania	7.1	0.6			8
Luxembourg	24.1	4.2	34.5	−30	17
Madagascar	0.01	0			0
Malaysia	1.5	0.9			60
Montenegro	3	0			0
Netherlands	25.2	4.6	24.3	4	18
Niger	0.04	0			0

Country	*Procedures (frequency per 1 000 population)* [a,b]			*Change compared to UNSCEAR 2008 Report (%)*	*Proportion of PET to total (%)*
	Current evaluation		*UNSCEAR 2008*		
	Total	PET			
North Macedonia	1.5	1	4	−61	67
Norway	8.4	2.3	10.9	−23	27
Pakistan	0.9	0.04			5
Philippines	0.2	0.02			10
Poland	5.4	1.2	3	79	23
Romania	1.9	0.5	2.8	−33	25
Russian Federation	3.4	0.2			6
Saudi Arabia	3.2	0.003			0
Spain	13.4	1.4	16.9	−20	10
Sudan	0.2				0
Sweden	10.3	2.1	10.8	−5	21
Switzerland	16.7	5	11.7	43	30
Thailand	0.9	0.05			5
United Arab Emirates	1.5	0.3			21
Ukraine	6.8	0.1			1
United Kingdom	9.9	2.4			24
United States	42.1	5.8			14

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when available; otherwise, cells have been kept empty.

D19. Table D2 presents the frequency of each major procedure performed using gamma cameras and/or SPECT systems in the 35 countries that provided this information. It shows that in the United States cardiovascular procedures account for more than 50% of all annual SPECT procedures with a rate of 19.9 per 1,000 population, almost 3 times greater than the next highest, Greece, with 7 per 1,000 population. The distribution in the United States differs widely from that in other countries, where often skeletal procedures have the highest frequency.

Table D2. Frequency per 1,000 population for nuclear medicine diagnostic procedures (using either gamma camera or SPECT) as reported to UNSCEAR Global Survey

SPECT: Single-photon emission computed tomography

Country	*Nuclear medicine procedures (frequency per 1 000 population)* [a,b]										
	Total [c]	*Cardio-vascular*	*Endo-crine*	*Gastro-intestinal*	*Renal*	*Infec-tion*	*Nervous system*	*Oncology*	*Pulmo-nary*	*Skeletal*	*Lymph-atics*
Argentina	13.3	4.9	0.3	0.5	0.2	0.05	0.1		0.05	5.9	1.2
Australia	22.8	5.3	2.1	0.9	0.7	0.3	0.3	0.2	2.3	10	0.8
Brazil	4.8	3.3	0.2	0.03	0.4		0.001	0.04	0.07	0.6	0.07
Bulgaria	2.5	0.06	0.3	0.01	0.1	0.002	0.03	0.05	0.2	1.7	
Belarus	12				8.3				0.07	1.8	
China	1.5	0.07	0.3		0.2					0.8	
Croatia	8.1	1.2	1.7		0.8	0.07	0.09		0.3	2.8	
Cyprus	5.7	2.1	1.1		0.9				0.2	1.4	
Czech Republic	12.8	2.1	0.3	0.07	1	0.1	0.2	0.07	3.4	4.7	0.9
Denmark	21.9	4	3	0.1	3.6	0.07	0.3	0.02	2.1	2.8	0.5
Estonia	3.2	0.4	0.6	0.01	0.2	0.01	0.09	0.6	0.1	0.5	0.09
Finland	5.9	1	0.04	0.03	0.3		0.2	1	0.4	1.9	
France	13.3	4.2	1	0.03	0.2		0.5		0.8	5.3	
Germany	30.1	6.6	13.6	0.04	0.7	0.06	0.2	0.7	0.9	7.1	
Greece	12.8	7	0.8		0.7	0.05	0.06	0.02	0.3	3.4	
Iceland	4.3	0.3	0.5	0.1	0.4	0.03	0.4	0.7	0.4	3.2	
Japan	9.1	2.1		0.03			1.6	0.3	0.2	3.3	
Lithuania	6.6	0.9	1	0.01	0.5	0.4	0.3	0.006	0.1	2.7	
Luxembourg	19.9	2.7	5.8	0.1	0.6	0.3	0.5	0.1	0.9	7.9	0.6
Montenegro	3		0.6	0.01	0.3				0.03	1.4	0.05
Niger	0.04	0.01	0.004	0.001	0.002			0.009		0.006	
Norway	6.1	1.5	0.8	0.07	0.8	0.03	0.5	0.8	0.2	1.2	0.06

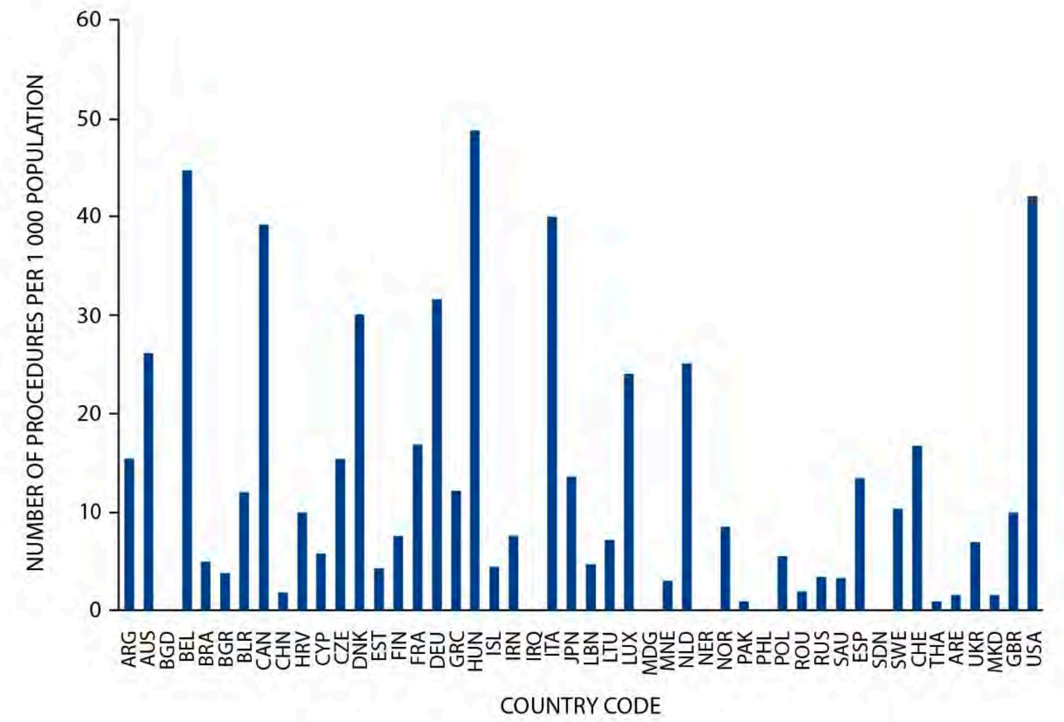
Country	*Nuclear medicine procedures (frequency per 1 000 population)* [a,b]										
	Total [c]	*Cardio-vascular*	*Endo-crine*	*Gastro-intestinal*	*Renal*	*Infec-tion*	*Nervous system*	*Oncology*	*Pulmo-nary*	*Skeletal*	*Lymph-atics*
Philippines	0.2	0.005	0.04	0.001	0.02					0.1	
Poland	4.2	0.6	1.2	0.04	0.6		0.02	0.4	0.1	1.5	0.2
Romania	1.4	0.1	0.2	0.03	0.09		0.002		0.03	0.9	0.06
Russian Federation	3.1	0.2	0.4	0.1	0.9		0.02	0.02	0.08	1.5	
Spain	12.1	2.6	1.3		0.8	0.4	0.7	0.3	0.4	5.6	
Sudan	0.2	0.001	0.09	0.001	0.03					0.06	0.001
Sweden	8.2	2.8	0.6	0.1	0.8	0.03	0.2	0.8	1.1	1.7	
Switzerland	11.7	1.7	0.3	0.006	0.4	0.8	0.09	0.02	0.6	2.5	
Thailand	0.8	0.1	0.1	0.02	0.04	0.002	0.002	0.009	0.01	0.4	0.01
United Arab Emirates	1.2	0.3	0.3	0.04	0.2	0.01	0.003	0.03	0.03	0.3	0.007
Ukraine	6.7	0.003			0.7		0.006		0.004	1.2	
United Kingdom	7.6	2	0.4	0.4	0.7	0.04	0.2	0.5	0.6	2.6	0.4
United States	36.3	19.9	1.8	2.9	1.1	0.9	0.6	1.2	2.1	5.2	

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Empty cell indicates no data available.

[c] Values as reported; may not equal sum of all categories.

Figure D-I. Annual frequency of diagnostic nuclear medicine procedures per 1,000 population as reported to UNSCEAR Global Survey



D20. Twenty-nine countries provided information on their PET activities. The annual frequency of PET procedures per 1,000 population is given in table D3, which clearly shows that oncology remains the principal use of PET imaging accounting for more than 90% of all PET procedures in most countries.

Table D3. Frequency of PET procedures per 1,000 population as reported to UNSCEAR Global Survey

PET: Positron emission tomography

Country	*PET procedures (frequency per 1 000 population)* [a,b]					
	Total [c]	*Cardio-vascular*	*Infection*	*Nervous system*	*Oncology*	*Skeletal*
Argentina	2.1				2.1	
Australia	3.4			0.05	3.3	
Belgium	4				4	
Brazil	0.1	0.02			0.1	0.02
Bulgaria	1.3	0.001		0.003	1.3	
Croatia	1.8	0.21			1.6	
Czech Republic	2.6				2.6	0.04
Denmark	8.2	0.80	0.45	0.09	6.6	0.01
Estonia	1			0.01	0.9	0.07

Country	*PET procedures (frequency per 1 000 population)* [a,b]					
	Total [c]	*Cardio-vascular*	*Infection*	*Nervous system*	*Oncology*	*Skeletal*
Finland	1.6	0.09		0.14	1.1	0.04
France	3.6				3.6	
Germany	1.7	0.05		0.16	1.5	
Greece	0.5				0.5	
Japan	4.5	0.03		0.14	4.4	
Lithuania	0.6	0.005		0.01	0.6	
Luxembourg	4.2				4.2	
Norway	2.3	0.008		0.17	2.1	
Philippines	0.02				0.02	
Poland	1.2	0.002	0.001	0.0002	1.2	0.004
Romania	0.5				0.5	
Russian Federation	0.2			0.01	0.2	
Spain	1.4				1.4	
Sweden	2.1	0.02	0.001	0.40	1.6	0.22
Switzerland	5				5	
Thailand	0.05			0.005	0.04	
United Arab Emirates	0.3	0.004			0.3	
Ukraine	0.1		0.008		0.08	
United Kingdom	2.4	0.04		0.04	2.3	
United States	5.8	0.23		0.17	5.4	

[a] Values are rounded; however extended precision has been preserved to illustrate differences.
[b] Empty cell indicates no data available.
[c] Values as reported; may not equal sum of all categories.

D21. The numbers of therapy procedures using radionuclide were reported by 41 countries and are presented in table D4 and figure D-II as a frequency per 100,000 population. Thirty-three countries provided detailed numbers for the major procedures of radionuclide therapy. The treatment of thyroid disease using ^{131}I accounts for an average of 74% of all radionuclide therapy procedures. Protein-receptor radionuclide therapy using either ^{90}Y or ^{177}Lu-octreotide for neuroendocrine tumours and ^{177}Lu-PSMA for prostate cancer, is now becoming routinely available in many countries and represents approximately 5% of the reported procedures. Germany reported a very high frequency of radio-synovectomy procedures (87/100,000), more than 10 times higher than any other country.

Table D4. Frequency of radionuclide therapy procedures per 100,000 population as reported to UNSCEAR Global Survey

PRRT: Protein-receptor radionuclide therapy; SIRT: Selective internal radiation therapy; MIBG: Meta-iodobenzylguanidine

Country	*Radionuclide therapy procedures (frequency per 100 000 population)* [a,b]								
	All therapy [c]	*Thyroid benign (^{131}I)*	*Thyroid cancer (^{131}I)*	*Bone mets (^{89}Sr, ^{153}Sm, ^{223}Ra)*	*PRRT (^{90}Y, ^{177}Lu)*	Polycythaemia *(^{32}P)*	Radiosynovectomy *(^{90}Y, ^{153}Sm ^{169}Er, ^{186}Re)*	*SIRT (^{90}Y)*	*MIBG (^{131}I)*
Argentina	39.8	0.7	24.6	2.2				2.2	0.7
Australia	17.2	13.5	2.5	0.2		0.01	0.2	0.8	
Bangladesh	25								
Belgium	49.5	40.3	3.3	3.1		0.18		2.6	
Brazil	8.6	6.1	1.7	0.06	0.1	0.005	0.5	0.03	0.02
Bulgaria	3.2	1.5	0.8	0.2					
Belarus	17.8								
Canada	32.2								
China	43.4	15.3	3.1						
Cyprus	26.8	6.8	20						
Czech Republic	18.5	3.8	11.2	3.4					0.1
Denmark	38.2	30.7	0.8		4.1				0.9
Estonia	56.3	29.7	32.3	0.2	2.5		0.2		
Finland	34.2	17.2	10.4	0.2	2	4.2		0.2	
Germany	135.5	25.6	17.1		2.7		87.1	2	
Greece	27.5	2.8	21.9	1.6	0.3		0.8		0.03
Hungary	15.3								
Iceland	32.3	7.6	6.1	18.6					
Iran (Islamic Republic of)	3.9								
Iraq	4.7								
Japan	8.3	3.9	2.9						
Lebanon	17.1	1.7	0.8						

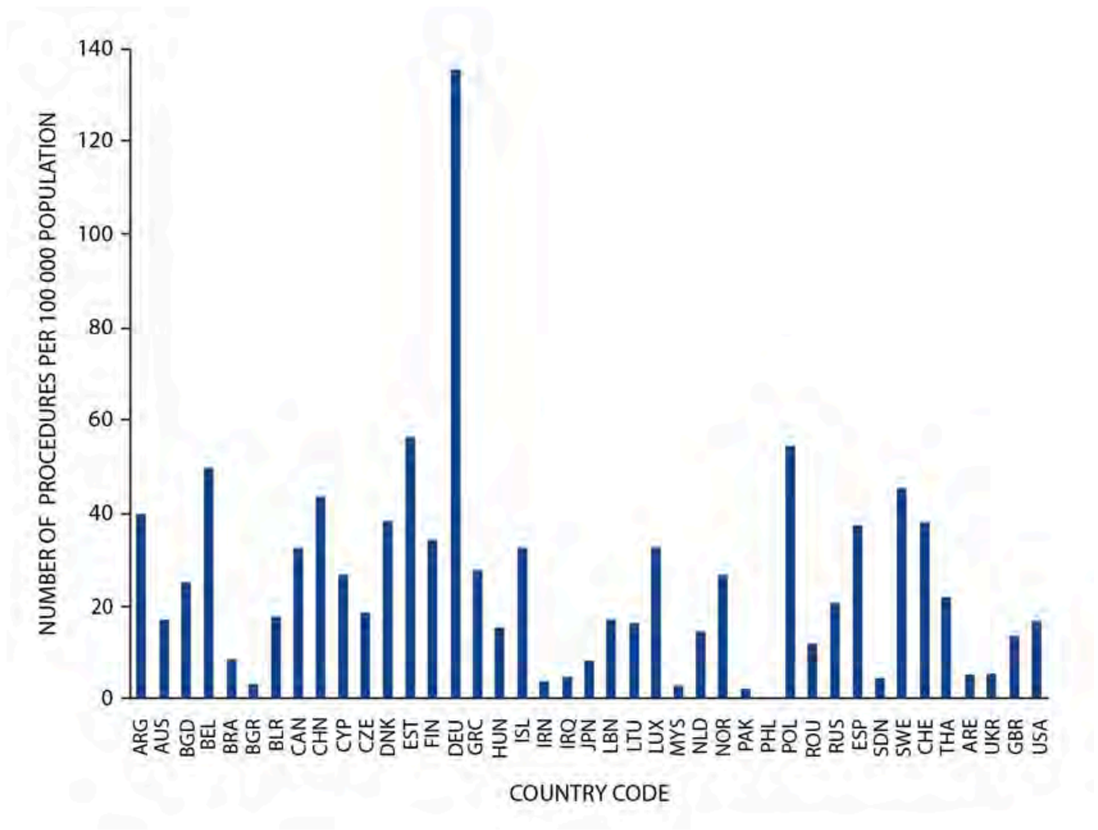
Country	*Radionuclide therapy procedures (frequency per 100 000 population)* [a,b]								
	All therapy [c]	*Thyroid benign (^{131}I)*	*Thyroid cancer (^{131}I)*	*Bone mets (^{89}Sr, ^{153}Sm, ^{223}Ra)*	*PRRT (^{90}Y, ^{177}Lu)*	Polycythaemia *(^{32}P)*	Radiosynovectomy *(^{90}Y, ^{153}Sm ^{169}Er, ^{186}Re)*	*SIRT (^{90}Y)*	*MIBG (^{131}I)*
Lithuania	16.2	11.9		2.1					
Luxembourg	32.7	31.6					1.1		
Malaysia	2.8								
Netherlands	14.5	5.4	5.5	1.7	1.9	0.1			
Norway	26.6	12.5	3.5	10.2	0.04	0		0.2	0.1
Pakistan	2.2								
Philippines	0.3	0.1	0.2						
Poland	54.4	33.9	7.2	1.9	0.2		7.6		0.1
Romania	12	2.2	9.9						
Russian Federation	20.5	4.8	13.7	2.1					0.1
Spain	37.2	18.2	13.6	0.8	1.6			3	
Sudan	4.4	0.7	0.1						
Sweden	45.3	16.3	5.7	19.4	0.9	0.8	0.05	0.08	0.03
Switzerland	38.1	7.1	10.7				1.7	4.3	0.1
Thailand	21.8	13	8.8	0.002	0.002		0.003	0.01	0.01
United Arab Emirates	5.1	2.2	2.8	0.04			0.04		
Ukraine	5.8		4.3	0.5	0.3	0.1			0.5
United Kingdom	13.3	5.6	2.1	3.7	1	0.1	0.2	0.5	0.1
United States	16.7	15	1.7						

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Empty cell indicates no data available.

[c] Values as reported; may not equal sum of all categories.

Figure D-II. Frequency of therapeutic nuclear medicine procedures per 100,000 population as reported to UNSCEAR Global Survey



B. Literature review data on nuclear medicine procedures and contribution to population dose

D22. The population dose from nuclear medicine examinations was reported in 17 of the reviewed nuclear medicine articles, corresponding to 15 individual countries and one region (Europe). These articles are summarized in table D5. Eleven of the articles provided an analysis of the contribution to the population dose from the major nuclear medicine procedures.

D23. The frequency of nuclear medicine procedures in relation to the total number of medical imaging procedures was relatively small, ranging from 0.2% to 6.2% (average 1.9%). However, the contribution to the collective effective dose was higher (0.7% to 26%, average 8.6%), resulting in an average effective dose of 0.12 mSv per caput. Although these articles reported on national surveys which had been conducted over a 13-year period (2002–2015), there was no correlation between per caput effective dose and year of study. Rather, the wide range of reported doses (0.0025 mSv in Romania to 0.77 mSv in the United States) reflected both the differences in the frequency of procedures and also the differences in the type of procedures performed. This was particularly evident in the Republic of Korea, where PET/CT procedures contributed 56% of the 0.15 mSv per caput effective dose, with cardiac studies contributing only 12%, and in the United States, where the 0.77 mSv per caput effective dose was primarily due to the very high proportion of cardiac studies (85%).

D24. If the six non-European countries are considered separately, the per caput effective dose was 0.23 mSv, compared with the average of 0.07 mSv for the eleven European papers (nine countries). This latter value is in keeping with the value of 0.05 mSv reported for 36 European countries in the European Commission Dose Data Med 2 project (EC DDM 2) [E5].

D25. A comparison of the procedure frequency from the literature and from the UNSCEAR Global Survey is given in table D6 for nine countries included in table D5, which have provided data for the current survey. Countries in which the data was collected in more recent years, such as Croatia and the Russian Federation, showed good agreement with the current survey. While the values from some of the European countries showed a reduction in nuclear medicine procedures of up to 33%, other countries, such as Romania (110%) and Bulgaria (42%), reveal a significant increase. Values from Australia increased by 30% while those from the United States decreased by 32%, reflecting changes in technology, radiopharmaceuticals and referral patterns in each country.

D26. The EC DDM 2 project [E5] provided comprehensive information on 36 European countries regarding frequencies and radiation dose of diagnostic radiological examinations and nuclear medicine procedures. The information presented in the EC DDM 2 project is based on national surveys carried out between 2007 and 2010.

D27. Overall, the total frequency of diagnostic nuclear medicine procedures in Europe was 14 per 1,000 population. Table D7 shows the average European frequencies for the major nuclear medicine procedures. The total frequencies are somewhat lower than the HCL I countries' mean frequency of 19 per 1,000 population for 1997–2007, according to the UNSCEAR 2008 Report [U9].

D28. The frequency of paediatric procedures was reported for France by Étard et al. [E11] for 2010. Nuclear medicine procedures accounted for 0.3% of all paediatric medical imaging leading to a per caput effective dose of 0.006 mSv. Bone scans (48%) and renal scans (36%) were the main procedures performed in the children.

D29. The frequency per 1,000 population of nuclear medicine diagnostic procedures continues to vary widely across the world. In many countries, the annual frequency of procedures remained below 10 per 1,000 population while the highest recorded frequency in the current survey was almost 50 per 1,000 population in Hungary.

Table D5. Frequency of nuclear medicine procedures per 1,000 population and corresponding contribution to collective effective dose from nuclear medicine procedures in published literature (2006–2018)

CT: Computed tomography; PET: Positron emission tomography

Country or region	*Year*	*Frequency of procedures per 1 000 population* [a,b]	*Proportion of all diagnostic procedures (%)* [a,b]	*Contribution to collective effective dose (%)* [a,b]	*Per caput effective dose (mSv)* [a,b]	*Contributions to collective effective dose (%)* [a,b]						*Reference*
						Bone	*Lung*	*Thyroid*	*Cardiac*	*Renal*	*PET/CT*	
Australia	2010	20.2	6.2	10	0.11	33			42			[H6]
Bulgaria	2007	2.6			0.01							[K14]
Croatia	2015	9.8	1.5	6	0.03	28	1.3	12.3	19	2.1	26	[K15]
Europe (EC DDM 2)	2010	14		5	0.06	39	1.6	6.6	28		16	[B20, E5]
Finland	2009	7.7		6.3	0.03						8	[B19]
France	2007	19	1.6	10.2	0.13	23	2.4	3	36	0.3	31	[E10]
Iran (Islamic Republic of)	2014	22.6			0.12	6.6		2.1	77		0.5	[T1]
Ireland	2010	6.5	1	9	0.05	32	1.5	6	3	1	54	[O1]
Italy (Emilia-Romagna region)	2006		2	10	0.10							[C12]
Italy (Aosta Valley Region)	2011	10.4	1.8	5.9	0.12							[A2]
Republic of Korea	2013	12.8	0.3	9.7	0.15			7	12	5.6	56	[L3]
Luxembourg	2002	36		7.6	0.15							[S12]
Portugal	2010			8	0.08	22		3	48		10	[T3]
Romania	2012	0.9	0.3	0.7	0.003	52		9	3	2	33	[G5]
Russian Federation	2015	3.5	0.2	1.7	0.009							[B6]
Taiwan, China	2008	13.6	1.8	13.6	0.10	36	1	1.7	28	3.7	9.1	[C6]
United States	2006	62.2	4.5	26	0.77	9	1	0.2	85	0.3	1.8	[M10]

[a] Values are rounded; however significant figures have been preserved.

[b] Empty cell indicates no data available.

Table D6. Comparison of frequency of nuclear medicine procedures per 1,000 population as reported to UNSCEAR Global Survey with published study values

Country	*Frequency of procedures per 1 000 population*		*Study year*	*Reference*
	Current evaluation	*Study value*		
Australia	26.2	20.2	2010	[H6]
Bulgaria	3.7	2.6	2007	[K14]
Croatia	9.9	9.8	2015	[K15]
Finland	7.5	7.7	2009	[B19]
France	16.8	19	2007	[E10]
Luxembourg	24.1	36	2002	[S12]
Romania	1.9	0.9	2012	[G5]
Russian Federation	3.4	3.5	2015	[B6]
United States	42.1	62.2	2006	[M10]

Table D7. Average frequency of nuclear medicine procedures per 1,000 population in Europe as reported to the EC DDM 2 project [E5]

PET: Positron emissions tomography

Nuclear medicine procedure	*Average frequencies per 1 000 population for 36 European countries*
Bone scan (^{99m}Tc)	3.5 (*N*=35)
Heart total	2.6 (*N*=33)
Lung perfusion (^{99m}Tc)	0.5 (*N*=35)
Thyroid total	1.8 (*N*=35)
Renal total	0.8 (*N*=35)
Brain	0.1 (*N*=28)
PET	0.4 (*N*=17)
PET and diagnostic computed tomography	0.4 (*N*=15)

IV. ADMINISTERED ACTIVITY AND EFFECTIVE DOSE FOR NUCLEAR MEDICINE PROCEDURES

A. UNSCEAR Global Survey data

D30. Table D8 summarizes the average administered activities for each major nuclear medicine procedure imaged with a gamma camera and/or a SPECT system as reported to the UNSCEAR Global Survey, and table D9 presents similar data for PET procedures.

Table D8. Administered activities for nuclear medicine procedures using gamma camera or SPECT as reported to UNSCEAR Global Survey

SPECT: Single-photon emission computed tomography

Country	*Administered activities per procedure (MBq)* [a]															
	Nervous system		*Skeletal*	*Cardiovascular*		*Lung*	*Endocrine*		*Gastro-intestinal*	*Genito-urinary*	*Oncology*			*Infection inflammation*		*Lymph-atics*
	^{99m}Tc	^{123}I	^{99m}Tc	^{99m}Tc	^{201}Tl	^{99m}Tc	^{99m}Tc	^{123}I	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{111}In	^{123}I	^{99m}Tc	^{67}Ga	^{99m}Tc
Argentina	1 140		1 088	925		185	370		189	185				1 147		
Australia	775		890	1 202	140	132	327		169	376			200	636	211	53
Belgium	709	191	765	742	110	207	165	14	45	173						
Brazil	964		1 008	838		149	222		373	190					182	
Bulgaria	642	170	603	680		119	293		105	188	366			450		
Canada	740	111	925	1 184	93	400	370	74	19	300	925		74	370	296	74
China			740	833			185									
Croatia	855	111	633	560		155	97			140				555		
Cyprus			666	574	74	230	400			194						
Czech Republic	747	183	786	832	102	207	189	20	141	205		220		723		
Denmark		170	668	616		158	164			95				423		
Estonia		228	683	417		101	216			99	747		266	744		
Finland	692	176	591	537	113	103	299	173	186	110	99		330			
France			680			240	150	9		190						
Germany	740	180	650	400	75	120	70		100	100		150		800		
Greece	665	195	660	670	105	180	150			200		145			170	
Iceland	740	180	680	740		125	326		222	248				740		
Japan	611	179	714	848	108	218			552							
Lebanon			740	1 500		92	74		74	148						
Lithuania	690	263	488	500		100	336	370	450	200			370			

Country	*Administered activities per procedure (MBq)* [a]															
	Nervous system		*Skeletal*	*Cardiovascular*		*Lung*	*Endocrine*		*Gastro-intestinal*	*Genito-urinary*	*Oncology*			*Infection inflammation*		*Lymph-atics*
	^{99m}Tc	*^{123}I*	*^{99m}Tc*	*^{99m}Tc*	*^{201}Tl*	*^{99m}Tc*	*^{99m}Tc*	*^{123}I*	*^{99m}Tc*	*^{99m}Tc*	*^{99m}Tc*	*^{111}In*	*^{123}I*	*^{99m}Tc*	*^{67}Ga*	*^{99m}Tc*
Luxembourg			820	740			99									
Malaysia			784	340			375		78	209				1 030		38
Niger			700	1 110	110	296	185	110	185	185						
Norway	771	185	691	554		198	324	129	88	78	97	153		647		79
Philippines			1 037	1 087	95		345		403	198						
Poland	740		740	800		370	80		185	120						
Romania			660	850		222	167		689							67
Russian Federation	560	225	500	490		150	100	130	130	150	470					
Saudi Arabia			750	1 110		150	370	185	185	222					370	74
Spain	734	186	771	764		208	449			171		156		372	230	
Sweden	812	185	530	486		120	106	196		79		170	196	846		
Thailand	601		710	647	98	436	243		212	114	719					
United Arab Emirates	740		714	1 076	112	320	323		204	158				537		
Ukraine	740		750	550		550	100			100						
Average	**746**	**183**	**730**	**764**	**103**	**208**	**232**	**128**	**217**	**171**	**489**	**166**	**239**	**668**	**243**	**64**

[a] Empty cell indicates no data available.

Table D9. Administered activities for nuclear medicine procedures using PET system as reported to UNSCEAR Global Survey

PET: Positron emission tomography

Country	*Administered activities (MBq)* [a]						
	Oncology		*Cardiovascular*		*Skeletal*	*Nervous system*	*Infection - inflammation*
	^{18}F	^{68}Ga	^{18}F	^{15}O	^{18}F	^{18}F	^{18}F
Argentina	344						
Australia	262	182				370	
Belgium	277						
Brazil	320		278		260		
Bulgaria	300		1 036				
Canada	444		740			370	740
China	370		296			296	
Croatia	230		230				
Czech Republic	309				187		
Denmark	295				295		
Estonia	291				200	181	240
Finland	311		291		241	211	
France	300						
Germany	350				250	200	
Greece	345						
Japan	202	410	234				
Lithuania	340				329		
Luxembourg	296						
Malaysia	327				304		
Norway	232		220			186	
Philippines	280						
Poland	400		300			300	490
Romania	291						
Russian Federation	280					360	
Spain	336						
Sweden	274	153		408	203	299	
Thailand	318	187		555		296	
Ukraine	350						350
Average	**309**	**260**	**399**	**482**	**264**	**279**	**455**

[a] Empty cell indicates no data available.

D31. Table D10 presents DLP values for the computed tomography component of SPECT/CT studies, and table D12 presents similar data for PET/CT studies. Table D11 shows the percentage of SPECT procedures that used co-registered computed tomography acquired with a SPECT/CT system. This latter value varies significantly both between countries and between different procedures. No country reported using SPECT/CT for renal procedures.

Table D10. Dose length product for nuclear medicine procedures using computed tomography components as reported to UNSCEAR Global Survey

Country	*Dose length product per procedure (mGy cm)* [a]							
	Nervous	*Skeletal*	*Cardio-vascular*	*Lung*	*Endo-crine*	*Gastro-intestinal*	*Oncol-ogy*	*Infection - inflammation*
Australia	94	210	66	115	204	213	180	229
Czech Republic	220	150	80					
Estonia		628					136	
Finland	84	30	15	11	81	12	18	
Iceland			50	73	389		130	100
Malaysia		120	30					
Russian Federation		210	32	265	270			
Thailand	114	242	17	198	225	409	409	
Average	**128**	**227**	**41**	**132**	**234**	**211**	**175**	**165**

[a] Empty cell indicates no data available.

Table D11. Nuclear medicine procedures using computed tomography component as reported to UNSCEAR Global Survey

CT: Computed tomography; SPECT: Single-photon emission computed tomography

Country	*Percentage of nuclear medicine procedures using CT component of SPECT/CT (%)* [a]							
	Nervous	*Skeletal*	*Cardio-vascular*	*Lung*	*Endo-crine*	*Gastro-intestinal*	*Oncol-ogy*	*Infection inflammation*
Australia	80	66	71	23	19	6	72	62
Czech Republic	50	30	70					
Estonia		95					100	
Finland	35	8	27	11	40	10	13	
Iceland		10	100	100	42		32	100
Russian Federation		20	5	1	10			
Thailand	50	6	55	13	8	1	53	
Average	**54**	**34**	**55**	**30**	**24**	**6**	**54**	**81**

[a] Empty cell indicates no data available.

Table D12. Dose length product for nuclear medicine procedures using PET/CT system as reported to UNSCEAR Global Survey

CT: Computed tomography; PET: Positron emission tomography

Country	*Dose length product per procedure (mGy cm)* [a]				
	Oncology	*Cardiovascular*	*Skeletal*	*Nervous system*	*Infection - inflammation*
Australia	591			152	
Brazil	837	838	1 056		
Bulgaria	365	558			
China	715	715		715	
Czech Republic	450				
Estonia	570			59	542
Finland	189	110	689	45	
Lithuania			411		
Malaysia	1 261		1 114		
Russian Federation	800			700	
Thailand	479			259	
Average	**626**	**555**	**817**	**322**	**542**

[a] Empty cell indicates no data available.

D32. Table D13 presents the effective dose corresponding to those procedures listed in table D8 and, similarly, table D14 shows the corresponding effective doses for the PET procedures listed in table D9. Table D15 summarizes the effective dose from the computed tomography component of the SPECT/CT procedures and table D16 presents the computed tomography dose for the PET/CT procedures for those countries which recorded this information.

D33. The effective dose was calculated using the dose coefficients published in the user manual for the UNSCEAR Global Survey [U11]. The coefficients for the radiopharmaceutical dose (effective dose in mSv per administered activity in MBq) were primarily taken from ICRP publication 128 [I15]. For the computed tomography dose the E/DLP coefficients (mSv/mGy cm) were adopted from the European guidance on estimating population doses from medical X-ray procedures [E3]. A number of countries did not provide the administered activity and/or the DLP, but directly provided an estimate of the effective dose. These are indicated in italics in tables D13–D16.

Table D13. Effective dose (mSv) calculated from administered radiopharmaceutical for nuclear medicine procedures using gamma camera or SPECT system as reported to UNSCEAR Global Survey

SPECT: Single photon emission computed tomography. Reported values are in italics

Country	Effective dose (mSv)[a,b]																	
	Nervous system		Skeletal	Cardio-vascular		Lung	Endocrine		Gastro intestinal	Genito urinary	Oncology					Infection inflammation		Lymph atics
	^{99m}Tc	^{123}I	^{99m}Tc	^{99m}Tc	^{201}Tl	^{99m}Tc	^{99m}Tc	^{123}I	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{11}In	^{123}I	^{131}I	^{67}Ga	^{99m}Tc	^{67}Ga	^{99m}Tc
Argentina	8.8		5.3	8.3		2	3.3		0.9	1.6						12.6		
Australia	7.2		4.4	10.8	19.6	1.5	4.3		2.9	1.8			2.6	10.4		7	21.1	0.06
Belgium	6.6	9.6	3.7	6.7	15.4	2.3	2.1	3.1	0.8	1.2								
Brazil	7.4		4.9	7.5		1.6	2.9		3.5	1.7					22.2		18.2	
Bulgaria	6	8.5	3	6.1		1.3	3.8		1.4	1.3	3.3					5		
Canada	6.9	5.6	4.5	10.7	13	4.4	4.8	16.3	0.2	2.1	8.3		1			4.1	29.6	0.09
China			3.6	7.5			2.4											
Croatia	8	5.6	3.1	5		1.7	1.3			1						6.1		
Cyprus			3.3		10.4	2.5	5.2			1.4								
Czech Republic	6.9	9.1	3.9	7.5	14.3	2.3	2.5	4.4	2.4	1.4		11.9				8		
Denmark		8.5	3.3	4.3		1.7	2.1			0.7								
Estonia		11.4	3.3	3.8		1.1	2.8			0.7	0.4		3.5			8.2		
Finland	6.4	8.8	2.9	4.8	15.9	1.1	3.9	38.1	0.9	0.8	0.9		4.3					
France	*6.9*		3.3	*9*		2.6	2	2		1.3								
Germany	5.7	9	3.2	3.6	10.5	1.3	0.9		0.7	0.7		8.1				8.8		
Greece	6.2	9.8	3.2	4	14.7	2	2			1.4		7.8					17	
Iceland	6.9	9	3.3	6.7		1.4	4.2		3.8	1.7						8.1		
Japan	5.7	8.9	3.5	7.6	15.1	2.4			9.4									
Lebanon			3.6	13.5		1	1		1.3	1								
Lithuania	5.3	13.2	2.4	4.5		1.1	4.4	81.4	7.7	1.4			4.8					

Country	Effective dose (mSv) [a,b]																	
	Nervous system		Skeletal	Cardio-vascular		Lung	Endocrine		Gastro intestinal	Genito urinary	Oncology					Infection inflammation		Lymph atics
	^{99m}Tc	^{123}I	^{99m}Tc	^{99m}Tc	^{201}Tl	^{99m}Tc	^{99m}Tc	^{123}I	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{11}In	^{123}I	^{131}I	^{67}Ga	^{99m}Tc	^{67}Ga	^{99m}Tc
Luxembourg			4	6.7			1.3											
Malaysia			3.8	3.1			4.9		0.7	1.5						5		0.09
Niger			3.4	10	15.4	3.3	2.4	24.2	3.1	1.3	*5.9*							
Norway	7.2	9.3	3.4	5		2.2	4.2	28.3	0.4	0.5	0.9	8.3				3.2		0.09
Philippines			5.1	9.8	13.3		4.5		6.9	1								
Poland	6.9		3.6	7.2		4.1	1		1.7	0.6								
Romania			3.2	7.7		2.4	2.2		9									0.08
Russian Federation	4.3	11.3	2.5	4.4		1.7	1.3	28.6	1.2	0.7								
Saudi Arabia			3.7	10		1.7	4.8	40.7										0.09
Spain	6.8	9.3	3.8	6.9		2.3	5.8			1.2		8.4				4.1	23	
Sweden	7.6	9.3	2.6	3.6		1.3	1.4	2.5	0.2	0.6		9.2	2.5			9.3		
Thailand	4.6		3.5	4.5	13.7	4.8	3.2		3.6	0.8	6.5			4.8	17.1			
United Arab Emirates	6.9		3.5	9.7	15.6	3.5	4.2		3.5	1.1		9				5.9		
Ukraine	6.9		3.7	5		6.1	1.3			0.7								
Average	**6.6**	**9.2**	**3.6**	**6.8**	**14.4**	**2.3**	**3**	**24.5**	**2.9**	**1.1**	**3.7**	**9**	**3.1**	**7.6**	**19.7**	**6.8**	**21.8**	**0.08**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Empty cell indicates no data available.

Table D14. Effective doses calculated from administered radiopharmaceutical for nuclear medicine procedures using PET as reported to UNSCEAR Global Survey

PET: Positron emission tomography. Reported values are in italics

Country	*Effective dose (mSv)* [a]						
	Oncology		*Cardiovascular*		*Skeletal*	*Nervous system*	*Infection - inflammation*
	^{18}F	^{68}Ga	^{18}F	^{15}O	^{18}F	^{18}F	^{18}F
Argentina	6.5						
Australia	5	4.7				7	
Belgium	5.3						
Brazil	6.1		5.3		4.4		
Bulgaria	5.7		19.7				
Canada	8.4		14.1		6.3		14.1
China	7		5.6			5.6	
Croatia	4.4		4.4				
Czech Republic	5.9				3.2		
Denmark	5.6				5		
Estonia	5.5				3.4	3.4	4.6
Finland	5.9	*2.9*	5.5	*1*	4.1	4	
France	5.7						
Germany	6.7				4.3	3.8	
Greece	6.6						
Japan	3.8	10.5	4.4				
Lithuania	6.5				5.6		
Luxembourg	5.6						
Malaysia	6.2				5.2		
Norway	4.4		4.2			3.5	
Philippines	5.3						
Poland	7.6		5.7			5.7	9.3
Romania	5.5						
Russian Federation	5.3					3	
Spain	6.4						
Sweden	5.2	3.9		0.45	3.5	5.7	
Thailand	6	3.7				5.6	
United Arab Emirates	5.4	9.5	7	0.61	6.3		
Ukraine	6.7						6.7
Average	**5.9**	**5.9**	**7.6**	**0.7**	**4.7**	**4.7**	**8.6**

[a] Empty cell indicates no data available.

Table D15. Effective dose from computed tomography component for nuclear medicine procedures using SPECT/CT system as reported to UNSCEAR Global Survey

CT: Computed tomography; SPECT: Single photon emission computed tomography. Reported values are in italics

Country	*Effective dose (mSv)* [a]						
	Nervous	*Skeletal*	*Cardio-vascular*	*Pulmon-ary*	*Gastro-intestinal*	*Onco logy*	*Infection - inflammation*
Argentina		*2*	*2*				
Australia	0.2	2.9	0.9	1.6	3.2	3.1	3.4
Czech Republic	0.5	2.1	1.1				
Estonia		8.8				2	
Finland	0.2	0.4	0.2	0.2	0.2	0.3	
Iceland			0.7	1		2	1.5
Malaysia		1.7	0.4				
Russian Federation		2.9	0.4	3.7			
Thailand	0.2	3.4	2.3	2.8	6.1	6.1	
Average	**0.3**	**3**	**1**	**1.9**	**3.2**	**2.7**	**2.5**

[a] Empty cell indicates no data available.

Table D16. Effective dose from computed tomography component for nuclear medicine procedures using PET/CT system as reported to UNSCEAR Global Survey

CT: Computed tomography; PET: Positron emission tomography. Reported values in are italics

Country	*Effective dose (mSv)* [a]						
	Oncology		*Cardiovascular*		*Skeletal*	*Nervous system*	*Infection - inflammation*
	^{18}F	*^{68}Ga*	*^{18}F*	*^{15}O*	*^{18}F*	*^{18}F*	*^{18}F*
Argentina	*16.3*						
Australia	8.9	9				0.3	
Brazil	12.6		11.7		15.8		
Bulgaria	5.5		7.8				
China	10.7		10			1.5	
Czech Republic	6.8						
Estonia	8.5					0.1	8.1
Finland	2.8	3.4	1.5	0.9	10.3	0.1	
Lithuania					6.2		
Malaysia	18.9				16.7		
Russian Federation	12					1.5	
Thailand	7.2	7.2				0.5	
Average	**10**	**6.5**	**7.8**	**0.9**	**12.3**	**0.7**	**8.1**

[a] Empty cell indicates no data available.

B. Literature review data

D34. Most estimates of the effective dose in the reviewed literature used the organ absorbed dose coefficients and effective dose coefficients (mSv/MBq) from ICRP publication 128 [I15]. This publication is a compendium comprising ICRP publication 53 [I8] and all subsequent addenda, and ICRP 60 [I9] for the tissue weighting factors, which were derived using the Medical Internal Radiation Dosimetry (MIRD) hermaphrodite mathematic phantom originally developed at Oak Ridge National Laboratory [C15]. The ICRP published revised tissue weighting factors in 2007 [I11] and developed ICRP computational voxel adult male and female models [I12] and will be publishing a revision of ICRP 128 [I15] using these voxel models and the updated tissue weighting factors.

D35. The administered activity for each nuclear medicine procedure varies considerably both within a country and between countries. Table D17 includes the mean activities of published national surveys from both European [E5] and other countries.

Table D17. Mean activity administered to adult patients per nuclear medicine diagnostic procedures as reported in literature

PET: Positron emissions tomography

Country or region	*Mean activity administered per procedure (MBq)* [a]												
	Year	*Bone*	*Myocardial*		*Whole body PET*	*Cardiac blood pool*	*Inflam-mation*	*Renal*	*Lung*	*Brain*	*Hepato-biliary*	*Thyroid*	*Reference*
		^{99m}Tc	^{201}Tl	^{99m}Tc	^{18}F	^{99m}Tc	^{67}Ga	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{99m}Tc	^{99m}Tc	
Australia	2010	800	120	1 300	370	1 000	200	300	200	800	200	200	[H6]
Belgium	2015–2017	750	110	1 360	270			200	200	740		165	[F2]
Bulgaria	2007	740		1 100				185	150			100	[K14]
	2013	570		925					158			74	[A13]
	2013				285								[A14]
Croatia	2015	633		1 240	230		77	120	154	855		98	[K15]
Europe (EC DDM 2)	2010	662	99	1 250	351	696	177	178	157	704		158	[E5]
Finland	2007	700		1 100	370	750		300	150			150	[K14]
Germany	2004				370								[B32]
	2007–2008	661	74	970					160				[B33]
Iran (Islamic Republic of)	2014	628	89	1 324			141	352	145	740	162	92	[T1]
Italy (region)	2011	942	144	1 150			354		362	971	210	163	[A2]
Japan	2016		110	1 007									[O7]
Russian Federation	2013				300			235	132		130	205	[Z2]
Taiwan, China	2008	888	89		370	740	111	222	296	740		185	[C6]
United Kingdom	2016	800		800	400								[I7]
United States	2006	1 110	185	1 500	740	1 100	150	370	185	740	185	370	[M9]
	2013			1 480									[D6]

[a] Empty cell indicates no data available.

D36. For all EC DDM 2 [E5] 36 countries, the mean effective dose was 0.054 mSv per caput and nuclear medicine contributed 5% to the total per caput effective dose for all medical imaging procedures of 1.10 mSv. The total average annual effective dose per caput ranged from 0.002 mSv in Romania to 0.162 mSv in Greece. Although large national differences in the average population dose from nuclear medicine procedures have been observed, the seven procedures (TOP 7) shown in table D18 were identified as being among the highest contributors to the collective effective dose in all EC DDM 2 [E5] countries, accounting for 91.3% of the total per caput effective dose.

Table D18. Procedures identified as highest contributors to total collective effective dose of nuclear medicine procedures in EC DDM 2 project (TOP 7) [E5]

CT: Computed tomography; FDG: Fluoro-2-D-deoxyglucose; MIBI: Methoxy isobutyl isonitrile; MAA: Macroaggregated albumin; PET: Positron emission tomography

Procedures TOP 7	*Nuclear medicine procedure*	*Radiopharmaceutical*	*Median (min-max) contribution to total per caput effective dose (%)*
Bone	Bone imaging	^{99m}Tc phosphates/ phosphonates	38.7 (6.4–85.6)
Heart (^{201}Tl)	Myocardial perfusion	^{201}Tl Chloride	3.8 (0.3–55.1)
Heart (^{99m}Tc)	Myocardial perfusion, exercise and rest	^{99m}Tc MIBI	14.2 (1.6–50.2)
	Myocardial perfusion, exercise and rest	^{99m}Tc Tetrofosmin	10.2 (2–37.8)
Tumour imaging PET and PET/CT	Tumour imaging PET	^{18}F-FDG	8.1 (0.2–24.6)
	Tumour imaging PET and diagnostic CT	^{18}F-FDG	8.1 (0.4–33.9)
Thyroid (^{99m}Tc)	Thyroid imaging (no blocking)	^{99m}Tc pertechnetate	3.9 (0.1–51.5)
Thyroid (^{131}I)	Thyroid metastases (after ablation, uptake 0%)	^{131}I	2.7 (0.1–75.2)
Lung	Lung perfusion	^{99m}Tc MAA	1.6 (0.2–24.9)
Total median			**91.3**

1. Myocardial perfusion imaging

D37. Myocardial perfusion imaging (MPI) is one of the main contributors, and in some countries the major contributor, to the nuclear medicine component of the population dose (table D5). Over the past two decades, its use has grown rapidly worldwide to 15–20 million procedures annually and diffusion of technology and expertise has led to its continued adoption across the world. A variety of protocols can be used to perform MPI on SPECT and PET cameras, and a variety of approaches and best practices have been developed to lower radiation exposure to patients. In 2013, the International Atomic Energy Agency (IAEA) undertook a study known as IAEA Nuclear Cardiology Protocols Cross-Sectional Study (INCAPS) to characterize worldwide nuclear cardiology practice and its impact on radiation exposure to patients and populations, including variation in radiation doses and the use of best practices and dose-lowering techniques [E7].

D38. The INCAPS [E7] collected data on 7,911 patients undergoing MPI in 308 laboratories in 65 countries, during a specified one-week period between 19 March and 22 April 2013. Mean patient age was 64.1±12 years, and 41% were female. Mean effective dose (E) for all patients was 10.0±4.5 mSv (range 2.2–24.4 mSv). The distribution of patient effective doses showed a slight positive skew, with 978 patients (12%) receiving an estimated E of >15 mSv. Both mean and median E differed between laboratories, countries, and world regions ($P < 0.001$ for each). Worldwide, only 30% of laboratories had median $E \leq 9$ mSv as recommended in professional society guidelines [C3].

D39. The burden of radiation to patients undergoing MPI differed between world regions. Europe had both the lowest mean (7.9 mSv) and median (8.0 mSv) E, and the highest proportion of patients with $E \leq 9$ mSv (60%). Latin America (11.8 mSv) and Asia (11.4 mSv) had the highest mean effective doses and the second lowest proportion of patients with $E \leq 9$ mSv (27 and 24%, respectively).

D40. The acquired data were also used to determine each laboratory's adherence to eight best practices with bearing on radiation exposure, on the basis of current clinical practice guidelines [C3]. These quality indices (QIs) included practices such as avoiding administering too much isotope, avoiding higher dose isotopes (viz. thallium-201), and using newer technologies that can lower radiation doses [E7]. The INCAPS found lower E in patients who underwent MPI in laboratories adhering to more of the specified best practices, thereby providing validation of these practices. The lowest median E (8.0 mSv) and highest proportion of laboratories with median $E \leq 9$ mSv occurred in Europe, which had the second highest regional best practice adherence (mean laboratory QI 6.2) and was home to more than three quarters of all laboratories observed worldwide with perfect QI scores of eight. The highest median radiation dose (12.1 mSv) and lowest proportion of laboratories with median $E \leq 9$ mSv (11%) occurred in Latin America, which also had the lowest proportion of laboratories with QI scores of at least 6. North American laboratories also performed poorly in terms of mean E and QIs. The INCAPS data have been further analysed on a regional basis for Oceania (Australia and New Zealand) [B18], Europe [L8], Latin America [V7] and the United States [M6].

D41. Japan was represented by only one laboratory in the INCAPS study. However, a nationwide survey was conducted there in 2016 with responses from 431 facilities [O7]. The mean effective dose E was 14.0±5.5 mSv (range: 3.9 to 25.2 mSv), which was higher than that reported in most countries in the INCAPS probably because more than 50% of the facilities still used ^{201}Tl chloride.

2. Patient dose from hybrid imaging

D42. As noted above, whole-body PET imaging is now routinely performed together with a low-dose whole-body CT scan (usually head to mid-thigh) for both attenuation correction of the PET images and for improved anatomical localization of any observed lesions. ^{18}F-FDG PET imaging has become the mainstay of nuclear oncology. The effective dose from the computed tomography component is often of similar magnitude to that from the radiopharmaceutical (table D19), so that a total procedure dose of 14 mSv is not uncommon. The introduction of time-of-flight PET scanners has the potential to reduce this dose by allowing images of an equivalent diagnostic quality to be produced using a lower activity of ^{18}F. In a national survey of French PET units, Étard et al. [E9] found that the average ^{18}F-FDG administered activity was significantly less in the units with time-of-flight (3.4 MBq/kg) compared with those units without this technology (4.6 MBq/kg).

D43. PET/CT systems are increasingly being used in the paediatric malignancy care and often require multiple procedures over a period of time. Chawla et al. [C4] studied 248 PET/CT procedures performed on 78 patients, aged 1.3 to 18 years. The average number of procedures per patient was 3.2 (range 1 to 14) and the average cumulative effective dose was 64.4 mSv (range 2.7 to 326 mSv).

Table D19. Effective dose from PET/CT whole-body procedures in adults performed using ^{18}F-FDG

CT: Computed tomography; FDG: Fluoro-2-D-deoxyglucose; PET: Positron emission tomography

Country	*Year/Period*	*^{18}F-FDG (MBq)*	*PET dose (mSv)*	*Low dose CT (mSv)*	*Total dose (mSv)*	*Reference*
Australia	2010	304	6	8.2	14.2	[W9]
France	2011	300	5.7	8.6	14.3	[E9]
Germany	2004	370	7	2.9	9.9	[B32]
Republic of Korea	2015	370	5.9	6.3	12.2	[K18]
Russian Federation	2011–2013	220–380	4–7	6	10–13	[Z2]
	2014–2017	280	5.3	13.3 [a]	18.6	[C9]
Taiwan, China	2008	370	6.8	5.9	12.7	[C6]
United Kingdom	2015	400	7.6	6.5	14.1	[I7]

[a] Scans were mainly performed as diagnostic scans rather than using a low dose protocol [C9].

D44. There are few published data on surveys of the effective dose from SPECT/CT procedures. However, two national surveys have been conducted in Australia [A9] and in the United Kingdom [I7]. Both surveys included the median DLP from the computed tomography component of the SPECT/CT study, which are presented in table D20 together with the effective dose calculated using the E/DLP conversion factors published by Shrimpton et al. [S14]. In both studies, the computed tomography acquisition parameters had been optimized for either attenuation correction only, or for attenuation correction and lesion localization.

Table D20. Dose length product (mGy cm) and corresponding effective dose components from computed tomography of clinical attenuation correction and anatomical localization examinations in adults using SPECT/CT in Australia and United Kingdom

CT: Computed tomography; DLP: Dose length product

Examination	*Country*	*DLP (mGy cm) Median*	*CT component Effective dose (mSv)*
Cardiac [a]	Australia [A10]	40	1
	United Kingdom [I7]	34	0.8
Skeletal (lumbar spine)	Australia [A10]	170	3.4
	United Kingdom [I7]	114	2.3
Parathyroid	Australia [A10]	205	1.2
	United Kingdom [I7]	122	0.7
Sentinel node	Australia [A10]	115	3.1
	United Kingdom [I7]	153	4.1
Brain	Australia [A10]	225	0.5
Pulmonary	Australia [A10]	95	2.6
Metaiodbenzylguanidine	Australia [A10]	161	3.9
Post-thyroid ablation	United Kingdom [I7]	128	3.5

[a] Attenuation correction only.

V. DISTRIBUTIONS BY AGE AND SEX

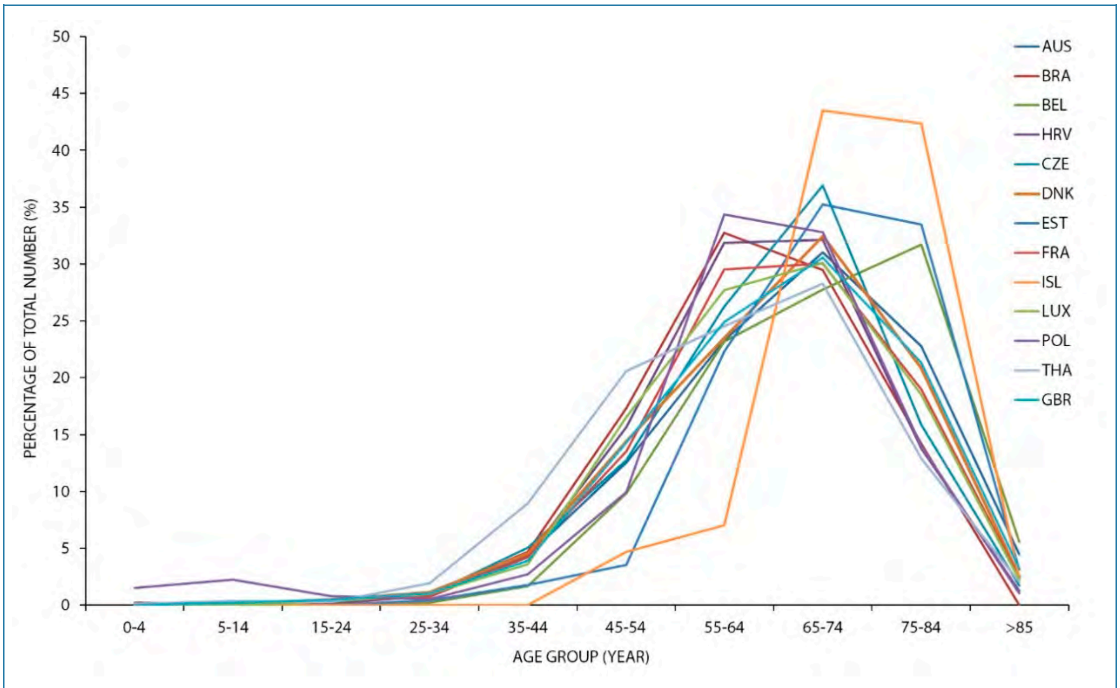
A. UNSCEAR Global Survey data

D45. The age distributions and the percentage of males and females are presented for the two most common SPECT procedures, cardiovascular (^{99m}Tc and ^{201}Tl combined) (figure D-III) and skeletal (figure D-IV), and for the PET oncology procedures (figure D-V).

D46. The age distributions of cardiac studies (figure D-III) are all very similar, peaking between ages 55 and 74. The exceptions are Iceland, which peaks later, and Poland, which has a significant paediatric contribution. The sex ratio (table D21) is quite variable, with four countries that examined more males than females, five countries more females than males, and four countries approximately the same number of each.

Figure D-III. Age distribution for nuclear medicine SPECT cardiovascular procedures

SPECT: Single photon emission computed tomography



D47. Figure D-IV shows that most countries have the highest distribution of SPECT skeletal procedures in the 65–74 age range. The exceptions are Belgium and Luxembourg, which peak in the 45–54 age range. The sex ratio (table D22) is highly variable with five countries that examined more male patients than females and seven countries more female patients than males, and Poland examined approximately the same number for both sexes.

D48. Most of the countries (figure D-V) show a broad peak in the age distribution for PET oncology procedures between approximately 55–84 years. The Brazilian data include a significant contribution from paediatric and young adult patients. In most countries more male patients are undergoing PET oncology procedures with Estonia being an exception examined more females than males (table D23).

Table D21. Distribution of male and female patients undergoing SPECT cardiovascular procedures

SPECT: Single photon emission computed tomography

Country	*Distribution (%)*	
	Male	*Female*
Australia	50.4	49.6
Belgium	56.1	43.9
Brazil	44.8	55.2
Croatia	51.7	48.3
Czech Republic	54.3	45.7
Denmark	49.2	50.8
Estonia	40.6	59.4
France	59.6	40.4
Iceland [a]	23.5	76.5
Luxembourg	57.6	42.4
Poland	43.7	56.3
Thailand	31.2	68.8
United Kingdom	51.6	48.4

[a] Data are based on only 85 patients in total (20 males and 65 females).

Figure D-IV. Age distribution for nuclear medicine skeletal procedures (gamma camera/SPECT)

SPECT: Single photon emission computed tomography

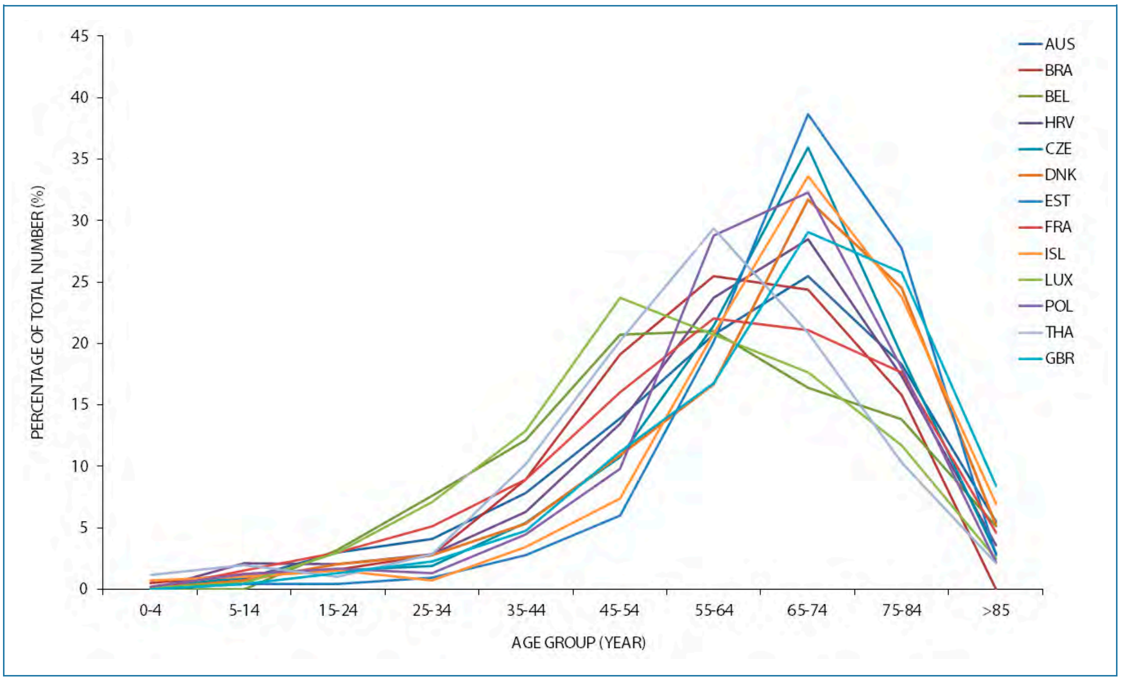


Table D22. Distribution of male and female patients undergoing gamma camera and/or SPECT skeletal procedures by country

SPECT: Single photon emission computed tomography

Country	*Distribution (%)*	
	Male	*Female*
Australia	44.2	55.8
Belgium	38.4	61.6
Brazil	60.5	39.5
Croatia	44.9	55.1
Czech Republic	46.1	53.9
Denmark	60	40
Estonia	72.9	27.1
France	41.5	58.5
Iceland	56	44
Luxembourg	38.5	61.5
Poland	49.5	50.5
Thailand	39	61
United Kingdom	55.5	44.5

Figure D-V. Age distribution for nuclear medicine PET oncology procedures

PET: Positron emission tomography

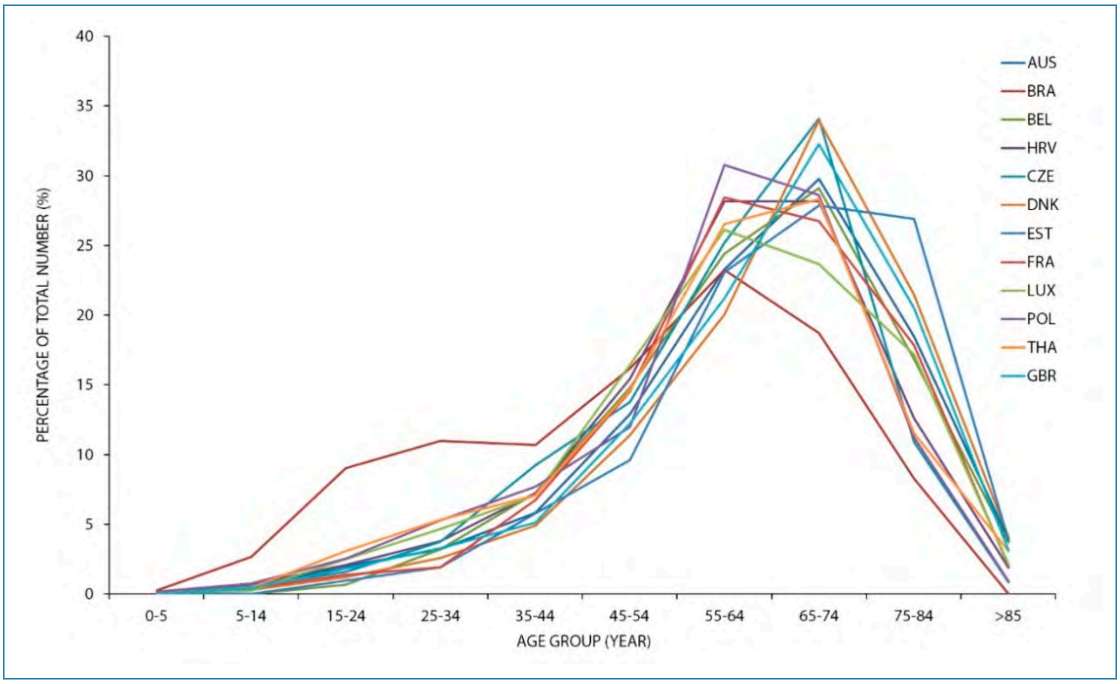


Table D23. Distribution of male and female patients undergoing PET oncology procedures

PET: Positron emission tomography

Country	*Distribution (%)*	
	Male	*Female*
Australia	57.7	42.3
Belgium	59.1	40.9
Brazil	51	49
Croatia	51.1	48.9
Czech Republic	50.5	49.5
Denmark	54	46
Estonia	47.1	52.9
France	52.1	47.9
Luxembourg	55.9	44.1
Poland	51.5	48.5
Thailand	54.9	45.1
United Kingdom	55.5	44.5

B. Literature review data

D49. The age distribution of patients undergoing nuclear medicine procedures is rarely reported, but has been published for the United States [M9], Luxembourg [S12] and Germany [B33] and is summarized in tables D24 and D25. In these countries, most patients are in the 40–75 year age range.

Table D24. Comparison of age distribution of nuclear medicine patients in Luxembourg [S12] and United States [M9]

Country	*Distribution (%) per age group (year)*									
	0–10	*11–17*	*18–24*	*25–34*	*35–44*	*45–54*	*55–64*	*65–74*	*75–84*	*>85*
Luxembourg	1	0.7	4.6	11	15.8	18.8	18.9	19.1	8.8	1.3
United States	1.1	1.2	1.5	5.8	10.5	19.2	22	20.9	14.7	3.2

D50. The age distribution in the United States in 2003 was virtually identical to the age distribution found for all nuclear medicine procedures in 1980 [M9]. At that time, 37.8% of procedures were carried out in patients aged 45 to 64 years and 39% were in patients over the age of 64. These can be compared with 41.2 and 38.8%, respectively, found for the same age groups in 2003.

D51. The age distribution is not the same for all procedures as shown in table D25. In Germany [B33] myocardial studies are rarely performed in patients under the age of 45 years and only 10–15% were older than 75 years, while the distribution is quite different for lung procedures, where up to 20% of patients were aged less than 45 and 25% were over 75.

Table D25. Age distribution for SPECT procedures performed in Germany (2007–2008) [B33]

MAA: Macroaggregated albumin; MIBI: Methoxy isobutyl isonitrile; SPECT: Single photon emission computed tomography

Examination	*Distribution (%) per age group (year)*				
	16–30	*31–45*	*46–60*	*61–75*	*>75*
Brain	1.7	10.2	22.1	48.6	17.4
Tumour imaging, octreotide	4.2	11.2	32	43.5	9.1
Skeleton, malignant disease, bisphosphonates	1.6	8.2	27.3	46	16.9
Skeleton, benign disease, bisphosphonates	4.2	13.7	29.3	36	16.8
Lung, ventilation	6.4	15.2	19.4	37.3	21.7
Lung, perfusion, ^{99m}Tc-MAA	4.2	9.2	20.5	42.5	23.6
Myocardium, ventriculography	2.2	10.8	34.8	42.8	9.4
Myocardium, vitality, ^{201}Tl chloride	0.8	8.4	31	47.6	12.2
Myocardium, vitality, MIBI	0.4	5.2	26.1	52.6	15.7
Parathyroid, MIBI	3.4	14.3	29.5	39.1	13.7

D52. Zvonova et al. [Z2] reported on the number of nuclear medicine procedures among children in 10 hospitals in the Russian Federation in 2011–2013 (table D26). The authors indicated that 12.7% of the procedures were performed in children aged 0–2, 23.1% in the 3–7 age range, 31.8% in the 8–12 age range and 32.4% in the 13–17 age range. The majority of all nuclear medicine procedures for each age group were renal scans. The contribution of bone, lung and heart examinations increased with age, while whole body and liver examinations remained approximately constant.

Table D26. Age distribution of nuclear medicine examinations in children in Russian Federation [Z2]

PET: Positron emissions tomography

Examined organ	*Number of procedures per age group (year)*				
	0–2	*3–7*	*8–12*	*13–17*	*0–17*
Kidney	135	244	368	376	1 123
Bone	1	19	51	61	132
Whole body[a]	58	59	52	63	232
Liver	26	25	39	46	136
Brain[a]	44	105	116	76	341
Lung	1	16	14	24	55
Heart	1	15	12	30	58
Thyroid	1	1	12	6	20
Other		1	4		5
Total	**267**	**485**	**668**	**682**	**2 102**

[a] PET procedures were performed in only one specialized hospital.

D53. O'Connor et al. [O2] reviewed computed tomography, MRI, nuclear medicine and ultrasound studies in paediatric patients in Ireland in the period 2003–2012 and found a 13% increase in nuclear medicine procedures. Approximately 70% of these studies were renal examinations. Table D27 shows the number of procedures by age groups reported in this study, with the percentage of the total.

Table D27. Age distribution of paediatric nuclear medicine procedures in Ireland [O2]

Parameter	*Number of procedures per age group (year)*						
	0–3	*3–6*	*6–9*	*9–12*	*12–15*	*15–18*	*0–18*
Number of procedures	7 655	2 938	1 797	1 309	974	548	15 221
Proportion to the total (%)	50	19	12	9	6	4	100

D54. There are a number of schemes for determining the appropriate activity of a radio-pharmaceutical to be administered to a child. These are usually based on either the age or the weight of the child. One scheme published by the European Association of Nuclear Medicine can be accessed online [E1]. Zvonova et al. [Z2] reported on the activities administered to children and the corresponding range of effective doses from nuclear medicine procedures in the Russian Federation in 2013. These results are presented in tables D28 and D29.

Table D28. Administered activities to children and adults in Russian Federation [Z2]

DTPA: Diethylenetriaminepentaacetic acid; FDG: Fluoro-2-D-deoxyglucose; IDA: Iminodiacetic acid; MAA: Macroaggregated albumin; MAG_3: Mercaptoacetyltriglycine; MIBG: Meta-iodobenzylguanidine

Examined organ	*Radiopharmaceutical*	*Administered activity (MBq) per age group (year)*				
		0–2	*3–7*	*8–12*	*13–17*	*Adults*
Kidney	^{99m}Tc-DTPA	10–40	20–50	20–70	50–200	70–400
	^{99m}Tc-MAG3	4–40	15–50	4–70	11–120	40–250
	^{123}I-hippuran	2–10	6–30	8–40	10–70	2–30
Whole body	^{123}I-MIBG	25–80	75–120	100–130	160	150–300
	^{18}F-FDG	100	150	200	200–250	220–380
Lymphatic system	^{67}Ga-citrate		30–40	100–250	100	100–500
Liver	^{99m}Tc-IDA	40	50	60	80	60–200
	^{99m}Tc-colloids	10–40	25–50	50–70	25–80	60–160
Lung	^{99m}Tc-MAA	7	20–80	30–100	40–130	75–190
Brain	^{11}C-methionine	50–100	100–300	300–500	500–700	500–700
	^{18}F-FDG	65	80	120	140	140
Thyroid	^{99m}Tc-pertechnetate	60	74	74–300	18–100	40–370
	^{123}I-NaI	5–10	5–10	5–10	5–10	5–10

Table D29. Effective dose (mSv) from nuclear medicine procedures in Russian Federation [Z2]

CT: Computed tomography; PET: Positron emission tomography; SPECT: Single photon emission computed tomography

Examined organ	*Effective dose (mSv) per age group (year)*				
	0–2	*3–7*	*8–12*	*13–17*	*Adults*
Kidney	0.1–2	0.1–2	0.2–2	0.2–2	0.5–2
Heart	7–8	4–7		3–6	2–5
Liver	2–4	1–2	1–2	1–2	1–4
Lung	0.5	2–3	1–2	1–2	1–2
Bone	~2	3–9	1–2	1–2	2–3
Bone (SPECT/CT)		8–14	5–6	5–6	4–5
Thyroid (^{99m}Tc and ^{123}I)	1–2	~2	~2	~1	1–2
Whole body (^{99m}Tc and ^{123}I)	2–5	2–6	3–8	3–9	2–4 [a]
Lymphatic system		~12	~50	~12	10–40
Whole body PET (^{18}F-FDG)	~10	~8	~7	5–6	2–7
Whole body PET/CT (^{18}F-FDG)	~20	~18	~17	13–14	8–13
Brain PET (^{18}F and ^{11}C)	2–6	4–8	4–8	4–8	1–8
Brain PET/CT (^{18}F and ^{11}C)	3–7	5–9	5–9	5–9	2–9

[a] Adult patients obtain the greatest doses from examinations with ^{111}In-octreotide (with effective doses up to 13 mSv).

D55. Bartlett et al. [B10] examined the paediatric nuclear medicine procedures performed in Australia between 1985 and 2005. Although the number of procedures increased by a factor of four during that period, peaking around the year 2000, the age distribution of the patients remained fairly constant. Most services were either bone scans (45%) or renal scans (29%), with renal scans predominating at younger ages and bone scans at older ages. For example, in the 0–3 age group, renal and bone scans accounted for 71% and 10% of all scans performed while in the 17–19 age group, the figures were 5 and 58%, respectively. The median effective dose per patient ranged from 1.3 mSv (4–7 years old) to 2.8 mSv (13–16 years old).

VI. STAFF AND DEVICES

D56. Table D30 demonstrates the wide disparity in the availability of trained nuclear medicine professionals across the world as reported in the UNSCEAR Global Survey. The number of physicians practicing nuclear medicine in the United States is almost ten times higher than most other countries although the rate of nuclear medicine procedures is comparable to that of many European countries (table D1) reflecting the differences in the health care delivery models in the different countries. The data provided by Belgium did not differentiate between radiation technologists working in nuclear medicine from those working in radiology so has not been included. The data from the United Kingdom are unusual, with approximately two medical physicists and seven radiation technologists per nuclear medicine physician.

D57. Table D31 presents the staff of nuclear medicine departments in Latin American countries [P1]. The data were obtained from the IAEA Nuclear Medicine Database (NUMDAB), and also from the several ongoing IAEA regional projects. Similarly, table D32 shows information on nuclear medicine staffing in countries of the Middle East [P2]. These data were also obtained from the IAEA NUMDAB database.

D58. Tables D33, D34 and D35 show the nuclear medicine equipment reported to the current UNSCEAR Global Survey, the IAEA NUMDAB data from Latin America and the Middle East, respectively. In a number of countries SPECT/CT systems are slowly replacing SPECT systems. For example, table D33 shows that in Switzerland all 52 SPECT systems are now hybrid systems, while two thirds of the SPECT systems in Australia incorporate a computed tomography scanner. The availability of PET systems is highly variable with some countries having more than 5 per million population (e.g., Denmark 7.4, United States 5.2), while Brazil is the only country in Latin American, and Kuwait, Lebanon and Turkey the only Middle Eastern countries, to have more than one PET system per million population.

Table D30. Number of nuclear medicine staff by country in absolute number and per million population as reported to UNSCEAR Global Survey

Country	*Nuclear medicine physicians*		*Nuclear medicine medical physicists* [a]		*Nuclear medicine technologists* [a]		*Radiopharmacists/ radiochemists* [a]		*Nurses in nuclear medicine* [a]	
	Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Argentina	374	9.3	13	0.3	208	5.2				
Australia	247	10.4	20	0.8	1 015	42.8	25	11	50	2.1
Bangladesh	126	0.8								
Belarus	43	4.5			50	5.3			50	5.3
Belgium	308	27.5	35	3.1			48	4.3		
Brazil	792	3.9	196	1	518	2.5	393	1.9	2 350	11.5
Brunei Darussalam	1	2.4	1	2.4	3	7.2	5	12	2	4.8
Bulgaria	57	7.7	13	1.8	34	4.6	18	2.4	30	4.1
Canada	280	7.6	26	0.7	668	18.2				
China	3 904	3.2	87	0.1	2 777	2.3	174	0.1	1 736	1.4
Croatia	74	18	9	2.2	41	10	41	10	65	15.8
Cyprus	7	7.4	4	4.2	7	7.4				
Czech Republic	199	18.8	34	3.2	75	7.1	57	5.4	314	29.7
Denmark	110	19.3	25	4.4			27	4.7		
Estonia	11	8.4	5	3.8	18	13.7	2	1.5	3	2.3
Finland	104	19								
France	648	9.9	74	1.1	1 470	22.4	126	1.9		
Germany	1 000	12.3								
Greece	296	27	277	25.3	114	10.4	86	7.8	133	12.1
Iceland	3	8.7								
Indonesia	45	0.2	13	0.1	13	0.1	4	0.02	26	0.1
Japan	1 393	11								

Country	*Nuclear medicine physicians*		*Nuclear medicine medical physicists*[a]		*Nuclear medicine technologists*[a]		*Radiopharmacists/ radiochemists*[a]		*Nurses in nuclear medicine*[a]	
	Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Lebanon	15	3.1			25	5.2				
Lithuania	22	7.6	7	2.4	20	6.9			15	5.2
Luxembourg	12	21.1	1	1.8	30	52.7			2	3.5
Malaysia	37[a]	1.1	75	2.3	226	6.9	60	1.8	184	5.6
Montenegro	4	6.7	1	1.7	6	10				
Netherlands	190	11.3								
Niger	4	0.2	1	0.1	2	0.1			1	0.1
North Macedonia	27	13	6	2.9	17	8.2	8	3.9	4	1.9
Philippines	159	1.6	17	0.2	122	1.2	4	0.04		
Poland	296	7.7	63	1.6						
Romania	71	3.6	26	1.3						
Russian Federation	400	2.7	40	0.3	650	4.4			150	1
Spain	630	13.5	77	1.6						
Sudan	12	0.3	20	0.6	25	0.7				
Sweden	220	22	80	8						
Switzerland	150	17.8	40	4.8	500	59.4	33	3.9		
Thailand	66	1	25	0.4	93	1.4	29	0.4	60	0.9
Ukraine	95	2.2	6	0.1					470	11.1
United Arab Emirates	21	2.3	13	1.4	39	4.2	4	0.4	17	1.8
United Kingdom	160[b]	2.4	300	4.6	1 150	17.5	30	0.5	75	1.1
United States	27 522[c]	85.2	9 217	28.5	16 307	50.5	11 344	35.1	14 889	46.1

[a] Empty cell indicates no data available.

[b] Malaysia reported an additional 50 other physicians conducting nuclear medicine procedures.

[c] Nuclear medicine physicians in the United Kingdom includes 85 radiologists.

[d] The numbers reported for the United States reflect the number of clinicians and other professionals whose work involves nuclear medicine. They are not all nuclear medicine physicians, nurses, etc.

Table D31. Staff of nuclear medicine departments in Latin American countries [P1], excluding those reported to UNSCEAR Global Survey

Country	*Population (in millions)*	*Nuclear medicine physicians*		*Nuclear medicine medical physicists* [a]		*Nuclear medicine technologists* [a]		*Radiopharmacists/ radiochemists* [a]	
		Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Bolivia	9.9	13	1.3	1	0.1	10	1.0	11	1.1
Chile	17	44	2.6	2	0.1	61	3.6	9	0.5
Colombia	45.7	82	1.8	12	0.3	86	1.9	24	0.5
Costa Rica	4.6	5	1.2	1.2	0.3	20	4.3	8	1.8
Cuba	11.2	35	3.1	24	2.1	65	5.8	13	1.1
Dominican Republic	10	13	1.3	1	0.1	16	1.6		
Ecuador	13.6	10	0.7			14	1.0		
El Salvador	6.1	2	0.3			5	0.8		
Guatemala	14	4	0.3			12	0.9		
Haiti	10	0	0.0			0			
Honduras	7.5	1	0.1			2	0.3		
Jamaica	2.7	1	0.4			0			
Mexico	116	242	2.1	6	0.1	128	1.1		
Nicaragua	5.7	2	0.4			2	0.4	1	0.2
Panama	3.4	5	1.5	1	0.3	8	2.4		
Paraguay	6.3	3	0.5			6	1		
Peru	29.1	47	1.6	5	0.2	59	2	4	0.1
Uruguay	3.4	32	9.7			44	13	16	4.8
Venezuela	28.6	23	0.8	31	1.1	40	1.4	3	0.1
Total	**571.8**	**1 265**	**2.2**	**129**	**0.2**	**2 205**	**3.9**	**146**	**0.3**

[a] Empty cell indicates no data available.

Table D32. Staff of nuclear medicine departments in Middle East countries [P2], excluding those reported to UNSCEAR Global Survey

Country or region	*Population (in millions)*	*Nuclear medicine physicians* [a]		*Nuclear medicine medical physicists* [a]		*Nuclear medicine technologists* [a]		*Radiopharmacists/ radiochemists* [a]	
		Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Bahrain	1.3	5	3.7	2	1.5	5	3.7	2	1.5
Egypt	83.4	105	1.3	32	0.4	95	1.1	12	0.1
Iran (Islamic Republic of)	78.5	200	2.5	123	1.6	400	5.1	23	0.3
Iraq	34.3	11	0.3	21	0.6	10	0.3	5	0.1
Israel	8.2	75	9.1	7	0.9	85	10.3	5	0.6
Jordan	6.6	29	4.4	20	3	34	5.1	5	0.8
Kuwait	3.5	50	14.4	10	2.9	150	43.1	10	2.9
Oman	3.9	9	2.3	14	3.6	17	4.3	0	0
Palestine, State of	4.4	1	0.2	0	0	1	0.2	0	0
Qatar	2.3	5	2.2	3	1.3	13	5.7	3	1.3
Saudi Arabia	29.4	79	2.7	60	2	172	5.9	25	0.9
Syria	23.3	10	0.4	25	1.1	10	0.4	5	0.2
Turkey	75.8	535	7.1	250	3.3	850	11.2	70	0.9
Yemen	25	6	0.2	3	0.1	6	0.2	2	0.1
Total	**390.6**	**1 157**	**3**	**586**	**1.5**	**1 953**	**5**	**173**	**0.4**

[a] Zero values are indicated when available; otherwise, cells have been kept empty.

Table D33. Equipment used in nuclear medicine reported to UNSCEAR Global Survey

CT: Computed tomography; PET: Positron emission tomography; SPECT: Single photon emission computed tomography

Country	*Total SPECT*[a,b]		*SPECT/CT*[a,b]		*Total PET*[a,b]		*PET/CT*[a,b]		*Gamma cameras (Planar)*[a,b]		*Single channel spectrometer*[a,b]	
	Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Argentina	287	7.2	8	0.2	28	0.7	10	0.2	40	1	274	6.8
Australia	400	16.8	260	11	44	1.9	40	1.7	40	1.7	12	0.5
Bangladesh	13	0.1			4	0.03			72	0.5	35	0.2
Belarus	18	1.9	1	0.1					7	0.7		
Belgium	205	18.3	129	11.5	26	2.3	24	2.1	130	11.6		
Brazil	784	3.8	10	0.05	130	0.6	130	0.6	138	0.7		
Brunei Darussalam	1	2.4	1	2.4	1	2.4	1	2.4			2	4.8
Bulgaria	15	2	5	0.67	7	1	7	1	2	0.3	1	0.1
Canada	330	9	261	7.1	51	1.4	51	1.4				
China	555	0.5	215	0.2	198	0.2			17	0.01		
Croatia	7	1.7	7	1.7	5	1.2	5	1.2	12	2.9		
Cyprus	10	10.5	1	1.1								
Czech Republic	131	12.4	46	4.3	35	3.3	15	1.4	30	2.8	45	4.3
Denmark	55	9.6	41	7.2	42	7.4	39	6.8	42	7.4		
Estonia	3	2.3	3	2.3	3	2.3	3	2.3			4	3
Finland	35	6.4	35	6.4	29	5.3	13	2.4				
France	474	7.1	298	4.4	162[c]	2.4	158	2.4				
Germany					150	1.8						
Greece	147	13.4	7	0.6	5	0.5	5	0.5	5	0.5		
Iceland	4	11.6	1	2.9								
Japan	1 432	11.3	346	2.7	536[d]	4.2	489	3.9				
Lebanon	17	3.5	2	0.4	28	5.8	14	2.9	1	0.2		
Lithuania	1	0.3	1	0.3	2	0.7	2	0.7	8	2.8		
Luxembourg	7	12.3	1	1.8	2	3.5	1	1.8	2	3.5		

Country	*Total SPECT*[a,b]		*SPECT/CT*[a,b]		*Total PET*[a,b]		*PET/CT*[a,b]		*Gamma cameras (Planar)*[a,b]		*Single channel spectrometer*[a,b]	
	Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Malaysia	10	0.3	10	0.3	21	0.6	21	0.6	4	0.1		
Montenegro	1	1.7	1	1.7					1	1.7		
Netherlands					58	3.4			160	9.5		
Niger	2	0.1									1	0.1
North Macedonia	6	2.9	2	1	6	2.9	3	1.4	2	1		
Philippines	4	0.04	4	0.04	6	0.06	6	0.06	55	0.5		
Poland	76	2	42	1.1	26	0.7	26	0.7	18	0.5		
Romania	14	0.7	7	0.4	12	0.6	12	0.6	32	1.6	2	0.1
Russian Federation	168	1.1	80	0.5	19	0.1	19	0.1	60	0.4	94	0.6
Spain	78	1.7	78	1.7	92	2	75	1.6				
Sudan	5	0.1							2	0.06		
Sweden	61	6.1	50	5	20	2	17	1.7	5	0.5	25	2.5
Switzerland	52	6.2	52	6.2	41	4.9	39	4.6	15	1.8	10	1.2
Thailand	26	0.4	19	0.3	14	0.2	14	0.2			23	0.3
Turkey	359	4.5	39	0.5	136	1.7	133	1.7				
Ukraine	19	0.4	4	0.1	3	0.1	3	0.1	21	0.5	29	0.7
United Arab Emirates	21	2.3	6	0.6	4	0.4	4	0.4	1	0.1		
United Kingdom	460	7	240	3.7	77[e]	1.2	70	1.1	40	0.6		
United States	12 931	40	1 967	6.1	1 680	5.2	1 596	4.9	1 124	3.5		

[a] Empty cell indicates no data available.

[b] Values are rounded; however extended precision has been preserved to illustrate differences.

[c] Includes 4 PET/MRI systems.

[d] Includes 9 PET/MRI systems.

[e] Includes 7 PET/MRI systems.

Table D34. Equipment used in nuclear medicine centres in Latin American countries [P1], excluding those in UNSCEAR Global Survey

CT: Computed tomography; PET: Positron emission tomography; SPECT: Single photon emission computed tomography

Country	*Population (in millions)* [a]	*SPECT* [a,b]		*SPECT/CT* [a,b]		*Gamma cameras (Planar)* [a,b]		*Total gamma cameras* [a,b]		*PET* [a,b]	
		Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Bolivia	9.9	8	0.8	0	0.0	3	0.3	11	1.1	0	0.0
Chile	17	45	2.6	6	0.4	4	0.2	55	3.2	10	0.6
Colombia	45.7	78	1.7	4	0.1	0	0.0	82	1.8	9	0.2
Costa Rica	4.6	7	1.5	0	0.0	2	0.4	9	2	1	0.2
Cuba	11.2	13	1.2	1	0.1	1	0.1	15	1.3	1	0.1
Dominican Republic	10	12	1.2	0	0.0	1	0.1	13	1.3	1	0.1
Ecuador	13.6	3	0.2	3	0.2	1	0.1	7	0.5	2	0.1
El Salvador	6.1	2	0.3	0	0.0	0	0.0	2	0.3	0	0.0
Guatemala	14	3	0.2	0	0.0	4	0.3	7	0.5	0	0.0
Haiti	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Honduras	7.5	2	0.3	0	0.0	0	0.0	2	0.3	0	0.0
Jamaica	2.7	1	0.4	0	0.0	1	0.4	2	0.7	0	0.0
Mexico	116	260	2.2	25	0.2	0	0.0	285	2.5	35	0.3
Nicaragua	5.7	1	0.2	0	0.0	0	0.0	1	0.2	0	0.0
Panama	3.4	3	0.9	4	1.2	0	0.0	7	2.1	1	0.3
Paraguay	6.3	5	0.8	0	0.0	0	0.0	5	0.8	1	0.2
Peru	29.1	35	1.2	2	0.1	2	0.1	39	1.3	3	0.1
Uruguay	3.4	14	4.2	3	0.9	0	0.0	17	5.1	2	0.6
Venezuela	28.6	28	1	1	0.0	13	0.5	42	1.5	6	0.2
Total [c]	**571.8**	**1 064**	**1.9**	**87**	**0.2**	**80**	**0.1**	**1 231**	**2.2**	**161**	**0.3**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when reported.

[c] Total values as reported in [P2], including countries that reported data to the UNSCEAR Global Survey.

Table D35. Equipment used in nuclear medicine centres in Middle East countries [P2], excluding those reported to UNSCEAR Global Survey

CT: Computed tomography; PET: Positron emission tomography; SPECT: Single photon emission computed tomography

Country	*Population (millions)* [a]	*Gamma cameras and SPECT* [a,b]		*SPECT/CT* [a,b]		*Gamma cameras* [a,b]		*PET* [a,b]	
		Number	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*	*Number*	*Per million population*
Bahrain	1.3	3	2.2	1	0.7	4	0.7	1	0.7
Egypt	83.4	65	0.8	9	0.1	74	0.1	15	0.2
Iran (Islamic Republic of)	78.5	200	2.5	8	0.1	208	0.1	3	0.04
Iraq	34.3	5	0.1	0	0.0	5	0.0	0	0
Israel	8.2	63	7.7	26	3.2	89	3.2	9	1.1
Jordan	6.6	13	2	0	0.0	13	0.0	6	0.9
Kuwait	3.5	30	8.6	6	1.7	36	1.7	6	1.7
Oman	3.9	3	0.8	2	0.5	5	0.5	2	0.5
Palestine, State of	4.4	1	0.2	0	0.0	1	0.0	0	0
Qatar	2.3	3	1.3	1	0.4	4	0.4	1	0.4
Saudi Arabia	29.4	49	1.7	34	1.2	83	1.2	13	0.4
Syria	23.3	2	0.1	2	0.1	4	0.1	2	0.1
Yemen	25	5	0.2	0	0.0	5	0.0	0	0
Total [c]	**390.6**	**803**	**2.1**	**107**	**0.3**	**910**	**0.3**	**194**	**0.5**

[a] Values are rounded; however extended precision has been preserved to illustrate differences.

[b] Zero values are indicated when reported.

[c] Total values as reported in [P2], including countries that reported data to the UNSCEAR Global Survey.

VII. TRENDS

A. Frequency of nuclear medicine procedures

D59. Eleven articles presented data on trends in exposure from nuclear medicine. The biggest change in the past decade has been the steady increase in the number of PET procedures. For example, in Finland PET procedures increased by 70% between 2006 and 2009 even though there was a slight decrease in the overall number of nuclear medicine procedures [B19]. In Japan, while single-photon studies decreased by 19% between 2007 and 2012, PET studies increased by 25% during the same period [K10]. Similarly, a 3% annual decline in nuclear medicine procedures between 1996 and 2010 was reported in the United States while PET studies simultaneously increased by 57% annually [S18]. In the United States, there have also been significant changes in the type of nuclear medicine procedures performed. Between 1980 and 2006, cardiac procedures increased by 450% while lung procedures decreased by 38% compared to 1982 [M10].

D60. In other countries the number of nuclear medicine procedures continued to increase. In France they increased by 40% between 2002 and 2007 [E10], in Taiwan, China they increased by 42% between 1997 and 2008 [C6], while in the Republic of Korea they increased by 90% between 2006 and 2013 with PET/CT increasing by 30% [L3] (table D36).

Table D36. Trends of nuclear medicine procedure frequencies and related collective effective doses in Republic of Korea for the period (2006-2013) [L3]

Parameter	*Year*							
	2006	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
Frequency per 1 000 population	336	431	489	532	578	603	618	640
Collective effective dose (man Sv)	3 590	4 838	5 662	6 212	6 791	7 065	7 299	7 606
Annual per caput effective dose (mSv)	0.07	0.10	0.11	0.12	0.13	0.14	0.14	0.15

D61. Mettler et al. [M9] reported on the change in nuclear medicine procedures in the United States between 1973, 1982 and 2005, in terms of both the absolute number of procedures and the percentage of the total of procedures (table D37). Although PET scans were available in the United States in 2005 these were not included in the number of examinations reported, although Mettler et al. estimated the number to be approximately 5% of all nuclear medicine procedures. The most significant change noted was the rapid rise in the number of cardiac procedures which increased by a factor of 10 between 1982 and 2005 so that they accounted for 57% of all procedures in 2005. During the same period, the use of ^{201}Tl chloride for many of the myocardial perfusion studies was replaced by ^{99m}Tc radiopharmaceuticals (sestamibi or tetrofosmin), which resulted in substantially lower patient doses per procedure. The current UNSCEAR Global Survey indicates that this trend has reversed in the past decade with cardiac procedures declining. There have been similar trends for some other procedures, notably bone scans. PET tumour imaging has increased, now accounting for 14.6% of all nuclear medicine procedures.

Table D37. Comparison of diagnostic nuclear medicine procedures in the United States since 1973 [M9] and reported to UNSCEAR Global Survey

PET: Positron emission tomography. Empty cell indicates no data available

Procedure	*1973*		*1982*		*2005*		*Current evaluation*	
	Number (1 000)	*Proportion (%)*	*Number (1 000)*	*Proportion (%)*	*Number (1 000)*	*Proportion (%)*	*Number (1 000)*	*Proportion (%)*
Bone	125	3.6	1 811	24.5	3 450	20	1 670	12.3
Cardiac	33	1	950	12.8	9 800	57	6 440	47.6
Lung	417	11.9	1 191	16.1	740	4	690	5.1
Thyroid	460	13.1	677	9.1	339	2	590	4.4
Renal	122	3.5	236	3.2	470	3	360	2.7
Gastro	535	15.2	1 603	21.7	1 210	7	930	6.9
Brain	1 510	43	812	11		<2	200	1.5
Infection					380	2	280	2.1
Tumour	14	0.4	121	1.6	340	2	400	3
PET							1 970	14.6
Other	294	8.4				<2		
Total	**3 510**	**100**	**7 400**	**100**	**17 200**	**100**	**13 530**	**100**

D62. The EC DDM 1 project [E3] included studies conducted within the period 1998–2005, and EC DDM 2 project [E5], included studies for the period 2007–2011. The EC DDM 1 project included eight European countries, one of which, Belgium, did not provide data for the EC DDM 2, leaving seven countries for which a comparison of the frequency of nuclear medicine procedures is presented in table D38. Overall, the frequency of these procedures decreased between the two surveys although the changes were not consistent across the seven countries.

Table D38. Comparison of averaged frequency per 1,000 population between EC DDM 1 [E3] and EC DDM 2 [E5] projects for specific nuclear medicine procedures

Country	*Bone scan (^{99m}Tc)*		*Heart*		*Thyroid*		*Lung perfusion (^{99m}Tc)*		*Renal*	
	DDM 1	*DDM 2*	*DDM 1*	*DDM 2*	*DDM 1*	*DDM 2*	*DDM 1*	*DDM 2*	*DDM 1*	*DDM 2*
Germany	11	10	5	5	17	15	3	0.7	3	1
Luxembourg	13	14	6	4	11	10	2	1	1	0.5
Netherlands	6	6	4	3	1	0.5	3	0.4	1	0.8
Norway	4	3	3	2	1	0.7	1	0.2	1	0.9
Sweden	3	2	2	3	1	0.7	1	0.6	2	0.6
Switzerland	5	4	3	2	1	0.6	1	0.3	1	0.2
United Kingdom	3	3	2	2	0.3	0.3	3	2	2	1

D63. The Japan Radioisotope Association has performed a nationwide survey of in vivo and in vitro nuclear medicine practice every five years since 1982. The most recently reported survey was in 2017 [J9]. In 2017, there were 1,249 institutes performing nuclear medicine procedures, with 1,156 performing single photon imaging and radionuclide therapy. There were 389 institutes with PET imaging facilities, which represented an increase of 32% over 5 years. Although the number of gamma cameras in Japan fell from 1,425 in 2012 to 1,332 in 2017, this now included 314 SPECT/CT systems, more than double the number in 2012 (149). Table D39 presents the annual estimates of nuclear medicine procedures in Japan from 1992 to 2017. During that 25-year period, the number of single-photon procedures has decreased by 34% while the number of PET procedures has increased by a factor of 120. The number of therapy procedures remained relatively constant from 1992 to 2007, but has increased by 117% in the past decade due to a continued increase in the treatment of thyroid disorders (both hyperthyroidism and thyroid cancer) and the introduction of ^{89}Sr therapy for bone pain palliation and ^{90}Y-ibritumomab tiuxetan (Zevalin) for lymphoma.

Table D39. Annual number of nuclear medicine procedures in Japan [J9]

PET: Positron emission tomography

Modality category	*Year*					
	1992	*1997*	*2002*	*2007*	*2012*	*2017*
Diagnostic nuclear medicine procedures	1 650 000	1 860 000	1 621 200	1 417 700	1 149 900	1 083 800
PET procedures	5 900	11 200	26 100	414 300	575 800	711 800
Radionuclide therapies	4 000	3 100	5 000	6 500	10 500	14 100

D64. The trends reported in the literature are supported by the changes observed between the UNSCEAR 2008 Report [U9] and the current survey. As shown previously in table D1, the frequency of nuclear medicine procedures per 1,000 population has fallen significantly in a number of European countries, while increasing significantly in others. The average change in frequency of nuclear medicine procedures since the UNSCEAR 2008 Report [U9] was +14%, with a population-weighted average change of +3% (excluding the very high percentage change recorded in Belarus).

D65. Table D40 examines the changes between the UNSCEAR 2008 Report [U9] and UNSCEAR Global Survey for those countries which reported radionuclide therapy data in both surveys. Six countries showed reductions in the frequency of radionuclide therapy, while others showed substantial increases. Overall, for the 14 countries there was an average increase of 33%, with a population-weighted increase of 10%, since the UNSCEAR 2008 Report [U9].

Table D40. Comparison of averaged radionuclide therapy frequencies per 100,000 population between UNSCEAR 2008 Report [U9] and UNSCEAR Global Survey

Country	*UNSCEAR 2008 Report [U9]*	*Current evaluation*	*Variation (%)*
Czech Republic	27.2	18.5	−32
Estonia	41.4	65.5	58
Finland	44	34.2	−22
Greece	12	27.5	129
Hungary	32.9	15.3	−54
Iceland	34.7	32.3	−7
Japan	3.5	8.3	139
Luxembourg	10.8	32.7	202
Netherlands	38.4	14.5	−62
Norway	20.9	26.6	27
Poland	33.6	54.4	62
Sweden	34.5	45.3	31
Switzerland	30.9	38.1	23
United Kingdom	24.4	13.3	−46

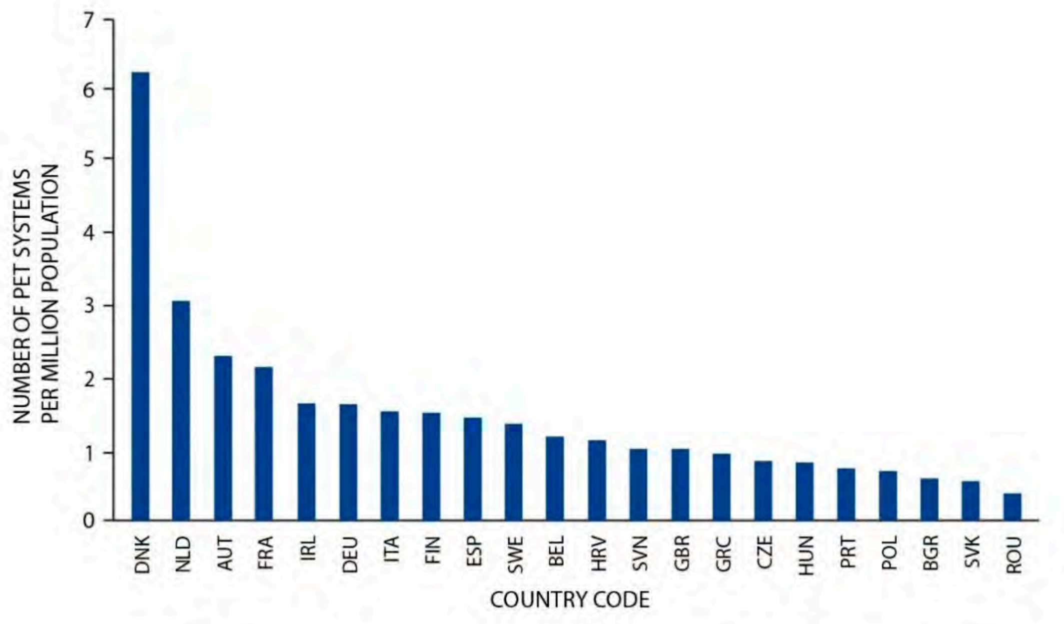
B. Trends in nuclear medicine imaging systems

D66. Throughout the world, PET/CT systems have now largely replaced stand-alone PET systems. Commercial SPECT/CT systems have been available since about 2005, however information on their distribution is very limited. A nationwide survey was conducted in the United Kingdom in 2014 and found 193 SPECT/CT systems at 135 sites compared to 57 sites with PET/CT [I7]. In Belgium, the Federal Public Service provides regularly updated online maps of the distribution of PET/CT and SPECT/CT systems [S21]. In the Republic of Korea, PET/CT procedures ranked the highest average annual increasing rate of 49.4% and have rapidly increased by 800% between 2006 and 2013 in tandem with an increase in the number of PET-CT scanners of over 200% during the same period [L3].

D67. The European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry published age and density (number of systems in use per million population) data of computed tomography, angiography equipment, MRI and molecular PET equipment. The density profile for PET equipment installed in Europe from 2015 is shown in figure D-VI [C11].

Figure D-VI. Density of installed PET systems per million population in Europe in 2015 [C11]

PET: Positron emission tomography



D68. Table D33 presents a detailed analysis on the use of hybrid systems across the world as found in the UNSCEAR Global Survey. Thirty-three countries provided data on PET and PET/CT systems. Of these, 16 used PET/CT systems exclusively while in a further eight countries PET/CT accounted for more than 90% of installations. Although data on PET/MRI systems were not requested in the current survey, Japan reported that nine of the 536 PET systems were combined PET/MRI units. Forty countries reported on SPECT and SPECT/CT systems. Globally, SPECT/CT accounted for 22% of all SPECT installations and this number is likely to rise as older SPECT systems are replaced.

D69. It is important to note that in many cases performed on a SPECT/CT system, the computed tomography component is not used. This is highlighted in table D11 which presents the percentage of studies that included a computed tomography scan. Finland, which has only SPECT/CT systems, used the computed tomography in a maximum of 40% of cases. Usually, the SPECT study is performed first, and computed tomography is performed only if the SPECT scan was abnormal, and the anatomical localization of the abnormality is in doubt.

VIII. SUMMARY

D70. The UNSCEAR Global Survey included a detailed questionnaire on nuclear medicine practice across the world and the submitted data were analysed to estimate the frequency of nuclear medicine procedures, the administered activity of each radiopharmaceutical, and the resulting effective dose for each country. For hybrid systems, the frequency of computed tomography examinations together with the corresponding dose-length product and effective dose were calculated.

D71. The effective dose from the administered radiopharmaceutical has been calculated from dose coefficients (mSv/MBq) from ICRP publication 128 [I15], which uses a mathematical human phantom and ICRP 60 tissue weighting factors [I9]. A revised publication by the ICRP is expected to be available soon, which will use anthropomorphic models derived from whole body computed tomography and tissue weighting factors from ICRP 103 [I11].

D72. The frequency of radionuclide therapy was found to have increased by 33% since the UNSCEAR 2008 Report [U9]. In the past decade, a number of new therapies have been introduced clinically and are now available in many countries. These include ^{90}Y-microspheres for the treatment of liver tumours, ^{177}Lu-octreotide for neuroendocrine tumours and ^{177}Lu-PSMA for prostate cancer. Statistics on the use of these newer therapies are often limited, so the frequencies estimated in the current evaluation are likely to be an underestimate. There is considerable research activity underway into “theranostics”, in which the same chemical vector is used for both diagnosis and treatment, using different radionuclides. This is likely to lead to the establishment of these new procedures in routine clinical practice in many countries.

D73. The uncertainty in each of these estimations arises from several sources. Firstly, a number of countries conducted a survey of a limited number of nuclear medicine practices and then extrapolated the data to the whole country. This can lead to an over- or underestimate, depending on how representative of the whole country the sample sites were. Secondly, often a number of different radiopharmaceuticals are available for any one procedure and the particular one used may vary from site to site and also from patient to patient, depending on their clinical history. Thirdly, while computed tomography is now used in almost all PET procedures, this is not the case with SPECT. Although the number of SPECT/CT installations has increased markedly in the past decade, the survey showed (table D11) that the computed tomography component is usually used in less than 55% of cases. It is a common practice to perform the SPECT study first, and then perform the computed tomography only if the study is abnormal and the anatomical localization of the abnormality cannot be clearly identified from the SPECT images. This level of detail is often not available in national surveys but needs to be considered for future surveys.

D74. Despite the limitations of the UNSCEAR Global Survey, the results indicate that the frequency of nuclear medicine procedures, while declining in a number of European countries and United States, has increased globally by about 16% since the UNSCEAR 2008 Report [U9]. The frequency of diagnostic nuclear medicine procedures was found to average 12.4 per 1,000 population contributing to about 7% to the global collective effective dose. PET procedures continue to increase in number and now represent 17% of all nuclear medicine procedures. The use of PET is likely to increase further with their growing role in cancer care and the initiation of new radiopharmaceuticals that are currently under clinical development.

APPENDIX E. TRENDS IN USE OF RADIATION THERAPY

I. INTRODUCTION

E1. Radiation therapy for cancer treatment, unlike most other cancer treatment modalities, is a precise and extremely quantitative modality. In contrast to surgery, where the target tissue must often be exposed so as to be visible to the surgeon, radiation therapy is largely non-invasive and requires means other than the physician's vision to guide the radiation beam. The identification of the target tissue is critical because, as was stated by the Harold Johns, "if you can't see it, you can't hit it, and if you can't hit it, you can't cure it" [N5]. Early radiation therapy treatments, therefore, relied on the physician's best estimate of tumour location, and skin markings made through the use of X-ray imaging systems [H8, T6].

E2. Today, radiation therapy is delivered through external beams of radiation (*teletherapy*) or by placing radioactive sources into or near the tumour tissue (*brachytherapy*). External radiation beams may consist of high-energy X- or gamma rays, electrons, protons, neutrons, or heavier charged particles. Gamma-ray beams are most often produced by high-activity sources of ^{60}Co, while all other external radiation beams are produced by linear accelerators.

E3. Early radiation therapy treatment guidance consisted of X-ray imaging prior to treatment using conventional X-ray imaging equipment. A major step forward came with the introduction of electronic portal imaging equipment. Early devices generally consisted of two-dimensional arrays of semiconductor detectors that captured a portal image electronically, replacing radiographic film and the need for a film developer. These devices became available in the 1990s, but the technology improved substantially in the early 2000s, yielding to images of higher quality than the portal films they replaced. Manufacturers began producing linear accelerators equipped with this technology as a standard. Two key features were *(a)* the availability of images almost instantly after exposure, and *(b)* the ability to compare images digitally with digitally reconstructed radiographs produced by treatment-planning systems based on images acquired at computed tomography simulators. This milestone allowed true adaptive therapy, meaning that the treatment could potentially be modified to account for variations in the patient's position on a daily basis. Today, this technique is used to adjust the patient's position following a comparison of 3D-images with 2D-images from the planning system [M13, M14].

E4. Around the year 2000, linear accelerators manufacturers began to mount on-board kilovoltage (kV) imagers on the gantries of the systems, or elsewhere in the treatment rooms, so that almost diagnostic-quality orthogonal patient radiographs could be obtained in the treatment position by rotating the gantry. These imaging systems facilitated the comparison of projection radiographs from the on-board imaging system, leading to vastly-improved 2D/3D matching [M1]. The 3D-images are compared with reconstructed 2D-images from the planning computed tomography, and displacements that can be detected by software.

E5. With the introduction of kV on-board imaging systems, there was a revival of a proposal from years earlier to create computed tomography images by acquiring transmission data from a portal imaging system, but instead using the kV on-board imaging system. Rather than obtaining a single slice of information, the device could use the entire area of the flat-panel image receptor [J1, J2]. Computed tomography volumetric image data sets obtained from the projection beam of a kV source are known as cone beam computed tomography (CBCT) and their use has enhanced image-guided radiation therapy (IGRT) considerably [M13, T5, W6].

E6. The use of kV (or MV) imaging for treatment guidance carries a potential for deleterious effects resulting from additional radiation exposure. Cheng et al. [C7] have estimated the dose from imaging, which can vary from a few milligray to as much as 16 centigray. While it is recognized that, in general, the dose from imaging is far smaller than the dose from the radiation therapy itself, the volume irradiated by imaging systems is generally far larger and likely to include sensitive normal tissues such as the lens of the eye or breast tissue. Even though the dose from individual kV planar images or CBCT scans is relatively low, the use of daily image guidance can result in the dose over a course of treatment being significant in terms of biological effects [H1]. Consequently, the benefits of X-ray-based IGRT should be weighed against possible detriment to the patient.

E7. Techniques for cranial fixation and for delivering radiation through smaller field sizes than those previously used led to the introduction in the late 1980s of brain stereotactic radiosurgery, or the use of radiation as a surgical tool to obliterate small (~1 cm or smaller) intracranial targets [L11]. In the late 1990s and early 2000s, the aforementioned increase in the use of imaging, and also improvements in delivery systems and developments by individual researchers, contributed to the ability to target tumours using stereotactic radiosurgery even more precisely. Later, stereotactic radiosurgery techniques were extended to extracranial targets in what today is called stereotactic body radiation therapy or stereotactic ablative body radiation therapy [B13]. These techniques required modification of patient fixation techniques to allow repeat and reproducible fixation for multiple fractions, typically 3–5, to be delivered to targets in the spine, thorax or pelvis.

E8. Until the late 1990s, radiation dose was delivered through external beams of uniform intensity. Exceptions to this included the use of wedged fields, and when missing-tissue compensating filters and dose-compensating filters were employed. In both cases, the intent was to compensate for overlapping treatment fields, irregularities in the patient surface, or non-uniformities in tissue density. In 1988, Brahme published a description of an optimization technique that delivered extremely conformal dose distributions through the use of non-uniform radiation beams [B29]. Once computer-controlled technology became available, and treatment machines were delivered equipped with multi-leaf collimators, Brahme's optimization technique was capitalized upon by Webb [W4], who quickly developed intensity-modulated radiation therapy (IMRT) into a successful and valuable clinical tool. Within a few years, IMRT had been adopted by a large number of clinics and today it and several variants are used extensively by most advanced radiation therapy centres. One of the variants of IMRT is volumetric modulated arc therapy (VMAT), in which the radiation beam intensity is modulated while the treatment unit gantry is rotated around the patient [O8]. VMAT requires customized optimization software and can often speed the delivery process substantially.

E9. Particle-beam therapy allows highly precise radiation delivery, as the range of the beam can be controlled, and little dose is scattered out of the beam. Particle-beam therapy might permit delivery of higher doses to tumours situated close to critical organs. From its introduction until the early 2000s, particle-beam therapy (with protons or heavier charged particles) was most often administered using passive scattering techniques, in which the particle beam is spread laterally by inserting material in the beam upstream from the patient. Beams of different energies are delivered so that the individual Bragg peaks are positioned at depths distributed through the target volume, which creates a "spread-out Bragg Peak". Beginning in the early 2000s, "spot scanning" techniques were introduced to spread the beam laterally; the dose is delivered by individual pencil beams. The beams are steered electromagnetically to deliver dose in an array that spans the cross-section of the tumour as projected perpendicular to the beam axis. To control the dose distribution in the depth direction, the energy of each "spot" is adjusted so that the spots are distributed. A key advantage is that the operator has control over the modulation of beam intensity from one part of the target volume to another [L9]. Such intensity modulation can be exploited in a manner similar to IMRT, as described earlier.

II. RECAPITULATION OF PREVIOUS UNSCEAR REPORTS

E10. Radiation therapy involves the delivery of high absorbed doses to carefully delineated target volumes for the treatment of malignant or benign conditions. Resources for radiation therapy are distributed unevenly around the world, with significant variation in radiation therapy practice both among and often within individual countries. In the 1990s, many cancer patients had little or no access to radiation therapy services. Global annual numbers of complete treatments by the two main modalities, teletherapy and brachytherapy, were estimated from the scarce national survey data available, supplemented using a global model, although the uncertainties in this approach were likely to be significant. The world annual total number of treatments for 1991–1996 was estimated to be about 4.7 million, with teletherapy accounting for over 90% of the treatments [U6]. The corresponding average annual frequency of 0.9 treatment per 1,000 population was similar to the level quoted for 1985–1990 on the basis of an estimated total number of 4 million treatments [U5].

E11. Cancer is likely to be an increasingly important disease in populations with extending lifespan, and this will probably cause radiation therapy practice to grow in most countries. The World Health Organization (WHO) estimated that by 2015, the annual number of new cancer cases worldwide would rise to about 15 million, from nine million in 1995, with about two thirds of these cases occurring in low-income countries. If half of these cases patients were treated with radiation, at least 10,000 external beam therapy machines would be required in addition to a large number of brachytherapy units.

E12. In the period 1997–2007, the global use of radiation therapy increased to 5.1 million treatment courses, from 4.7 million treatment courses in 1991–1996. About 4.7 million patients were treated with external beam radiation therapy, while 0.4 million were treated with brachytherapy. The number of linear accelerator treatment units increased to about 10,000 worldwide, mainly in health-care level (HCL) I countries. HCL II countries appeared to show a decrease, but this was probably due to the lack data. At the same time, the number of brachytherapy treatments and the number of after loading brachytherapy units appeared to have changed only very little [U9].

E13. Radiation therapy involves the delivery of high doses to patients, hence with an attendant potential for accidents with serious patient health consequences (arising from over- or underexposure relative to prescription). Quality assurance programmes helped to ensure high and consistent standards of practice so as to minimize the risks of accidents. Effective programmes comprehensively address all aspects of radiation therapy, including *(a)* the evaluation of patients during and after treatment; *(b)* the education and training of physicians, technologists and medical physicists; *(c)* the commissioning, calibration and maintenance of equipment; *(d)* the independent audits for dosimetry and the treatment planning; and *(e)* the protocols for treatment procedures and the supervision of delivery.

III. FREQUENCIES OF RADIATION THERAPY PRACTICES

E14. This section presents information on trends in the frequencies of radiation therapy courses resulting from the submissions to the UNSCEAR Global Survey (2009-2018) also summarized in electronic attachment E-1. Furthermore, the data presented here were supplemented with information from reviews of the published literature.

A. UNSCEAR Global Survey data

E15. Radiation therapy data were received from 49 countries, most of which provided "essential" data, however, some of the data appeared to be unrealistic, possibly due to misunderstandings regarding the data requested. The questionable data were highlighted in the evaluation. In several cases, the "essential" data provided were inconsistent with the "detailed" data provided. These data were also identified in the sections below. In the "essential" questionnaire, the distinction was not made between benign and malignant diseases, although this distinction was made in the "detailed" questionnaire. Only 10 countries provided detailed data on patient treatment frequencies although 34 provided total values. The data provided by Member States were regrouped into 10-year intervals.

E16. This evaluation also requested information on uncertainties, which was addressed by several countries. Some countries reported large uncertainties in their data for the detailed frequency data: Argentina 40%; Brazil, 50%; Finland, 35%; Lebanon, 60%; Philippines, 75%; Romania, 50%; and Switzerland, 95%.

E17. The figures and tables in this section illustrate the variations in availability of radiation therapy services in different countries. While the data are relatively sparse, a number of conclusions have been drawn that indicate differences among regions and countries and help to highlight those areas where the smaller numbers of facilities and staff contribute to limitations in access to radiation therapy services. Some data are also provided to illustrate differences in numbers of patients treated by country, which also support conclusions drawn regarding access to radiation therapy in these countries. The quantity "courses of treatment" (or "treatment courses") has been used rather than number of patients. A course of treatment may consist of a single delivery of radiation, but it more often refers to a series of 20 or 30 individual treatments, called "fractions". The quantity "courses of treatment" is used as an indicator of the volume of work performed in radiation therapy centres and the availability of radiation therapy resources in a country. In many cases, data on the numbers of courses of radiation therapy are reported in relation to the population of each country, e.g., radiation therapy treatment courses per 100,000 population. However, the denominator chosen for radiation therapy is two orders of magnitude larger than that for diagnostic radiology, due to the generally smaller numbers of radiation therapy patients.

E18. In the figures and tables below, the data reported were used directly and without modification from the results of the UNSCEAR Global Survey, with a few exceptions. Cancer incidence data were cited from the GLOBOCAN online database [I5] as of 2018. In a few cases, the total numbers of treatment courses were inconsistent between the "essential" and the "detailed" data. In such cases, the value from the "detailed" spreadsheet was usually chosen, provided it was also consistent with the individual values from which it was presumably summed. In a few cases, countries provided data for specific parameters such as treatment site but did not provide the total number of treatments. In these cases, the individual country data were summed to determine the total value. Some data provided by Chile, Pakistan and the Russian Federation were not reported as they may have reflected the number of treatment fractions rather than the number of patients treated.

E19. The annual number of courses of radiation therapy per population is an indication of a country's infrastructure, the access patients have to radiation therapy services, and the prevalence of certain cancer types. However, it might also indicate societal philosophies regarding the treatment of cancer or the recognition of radiation therapy as a viable modality for cancer therapy (table E1).

Table E1. Courses of treatment with brachytherapy or external beam therapy per year per 100,000 population

Country	*Brachytherapy treatment courses per 100 000 population* [a]	*External beam treatment courses per 100 000 population*
Argentina	3.8	52
Australia	11.6	263.7
Bangladesh	5.2	16.5
Belarus	28.1	153
Belgium	18	309.7
Brazil	9.2	118.4
Brunei Darussalam	0.0	60.3
Bulgaria	5.6	241.6
Canada	13.5	263.5
China		66
Cyprus	10	150.5
Czech Republic	9.3	160.7
Denmark	4.6	362.2
Estonia	11.6	163.6
Finland	3.7	296.1
France	9.9	239.2
Germany		437.2 [b]
Greece	3.6	51
Hungary	25.7	175.2
Iceland	4.4	236.4
Iran (Islamic Republic of)	5.2	78.5
Italy	16.5	363.1
Japan	9.2	188.3
Lebanon	2.9	89.8
Lithuania	21.7	181
Luxembourg	5.7	244.8
Madagascar	0.0	0.6
Malaysia	5.5	38.1
Montenegro	12.7	183.2
Norway	5.1	245.1

Country	*Brachytherapy treatment courses per 100 000 population* [a]	*External beam treatment courses per 100 000 population*
Pakistan	1.4	5.3
Philippines	1.3	33.2
Poland	28.1	196.4
Romania	8.1	158.8
Russian Federation	10.6	289.9
Saudi Arabia	2.4	25.2
Spain	19.4	243
Sudan		8.4 [b]
Suriname	10.2	57.8
Sweden	16.5	235
Switzerland	23.8	368.2
Thailand	25.2	63.4
Ukraine	0.4	12.8
United Arab Emirates	0.7	11
United Kingdom	8.6	222.9
United States	10.4	308.5

[a] Zero values are indicated when available; otherwise, cells have been kept empty.

[b] The country reported only the total number of radiation therapy patients, which includes patients treated for benign conditions as well as those treated for malignancies. The reported number has been placed in the column for external beam patients.

E20. While the number of treatment courses in a country is of interest, a better indication of the availability of and access to radiation therapy may be the number of courses of treatment relative to the incidence of cancer in the country. Table E2 shows a comparison of these two parameters. The data for cancer incidence are taken from the WHO GLOBOCAN [I5] database as of 2018. The data are presented as a percentage of cancer incidence. Figure E-I summarizes the countries participated in the UNSCEAR Global Survey. When comparing some of the countries in the same regions, the numbers of patients treated were considerably higher. It is possible that these countries reported the number of treatment fractions delivered, rather than the number of courses of treatment, which might increase the value by a factor of approximately 18, on the basis of the data provided by countries for numbers of fractions delivered. However, several other countries (e.g., Indonesia, Madagascar and Ukraine) reported very low numbers of treatments.

Table E2. Number of courses of radiation therapy treatments delivered scaled by cancer incidence in each country

Country	*Cancer incidence (GLOBOCAN 2018) [I5]*	*External beam and brachytherapy treatment courses/cancer incidence (%)*
Argentina	129 047	17.3
Australia	197 876	33
Bangladesh	150 781	23
Belarus	42 287	40.6
Belgium	79 931	46
Brazil	559 371	46.6
Brunei Darussalam	908	28
Bulgaria	35 378	48.9
Canada	249 077	40.8
China	4 285 033	21.5[a]
Cyprus	4 829	31.6
Czech Republic	65 456	27.5
Denmark	40 796	51.3
Estonia	7 664	29.9
Finland	33 271	49.3
France	455 618	36.1
Germany	608 742	58.3[a]
Greece	67 401	8.9
Hungary	70 454	28.2
Iceland	1 510	54
Indonesia	348 809	0.02
Iran (Islamic Republic of)	110 115	57.1
Iraq	25 320	11.3
Italy	409 808	56.1
Japan	883 395	28.4
Lebanon	17 294	10.5
Lithuania	16 351	35.8
Luxembourg	3 271	41.9
Madagascar	18 074	0.9
Montenegro	2 366	49.7
Norway	34 299	38.6
Pakistan	173 937	8.1
Philippines	141 021	24.7

Country	*Cancer incidence (GLOBOCAN 2018) [I5]*	*External beam and brachytherapy treatment courses/cancer incidence (%)*
Poland	185 630	46.5
Romania	83 461	39.3
Saudi Arabia	24 485	43.6
Spain	270 363	45.3
Sudan	25 746	13.5[a]
Suriname	1 042	36.4
Sweden	60 853	41.3
Switzerland	56 506	58.4
Thailand	170 495	34.5
Ukraine	169 817	3.3
United Arab Emirates	4 707	23
United Kingdom	446 942	33.7
United States	2 129 118	48.4

[a] Data provided include radiation therapy patients treated for benign as well as for malignancy conditions.

Figure E-I. Percentage of patients treated with radiation therapy per cancer incidence (GLOBOCAN 2018 data [I5])

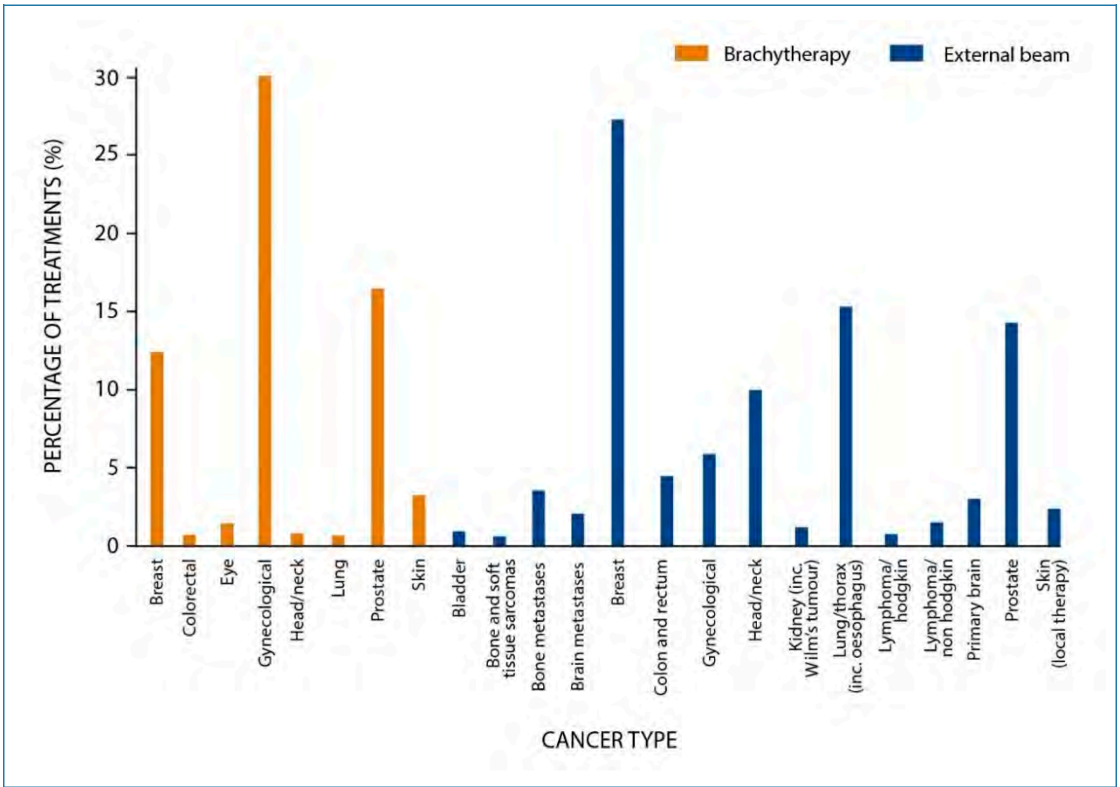
E21. The UNSCEAR Global Survey data provided an opportunity to evaluate the frequency with which different cancers were treated with radiation therapy, in terms of the global population. Table E3 and figure E-II show these data for treatments with brachytherapy and external beam radiation. Not surprisingly, patients treated for gynaecological cancer account for more than 60% of all patients treated with brachytherapy, while prostate cancer accounts for more than another 15%. Breast, head and neck, lung and prostate are the sites most often treated with external beam radiation therapy.

Table E3. Most frequently treated cancer sites and percentage of annual treatments with brachytherapy or external beam therapy worldwide

Modality category	Cancer site	Percentage of treatments worldwide (%)
Brachytherapy	Breast	12.4
	Colorectal	0.6
	Eye	1.4
	Gynaecological	64.3
	Head/neck	0.8
	Lung	0.6
	Prostate	16.4
	Skin	3.2
External beam	Bladder	0.9
	Bone and soft tissue sarcomas	0.6
	Bone metastases	3.5
	Brain metastases	2
	Breast	27.2
	Colon and rectum	4.4
	Gynaecological tumour	5.9
	Head/neck	9.9
	Kidney (including Wilms' tumour)	1.2
	Lung/thorax (including oesophagus)	15.2
	Lymphoma/Hodgkin	0.7
	Lymphoma/Non-Hodgkin	1.5
	Primary brain	3
	Prostate	14.2
	Skin (local therapy)	2.3
	Total body irradiation	0.1

Figure E-II. Percentage of diseases accounting for most radiation therapy treatments worldwide

The ordinate is expanded for clarity. Gynaecological disease accounts for 64% of all brachytherapy treatments



B. Literature review data

E22. The incidence of cancer worldwide, in terms of absolute numbers, has been growing steadily and is continuing to grow. In 2012, 14.1 million new cases of cancer were reported, and 8.2 million deaths were caused by cancer. These numbers are expected to rise to 24.6 and 13 million, respectively by 2030 [A12]. Except in high-income countries, the access to radiation therapy is extremely limited, and for much of the world's population, non-existent. This situation has developed because, according to Atun et al. [A12] radiation therapy is rarely considered first when governments plan and build treatment capacity for cancer. Instead, surgery and chemotherapy were addressed first, and radiation therapy is too often relegated to last place. In low- and middle-income countries 80% of the cancer burden occurs, however, have only 5% of the world's resources. Consequently, more than 90% of the population of low-income countries have no access to radiation therapy.

E23. The Atun et al. study [A12] presented useful information based on the International Atomic Energy Agency (IAEA) Directory of Radiotherapy Centres (DIRAC) database. DIRAC includes data of the numbers of radiation therapy departments; and total numbers of megavoltage machines, linear accelerators and ^{60}Co units [P11]. Atun et al. [A12] modelled estimates of capacity (fractions per year), describing the estimated radiation therapy utilization rate, mean number of fractions per course of treatment, and outcome benefits (absolute/proportional) for the top ten cancers globally by incidence. Atun et al. [A12] also presented estimates of radiation therapy resources and modelled capacity and estimated the cost and substantial benefits to the global community of expanding radiation therapy resources. Some of these conclusions are echoed by Jaffray et al. [J3, J4] and Rodin et al. [R10].

E24. Abdel-Wahab et al. [A1] published a comprehensive review of the IAEA activities in support of radiation therapy worldwide. They quote a recent IAEA analysis of future needs for radiation therapy, which determined that more than 50% of patients requiring radiation therapy in low- and middle-income countries do not have access to such treatments. As indicated by Atun et al. [A12], the situation is even more drastic in low-income countries, where the proportion of patients requiring radiation therapy is higher than 90%. In terms of teletherapy equipment, an IAEA analysis showed that 4,300 machines are available in low- and middle-income countries but that 7,000 additional units are needed to provide sufficient radiation therapy treatments. This situation is expected to improve in the coming years however, a large proportion of patients needing radiation therapy will not have access to such treatments in the near future. The IAEA provides support for expansion of radiation therapy services through the supply of equipment, provision of expert services, and fellowships for training of health-care professionals.

E25. Pan et al. [P3] published information regarding patient treatments in the United States based on survey information conducted by the National Cancer Institute (NCI) in its Surveillance, Epidemiology and End Results Program [S25]. The authors extrapolated on the basis of estimates of the fraction of the total number of radiation therapy patients in the United States covered by the surveys. The authors emphasized that the NCI data reported only the frequency of each patient's first course of radiation therapy for a specific malignancy. However, as many patients have second (or more) courses, this led to an underestimate of the number of courses of radiation therapy.

E26. The NCI data excluded patients under palliative therapy rather than cancer cure treatments. As a result, Pan et al. [P3] reported annual utilization rates of about half those reported to the UNSCEAR Global Survey. The UNSCEAR data for the number of patients treated with external beam radiation therapy in 2017 was 996,313, while Pan et al. reported only 490,000 in 2015. Pan et al. also reported the number of patients by disease sites; however, which is also about half of the number reported to the UNSCEAR Global Survey. Pan et al. [P3] summarized the utilization rate of radiation therapy to be 26%; about half the rate reported to the UNSCEAR Global Survey (48.4%).

IV. DOSES IN RADIATION THERAPY

A. UNSCEAR Global Survey data

E27. Forty-nine countries provided data regarding patient doses to the UNSCEAR Global Survey. In radiation therapy, parameters of great interest are the site treated, the total dose delivered, the number of treatment fractions delivered, and the treatment technique used.

E28. The current survey data enabled examination of the therapeutic doses delivered to patients treated for a number of different cancers, using the major treatment modalities. Unfortunately, too few countries submitted data to make the analysis very expressive. Note that the UNSCEAR Global Survey did not request information about imaging doses although they are increasingly being viewed as of interest in long-term.

B. Literature review data

E29. Comprehensive data regarding prescribed doses in radiation therapy are available in many publications. A valuable source of information regarding doses from radiation therapy in the United States has been published by the NCRP [N1]. The report identifies some of the difficulties encountered when trying to summarize doses from radiation therapy procedures. These include the wide variety in prescribed tumour doses, which are tailored to each individual patient, and may vary by an order of magnitude or more depending on the stage of the patient's disease or the fractionation scheme chosen. The doses to healthy organs also vary widely as the ability to protect these organs is profoundly influenced by the extent of the cancer and the goals of the treatment. Further, the evolving technology of radiation therapy has greatly affected the doses to normal structures and enabled the delivery of greater tumour doses. However, the NCRP [N1] estimated equivalent doses delivered to organs and tissues for ten broad categories of treatment site and from these derived estimates of collective effective dose for external beam radiation therapy.

V. DISTRIBUTIONS BY AGE AND SEX

A. UNSCEAR Global Survey data

E30. Figures E-III to E-VIII illustrate the variations in age of diagnosis for cancer patients treated with radiation therapy. Only a small number of countries reported such data. Figure E-III also shows the age distribution for males treated for all cancers reported in the UNSCEAR Global Survey, for nine countries. Large similarity is observed, with the exception of the Philippines, for which the numbers reported did not seem to reflect the totals. Figure E-IV displays the age distribution data for female patients, where the age distribution data are shown as a proportion of the total number of patients (male and female) in each group.

E31. Figures E-V and E-VI present the age distribution for male and female lung cancer patients, respectively. Figure E-VII displays the age distribution data for male prostate cancer patients, while figure E-VIII displays these data for female breast cancer patients. Due to the lack of the data, it is not possible to draw firm conclusions, however, some differences were identified, such as the difference in age distribution for both male and female lung cancer patients among countries, and similar differences for prostate and breast cancer patients.

Figure E-III. Age distribution of male radiation therapy patients reported to UNSCEAR Global Survey

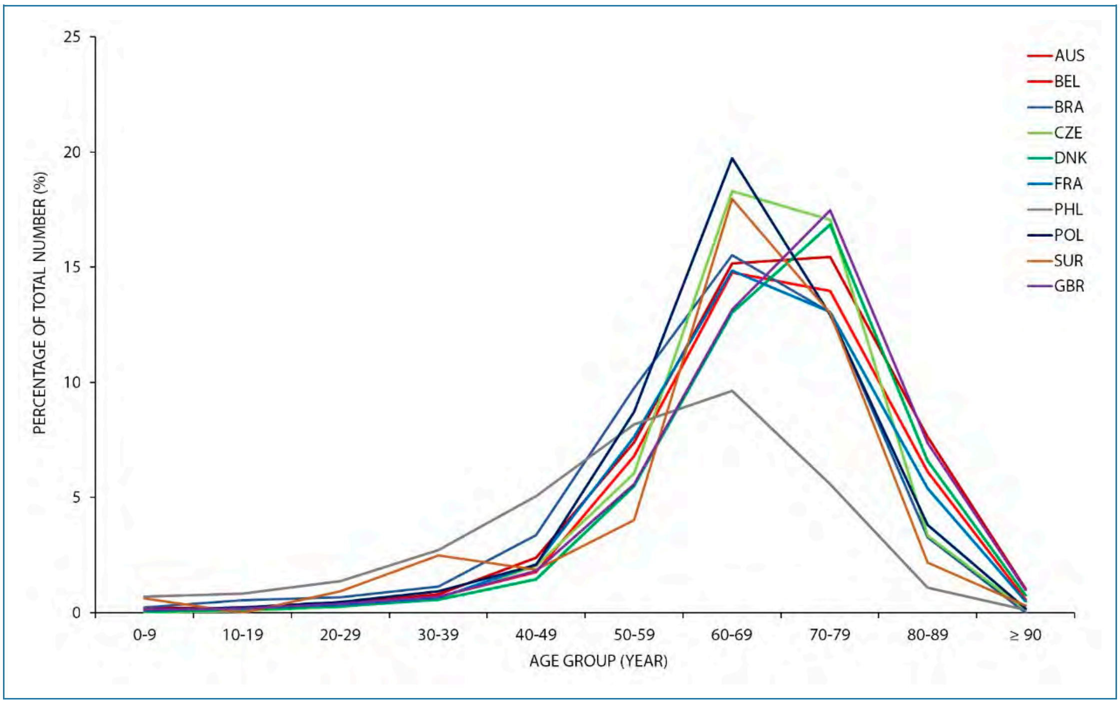


Figure E-IV. Age distribution of female radiation therapy patients reported to UNSCEAR Global Survey

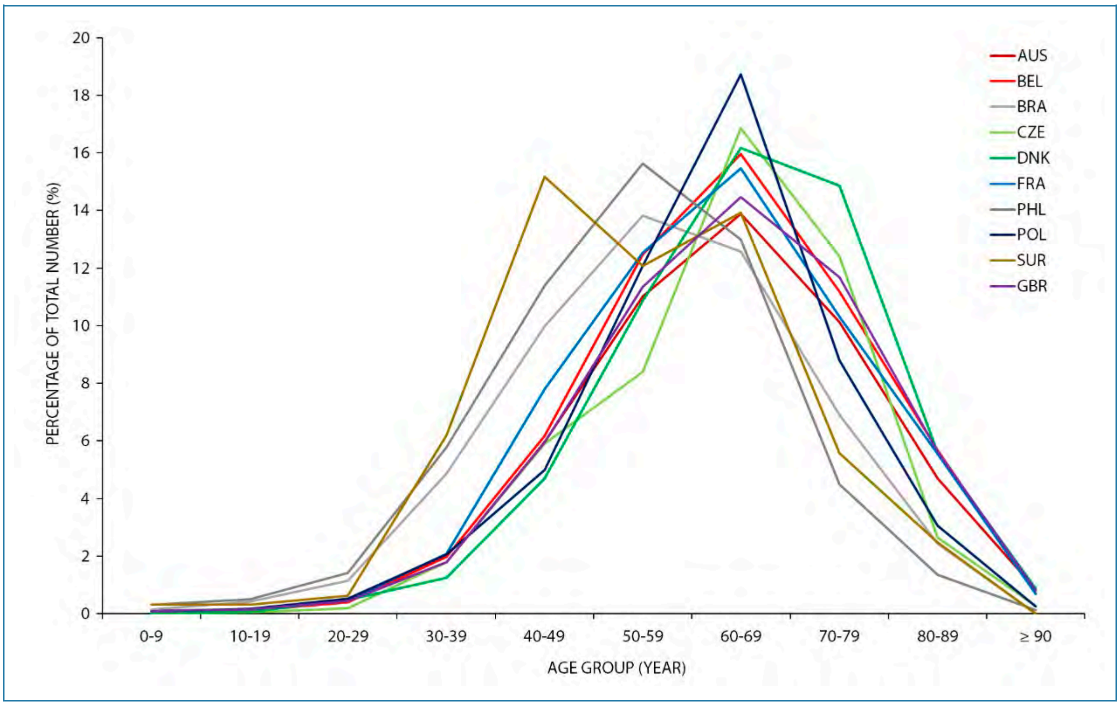


Figure E-V. Age distribution of male lung cancer patients reported to UNSCEAR Global Survey

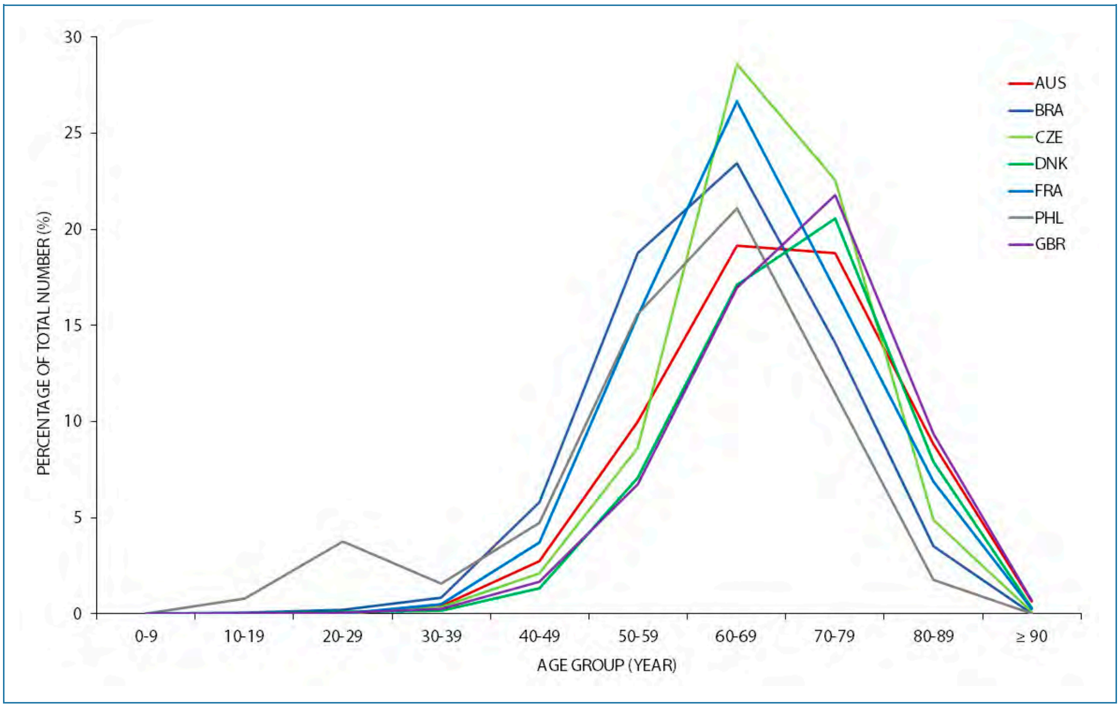


Figure E-VI. Age distribution of female lung cancer patients reported to UNSCEAR Global Survey

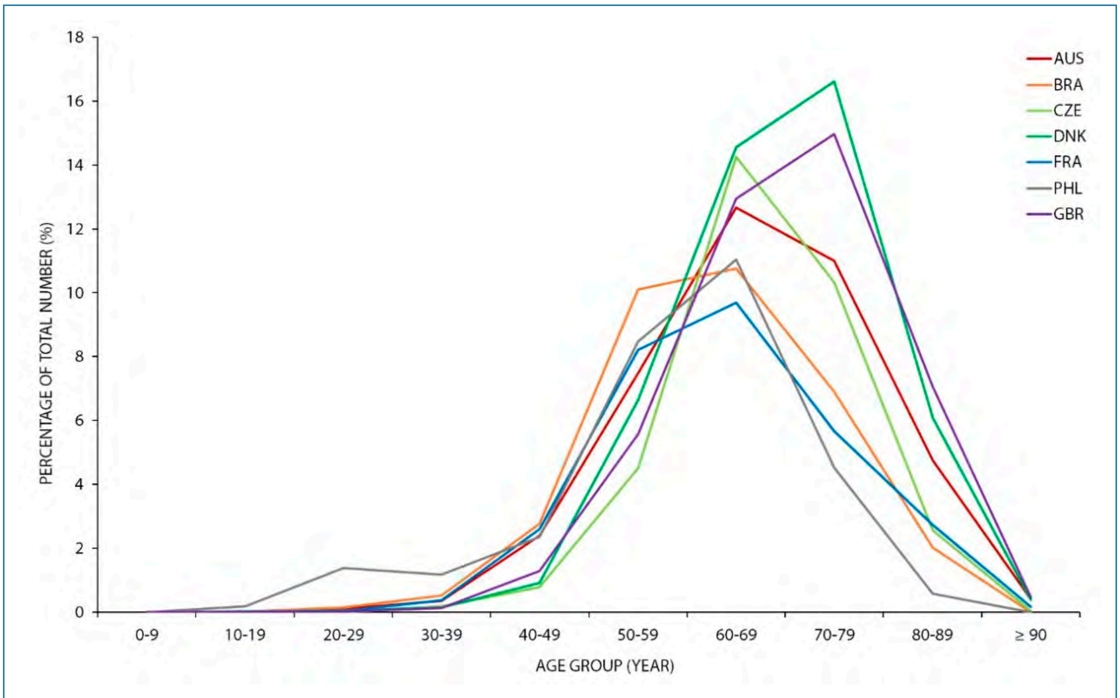


Figure E-VII. Age distribution of male prostate cancer patients reported to UNSCEAR Global Survey

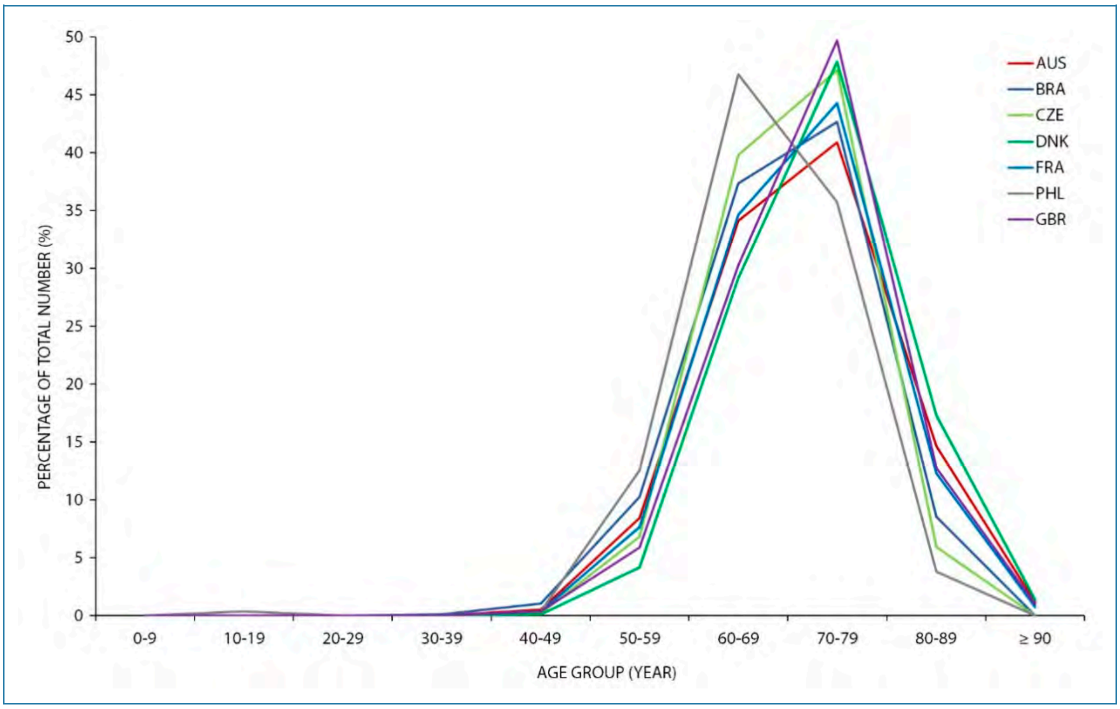
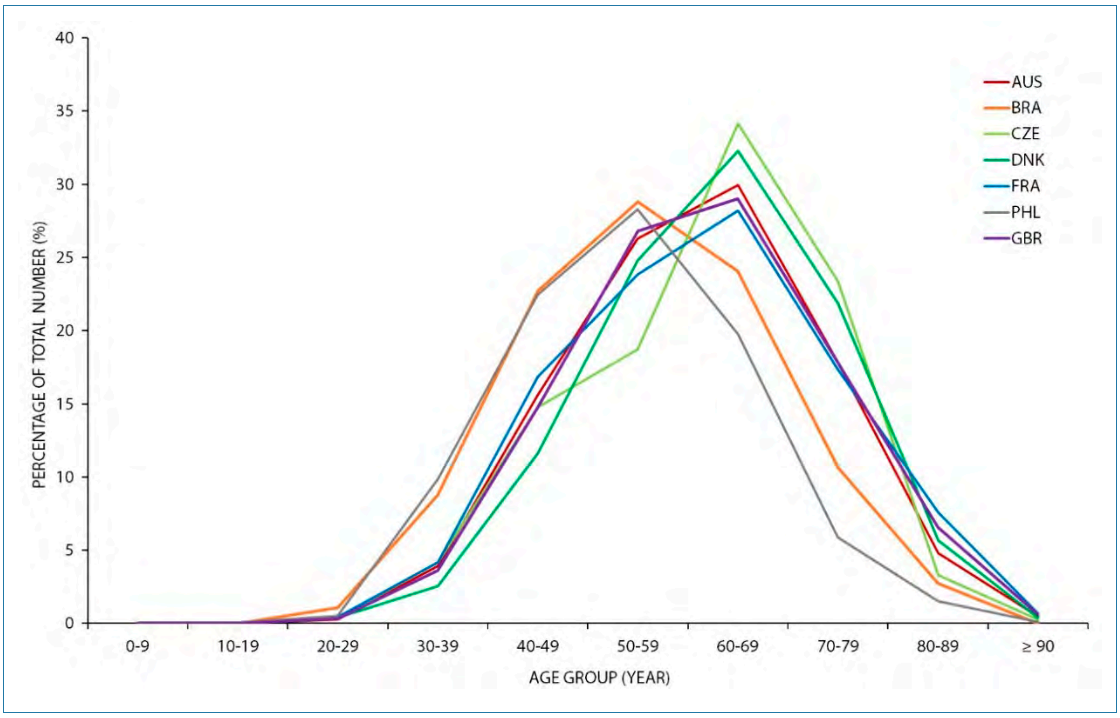


Figure E-VIII. Age distribution of female breast cancer patients reported to UNSCEAR Global Survey



B. Literature review data

E32. Relatively little data are available from the literature describing the distribution of radiation therapy patients by age and sex. Where such data were published, the results do not indicate unusual variations suggesting prevailing treatment of a specific age group or sex. Instead, variations reflect differences in the incidence of specific cancers.

VI. STAFF AND DEVICES

A. UNSCEAR Global Survey data

E33. Most countries provided the number of physicians registered in the country, including general practitioners, radiation oncologists and doctors, who use radiation but are not radiation oncologists (e.g., dermatologists or surgeons). In some countries, the number of registered physicians might be larger than the number who practice regularly; moreover, physicians who were identified as radiation oncologists might also practice in other specialties such as medical oncology or general practice.

E34. Table E4 presents the numbers of physicians per 100,000 population for all countries that provided data to the UNSCEAR Global Survey. Table E4 also shows the data for radiation oncologists per 100,000 population. The numbers of radiation oncologists, where reported, are generally small in comparison with the total numbers of physicians, and the numbers of general practitioners. However, this is not surprising as radiation oncology is a relatively small specialty. Of more interest is the variation in proportion of radiation oncologists between the countries reporting data.

E35. The numbers provided showed a quite large variations, with Indonesia, Iraq, Madagascar, Pakistan and Sudan reporting fewer than 0.1 radiation oncologists per 100,000 population, far less than most other countries. Chile reported very small numbers of both, but a smaller number of physicians than of radiation oncologists. The United Arab Emirates indicated a small number of radiation oncologists (0.1 per 100,000 population), but an overall number of physicians within a factor of 2 higher than most HCL I countries. Italy reported a number of total physicians per population that is about double the average in Western Europe and North America (table E4). In contrast, Denmark reported considerably more radiation oncologists per population than other Western European countries. While some of these data might be debatable, they support the observation that populations of high-income countries have more access to radiation therapy services than other parts of the world.

E36. Variations in the numbers of radiation oncologists per population are not surprising. It is common that these professionals have additional hospital roles in some countries other than the provision of radiation therapy services. For example, radiation oncologists are involved in research, which might be more prevalent for countries in Western Europe and North America than in other parts of the world. In Asia, radiation oncologists sometimes also provide medical oncology services.

Table E4. Physicians per 100,000 population reported to UNSCEAR Global Survey

Country	*Number of physicians per 100 000 population* [a]		
	All physicians	*General practitioners*	*Radiation oncologists*
Argentina	388.9		0.5
Australia	347.5	108.2	1.5
Bangladesh	47.2		0.2
Belarus	481.8	481.8	1.4
Belgium	392.8	136.4	1.6
Brazil	217	20	0.4
Brunei Darussalam			0.2
Bulgaria	412.9		0.8
Canada	226.5	117.6	1.5
Chile			0.5
China	217.9	13.5	1.1
Cyprus	309.3		1.9
Czech Republic	393.2	49.2	1.5
Denmark	403.5	78.9	3.9
Estonia	361.8	69.8	1.5
Finland	493.4	32.2	0.8
France	333.7	154.9	1.3
Germany	369.5		1.4
Greece	276.8	62.5	1.8
Hungary	309	65.3	0.4
Iceland	401.7		0.6
Indonesia	81.3	1.3	0.03
Iran (Islamic Republic of)	110		0.2
Italy	654.7	74.6	1.5
Japan	244.9		0.9
Lebanon	285.8	285.6	0.3
Lithuania	442.5	72.9	0.9
Luxembourg	316.7	95	1.1
Madagascar			0.03
Malaysia			0.4
Montenegro			1.5
Norway			2.6
Pakistan	94.6		0.07
Philippines	128.7		0.2

Country	*Number of physicians per 100 000 population* [a]		
	All physicians	*General practitioners*	*Radiation oncologists*
Poland	371.6	29.2	2
Romania	275.4	83.3	0.8
Russian Federation	371.6	47.9	0.1
Saudi Arabia			0.2
Spain	241.4		1.5
Sudan	10.6		0.05
Suriname			0.4
Sweden	450		0.8
Switzerland	429.7	98.7	1.4
Thailand	87.4	33.7	0.2
United Arab Emirates	204.2	0.02	0.1
United Kingdom	59	57	2.1
United States	266.5	34.5	1.5
Population weighted worldwide average			**0.85**

[a] Empty cell indicates no data available.

E37. In addition to the number of physicians, an indicator of the availability of radiation therapy services in a country is the number of radiation therapy centres. This is shown for the countries participated in the UNSCEAR Global Survey in table E5. Data are also extracted from the DIRAC database [P11]. In many cases, there are differences between national data and the DIRAC database, and some of the differences are quite large. For this evaluation, the national data have been used when countries reported more updated data than the DIRAC database.

Table E5. Radiation therapy centres as reported to UNSCEAR Global Survey and to DIRAC [P11]

Number of centres per 100,000 population are calculated from UNSCEAR Global Survey data

Country	*Radiation therapy centres* [a]		
	Current evaluation	*DIRAC [P11]*	*Per 100 000 population*
Argentina	154	81	0.38
Armenia	2	2	0.07
Australia	76	98	0.32
Bangladesh	12	17	0.01
Belarus	18	12	0.19
Belgium	37	36	0.33
Brazil	259	213	0.13
Brunei Darussalam	1	1	0.24
Bulgaria	17	18	0.24

Country	*Radiation therapy centres* [a]		
	Current evaluation	*DIRAC [P11]*	*Per 100 000 population*
Canada	51	51	0.14
Chile	20	26	0.11
China	1 413	1 075	0.10
Cyprus	1	2	0.11
Czech Republic	63	30	0.60
Denmark	7	8	0.12
Estonia	2	2	0.15
Finland	13	13	0.24
France	172	179	0.26
Germany	360	286	0.44
Greece	32	27	0.29
Hungary	12	13	0.12
Iceland	1	1	0.30
Indonesia	33	35	0.01
Iran (Islamic Republic of)	44	79	0.06
Iraq	12	11	0.04
Italy	193	191	0.32
Japan	788	766	0.62
Lebanon	12	13	0.25
Lithuania	4	5	0.14
Luxembourg	1	1	0.18
Madagascar	34	1	0.14
Malaysia	34	28	0.11
Montenegro	1	1	0.17
Norway	9	10	0.17
Pakistan	29	26	0.01
Philippines	36	36	0.04
Poland	44	41	0.11
Romania	21	25	0.11
Russian Federation	65	140	0.04
Saudi Arabia	13	14	0.04
Spain	149	127	0.32
Sudan	3	3	0.01
Suriname	1	1	0.18
Sweden	17	18	0.17

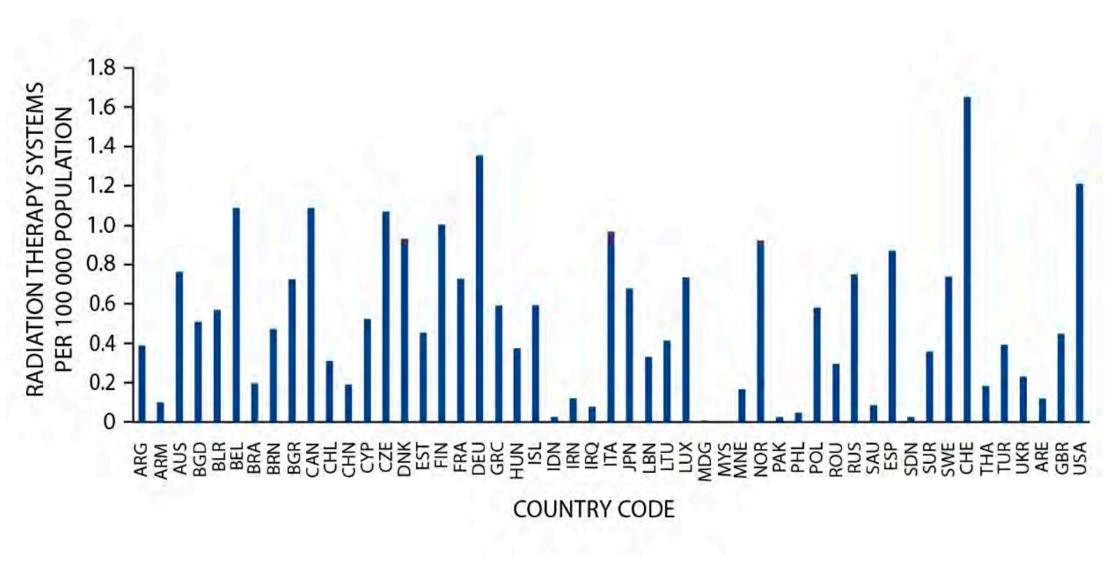
Country	*Radiation therapy centres* [a]		
	Current evaluation	*DIRAC [P11]*	*Per 100 000 population*
Switzerland	35	36	0.42
Thailand	35	33	0.05
Turkey		132	
Ukraine	51	51	0.12
United Arab Emirates	4	3	0.04
United Kingdom	59	70	0.09
United States	2 270	2 153	0.70
Population weighted worldwide average			**0.17**

[a] Empty cell indicates no data available.

E38. While the number of centres in a country relative to its population is an indicator of access to radiation therapy, the UNSCEAR Global Survey did not provide information about distribution of radiation therapy centres. Countries such as Canada and the United Kingdom have a small number of centres, but they are generally large and located in major population regions/cities. The United States have a large number of very small centres, but these are typically located in large population areas and there are regions with populations that are quite remote from the nearest radiation therapy centre.

E39. Another indication of access to radiation therapy is the number of radiation therapy treatment equipment. As part of the UNSCEAR Global Survey countries were asked to report the number of specific therapy treatment equipment and the total number of radiation therapy systems and figure E-IX presents the total number of equipment per 100,000 population by country. Western Europe and North America generally report larger amounts of equipment than do other parts of the world. Smaller numbers are seen in Latin America and Asia. It should be noted that countries may have interpreted the term used in the questionnaire “all radiation therapy systems” differently. Some countries included low-energy treatment systems and imaging systems dedicated to radiation therapy, while others did not. In addition, the term “imaging systems” may have been interpreted to mean the on-board kV imaging systems now included with many modern linear accelerators, in addition to conventional X-ray simulators and computed tomography scanners.

Figure E-IX. Radiation therapy systems per 100,000 population



E40. A relevant measure of radiation therapy quality may be drawn from the staffing at radiation therapy centres. Considerable variation is seen and there is somewhat of an inverse correlation with the number of centres. For example, the number of radiation oncologists per centre is large in Western Europe and Canada where are few, generally large, centres. In contrast, in the United States, the number of radiation oncologists per centre is very small, consistent with the high number of small centres.

E41. The trends are similar for radiation therapy medical physicists, with large numbers per centre seen in Western Europe and Canada and small numbers in the United States. The small numbers seen in some countries in Eastern Europe, Latin America, and Asia may not be an indication of small facility size but a reflection of the lower staffing levels in these countries. The relationship between staffing and the size of a centre is examined in more detail below.

E42. The type of equipment at radiation therapy centres is addressed in table E6 where the numbers of linear accelerators per 100,000 population are shown. Table E6 also shows the total number of treatment and imaging systems per 100,000 population per country. This may be an indication not only of the amount of equipment, and therefore the access to treatment the population would have, but also an indication of the modernity of the equipment, which could correlate with the quality of treatment.

Table E6. Linear accelerators and treatment and imaging systems in radiation therapy reported to UNSCEAR Global Survey

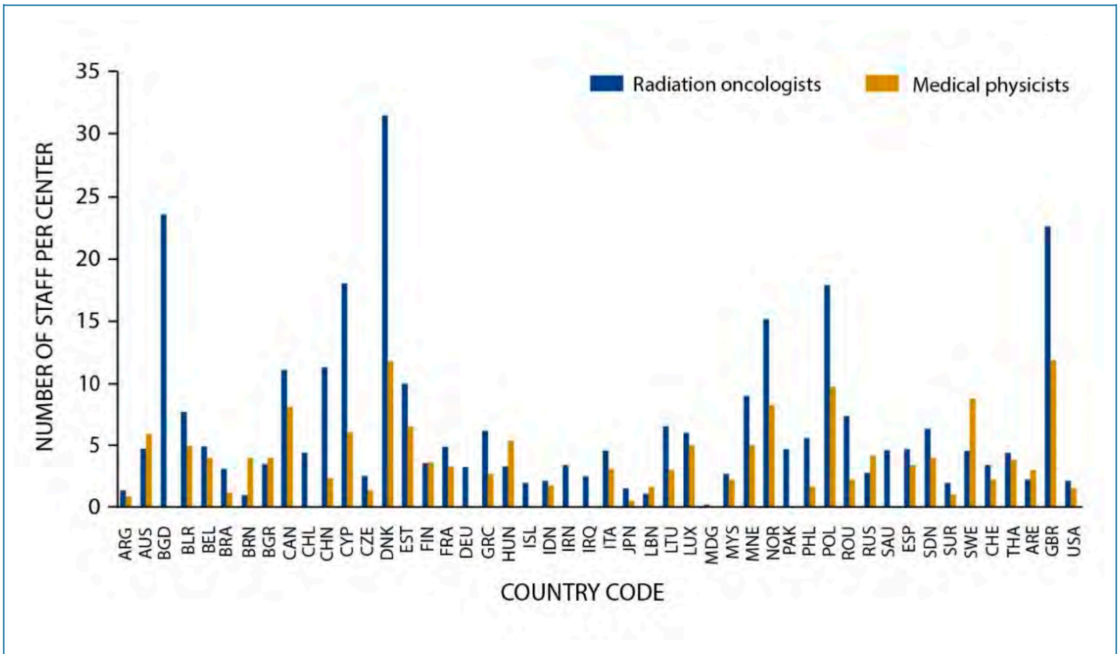
Country	*Linear accelerators per 100 000 population*	*Treatment and imaging systems per 100 000 population*
Argentina	0.25	0.39
Armenia	0.03	0.10
Australia	0.76	1.02
Bangladesh	0.01	0.02
Belarus	0.15	0.55
Belgium	0.85	1.09

Country	*Linear accelerators per 100 000 population*	*Treatment and imaging systems per 100 000 population*
Brazil	0.18	0.27
Brunei Darussalam	0.47	0.71
Bulgaria	0.41	0.75
Canada	0.76	0.78
Chile	0.21	0.32
China	0.14	0.19
Cyprus	0.32	0.53
Czech Republic	0.44	1.06
Denmark	0.93	1.21
Estonia	0.45	0.61
Finland	0.82	1.02
France	0.64	0.76
Germany	0.74	1.35
Greece	0.35	0.59
Hungary	0.27	0.64
Iceland	0.59	0.59
Indonesia	0.02	0.03
Iran (Islamic Republic of)	0.03	0.08
Iraq	0.08	0.08
Italy	0.71	0.89
Japan	0.68	0.96
Lebanon	0.33	0.42
Lithuania	0.42	0.73
Luxembourg	0.73	1.10
Madagascar	0.01	0.01
Malaysia	0.17	0.28
Montenegro	0.17	0.50
Norway	0.81	0.93
Pakistan	0.01	0.03
Philippines	0.04	0.07
Poland	0.42	0.57
Romania	0.12	0.30
Russian Federation	0.14	0.63
Saudi Arabia	0.09	0.10
Spain	0.53	0.74

Country	*Linear accelerators per 100 000 population*	*Treatment and imaging systems per 100 000 population*
Sudan	0.01	0.04
Suriname	0.36	0.54
Sweden	0.73	0.97
Switzerland	0.84	1.75
Thailand	0.11	0.19
Turkey	0.27	0.39
Ukraine	0.05	0.23
United Arab Emirates	0.08	0.12
United Kingdom	0.45	0.45
United States	1.11	1.11
Population weighted worldwide average	**0.29**	**0.37**

E43. An indication of treatment quality (and availability of medical professionals) is the level of staffing per radiation therapy unit. Figure E-X compares the average numbers of radiation oncologists and medical physicists per treatment system by country. All devices considered here were cobalt units, brachytherapy systems and simulators in order to assess the work volume per staff member.

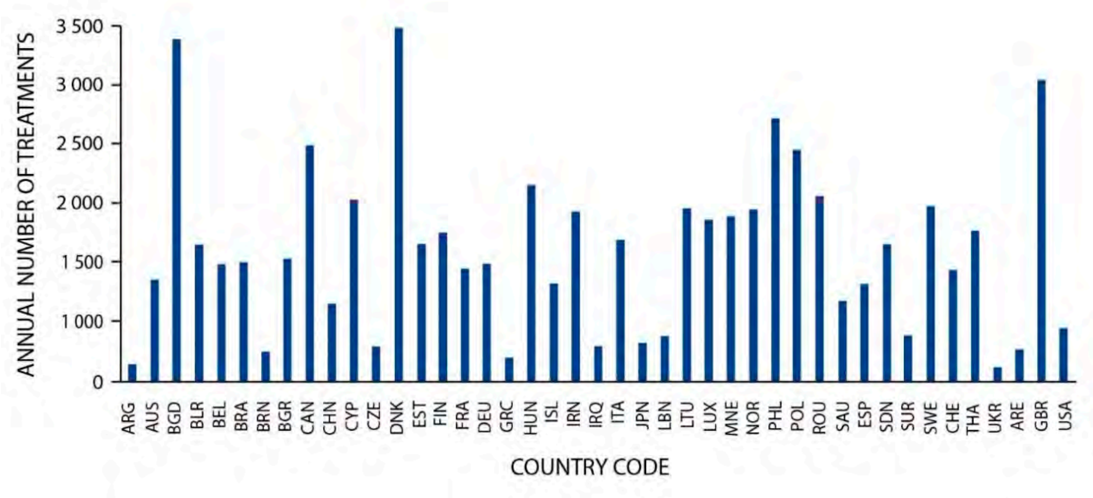
Figure E-X. Radiation oncologists and medical physicists per radiation therapy centre



E44. A different measure of patient access to radiation therapy is obtained by comparing the annual number of patients treated per centre, taken as an average by country (figure E-XI). Several countries, including Chile, Pakistan and the Russian Federation have been removed from the figure. These countries reported data that yielded extremely high annual values of patients per centre, several in excess of 10,000. In contrast, Indonesia reported an extremely small number of patients, which might reflect a misunderstanding of the type of data requested but could also reflect the functional status of equipment in the country. For comparison, and assuming an average of 18 treatment sessions per patient (a figure calculated from UNSCEAR Global Survey data) delivered in five sessions per week, a patient volume of 1,000 patients per centre suggests roughly 70 patients on treatment each day.

Figure E-XI. Annual number of patients treated per radiation therapy centre reported to UNSCEAR Global Survey

Countries with inconsistent data have been removed



E45. Using the information in figure E-XI one step further, the annual number of patients treated per radiation therapy machine is shown in figure E-XII. Even when several countries were excluded, these values vary by more than an order of magnitude. Indonesia reported only annually 1.2 patients per treatment machine, which probably indicates a misinterpretation of the data requested. Several other countries reported small numbers, which might be an indication that some of the equipment reported to be installed was not being used or was non-functional. In contrast, the Islamic Republic of Iran reported 706 patients per treatment machine, which corresponds to a patient load of roughly 50 patients treated per day and machine. This is certainly conceivable but is large for an average value. The annual average across countries (excluding some countries) is approximately 300 patients per machine. Chile, Pakistan and the Russian Federation reported more than 2,000 patients per machine annually.

E46. Another, even better, measure of workload is conveyed by the annual number of patients per radiation oncologist. These data are shown in figure E-XIII, where a country's annual number of radiation therapy patients is divided by the number of registered radiation oncologists. To put the data in perspective, and assuming that patients receive an average of 18 treatment courses, five days per week, a volume of 100 patients per year would suggest that a radiation oncologist is supervising treatment of an average of seven patients per day. This is a very small number; one would expect a radiation oncologist in a busy practice to supervise up to 30 patients per day. In an academic practice, the number might be reduced by half. The results suggested discrepancies in interpretation or reporting of data. In particular, Chile and the Russian Federation reported data to the UNSCEAR Global Survey suggesting that the average annual number of patients per radiation oncologist is extremely high.

Figure E-XII. Annual number of patients treated per radiation therapy machine reported to UNSCEAR Global Survey

Countries with inconsistent data have been removed

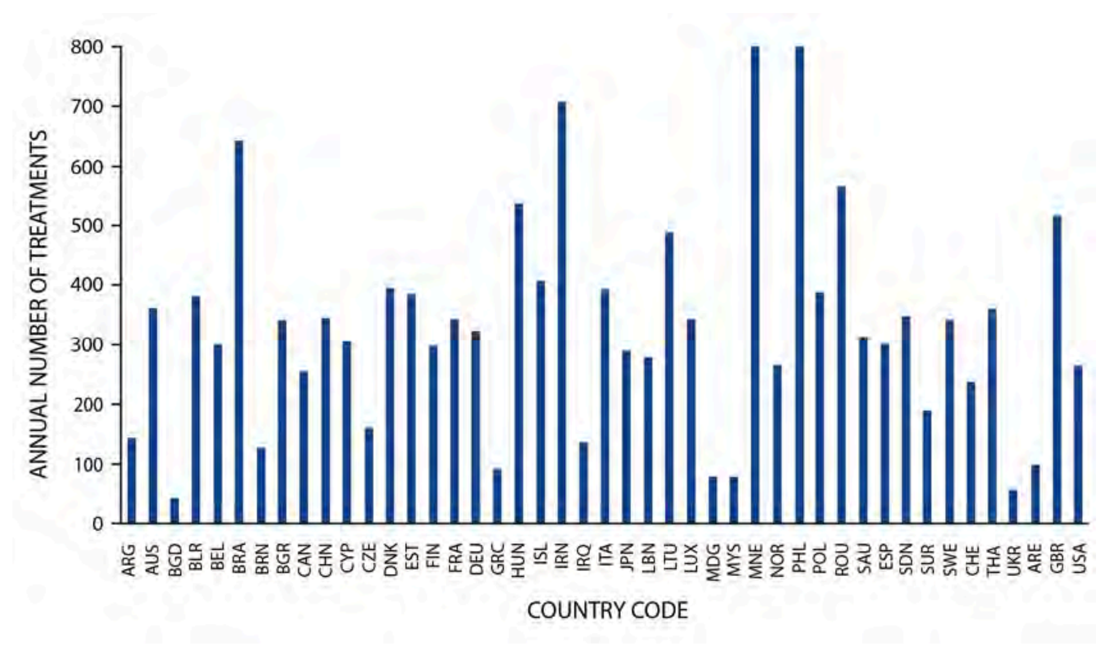
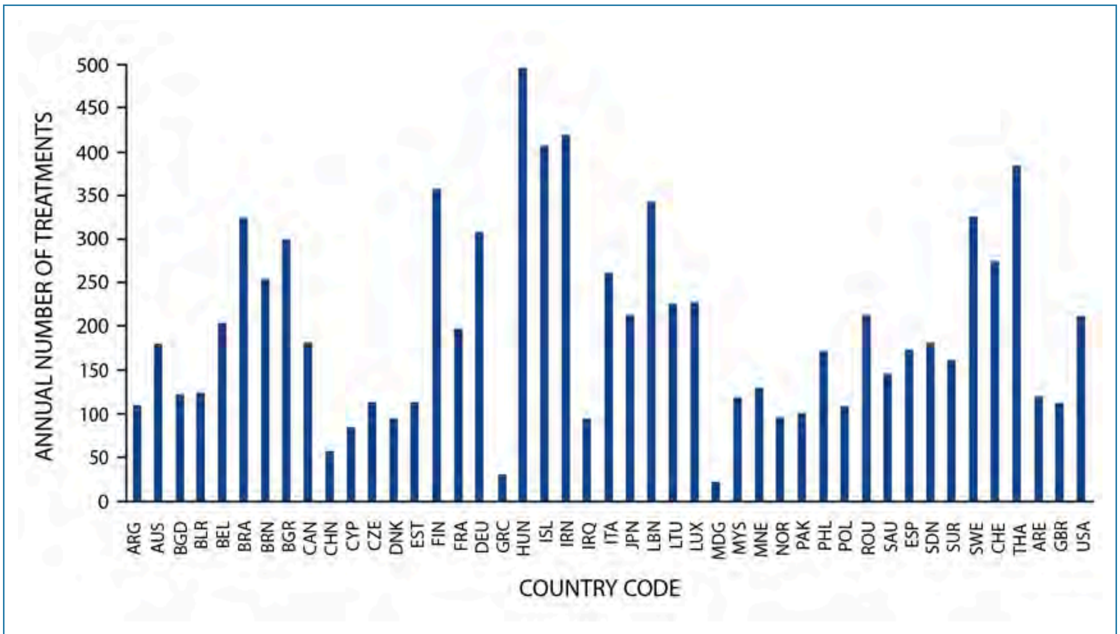


Figure E-XIII. Annual number of patients treated per radiation oncologists reported to UNSCEAR Global Survey

Countries with inconsistent data have been removed



B. Literature review data

E47. The UNSCEAR Global Survey requested data on the number of staff working in radiation therapy per country. In table E7, these data are compared with data from another survey conducted by International Organization for Medical Physics (IOMP) [T9]. It should be noted that IOMP reported numbers of all medical physicists, not only radiation therapy physicists. The differences are quite notable; in many cases, the value reported by IOMP is double or more than that supplied to the UNSCEAR Global Survey. One explanation is that IOMP counted medical physicists working in radiology and nuclear medicine in addition to those in radiation therapy. Further explanation for these differences might be that the UNSCEAR Global Survey asked government officials, or professionals having access to national databases, to complete the survey and the source of national data in many countries is most likely an official registry of licensed or otherwise credentialed individuals. On the other hand, IOMP contacted professional societies (in most cases, those affiliated with it), who may have referred to membership databases.

E48. Dad et al. [D2] discussed education and its role in improving cancer care worldwide. The American Society for Radiation Oncology formed an international education subcommittee to encourage a movement towards a more region-specific, needs-based approach to closing the gap in radiation therapy services to low- and middle-income countries. These efforts are intended to supplement ongoing global health initiatives with a focus on enhancing education and training in low- and middle-income countries through the use of modern information and communication technologies. Areas that require special attention include encouraging trainees interested in global health as a future career, addressing ethical issues that may arise in consideration of global health outreach, and using political advocacy as a vehicle for change. The authors encouraged collaboration with the industry to help achieve the goals established by United Nations Political Declaration of the High-Level Meeting of the General Assembly on the Prevention and Control of Non-Communicable Diseases in 2011 [G18]. There is an increased need for educational resources for medical physicists in many low- and middle-income countries, which contributes to the scarcity of radiation therapy in these countries [V1]. Collaboration between high income and low- and middle-income countries is therefore necessary [W8].

Table E7. Number of medical physicists reported to UNSCEAR Global Survey and IOMP [T9]

Data from UNSCEAR Global Survey includes radiation therapy physicists only while data from IOMP [T9] includes all registered medical physicists in a country

Country	*Current evaluation*	*IOMP [T9]*
Argentina	133	167
Australia	450	717
Belarus	88	
Belgium	145	215
Brazil	303	732
Brunei Darussalam	4	3
Bulgaria	68	84
Canada	411	726
China	3 294	1 600
Cyprus	6	60
Czech Republic	89	147

Country	*Current evaluation*	*IOMP [T9]*
Denmark	82	178
Estonia	13	
Finland	47	127
France	556	520
Greece	86	459
Hungary	64	96
Indonesia	58	
Italy	600	1 016
Japan	388	958
Lebanon	19	20
Lithuania	12	20
Luxembourg	5	
Norway	74	186
Philippines	60	110
Poland	425	210
Romania	48	134
Russian Federation	270	600
Spain	513	837
Sudan	12	28
Sweden	148	300
Switzerland	80	216
Thailand	134	150
United Arab Emirates	12	35
United Kingdom	698	1 700
United States	3 405	8 849
Total[a]	**12 894**	**29 179**

[a] Not necessarily the sum of all columns.

E49. Several authors have addressed specific needs in low- and middle-income countries, such as the scarcity of modern treatment planning and treatment delivery techniques. Falahatpour et al. [F1] has investigated the use of 2D planning systems in comparison to 3D planning. The use of 2D planning systems could allow both high and low dose regions to occur in the treated volume as compared with 3D planning. The significance of low dose regions within the treated volume cannot be overstated as it causes a measurable reduction in tumour control probability. Retrospective studies have indicated that a reduction in breast dose from 50 to 45 Gy can lead to a reduction in local control from 95 to 85% when differences in fractionation and tumour size are considered [A11].

E50. Redmond et al. [R2] pointed out that as cancer survival increases with improvement in systemic therapy, localized treatment such as radiation therapy, and immunotherapy, achieving durable local control of metastatic spinal disease will become increasingly important. In addition, as patients live longer, the risks of treatment will need to be mitigated as the opportunity for toxicity to present during a patient's lifetime will be greater. Continued advances in technology in the near future will allow increasingly precise treatment delivery.

E51. Grover et al. [G15] reviewed the role of brachytherapy and the barriers to providing both low dose rate (LDR) and high dose rate (HDR) brachytherapy in low- and middle-income countries. Cervical cancer is the fourth most common cancer affecting women worldwide. However, 90% of cervical cancer deaths occur in low- and middle-income countries, making it the leading cause of cancer-related deaths in women in these countries.

E52. Data are available for some specific regions and countries. For example, data on cancer and access to radiation therapy in South America have been described by Amendola et al. [A4, A5]. They conducted surveys in each country and reported the results in several publications. South American countries have different issues with access that depend on their economies, geography and social system. With a population of about 44 million in 2016, Argentina is the third most populous country in South America. According to Amendola et al., the country has 150 radiation oncologists and 60 medical physicists, falling short of IAEA recommendations [I2] for 180 radiation oncologists and 120 medical physicists. According to the DIRAC database [P11], there are currently 81 radiation therapy centres in the country, which together have 87 linear accelerators and 31 cobalt units. Radiosurgery, IMRT and brachytherapy are available in only a few centres. There are currently two cyberknife facilities. Even given the number of centres available, access for much of the population is restricted because the majority of the centres are private not accessible to everyone [A5]. Approximately 90% of the population have either no health insurance at all, or are covered by one of several public programmes, meaning that they have access to only 20% of radiation therapy centres (roughly 17) that are publicly owned. The government has recently implemented a plan to improve cancer care, and in 2015 signed an agreement to install a proton therapy centre.

E53. Brazil is the largest country in South America in terms of both geographic area and population. According to Amendola et al. [A5], in 2013 only about 28% of the population had health insurance. The remaining population relied on the public health care services. The government's goals of universal health care access have not been met. Cancer, requiring high-complexity treatment, is to be handled at the federal level. But the mechanisms to refer patients to centres where they can receive treatment are not developed. Amendola et al. [A5] estimated that, according to WHO guidelines for radiation therapy, more than 100,000 patients did not receive treatment in 2010 due to the lack of infrastructure. A federal initiative in 2014 was intended to fund the purchase of 80 linear accelerators but, according to Amendola et al., many of those units were yet to be installed in 2017, and the training and education to support the services were going to depend heavily on industry support. As of 2012, there were 314 linear accelerators and 62 cobalt units registered as operational in Brazil, or roughly one per 557,000 population. Most of these, and also many of the radiation oncology professionals, are located in the major population centres, leaving much of the sparsely populated regions with limited services.

E54. Chile is one of Latin America's more prosperous countries, with a relatively high per caput income, and a large governmental health care expenditure. About 80% of the population is covered by the public health care system, while those with higher incomes mostly have a private insurance. According to the DIRAC database [P11], there are 18 radiation therapy centres in the country with 34 linear accelerators. Amendola et al. [A5] reported that the country has an uneven geographic and economic distribution of radiation therapy centres, most of which are in populated urban centres, such as Santiago de Chile, and are mostly private.

E55. Colombia is second only to Brazil in the size of its population, with nearly 49 million as of 2016 [A5]. However, it has only 51 radiation therapy centres, with a total of 68 linear accelerators

[P11]. More importantly, its economy is less buoyant, resulting in limitations on access to health care for most of the population.

E56. According to Amendola et al. [A5], Peru has the third largest geographic area and the fourth largest population with about 32 million inhabitants. It is a relatively prosperous country, with 77% of the population living in urban areas. In 2007, the country had only two radiation therapy centres, but that number has increased recently and there are presently 19 centres, with 34 linear accelerators.

E57. Despite a quite advanced economy and an educated population, Uruguay has a high rate of cancer deaths, second only to the death rate from heart disease [A5]. In 2005, the Uruguayan government created a National Program for Cancer Control with the goal of improving cancer care and integrating the existing resources for care. Consequently, most of the radiation oncology centres are part of a government network, leaving only a few that are privately operated. Several centres specialize in cancers of a few clinical sites. According to a recent survey, 59.6% of the Uruguayan population have private, commercially available insurance with different plans; 30.5% use public health services; and 7.2% qualify for government assistance on the basis of income level. The remaining 2.5% have no insurance coverage, even though public health services are provided. In 2015, there were reported to be 14 linear accelerators, of which eight were in the private sector. Uruguay has one linear accelerator for every 239,000 population, ranking high among high-income countries.

E58. Goss et al. [G10] studied the status of radiation therapy and the access of cancer patients in Latin America. The South American countries, for the most part, are quite underserved in terms of radiation therapy services. In most cases, this stems from economic difficulties and low education levels. According to the study, the Latin American countries are currently overwhelmed by the challenge of cancer control. The authors reported that the annual incidence of new cancers is estimated to increase by 33.3%, to around 16.8 million cases by 2020. Without proactive planning, the increasing cancer incidence will severely tax the resources of the region. Goss et al. [G10] encourage prompt action to avoid dire human and economic consequences. Nicaragua, for example, has only two cobalt units to serve its population of 6.2 million, while El Salvador has a slightly larger population of 6.4 million with access to four linear accelerators and four cobalt units.

E59. A study of the cancer care provided to children in Mexico was undertaken to evaluate whether a government programme to provide funding resulted in increased coverage for cancer care (including radiation therapy) for children and adolescents [P6]. This population was adversely affected by a lack of support for treatment, especially among those not covered by the government social security health programme. This publication reported that after four years, funding had been made available to support cancer treatment for approximately 50% of the paediatric cancer cases without social security. The report was not able to determine if there was an increase in the provision of cancer care (i.e., the number of paediatric cancer units). However, it was presumed that hospitals increased their capability to be certified for this programme and receive the available funds. While the actual number of children treated may not have increased, it was clear that the cost of care shifted from the parents or other funders to the government programme, thus reducing the number of out-of-pocket payers.

E60. In Africa, in particular, there are very challenging issues regarding access to radiation therapy [B5]. As Atun et al. [A12] and Abdel-Wahab et al. [A1] have indicated, Africa faces an impending cancer crisis. Many countries lack the resources to fund equipment and maintenance or deficits in infrastructure, human resources and training. Addressing these issues will be crucial to tackling the increasing burden of cancer on the continent. There is a need for sustained government involvement and consistent funding. As one example, among African countries, Nigeria boasts the continent's largest population (191 million) and the largest economy, although the gross domestic product per caput ranks lower than other African countries [I19]. But, perhaps due to communication difficulties, the DIRAC database lists only two radiation therapy centres, one with a single operational cobalt unit, and one with a single operational linear accelerator [P11]. According to Irabor et al. [I19], the situation may be slightly better, as the authors list nine cancer centres having a total of five linear accelerators, two cobalt units and a few other pieces of radiation therapy equipment.

E61. In most parts of Europe, as in North America, radiation therapy facilities are sufficient in number and quality to address the needs of most of the population [R11]. However, there are regions in which the availability is limited, or the quality is inadequate. In Europe, a number of publications have attempted to analyse the current and future demand for radiation therapy. For instance, Borras et al. [B23] have evaluated the "optimum utilization proportion" of patients who should receive radiation therapy in four European countries. In addition, Borras et al. [B24] have estimated the number of patients who will need radiation therapy in Europe in 2025. Grau et al. [G12, G13] have reviewed radiation therapy services in Western European countries and claim that centralized cancer centres are more efficient and of higher quality in Europe than the decentralized centres found in some other countries, including the United States.

E62. The Health Economics in Radiation Oncology (HERO) project of the European Society for Radiotherapy and Oncology have the overall aim of developing a knowledge base of the provision of radiation therapy in Europe and building a model for health economic evaluation of radiation treatments [P9]. Lievens et al. reported on the personnel data collected in the HERO database [L4], on the availability of equipment and staffing [L5], and on evidence from the existing expense literature [L7]. The papers discuss how such data can be used to support reimbursement setting and investment cases for new radiation therapy equipment and infrastructure in Europe [L6]. It is noteworthy that the HERO project collected data from national professional organizations and not governments.

E63. Dunscombe et al. also reported on the equipment and staffing in European countries, where people generally have good access to radiation therapy [D12]. The paper offers an estimate of the number of patients treated per machine based on the HERO Consortium survey. In Europe, the number of courses of treatment per treatment machine varies from high values of 610 in Poland and 580 in the Czech Republic, to low values of 330 in Denmark and 320 in Switzerland. Among the nine countries providing data for the HERO project, the average value was 450 courses (patients) per machine per year. According to the DIRAC database [P11], the approximate number of treatment machines (linear accelerators plus cobalt-60 units) available worldwide is 14,285. Therefore, the worldwide capacity for radiation therapy patients can be estimated crudely as about 6.4 million courses of treatment per year.

E64. This figure for capacity can be compared with an estimate of demand for radiation therapy services. The global cancer burden has been estimated by WHO as 18 million new cancer cases in 2018 [I5]. Atun and others have estimated that 50% of cancer cases can benefit from radiation therapy; a figure that is supported by UNSCEAR Global Survey data for countries in Western Europe and the United States (table E2). Thus, in 2018, approximately nine million cancer patients could have been expected to benefit from radiation therapy while, as of 2017, the worldwide capacity appears to have been approximately 6.4 million. There are many reasons for the observed differences: *(a)* while the DIRAC database reflects the number of operational treatment units installed, the data do not indicate the availability of service or the downtime experiences with the equipment; therefore, the treatment capacity might be overstated; and *(b)* as can be seen from the UNSCEAR Global Survey, the utilization rates for radiation therapy equipment can vary considerably (figure E-XII). Moreover, while the distribution of treatment equipment is important, the availability of trained and qualified staff is also relevant.

E65. The situation in Eastern Europe is very challenging. Esiashvili [E8] has described progress in Eastern European countries to update their facilities. The cancer burden in Eastern Europe is affected mainly by the population density, which is becoming increasingly heterogeneous. Cancer mortality varies between countries and is influenced by multiple factors, including socioeconomic conditions, organization of health-care services, lifestyle and cultural differences. Overall, there is paucity of radiation therapy services in Eastern Europe, and a severe lack of trained and qualified staff. Atun et al. [A12] pointed out that low- and middle-income countries that wish to improve their radiation therapy access for patients need to consider cost effectiveness as it applies to the health care system.

E66. The HERO project asked participating organizations to report on staffing of radiation therapy departments [D12]. A comparison between the HERO data and the UNSCEAR Global Survey reveals quite similar results, as shown in table E8, with some notable exceptions. The data for physicists in several Eastern European countries are very different and might reflect the differences in the ways medical physicists are counted by different surveys. For several countries, the ratios of patients per radiation oncologist are quite different in the HERO and the UNSCEAR surveys, possibly reflecting differences in recording time spent in other activities such as academic work or treating patients with modalities other than radiation therapy.

Table E8. Numbers of radiation oncologists and medical physicists expressed in relation to the numbers of patients (courses of radiation therapy treatment)

Country	*Number of patients per radiation oncologist*		*Number of patients per medical physicist*	
	HERO[a]	*Current evaluation*	*HERO*[a]	*Current evaluation*
Belgium	220	204	300	253
Czech Republic	130	115	580	202
Estonia		88	210	176
France	280	197	360	296
Hungary	220	496	330	310
Lithuania	170	225	200	488
Luxembourg	240	228	290	274
Poland		110	770	203
Switzerland	170	275	230	412
United Kingdom	210	113		216

[a] Values indicated as from the HERO project published by Dunscombe et al. [D12].

E67. Countries in Southeast Asia face unique challenges. In the Philippines, Calaguas and Gubat [C1] have published data on issues limiting the population’s access to radiation therapy. Calaguas and Gubat noted that external beam radiation therapy can be delivered safely and accurately using cobalt and simple accelerators in most places where there currently are no radiation therapy facilities. The authors argue that there is still a place for cobalt units, as their demands on resources are smaller and they are more resistant to issues that cripple linear accelerators, such as unreliable water and electricity supply. According to the DIRAC database [P11], there are currently 34 linear accelerators and four cobalt units in the Philippines. Moreover, radiation therapy needs skilled and qualified human resources. There appears to be a need for more educational and training activities in the Philippines.

E68. Gondhowiardjo et al. [G8] published a review of status of radiation therapy and access to cancer patients in Indonesia. Much has been achieved in its 80-year history of radiation therapy, and the achievements in the last four years have been substantial. In a recent report, Gondhowiardjo et al. [G9] stated that as of 2019, there were a total of 66 megavoltage machines installed. The DIRAC database lists 33 linear accelerators and 14 cobalt units in Indonesia, suggesting that recent installations might not yet have been reported to the IAEA [P11]. Even with the recent increase in megavoltage equipment, this number is insufficient for Indonesia's population of more than 260 million. Shortages in radiation therapy services, such as in brachytherapy, indicate that further improvements are needed.

E69. In contrast, Singapore offers its population of 5.7 million 24 modern linear accelerators and a number of advanced technologies including IMRT [T4]. Japan is considered an advanced country with a robust economy and a well-educated population. Its 127 million inhabitants have very good access to 798 radiation therapy centres with a total of 860 linear accelerators and 66 cobalt units, according to the DIRAC database [P11]. Very advanced equipment is available, including proton therapy and carbon-ion therapy, as described by Kamada et al. [K2].

E70. In Asian countries, Coburn et al. [C10] identified a correlation between survival of gastric cancer with lower stage, lower grade, positive marital status, Asian ethnicity, younger age, lower T-stage, distal gastrectomy, female sex, and larger number of lymph nodes retrieved. There are clear implications for low- and middle-income countries in which staging, lymph node dissection and other good pathology practices are likely to be inadequate.

E71. The utilization of radiation therapy in the Republic of Korea has been analysed recently by Kim et al. [K9]. In the Republic Korea were 90 radiation therapy centres in 2015, containing 213 megavoltage treatment machines, including 196 linear accelerators, one proton accelerator, and 19 radionuclide units; and 31 remote brachytherapy afterloading devices. In 2016, 72,563 patients were treated with radiation therapy. The most frequent cancers treated were breast, lung, colorectal, liver and prostate. In 2015, the country's resources allowed a workload of an average of 310 patients per megavoltage radiation therapy unit. Korea's centres were relatively well staffed meaning that the average radiation oncologist treated 246 patients while each physicist was responsible on average for 501 patients.

E72. Goss et al. reviewed the status of cancer care and access to radiation therapy in China, India and the Russian Federation [G11]. They reported that cancer control in these countries must be addressed to avoid increases in human suffering and future economic effects. With its enormous population, China has 1,131 linear accelerators and 538 cobalt units, roughly one treatment unit for every 850,000 people [W3]. Clearly, more development and investment are needed here [W5]. India, with one billion inhabitants, has only 260 linear accelerators and 346 cobalt units, mostly in a few major population centres. And according to the DIRAC database [P11], the Russian Federation has 194 linear accelerators and 245 cobalt units for a population of 144 million. Further data and review regarding the likelihood of improvement in the public health system in the Russian Federation has been discussed by Jakab et al. [J5] and by Jargin [J7].

E73. In India, more than 1.5 million new cancer cases occur each year [A12, G14]. Following contemporary standards, more than 60% of these patients would benefit from radiation therapy, but the country is severely under-equipped and is likely to remain so well into the foreseeable future. There are several challenges in delivery of quality radiation therapy in India, which include lack of adequate infrastructure and availability of adequate radiation therapy professionals. Despite these challenges, there are ongoing efforts geared towards improvement of radiation therapy. These include increased investment in health and cancer care by the government, initiatives by cancer centres in India to acquire and improve their facilities, commitment by the government bodies to promote research and expansion of cancer centres, and efforts by national and international cancer societies to promote education and training of radiation professionals. Such changes are necessary to ensure that access to health care is available to all people in India, irrespective of their socioeconomic status [M5, P10]. Nepal has five linear accelerators and two cobalt units to serve a population of 29 million [G17].

E74. An effort to address the status and resources for staffing in the Asia-Pacific region was conducted by Kron et al. [K16]. The authors focused on the education, staffing levels and working conditions of medical physicists in the region. While there were similarities, there were also stark differences between countries. For example, according to the survey described in this annex, the number of megavoltage treatment machines varied from 0.13 in Indonesia to 7 per million population in Japan. Similarly, the number of radiation therapy patients per radiation oncology medical physicist varied from 2,000 in Sri Lanka to 250 in Taiwan, China.

E75. The United States is considered to have excellent resources for health care. According to the DIRAC [P11] and the Imaging and Radiation Oncology Core databases [I21], there are at least 3,600 linear accelerators and a few (128) cobalt units, for approximately one megavoltage unit per 88,000 population. However, as reported by Guadagnolo et al. [G16], the provision of cancer care in general, and particularly radiation therapy, for native American and Alaskan populations, falls below that found elsewhere in the country. In contrast, the use of advanced technologies has grown rapidly in most areas of the United States, and most Americans have access to these technologies. The growth of the use of IMRT has been described [M4], and also its use for treatment of lung cancer [S13] and for breast cancer [S20].

E76. Still, there is evidence that the type of cancer treatment offered to some populations in the United States, depends on their distance from a radiation therapy centre [S10]. The distance from the patient's home to the nearest radiation therapy facility was independently associated with breast cancer surgical therapy in the state of Virginia, which is characterized by a diverse rural and urban population. The relationship between longer distance to the nearest radiation therapy facility and higher mastectomy use was independent of tumour size, year of diagnosis, and patient age and race.

E77. In Canada, radiation therapy services are centralized at a few large and well-equipped centres. This implies large distances between rural populations and cancer care services. Lower radiation therapy utilization rates among elderly and out-of-area patients were determined by Wu et al. [W12]. The authors concluded that a simple referral pathway such as a community liaison provided by a palliative care nurse, and the judicious use of single-fraction therapy might increase the use of palliative radiation therapy.

VII. TRENDS

E78. Kilburn et al. [K7] identified a trend towards greater sparing of normal tissues and improved conformity with the target volume. This trend is made possible by the increase in technological sophistication of treatment delivery; specifically, in the use of image guidance and delivery techniques such as IMRT, VMAT, particle beams and stereotactic techniques.

E79. The trends in improved geometrical targeting have been accompanied by one towards higher tumour doses, or higher dose per fraction combined with a smaller number of fractions [M15]. These changes recognize the reduced doses delivered to normal tissues, enabling an escalation of tumour dose. Kilburn et al. demonstrated that the use of image guidance has allowed radiation oncologists to become more comfortable delivering higher doses, thus achieving greater tumour control without an increase in normal tissue toxicity [K7].

E80. In brachytherapy, there is a trend away from LDR implants towards HDR single-fraction or fractionated implants. For many diseases, HDR allows better conformity of the high-dose region with the target volume as the treatment planner can optimize the locations and dwell time of the source.

E81. Another trend involves the increase in multidisciplinary cancer therapy. While the use of combined therapies such as surgery or chemotherapy with radiation has been in place for decades, improvements, especially in drugs, have led to greater use of combination therapy. Data from clinical trials continue to inform the use of radiation therapy. Today, there is a greater emphasis on evidence-based medicine bringing the expectation that treatment techniques will be used outside research studies only if previously such studies have demonstrated value.

E82. A major challenge in radiation therapy is to avoid delivering radiation doses to healthy tissues that could create second malignancies in those tissues. Estimating the risk of second malignancies in cancer patients is confounded because cancer patients have an increased risk of a second cancer due to genetic predisposition, environmental or lifestyle factors. It is known that chemotherapy increases risk, especially of bone marrow related malignancies. The Committee recognizes the importance of second malignancies following radiation therapy and has commenced an evaluation which will address the dosimetric, biological and epidemiological aspects pertaining to the risk of second primary cancer after radiation therapy.

VIII. SUMMARY

E83. In the period 1997–2007, the global use of radiation therapy increased to 5.1 million treatment courses, from 4.7 million treatment courses in 1991–1996. In the period 2008–2018, a further increase in global use of radiation therapy was seen to approximately 6.2 million treatment courses. More than 5.8 million patients were treated with external beam radiation therapy, while about 0.4 million were treated with brachytherapy. The number of linear accelerators increased to more than 12,000 worldwide from about 10,000 in the previous period, and 5,000 in 1997–2007. A large increase was seen in HCL I countries. At the same time, the number of brachytherapy treatments and the number of after loading brachytherapy units appeared to have changed very little, as was the case during 1997–2007. Particle-beam therapy facilities have been developed worldwide, with the result that today there are 104 particle beam facilities in operation (carbon-ion facilities are counted independently of proton beam facilities). Another 41 centres are under construction, while 27 are believed to be in the planning stages [P11].

E84. Radiation therapy has undergone an evolution in the past several decades, with radical changes in available treatment equipment and radiation beam modalities. Treatment techniques also have advanced considerably. In the past two decades, stereotactic treatment has progressed from being an exceptional procedure available at only a few highly-specialized centres to widespread use in many locations, due to the availability of immobilization and positioning devices. IMRT is used today for at least half of the patients treated in centres in high-income countries and is being introduced in low- and middle-income countries.

E85. Image-guided radiation therapy has similarly undergone a rapid increase in use, due to the availability of kV imaging equipment on virtually all new medical linear accelerators. In high-income countries, it is rare for a patient to be positioned for treatment without the use of orthogonal kV X-ray images, or cone-beam computed tomography scans. Image-guided radiation therapy is also being introduced in low- and middle-income countries when equipment is replaced or upgraded. The use of MRI for treatment guidance is currently being introduced at a few centres with possibly a dozen MRI-linear accelerators installed and undergoing testing or clinical use.

E86. In many parts of the world, however, access to radiation therapy is extremely limited, and for many cancer patients who could benefit from treatment, it is unavailable. Low- and middle-income countries rarely consider radiation therapy when planning cancer treatment facilities, instead focusing on surgery and chemotherapy. Even in many high-income countries, poorer outcomes are seen in locations where patients must travel great distances to the nearest radiation therapy centre. In most low- and middle-income countries, radiation therapy is available to very few patients, in most cases simply because there are too few facilities to treat the patients. In some countries, there are no facilities. Even in the more prosperous low- and middle-income countries, radiation therapy is unavailable to many cancer patients who rely on social programmes because government funding for public services is restricted and, for the most part, radiation therapy services are available only at private hospitals.

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VOLUME I

Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly

Annex A: Evaluation of medical exposure to ionizing radiation

EVALUATING RADIATION SCIENCE FOR INFORMED DECISION-MAKING

In 1955 the United Nations General Assembly established the Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in response to concerns about the effects of ionizing radiation on human health and the environment. At that time fallout from atmospheric nuclear weapons tests was reaching people through air, water and food. UNSCEAR was to collect and evaluate information on the levels and effects of ionizing radiation. Its first reports laid the scientific grounds on which the Partial Test Ban Treaty prohibiting atmospheric nuclear weapons testing was negotiated in 1963.

Over the decades, UNSCEAR has evolved to become the world authority on the global levels and effects of exposure to ionizing radiation. UNSCEAR's independent and objective evaluations of the science are to provide for—but not address—informed policymaking and decision-making related to radiation risks and protection.

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