SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation

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ANNEX A

MEDICAL RADIATION EXPOSURES

CONTENTS

MEDICAL EXPOSURE TO IONIZING RADIATION

I. INTRODUCTION

1. The objective of the past reports of the Scientific Committee [U3, U4, U6, U7, U9, U10] with respect to medical exposures has been to establish the annual frequency of medical examinations and procedures involving the use of radiation, as well as their associated doses. Reviews have been performed of practice in diagnostic radiology, in the use of nuclear medicine and in radiation therapy. Data have been analysed to deduce temporal trends, to evaluate the collective population dose due to medical exposure, and to identify procedures for which the doses are major contributors to the total collective dose. In earlier UNSCEAR reports on doses from medical irradiation [U10, U11], the annual frequency of medical exposures was estimated on the basis of a very limited series of surveys, mainly but not exclusively performed in developed countries. Initially information was obtained under broad headings such as diagnostic radiography or diagnostic fluoroscopy [U11].

2. The purpose of this annex is to assess the magnitude of use of medical exposures around the globe in the period 1997–2007, to determine the relative contribution to dose from various modalities and procedures, and to assess trends. It is not within the mandate of the Committee to assess potential benefits from medical exposure. Documented detrimental effects resulting from medical exposures have been covered in other reports of the Committee and their associated scientific annexes, for example those on carcinogenesis (annex A, "Epidemiological studies of radiation and cancer", of the UNSCEAR 2006 Report [U1]) and accidental exposure (annex C, "Radiation exposures in accidents", of the UNSCEAR 2008 Report).

3. Exposure of the public resulting from contact with patients undergoing either treatment or a diagnostic procedure that uses sealed or unsealed radionuclides is considered in annex B, "Exposures of the public and workers from various sources of radiation", of the UNSCEAR 2008 Report. That annex also addresses exposures of the public arising from the disposal of radioactive waste from hospitals and the production of radionuclides for medicine.

4. Occupational exposure resulting from work involving the medical use of radiation occurs for persons administering the radiation to the patient or in some circumstances for persons nearby. Annex B also examines such occupational exposure in detail.

5. This annex presents a comprehensive up-to-date review of medical exposures to ionizing radiation. This review is based in part on an analysis of the responses to the UNSCEAR Global Survey of Medical Radiation Usage and Exposures and a critical assessment of the published literature on medical exposures. The purpose of this annex is to estimate the annual frequency (number of examinations per fixed number of people) of diagnostic and therapeutic medical procedures and the doses associated with them.

II. SCOPE AND BASIS FOR THE ANALYSIS

6. Medical exposures include [I3]: *(a)* the exposure of patients as part of their medical diagnosis or treatment; *(b)* the exposure of individuals as part of health screening programmes; *(c)* the exposure of healthy individuals or patients voluntarily participating in medical, biomedical, diagnostic or therapeutic research programmes.

7. There are substantial and distinct differences between medical exposure to radiation and most other exposures to radiation. Medical exposure is almost always voluntary and is generally accepted to bring more benefits than risks. In many developing countries, increasing the availability of appropriate medical procedures that use ionizing radiation results in a net health benefit.

8. Medical exposures typically involve only a portion of the body, whereas many other exposures involve the whole body. In addition, many persons who are exposed are not typical of the general population. Their average age is usually somewhat higher and they have medical conditions that may significantly affect the trade-off between the benefits and the risks of using radiation. In contrast, the introduction of new imaging technologies has in some instances resulted in increased use of paediatric radiology, influencing the age profile for the examinations performed. As a result of the above considerations, while the magnitude of medical exposures can be examined, it is very difficult or impossible to estimate the risks of adverse effects due to medical uses, still less to defensibly compare such estimates with those for other sources of exposure to radiation.

III. MEDICAL RADIATION EXPOSURE

9. There are three general categories of medical practice involving exposure to ionizing radiation: diagnostic radiology (and image-guided interventional procedures), nuclear medicine and radiation therapy.

10. Diagnostic radiology generally refers to the analysis of images obtained using X-rays. These include plain radiographs (e.g. chest X-rays), images of the breast (i.e. mammography), images obtained using fluoroscopy (e.g. with a barium meal or barium enema) and images obtained by devices using computerized reconstruction techniques such as computed tomography (CT). In addition to their use for diagnosis, interventional or invasive procedures are also performed in hospitals (e.g. placing a catheter in a blood vessel to obtain images). For the purposes of this annex, such uses are considered to be diagnostic exposures. Some of the procedures mentioned above are not always performed by diagnostic radiologists but may also be performed by others, including general medical physicians, cardiologists and orthopaedic surgeons, whose training in radiation protection may not be as thorough as that of diagnostic radiologists. Physicians also use imaging technologies that do not employ ionizing radiation, such as ultrasound and magnetic resonance imaging (MRI). Dental radiology has been included in the analysis conducted here of diagnostic radiology practice; however the terms "diagnostic dental radiology" and "diagnostic medical radiology" (mutatis mutandi) are used to distinguish dental exposures from other diagnostic exposures.

11. Nuclear medicine refers to the introduction of unsealed radioactive materials into the body, most commonly to obtain images that provide information on either structure or organ function. The radioactive material is usually given intravenously, orally or by inhalation. A radionuclide is usually modified to form a radiopharmaceutical that will be distributed in the body according to physical or chemical characteristics (for example, a radionuclide modified as 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, unsealed radionuclides are administered to treat certain diseases (most frequently hyperthyroidism and thyroid cancer). There is a clear trend towards increased therapeutic applications in modern nuclear medicine.

12. Radiation therapy refers to the use of ionizing radiation to treat various diseases (usually cancer). Sometimes radiation therapy is referred to as radiation oncology; however, benign diseases also may be treated. External radiotherapy refers to treatment of the patient using a radiation source that is outside the patient. This may be a machine containing a highly radioactive source (usually cobalt-60) or a high-voltage machine that produces radiation (e.g. a linear accelerator). Treatment can also be performed by placing metallic or sealed radioactive sources within the patient (brachytherapy). These may be placed either temporarily or permanently.

IV. METHODOLOGY AND SOURCES OF DATA

13. Evaluation of medical exposures consists of assessing the annual frequency and types of procedure being undertaken, as well as an evaluation of the radiation doses for each type of procedure. Annual frequency and dose data are derived from three main sources: the peer-reviewed scientific literature, official reports provided by member States, and the Surveys of Medical Radiation Usage and Exposures conducted by the secretariat on behalf of the Committee. As in previous reports, annual frequency data on procedures are stratified by health-care level (level I, II, III or IV), which are based on the number of physicians per head of population. The number of physicians per head of population has been shown to correlate well with the number of medical examinations performed using ionizing radiation [M39, M40]. This allows extrapolation to those countries for which the Committee has limited or no data.

14. The UNSCEAR 1982 Report [U9] was the first to use a survey, developed by WHO in cooperation with UNSCEAR, to obtain information on the availability of diagnostic radiology equipment and the annual frequency of diagnostic X-ray examinations in various countries. Examination frequency data in previous reports had been based upon surveys in a limited number of countries. Data from five continents were presented in the UNSCEAR 1982 Report [U9], which was also the first UNSCEAR survey to include an assessment of exposures from CT.

15. The four-level health-care model for the analysis of medical exposures was introduced in the UNSCEAR 1988 Report [U7] and has been used in the Committee's subsequent reports. In this model, countries were stratified according to the number of physicians per head of population. Level I countries were defined as those in which there was at least one physician for every 1,000 people in the general population; in level II countries there was one physician for every 1,000–2,999 people; in level III countries there was one physician for every 3,000–10,000 people; and in level IV countries there was less than one physician for every 10,000 people [U7].

16. The Committee also explored other approaches to the classification of health-care levels, for example by health-care expenditure or number of hospital beds. However, it

was found that there was a poor correlation between values for these parameters and the number of medical radiation procedures. Subsequent reports have therefore continued to use the four-level health-care model based upon the number of physicians per head of population [U3, U6]. Over the years this model has proved to be robust in estimating medical radiation exposures. One of the main advantages of the model is that it provides a consistent basis for the extrapolation of practice in a small sample of countries to the entire world. It also facilitates the comparison of trends in medical exposures over time [U7]. Consequently this health-care model has been used in the present analysis of worldwide exposure.

17. In order to evaluate the level of medical exposures worldwide, the UNSCEAR secretariat conducted a Survey of Medical Radiation Usage and Exposures by circulating a questionnaire to all Member States of the United Nations. The Committee bases its estimation of medical exposures upon an analysis of the questionnaire returns. Most of the responses have been received from countries defined by the Committee as health-care level I countries, which represent under a quarter of the world's population.

18. As annual frequency data were only available from those countries that undertake surveys of practice, the analysis of medical exposures has necessarily been based on extrapolating data from the fraction of countries where data were reported to all other countries in a given health-care level. Data on doses were also collected by survey and compared with those in the published literature. For each procedure, the number of procedures per head of population is multiplied by the effective dose per procedure and the relevant population size (i.e. population size for the respective health-care level). The collective effective dose (or population dose) for the global population is then deduced by performing the above calculation for all procedures across all health-care levels and summing the result for all procedures. The Committee also examines trends over time for various procedures, as well as trends over time in the global collective effective dose.

V. ASSESSMENT OF GLOBAL PRACTICE

A. Diagnostic radiology

19. The medical use of ionizing radiation remains a rapidly changing field. This is in part because of the high level of innovation by equipment supply companies [W1] and the introduction of new imaging techniques such as multislice CT and digital imaging.

20. In the UNSCEAR 2000 Report [U3] it was noted that 34% of the collective dose due to medical exposures arose from CT examinations. As a consequence, the increasing trend in annual CT examination frequency and the significant dose per examination have an important impact on the overall population dose due to medical exposures. The contribution of CT examinations to the population dose has continued to increase rapidly ever since the practice was introduced in the 1970s. In the area of CT examinations, the introduction of helical and multislice scanning has reduced scan times [I28]. As a consequence, it is now possible to perform more examinations in a given time, to extend the scope of some examinations, and to introduce new techniques and examinations. The ease of acquisition of images could result in unnecessary exposures of patients to radiation. This, combined with the increase in the number of machines, has a significant impact on population doses, particularly for countries with health-care systems at level I. An accurate assessment of medical exposures due to CT scanning is therefore particularly important.

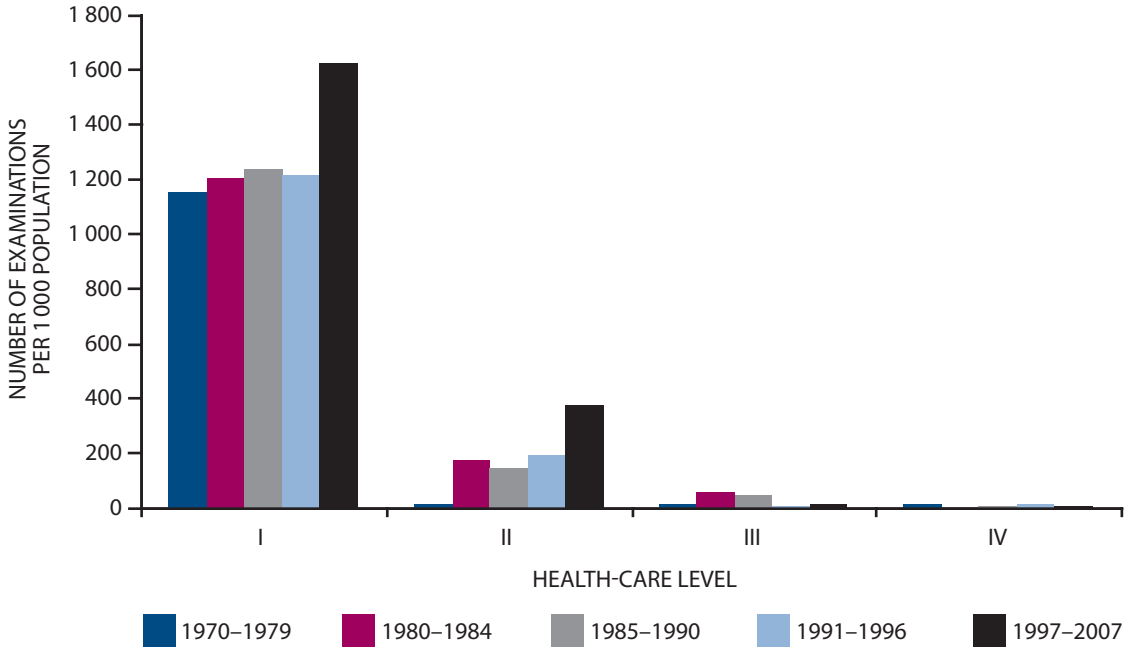
21. Digital imaging is another area of diagnostic radiology that has seen striking changes [I8]. Digital imaging using photostimulable storage phosphor devices was introduced into clinical practice in the 1980s. Since its introduction, there has been a gradual increase in its use. New types of digital imaging device are being introduced to the marketplace. These systems utilize a large-area direct digital detector for imaging and offer many advantages, one of which in principle is a lower dose per image compared with other devices. Thus there could be another era of rapidly changing practice in diagnostic radiology over the course of the next UNSCEAR Global Survey of Medical Radiation Usage and Exposures. This will initially influence population doses in health-care level I countries for radiographic and fluoroscopic examinations before the practice widely influences population doses in countries at other health-care levels. Population doses due to digital radiology will probably increase as a result of an increasing frequency of digital imaging examinations and procedures.

22. According to the current analysis, there are approximately 3.6 billion diagnostic radiology X-ray examinations (including diagnostic medical and dental examinations) undertaken annually in the world. Figure I presents trends in the annual frequency of diagnostic medical and dental radiological examinations for each health-care level.

23. The 24% of the population living in health-care level I countries receive approximately two thirds of these examinations. The annual frequency of diagnostic medical examinations alone (defined here as excluding dental radiology) in health-care level I countries is estimated to have increased from 820 per 1,000 population in 1970–1979 to 1,332 per 1,000 population in this survey. Comparative values for health-care level II countries exhibit 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 level I and II countries

occurred in the period 1997–2007. The estimated annual frequency of diagnostic medical examinations in health-care level III/IV countries has remained fairly constant over this period, although since there were limited data for these countries, there is considerable uncertainty associated with this estimate.

Figure I. Trends in the annual frequency of diagnostic medical and dental radiological examinations for each health-care level

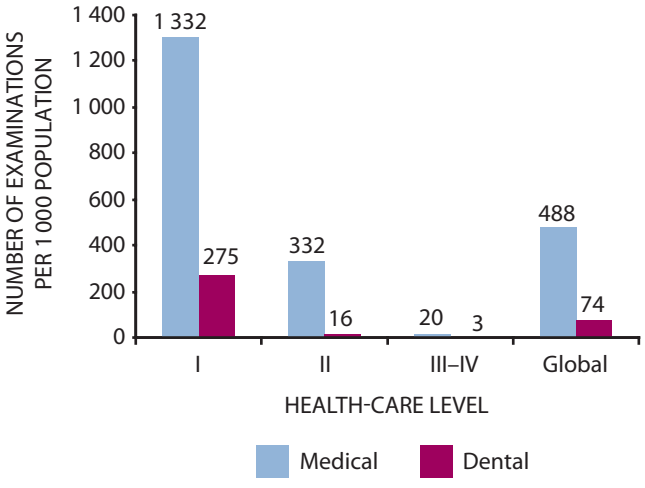


24. CT scanning accounts for 7.9% of the total number of diagnostic medical examinations in health-care level I countries, just over 2.0% in health-care level II countries and just under 14% in health-care level III/IV countries. However, the contribution of CT scanning to the total collective effective dose due to diagnostic medical examinations is approximately 47% in health-care level I countries, and 15% and 65% in health-care level II and III/IV countries, respectively (there is great uncertainty in the doses and frequencies for health-care level III/IV countries). According to this UNSCEAR Global Survey of Medical Radiation Usage and Exposures, CT scanning accounts for 43% of the total collective effective dose due to diagnostic medical radiology.

25. For diagnostic dental examinations, the annual frequency has remained fairly constant for health-care level I countries, being 275 per 1,000 population in this survey, compared with 320 per 1,000 population in the 1970–1979 survey. Over this period, there has been a substantial increase in the annual frequency of diagnostic dental examinations in health-care level II countries, rising from 0.8 per 1,000 population in 1980–1984 to 16 per 1,000 population in the current survey.

26. Figure II summarizes the variation in annual frequency of diagnostic medical and dental radiological examinations for each health-care level, as found in the current UNSCEAR Global Survey of Medical Radiation Usage and Exposures. Also shown in figure II are the global averages. There are wide variations in the frequency of diagnostic medical and dental examinations. For example, diagnostic medical examinations are over 66 times more frequent in health-care level I countries (where 24% of the global population live) than in health-care level III and IV countries (where 27% of the global population live). The change in annual frequency of diagnostic medical examinations reflects changes in population demographics, as most medical exposures are performed on older individuals. Globally, on average there are just over 488 diagnostic medical examinations and 74 dental examinations per 1,000 population. The wide imbalance in health-care provision is also reflected in the availability of X-ray equipment and of physicians.

Figure II. Variation in the annual frequency of diagnostic medical and dental radiological examinations for the respective health-care levels and the global average (1997–2007)



27. The variation in the annual collective effective dose between health-care levels for diagnostic medical and dental radiological examinations is summarized in figure III. Dental exposures account for less than 1% of the collective dose. On average, over 70% of the total collective effective dose is received by the 1.54 billion individuals living in health-care level I countries. The annual collective effective dose to the population of health-care level I countries from diagnostic medical examinations is estimated to be 2,900,000 man Sv, with 1,000,000 man Sv to the population of health-care level II countries, 33,000 man Sv to the population of health-care level III countries and 24,000 man Sv to the population of health-care level IV countries. The total annual collective effective dose to the global population from diagnostic medical exposures is estimated to be 4,000,000 man Sv.

Figure III. Variation in the annual collective effective dose from diagnostic medical and dental radiological examinations for the respective health-care levels and the global total (1997–2007)

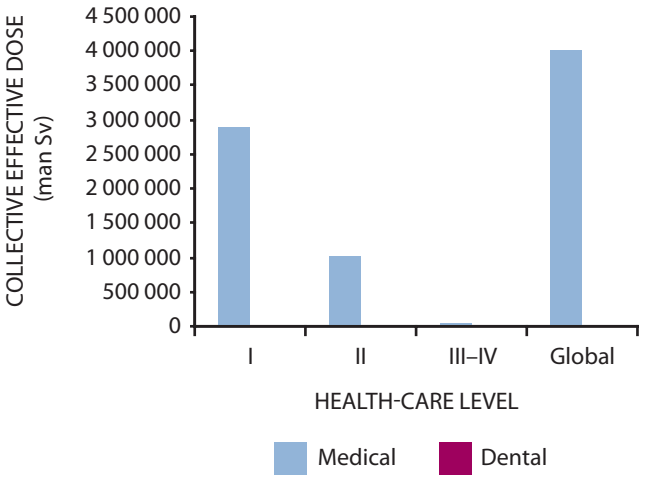
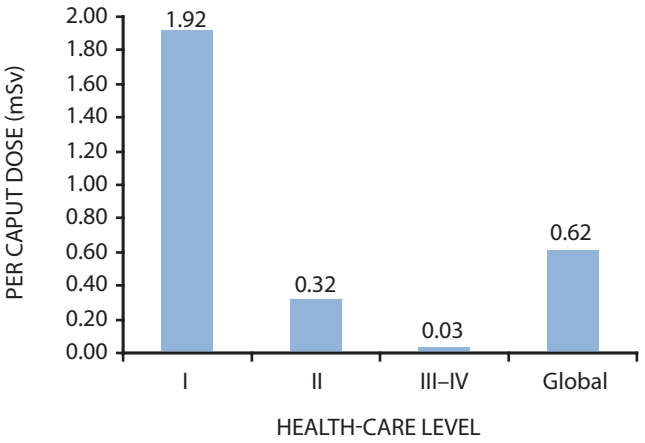
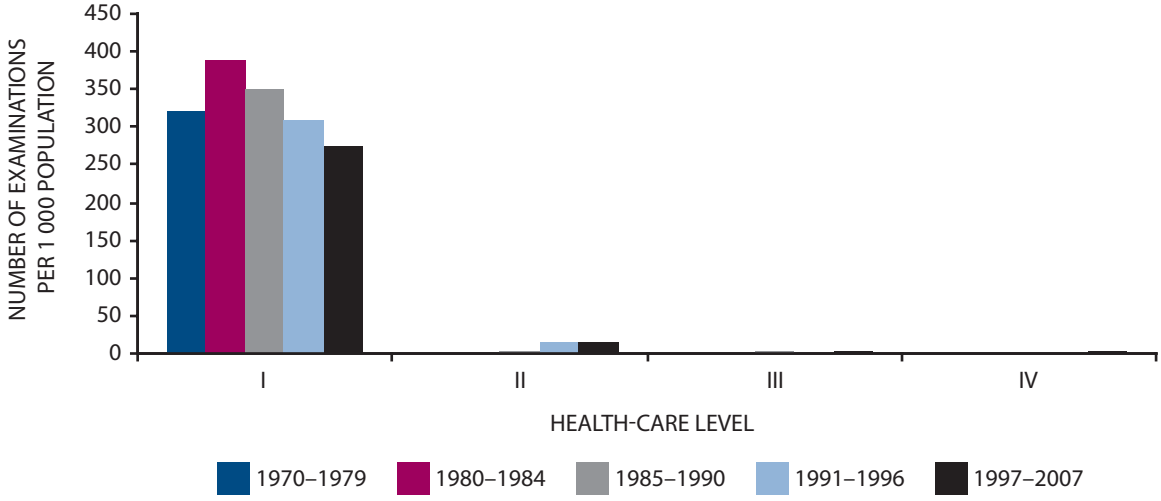


Figure IV. Variation in the annual per caput effective dose from diagnostic medical and dental radiological examinations for the respective health-care levels and the global average (1997–2007)



28. Figure IV shows the annual per caput effective dose for the various health-care levels and the average value across the global population (0.62 mSv) from diagnostic medical and dental radiological examinations. Temporal trends in the annual frequency of diagnostic dental radiological examinations have been obtained and are shown in figure V. Worldwide there are an estimated 480 million diagnostic dental examinations performed annually. Almost all of these are undertaken in level I countries. The contribution of dental examinations to annual per caput or collective effective dose is very small (much less than 1%). However, the number of dental examinations and the availability of equipment may be under-reported in many countries.

Figure V. Trends in the annual frequency of dental radiological examinations for each health-care level



29. For diagnostic dental radiology the collective effective dose to the population of health-care level I countries is estimated to be 9,900 man Sv, with 1,300 man Sv, 51 man Sv and 38 man Sv being received by the populations of health-care level II, III and IV countries, respectively. The total annual collective effective dose to the global population from diagnostic dental radiology is 11,000 man Sv.

30. In the period 1997–2007 covered by the 2008 UNSCEAR Report, the estimated annual collective effective dose to the world population from diagnostic medical and dental radiological examinations is estimated to be 4,000,000 man Sv (see table 1). Since the previous survey [U3], there has been a rise of approximately 1,700,000 man Sv. This increase results in part from an increase in the annual frequency of diagnostic medical and dental radiological examinations (from 1,230 per 1,000 population to 1,607 per 1,000 population in health-care level I countries; from 168 per 1,000 population to 348 per 1,000 population in health-care level II countries; and from 20 per 1,000 population to 23 per 1,000 population in health-care level III/IV countries), 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).

Table 1. Estimated annual per caput dose and annual effective dose to the world population from diagnostic medical and dental radiological examinations (1997–2007)

Health-care level	*Population (millions)*	*Annual per caput dose (mSv)*		*Annual collective effective dose (man Sv)*	
		Medical	*Dental*	*Medical*	*Dental*
I	1 540	1.91	0.006 4	2 900 000	9 900
II	3 153	0.32	0.000 4	1 000 000	1 300
III	1 009	0.03	0.000 051	33 000	51
IV	744	0.03	0.000 051	24 000	38
Global	6 446	0.62	0.002	4 000 000	11 000

31. Trends in dose for selected diagnostic medical examinations are shown in table 2. It is clear that doses for two typical radiological examinations (chest radiography and mammography) have been decreasing significantly. On the other hand, the dose from a CT examination, which is a relatively high-dose procedure, has decreased only slightly since the previous survey. However, the nature of CT scanning has changed over the years. In the 1970–1974 survey, only head scans were included; now most CT examinations are of other parts of the body.

Table 2. Trends in average effective doses resulting from selected diagnostic medical examinations in countries of health-care level I

Examination	*Average effective dose per examination (mSv)*			
	1970–1979	*1980–1990*	*1991–1996*	*1997–2007*
Chest radiography	0.25	0.14	0.14	0.07
Abdomen X-ray	1.9	1.1	0.53	0.82
Mammography	1.8	1	0.51	0.26
CT scan	1.3	4.4	8.8	7.4
Angiography	9.2	6.8	12	9.3

B. Nuclear medicine

32. There are approximately 33 million diagnostic nuclear medicine examinations performed annually worldwide. The 24% of the global population living in level I countries receive about 90% of all nuclear medicine examinations. The annual frequency of diagnostic nuclear medicine examinations in health-care level I countries is estimated to have increased from 11 per 1,000 population in 1970–1979 to 19 per 1,000 in this survey. Comparative values for health-care

level II countries also exhibit an increase, from 0.9 per 1,000 population in 1970–1979 to 1.1 per 1,000 in 1997–2007. For therapeutic nuclear medicine procedures, according to the global model, the annual frequency of nuclear medicine treatments in health-care level I countries has increased from 0.17 per 1,000 population in 1991–1996 to 0.47 per 1,000 in this survey, consistent with the trend towards more therapeutic applications. Comparative values for health-care level II countries exhibit an increase from 0.036 per 1,000 population in 1991–1996 to 0.043 per 1,000 in 1997–2007. Figures VI and VII present summaries of the annual frequencies of nuclear medicine examinations for the respective health-care levels and average annual numbers of examinations for each time period considered, respectively.

Figure VI. Annual frequency of diagnostic nuclear medicine examinations for the respective health-care levels and the global average (1997–2007)

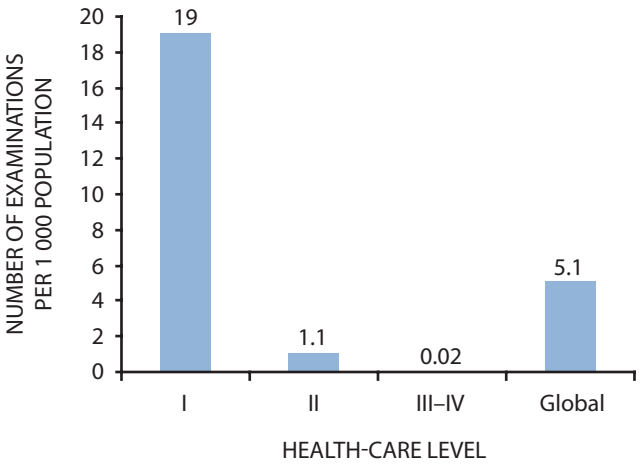
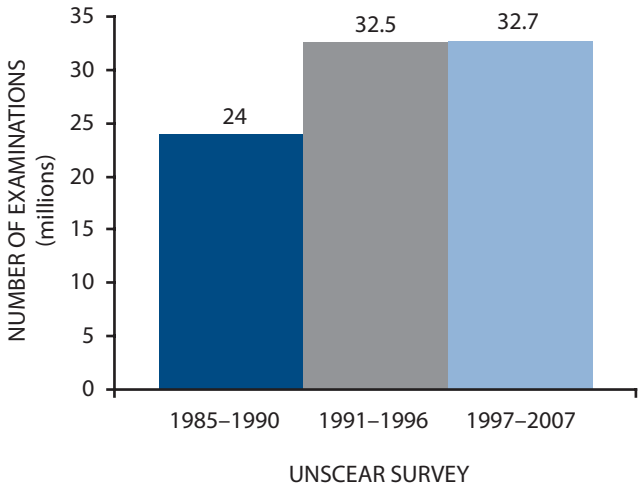


Figure VII. Annual number of diagnostic nuclear medicine examinations



33. In the period covered by the 2008 UNSCEAR Report, the annual collective effective dose to the world population due to diagnostic nuclear medicine examinations is estimated to be 202,000 man Sv. The trend in the annual collective effective dose from diagnostic nuclear medicine examinations over the last three surveys is summarized in figure VIII. There has been an increase in collective dose of nearly 50,000 man Sv, a rise of just over a third since the last report. The increase in the global collective effective dose from diagnostic nuclear medicine examinations results from three factors: an increase of nearly a third in the average effective dose per procedure (from 4.6 mSv in the UNSCEAR 2000 Report to the present estimate of 6.0 mSv) and an increase in the annual number of diagnostic nuclear medicine examinations to the world population. The annual collective effective dose for the respective health-care levels is shown in figure IX.

Figure VIII. Trend in the annual collective effective dose from diagnostic nuclear medicine examinations

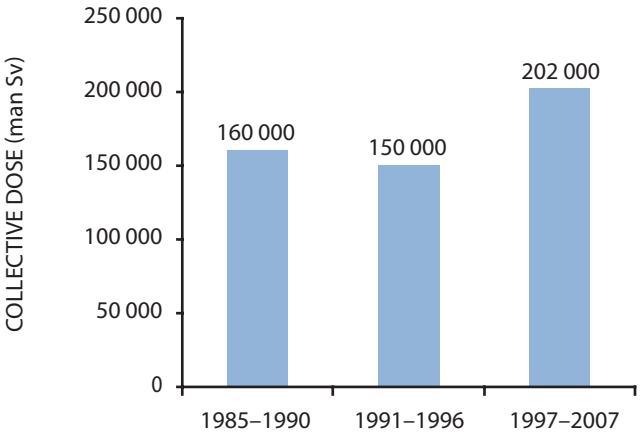
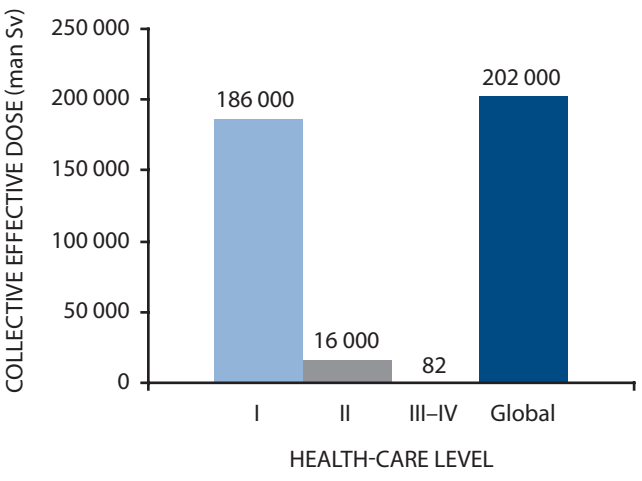


Figure IX. Annual collective effective dose from diagnostic nuclear medicine examinations for the respective health-care levels and the global total (1997–2007)



C. Radiation therapy

34. Worldwide in 1991–1995, approximately equal numbers of radiation therapy patients were treated using X-ray machines, radionuclide units and linear accelerators [U3]. Insufficient data were received for the period 1997–2007 to estimate the numbers of patients treated with each type of treatment device. The availability of linear accelerators worldwide was about 1.6 machines per million population. The availability of X-ray machines and of cobalt units was about equal, 0.4 per million population. In level I countries, however, the availability of treatment equipment was considerably greater than the world average (for example, there were 5.4 linear accelerators per million population). The total number of treatment machines also varied from one health-care level to another. The numbers of patients treated in different countries varied in approximate proportion to the availability of treatment equipment. The annual number of various types of treatment for each health-care level is shown in table 3. The 24% of the world population in the level I countries received approximately three-quarters of all radiation therapy treatments.

35. In the period 1997–2007, the global use of radiation therapy increased to 5.1 million treatments, from 4.7 million treatments 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, from about 5,000 in the previous period. A large increase was seen in level I countries. Level II countries appeared to show a decrease, but this is likely to be an artefact of the limited data received from the survey. At the same time, the number of brachytherapy treatments and the number of afterloading brachytherapy units appeared to have changed very little.

Table 3. Estimated annual number of radiation therapy treatments[a] in the world (1997–2007)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Population (millions)*	*Annual number of teletherapy treatments*		*Annual number of brachytherapy treatments[b]*		*Annual number of all radiotherapy treatments*	
		Millions	*Per 1 000 population*	*Millions*	*Per 1 000 population*	*Millions*	*Per 1 000 population*
I	1 540	3.5	2.2	0.18	0.12	3.6	2.4
II	3 153	1.2	0.4	0.20	0.06	1.4	0.4
III	1 009	0.06	0.06	(<0.05)[c]	(<0.01)[c]	0.1	0.06
IV	744	(0.03)[c]	(<0.01)[c]	(<0.01)[c]	(<0.005)[c]	(0.03)[c]	(0.01)[c]
World[d]	6 446	4.7	0.73	0.4	0.07	5.1	0.8

[a] Complete courses of treatment.
[b] Excluding treatments with radiopharmaceuticals.
[c] Assumed value in the absence of data.
[d] Global data include several countries not represented by levels I–IV.

VI. IMPLICATIONS FOR THE FUTURE ANALYSIS OF MEDICAL EXPOSURES

36. Because of the introduction of new techniques and equipment and the ever-increasing use of radiation in medicine, it is important to continue to assess the doses resulting from medical exposure to radiation [O2]. At present it appears that the world is entering another period of major technological changes, where the impact of these changes on the population dose worldwide in the future will be very difficult to predict. The introduction of the new technologies may also affect the age profile of the exposed population.

37. The present questionnaire that the Committee has used to collect information is quite detailed and asks for much more information than most countries routinely collect, and this may have discouraged some responses. For future surveys it would probably be useful to design a simpler questionnaire, taking into account feedback from those collecting, analysing or using the data. Comprehensive data from less industrialized countries are difficult to obtain, but given the large populations of these areas, the Committee would encourage those countries to develop their programmes to assess medical uses and exposures.

38. Just under half of the collective effective dose due to diagnostic radiology arises from three procedures: CT, angiographic examinations and interventional radiology. Therefore accurate comprehensive data on these procedures would improve the estimation of population dose. For diagnostic nuclear medicine, the main contributions to the collective effective dose arise from ^{99m}Tc bone scans, ^{201}Tl cardiovascular studies and iodine thyroid scans.

VII. SUMMARY AND CONCLUSIONS

39. Medical exposure remains by far the largest human-made source of exposure to ionizing radiation and continues to grow at a substantial rate. There are now about 3.6 billion medical radiation procedures performed annually. There is a markedly uneven distribution of medical radiation procedures (including both diagnostic medical and dental procedures) among countries, with about two-thirds of these procedures being received by the 24% of the world's population living in health-care level I countries. For level I and II countries, where 75% of the world's population resides, medical uses of radiation have increased from year to year as the benefits of the procedures become more widely known. While there are limited data on the annual frequency of examinations in countries with health-care levels III and IV, the annual frequency of diagnostic medical examinations has remained fairly constant. For diagnostic dental examinations the annual frequency has remained fairly constant for health-care levels I and II, but has substantially increased for health-care levels III and IV. In addition, the trend for increasing urbanization of the world population, together with a gradual improvement in living standards, inevitably means that more individuals can access health-care systems. As a consequence, the population dose due to medical exposures has continuously increased across all health-care levels.

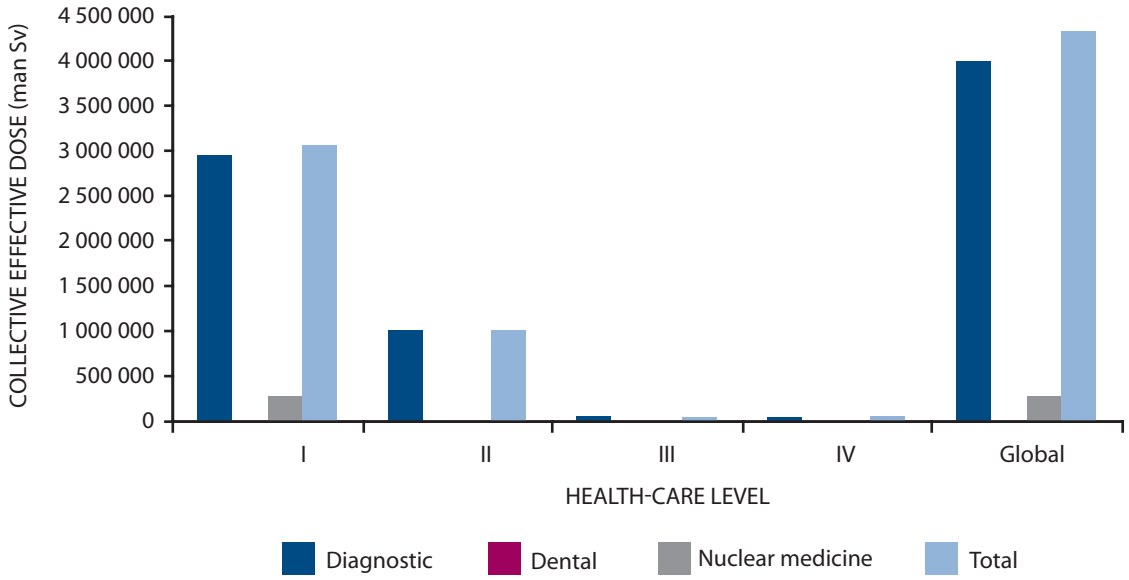
40. Table 4 and figure X summarize the annual collective effective dose from diagnostic exposures (including those due to diagnostic medical and dental radiology, and due to diagnostic nuclear medicine procedures) for the period 1997–2007. Most of the worldwide collective effective dose arises from diagnostic examinations in health-care level I countries. The total annual collective effective dose from all diagnostic exposures is approximately 4,200,000 man Sv.

Table 4. Annual collective effective dose from all diagnostic exposures (including those due to diagnostic medical and dental radiology, and due to diagnostic nuclear medicine procedures)

Health-care level	*Population (millions)*	*Annual collective effective dose (man Sv)*			
		Medical	*Dental*	*Nuclear medicine*	*Total*
I	1 540	2 900 000	9 900	186 000	3 100 000
II	3 153	1 000 000	1 300	16 000	1 000 000
III	1 009	33 000	51	82[a]	33 000
IV	744	24 000	38		24 000
World	6 446	4 000 000	11 000	202 000	4 200 000

[a] Refers to health-care levels III-IV.

Figure X. Annual collective effective dose from all diagnostic exposures for each health-care level and the global totals (1997–2007)



41. The annual per caput effective dose to the global population due to all sources of ionizing radiation is summarized in table 5 and figure XI. Natural background radiation represents just less than 80% of the total per caput effective dose of about 3 mSv. Diagnostic examinations result in a per caput effective dose of 0.66 mSv. Medical exposures now contribute around 20% of the average annual per caput dose to the global population. The total annual collective effective dose to the global population is estimated to be 19.2 million man Sv (see table 6), most of which arises from natural background radiation. Diagnostic exposures account for approximately 4.2 million man Sv. Annually there are approximately 3.1 billion diagnostic medical radiological examinations and 0.48 billion diagnostic dental radiological examinations.

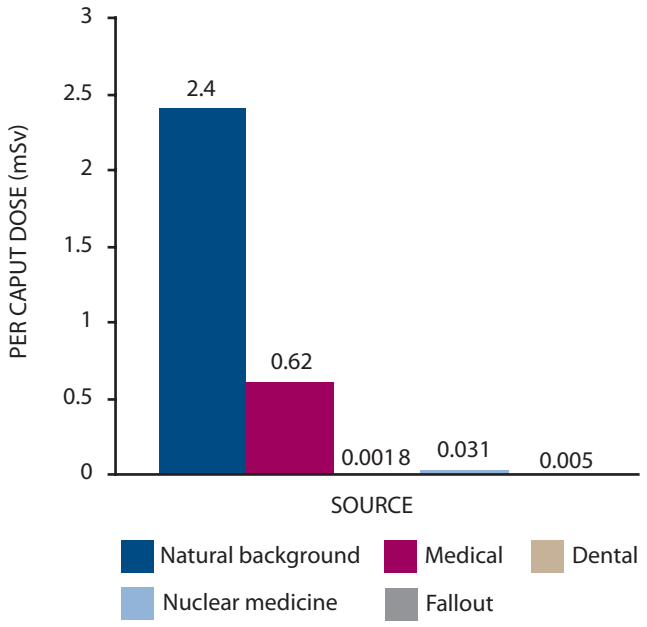
Table 5. Global annual per caput effective dose

Source	*Annual per caput effective dose (mSv)*	*Contribution (%)*
Natural background	2.4	79
Diagnostic medical radiology	0.62	20
Diagnostic dental radiology	0.001 8	<0.1
Nuclear medicine	0.031	1.1
Fallout	0.005	<0.2
Total	3.1	100

Table 6. Global annual total collective effective dose

Source	*Annual collective effective dose (man Sv)*	*Contribution (%)*
Natural background	16 000 000	79
Diagnostic medical radiology	4 000 000	20
Diagnostic dental radiology	11 000	<0.1
Nuclear medicine	202 000	1.0
Fallout	32 000	<0.1
Total	20 200 000	100

Figure XI. Annual per caput effective dose (mSv) 1997–2007



42. New medical X-ray technologies and techniques (particularly with respect to CT scanning) are proving increasingly useful clinically, resulting in rapid growth in the number of procedures in many countries and hence in a marked increase in collective dose. In at least one country, this has given rise to a situation where medical exposures have resulted in population and per caput doses equal to or greater than those from the previously largest source (i.e. natural background radiation); other countries will follow.

43. Diagnostic nuclear medicine has increased worldwide from about 23.5 million examinations annually in 1988 to an estimated 32.7 million annually during the period 1997–2007, and this has resulted in an annual per caput dose of about 0.031 mSv. The estimated annual collective dose has increased from about 74,000 man Sv in 1980 to an annual collective dose of about 202,000 man Sv by the end of the period 1997–2007. About half of the dose results from cardiovascular applications. The distribution of nuclear medicine procedures among countries is quite uneven, with 90% of examinations occurring in level I health-care countries, which represent about 24% of the world's population.

There were about 0.9 million patients treated therapeutically each year with unsealed radionuclides.

44. There were an estimated 5.1 million patients treated annually with radiation therapy during the period 1997–2007, up from an estimated 4.3 million in 1988. About 4.7 million were treated with teletherapy and 0.4 million with brachytherapy. The 24% of the population living in health-care level I countries received 71% of the total radiation therapy treatments.

45. Medical exposure has grown very rapidly over the last three decades in some industrialized countries. As an example, figures XII and XIII show that increases in medical uses in the United States in the period 1980–2006 resulted in an increase in the total annual per caput effective dose from 3.0 mSv to 6.2 mSv, making medical exposure comparable with the exposure due to natural background radiation [N26].

46. Table 7 summarizes the trends in diagnostic radiology practice since 1988. Over the period shown, the annual number of diagnostic radiological examinations has increased by a factor of 2.25 (see figure XIV). This increase has arisen in part because of the increase in the global population and because of the increase in the annual frequency of diagnostic radiological examinations by a factor of 1.7 (see figure XV). Over the same period the annual collective effective dose to the world population has increased from 1,800,000 man Sv in 1988 to 4,000,000 man Sv (see figure XVI). There has also been an upward trend in the annual per caput effective dose, as may be seen in figure XVII.

Figure XII. Annual per caput effective dose (mSv) for the United States population in 1980 [M37]

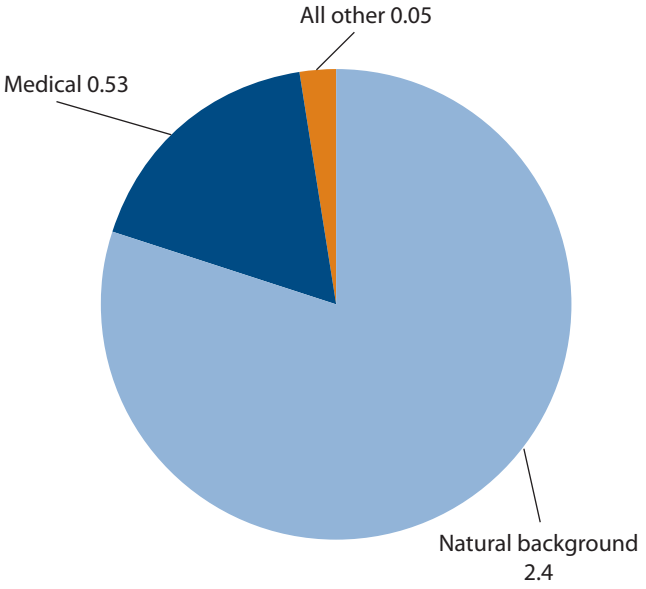


Figure XIII. Annual per caput effective dose (mSv) for the United States population in 2006 [N26]

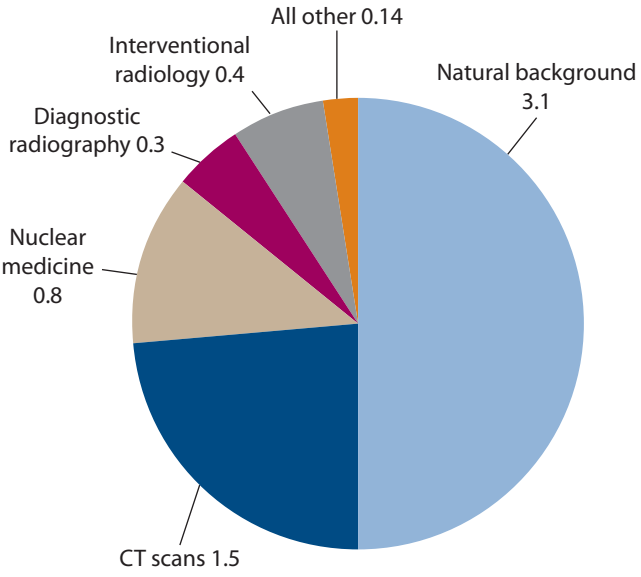


Table 7. Trends in the global use of radiation for diagnosis: diagnostic medical radiological examinations
From UNSCEAR Global Surveys of Medical Radiation Usage and Exposures

Survey	*Annual number of examinations (millions)*	*Annual frequency (per 1 000 population)*	*Annual collective effective dose (1 000 man Sv)*	*Annual per caput dose (mSv)*
1988 [U7]	1 380	280	1 800	0.35
1993 [U6]	1 600	300	1 600	0.3
2000 [U3]	1 910	330	2 300	0.4
2008	3 143	488	4 000	0.62

Figure XIV. Trend in the annual number of diagnostic medical radiological examinations

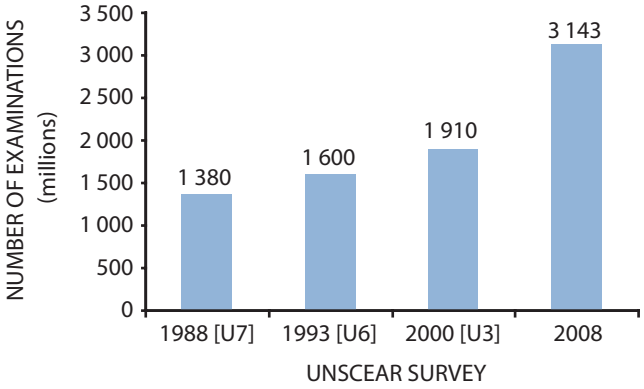


Figure XV. Trend in the annual frequency of diagnostic medical radiological examinations

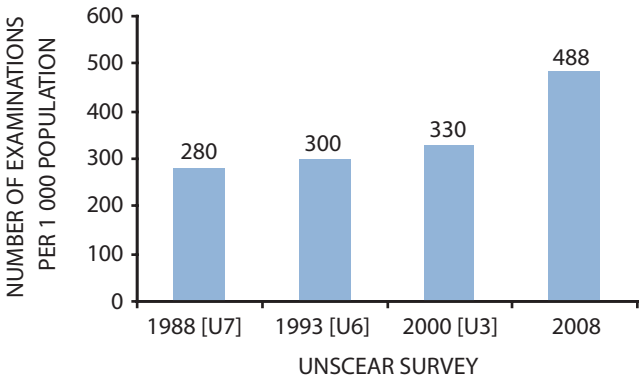


Figure XVI. Trend in the annual collective effective dose from diagnostic medical radiological examinations

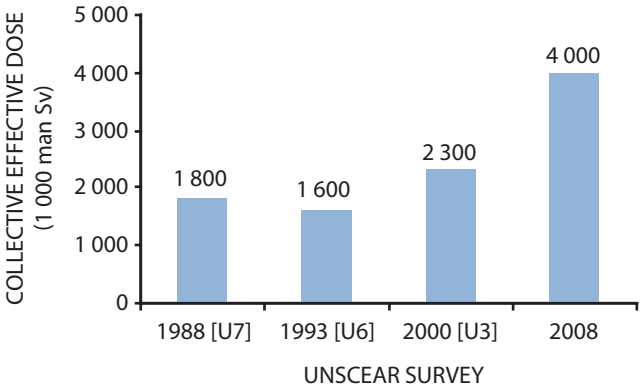
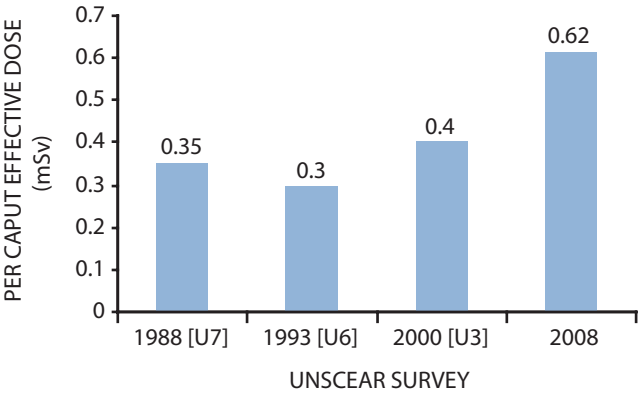


Figure XVII. Trend in the annual per caput effective dose from diagnostic medical radiological examinations



47. Trends in the global use of dental radiology are given in table 8. The number of dental radiological examinations has increased since 1988 (figure XVIII). This is mainly because of the increase in the world's population; the annual frequency of dental radiological examinations has remained fairly constant over this period (figure XIX). The annual collective effective dose has decreased since 1988 (figure XX). Given that the number of examinations has increased, this decrease results from the reduction in the dose per examination associated with the introduction of improved films and film–screen systems. Similarly, there has been a substantial decrease in the per caput dose due to dental radiology (figure XXI).

Table 8. Trends in the global use of radiation for diagnosis: dental radiology
Data from UNSCEAR Global Surveys of Medical Radiation Usage and Exposures

Survey	*Annual number of examinations (millions)*	*Annual frequency per 1 000 population*	*Annual collective effective dose (1 000 man Sv)*	*Annual per caput dose (mSv)*
1988 [U7]	340	70	17	0.003
1993 [U6]			18	0.003
2000 [U3]	520	90	14	0.002
2008	480	74	11	0.002

Figure XVIII. Trend in the annual number of dental radiological examinations

No data were obtained in the 1993 survey

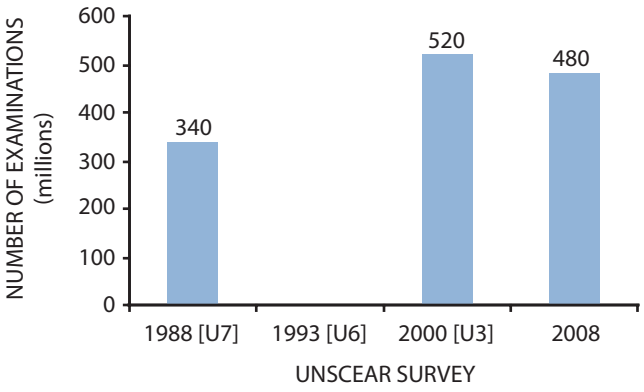


Figure XX. Trend in the annual collective effective dose from dental radiological examinations

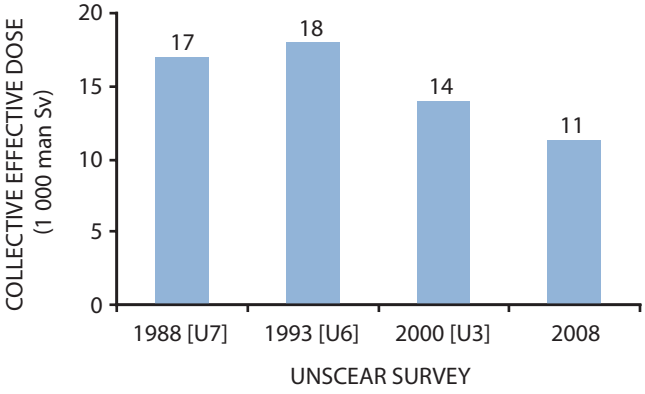


Figure XIX. Trend in the annual frequency of dental radiological examinations

No data were obtained in the 1993 survey

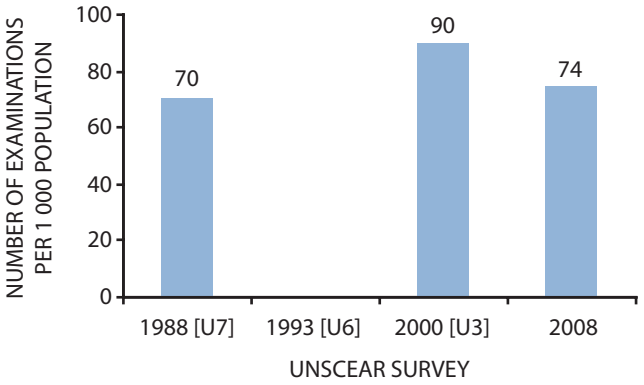
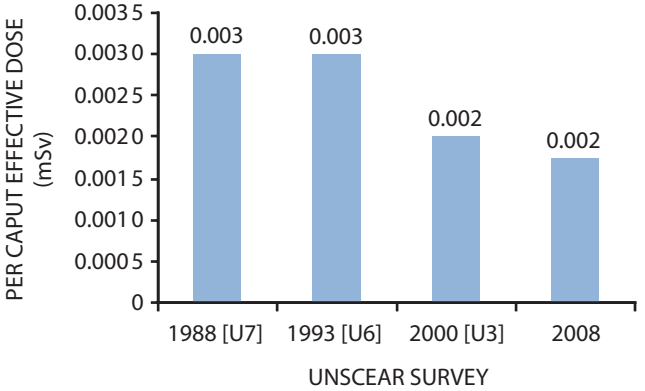


Figure XXI. Trend in the annual per caput effective dose from dental radiology



48. Trends in diagnostic nuclear medicine procedures are summarized in table 9. Since 1988 there has been a modest increase in the number of examinations, comparable with the increase in the global population (figure XXII). The annual frequency of diagnostic nuclear medicine procedures has remained fairly constant since 1988 (figure XXIII). However, the collective effective dose due to diagnostic nuclear medicine procedures has tripled (figure XXIV). This is because of the introduction of high-dose cardiac studies and a reduction in the frequency of other types of procedure. The annual per caput dose has remained constant since 1993 (after having doubled between 1988 and 1993) (figure XXV).

Table 9. Trends in the global use of radiation for diagnosis: nuclear medicine

Data from UNSCEAR Global Surveys of Medical Radiation Usage and Exposures

Survey	*Annual number of examinations (millions)*	*Annual frequency (per 1 000 population)*	*Annual collective effective dose (1 000 man Sv)*	*Annual per caput dose (mSv)*
1988 [U7]	23.5	4.7	74	0.015
1993 [U6]	24	4.5	160	0.03
2000 [U3]	32.5	5.6	150	0.03
2008	32.7	5.1	202	0.031

Figure XXII. Trend in the annual number of diagnostic nuclear medicine procedures

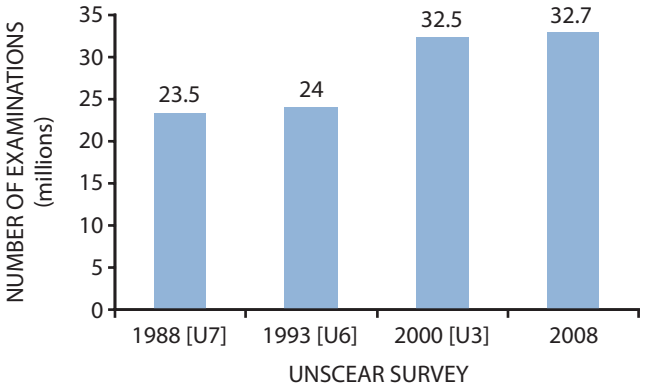


Figure XXIII. Trend in the annual frequency of diagnostic nuclear medicine procedures

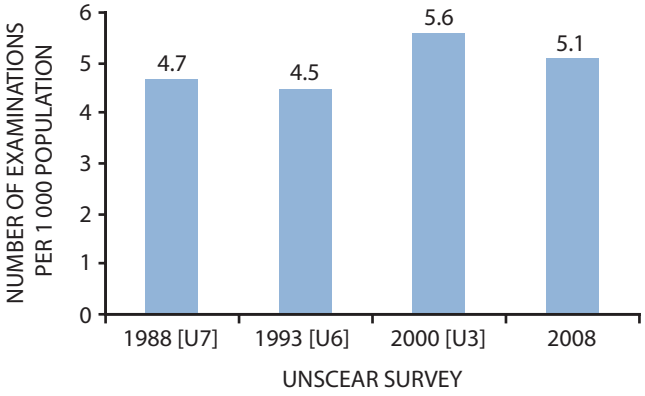


Figure XXIV. Trend in the annual collective effective dose from diagnostic nuclear medicine procedures

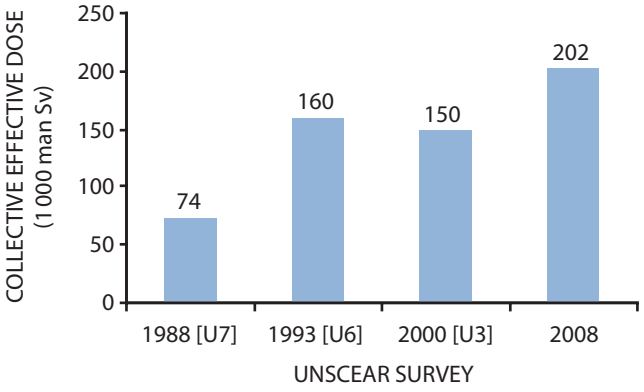
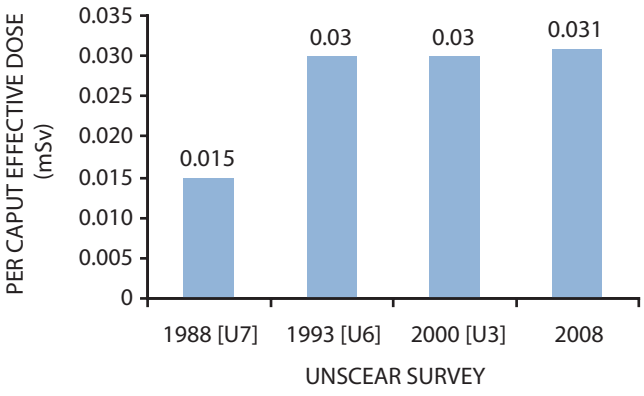


Figure XXV. Trend in the per caput effective dose from diagnostic nuclear medicine procedures



APPENDIX A.
METHODOLOGY FOR ESTIMATING WORLDWIDE MEDICAL EXPOSURES

I. INTRODUCTION

A1. As early as 1962 the Committee [U15] provided tables of information on medical exposures. Data were supplied by approximately 20 countries. The data indicated the total population and total annual frequency of examinations (expressed as annual number of examinations per 1,000 population in the general population). Emphasis was predominantly on gonadal dose and genetically significant dose, since at that time hereditary effects were felt to be very important. By 1972 the Committee [U11] had added estimation of marrow dose as well, but again only reporting the total annual frequency of examinations. In 1977 the Committee [U10] began to include data on the annual frequency of specific examination types for at least one country (Sweden). In the 1982 UNSCEAR Report [U9], data on the annual frequency of specific examinations were presented for 16 countries, and estimates of effective dose equivalent for various examinations were reported for two countries (Japan and Poland). Absorbed doses to some organs were also estimated. Genetically significant dose and marrow dose were no longer used at that time, having been replaced by effective dose equivalent as a quantity of interest.

A2. In the 1988 UNSCEAR Report [U7] the Committee greatly expanded its presentation on medical exposures and attempted to estimate global exposure rather than simply presenting country-specific data. This was possible as data from large countries, such as China and countries in Latin America, became available. In addition, the Committee decided to prepare and distribute a survey questionnaire to Member States aimed at acquiring data on medical exposures in addition to those that appeared in the published literature. This survey methodology has continued to the present day.

A3. The Committee recognized that estimation of the population dose due to medical exposures had significant weaknesses [U3, U9]. In spite of the efforts of the UNSCEAR secretariat, data were still available for only about a quarter of the world's population. Most of the data on frequency and types of radiological examination were mainly available from developed countries [M39]. A method was sought to extrapolate the existing data to other countries where no data were available. Members of the UNSCEAR secretariat examined possible correlations that might be helpful. Some correlations that were examined in relation to frequency of medical radiation exposures, but which were found not to be helpful, included the percentage of gross domestic product spent on health care, the number of hospital beds per 1,000 population, and the number of examinations or procedures per X-ray, nuclear medicine or radiation therapy machine. Mettler et al. developed an analytical model to estimate the availability and frequency of medical uses of radiation worldwide [M39]. Because frequency and equipment data are unavailable for many countries, Mettler et al. investigated data sources that were available and that correlated reasonably well with examination frequency. In their original paper they found that there was a good correlation between the number of people in the population divided by the number of physicians and the annual frequency of diagnostic radiological examinations. This subsequently led to the four-level health-care model, which has been used in recent UNSCEAR reports [M39, U3, U7, U9]. The model has also been used in performing analyses of diagnostic X-ray examinations [M40].

A4. The model used to analyse population exposure assigned countries to four health-care levels as follows:

- Level I with at least one physician for every 1,000 people;
- Level II with one physician for every 1,000–2,999 people;
- Level III with one physician for every 3,000–10,000 people;
- Level IV with less than one physician for every 10,000 people.

A5. The changes in the population distribution across the four health-care levels between 1970 and 2007 is shown in figure A-I. About half of the world's population live in countries that have 1,000–2,999 people per physician, and this percentage has stayed relatively constant for the last 25 years. There has been a gradual decline in the percentage of the world's population living in level I countries.

A6. While the distribution of population by health-care level has not changed significantly, the world's population has increased substantially, rising from just over 4 billion in 1977 to about 6.5 billion in 2006, an increase of over 60% (figure A-II).

A7. By analysing the available data using these health-care level criteria and data on the annual frequency of selected examinations from various countries, it was possible to obtain an average annual frequency for these examinations for a given health-care level and apply this value to the other countries of the same health-care level for which the Committee had no specific data. This allowed a global estimate of the number and type of examinations or procedures to be presented in the UNSCEAR 1988 Report [U7] as well as in all subsequent reports of the Committee [U3, U4, U6].

Figure A-I. Population distribution across the four health-care levels (1970–2007)

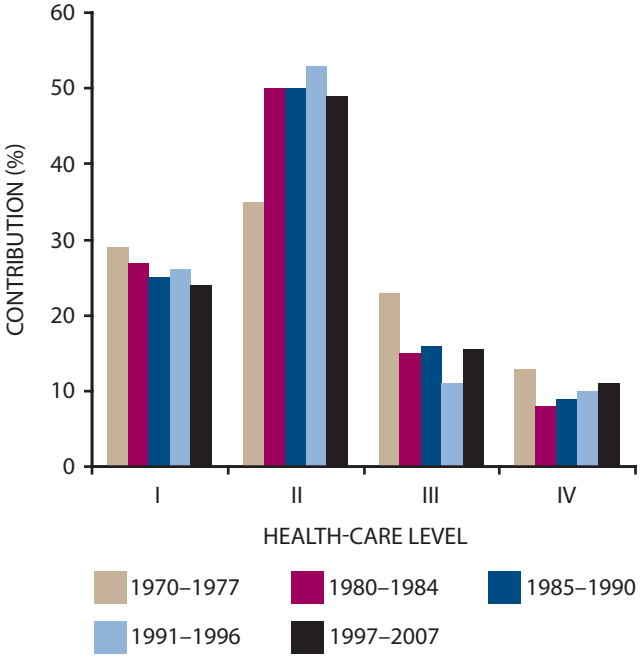
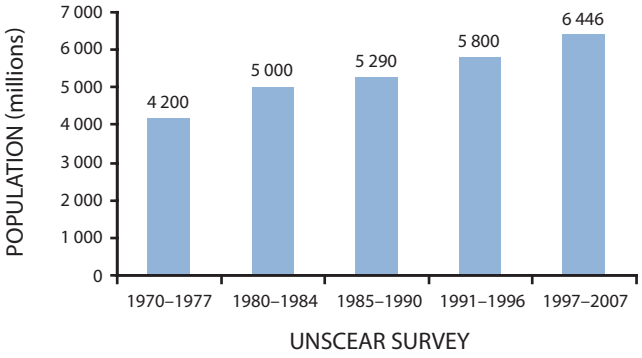


Figure A-II. Change in the global population over the period covered by the various UNSCEAR Global Surveys of Medical Radiation Usage and Exposures



A8. The UNSCEAR 1988 Report also presented the first estimate of collective effective dose equivalent to patients from diagnostic radiology and diagnostic nuclear medicine [U7]. This estimate was made by multiplying the total number of specific examinations by the effective dose equivalent per examination. The data collected on the calculated effective dose equivalent for various examinations were presented. In more recent reports of the Committee, effective dose has been used rather than effective dose equivalent [U3]. The specific dosimetric methodologies are presented below.

A9. The questionnaire used in the most recent UNSCEAR Global Survey of Medical Radiation Usage and Exposures comprises five parts. The first part requests general information and data on the number of practitioners for various groups in a country. Form 1 requests information on diagnostic and therapeutic equipment. Forms 2, 3 and 4 cover diagnostic radiological examinations, nuclear medicine procedures (both diagnostic and therapeutic) and radiation therapy treatments, respectively.

II. METHODOLOGY FOR ANALYSIS OF DOSIMETRY IN DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY

A10. This section comprises a review of the various approaches to patient dosimetry and is based upon the approach described by the International Commission on Radiation Units and Measurements (ICRU) in ICRU Report 74, "Patient dosimetry for X-rays used in medical imaging" [I46]. Further details on patient dosimetry may be found elsewhere [F1, F3, H34, I17, I32, J2, M22, N1, S17, S18, S19, U3, W16].

A11. Over the years, a number of patient dosimetric quantities have been developed. These dosimetric quantities will be described in subsequent paragraphs.

A12. The ICRU [I47] has defined energy fluence, Ψ, as the quotient of dR by da, where dR is the radiant energy incident on a sphere with a cross-sectional area da. This quantity specifies the energy carried by the photons in an X-ray beam:

$$\Psi = \mathrm{d}R/\mathrm{d}a \qquad \text{Units: J m}^{-2}$$

A13. Kerma, K, is defined at a point and is given by:

$$K = \mathrm{d}E_{er}/\mathrm{d}m \qquad \text{Units: J kg}^{-1} \text{ or Gy}$$

where dE_{er} is the sum of the initial kinetic energies of all the charged particles liberated by photons in a mass dm [I30]. For medical exposures, air kerma, K_a, is commonly used. Air kerma for photons of a single energy is given by:

$$K_a = \Psi\,(\mu_{tr}/\rho)_a \qquad \text{Units: J kg}^{-1} \text{ or Gy}$$

where $(\mu_{tr}/\rho)_a$ is the mass energy transfer coefficient for air. For medical exposures, the photon beam is usually not monoenergetic; in these circumstances the mass energy transfer coefficient must be weighted according to the energy distribution of the energy fluence.

A14. Air kerma rate, $\dot{K}_a$, is given by:

$$\dot{K}_a = \mathrm{d}K_a/\mathrm{d}t \qquad \text{Units: J kg}^{-1}\text{ s}^{-1}\text{ or Gy s}^{-1}$$

where $\mathrm{d}K_a/\mathrm{d}t$ is the increment of air kerma in a time interval $\mathrm{d}t$.

A15. The deposition of energy due to ionizing radiation in a material is quantified by the absorbed dose, D [I47]. Absorbed dose is defined as:

$$D = \mathrm{d}\bar{\varepsilon}/\mathrm{d}m \qquad \text{Units: J kg}^{-1}\text{ or Gy}$$

where $\mathrm{d}\bar{\varepsilon}$ is the mean energy imparted by the radiation to matter of mass $\mathrm{d}m$. Absorbed dose, D_t, to a material t is related to the energy fluence, Ψ, by the mass energy absorption coefficient in that material, $(\mu_{en}/\rho)_t$, under conditions of charged particle equilibrium. For photons of a single energy, D_t is given by:

$$D_t = \Psi\,(\mu_{en}/\rho)_t \qquad \text{Units: J kg}^{-1}\text{ or Gy}$$

In medical images where polychromatic X-ray photons are usual, the mean value of $(\mu_{en}/\rho)_t$, weighted according to the energy distribution of the energy fluence, is used. If bremsstrahlung is negligible,

$$(\mu_{en}/\rho)_t = (\mu_{tr}/\rho)_t \qquad \text{hence } D_t = K_t$$

A16. Absorbed dose rate, $\dot{D}$, is defined as [I30]:

$$\dot{D} = \mathrm{d}D/\mathrm{d}t \qquad \text{Units: J kg}^{-1}\text{ s}^{-1}\text{ or Gy s}^{-1}$$

Incident dose is the dose on the central axis of the X-ray beam at the point where the X-ray beam enters the patient; it does not include backscatter. Entrance surface air kerma (ESAK) is the air kerma on the central X-ray beam axis at the point where the X-ray beam enters the patient or phantom [I17, I46]; it includes the effect of backscatter (see figure A-II). ESAK is recommended by the ICRU for dosimetry in medical imaging. However, many of the publications reviewed in this report use entrance surface dose (ESD), which does not include the effect of backscatter. For consistency, ESD has been used in this report.

A17. The quantity "exposure", X, is defined by the ICRU [I47] as:

$$X = \mathrm{d}Q/\mathrm{d}m \qquad \text{Units: C kg}^{-1}$$

where $\mathrm{d}Q$ is the absolute value of the total charge of the ions of one sign produced in air when all the electrons and positrons liberated or created by photons in air of mass $\mathrm{d}m$ are completely stopped in air.

A18. For measurements of dose from medical exposures it is important that both the quantity and the measurement point must be specified. This is particularly important when specifying ESD. When making measurements close to the entrance surface of the patient or phantom, it is critical whether the quantity being measured is incident air kerma that ignores backscatter or ESAK that includes backscatter. Thus the distance from the measurement point to the entrance surface of the patient or phantom should be specified. Air kerma area product is deduced from the field size in a particular plane perpendicular to the central axis of the X-ray beam and the air kerma for the central axis in this plane (see figure A-III).

A19. The International Commission on Radiological Protection (ICRP) has recommended that average absorbed dose in a tissue or organ be the basic quantity for assessing stochastic risks [I48]. The ICRU [I2] has defined the average absorbed dose, D_T, in a specified organ or tissue T as the total energy imparted to the tissue, ε_T, divided by the mass, m_T:

$$D_t = \varepsilon_T/m_T$$

A20. The risk of a stochastic effect is dependent on the type and energy of the radiation as well as on the absorbed dose. As a consequence, the ICRP [I3] has recommended that the organ dose be weighted by a radiation weighting factor.

A21. For stochastic risk assessment, the ICRP [I3] has introduced the quantity equivalent dose, H_T. The equivalent dose in a tissue T is given by:

$$H_T = \sum_R w_R D_{T,R}$$

where $D_{T,R}$ is the average absorbed dose to tissue T from radiation R, and w_R is the radiation weighting factor ($w_R = 1$ for X-rays). For medical exposures, gauging the risks of stochastic effects is complicated because almost invariably more than one organ is irradiated. The ICRP introduced the unique quantity *effective dose equivalent* (H_e or *EDE*) in its Publication 30 [I36], and then redefined and renamed the quantity *effective dose* (E) in ICRP Publication 60 [I3], for expressing stochastic risk to radiation workers and to the whole population [I3]. To evaluate effective dose, the equivalent dose to a tissue or organ, H_T, is weighted by a dimensionless tissue weighting factor w_T. Multiplying the equivalent dose (H_T) of an organ or tissue by its assigned tissue weighting factor (w_T) gives a "weighted equivalent dose". The sum of weighted equivalent doses for a given exposure to radiation is the effective dose. Thus:

$$E = \sum_T w_T H_T$$
$$= \sum_T w_T \sum_R w_R D_{T,R}$$

A22. Table A1 summarizes the various tissue weighting factors (w_T) as prescribed by the ICRP over the years. Tissue weighting factors represent a judgement by the ICRP of the relative contribution of organs or tissues to the total detriment associated with stochastic effects [I46]. The sum of the tissue weighting factors is unity. Thus the numerical value of effective dose resulting from a non-uniform irradiation is intended to be that equivalent dose which, if received uniformly by the whole body, would result in the same total risk. (Whole-body doses are usually meaningless for assessing the risk of medical exposures, because non-uniform and localized energy deposition is averaged over the mass of the entire body.)

Figure A-III. Simple exposure arrangement for radiography illustrating some of the dosimetric and geometric quantities recommended for determination of patient dose [I17]

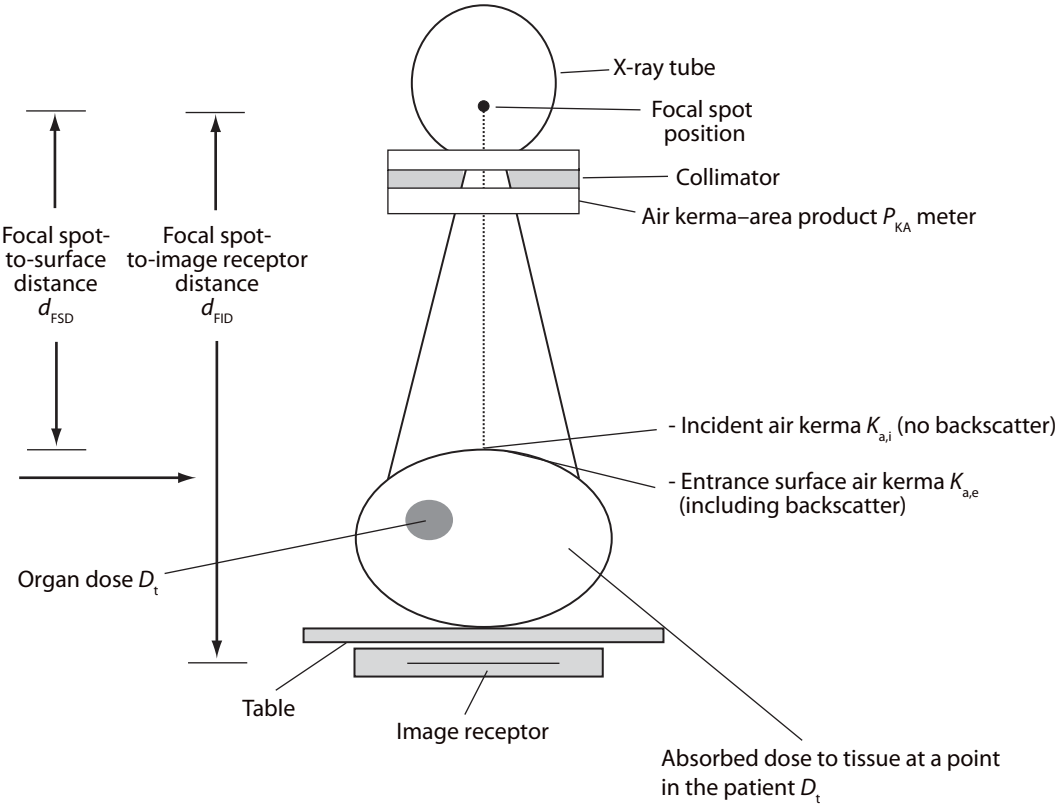


Table A1. Summary of tissue weighting factors [I3, I6, I36]

Organ	*Tissue weighting factors, w_T*		
	ICRP 30 [I36] 1979	*ICRP 60 [I3] 1991*	*ICRP 103 [I6] 2008*
Gonads	0.25	0.20	0.08
Red bone marrow	0.12	0.12	0.12
Colon		0.12	0.12
Lungs	0.12	0.12	0.12
Stomach		0.12	0.12
Bladder		0.05	0.04
Breasts	0.15	0.05	0.12
Liver		0.05	0.04
Oesophagus		0.05	0.04
Thyroid	0.03	0.05	0.04
Skin		0.01	0.01
Bone surfaces	0.03	0.01	0.01
Salivary glands			0.01
Brain			0.01
Remainder	0.30	0.05	0.12

A23. The tissue weighting factors are judged to be independent of the type and energy of radiation incident on the body. The nominal stochastic risk coefficients for effective dose to workers and members of the public are based on the notional risk of radiation-induced cancer and severe hereditary disorders averaged over these populations. Moreover, to assess the risks from exposures at low doses and dose rates, the ICRP has introduced a dose and dose-rate effectiveness factor (DDREF) of 2, which is included in the nominal stochastic risk coefficients.

A24. Both the radiation and tissue weighting factors are derived from the observed rates of expression of these effects in various populations exposed to radiation and from radiobiological studies. As more research evidence has become available, the ICRP has prescribed different values for these weighting factors [I6] (see table A1). Thus the reported effective dose equivalents are not strictly comparable with the reported values of effective dose for a particular examination, since their derivations involve different weighting factors. Another limitation of the use of effective dose in the assessment of medical exposures is that it may be difficult to perform a coherent trend analysis in the future. This may affect comparisons of the results between UNSCEAR reports.

A25. There are other issues regarding the use of effective dose to gauge the risk of potential effects from medical exposures. The most significant relates to differences in age, sex and health status of the medically exposed populations compared with the population characteristics used by the ICRP [I3, I6, I36] to derive its nominal risk coefficients [I46]. For example, the age distribution and life expectancy of patients having percutaneous transluminal coronary angioplasty (PTCA) procedures is different to that of the general population or a population of radiation workers [B25]. Consequently the ICRU suggests that effective dose should not be used for the assessment of risk from medical exposures [I46].

A26. The ICRP suggests that estimating stochastic risks for a specific population is sometimes better achieved using absorbed dose and specific data relating to the relative biological effectiveness of the radiation and risk coefficients, taking into account health status and/or life expectancy [I3, I6, I36, I46].

A27. The ICRU recommends that stochastic and deterministic risks associated with medical exposures be assessed from a detailed knowledge of organ doses, absorbed dose distribution, age and sex [I46]. Effective dose is not considered suitable for this purpose by the ICRU. However, many authors in the literature survey of reports on doses from medical examinations and in references cited in the present report have used effective dose, despite its limitations, as a surrogate quantity to assess patient exposures, in part because it is convenient to use. Effective dose has therefore been used in this report for purposes of comparison with previous publications despite its weaknesses for gauging risks as noted above.

A28. In most radiology procedures, the primary X-ray beam will directly irradiate only part of the patient. Effective dose is a risk-related quantity, which takes into account which organs are irradiated and by how much. It is a derived quantity and its evaluation provides a numerical value for the uniform whole-body exposure that would result in the same overall radiation risk as the respective partial-body exposure.

A29. In diagnostic radiology it is common practice to measure a radiation dose quantity that is then converted into organ doses and effective dose by means of conversion coefficients. These coefficients are defined as the ratio of the dose to a specified tissue or effective dose divided by the normalization quantity. Incident dose, air kerma, ESAK, ESD or kerma–area product (KAP) can be used as normalization quantities [I46].

A30. Estimating effective dose from values of organ doses is particularly difficult in radiology, because usually only part of the body is directly irradiated owing to the collimation of the X-ray beam to the area of clinical interest. In addition, often only part of an organ is included in the primary beam, the remainder being exposed to scattered radiation.

A31. Irrespective of which approach is adopted to estimate doses and risks resulting from diagnostic X-ray examinations, there are weaknesses. For example, there are considerable uncertainties on estimates or measurements of organ dose in many circumstances. There are also differences in the size and position of radiosensitive organs within the bodies of individuals and even within phantoms. Inspection of normalized organ dose data reveals some variability in this respect. There is a large difference in the organ dose depending on whether or not the organ is in the primary beam [I26, J1, K23, L21, P15, R19, R21, R22, S39, Z9, Z10, Z11, Z12, Z13]. All of these factors lead to uncertainty in organ dose estimation.

A32. These problems exist even if a well-defined part of the body is irradiated. For example, in head CT or dental radiology, the value for effective dose will be dependent upon whether the thyroid/oesophagus is assumed to be in the primary beam. Assumptions have also to be made about the amount and location of red bone marrow and about bone surfaces in the skull [L5, L6].

A33. There are three main approaches to the assessment of patient doses in diagnostic radiology: *(a)* direct dose measurements on a patient; *(b)* dose measurements in physical phantoms; and *(c)* Monte Carlo radiation transport calculations. The most common approach is the combination of an easily measurable quantity such as KAP with the respective conversion coefficients derived from Monte Carlo calculations. Direct measurement of patient dose is limited to relatively few superficial organs, such as the eye, skin, thyroid or testes.

A34. A general problem faced in clinical practice is the difficulty associated with making measurements on groups of patients whose size and build differ markedly from the

norm [F9]. In these circumstances one accepted approach is to perform the measurements on all patients undergoing this procedure during a measurement period and then take the average of the dose values as the outcome for a standard sized patient, 70 kg ± 10 kg. This will give a reasonable estimate of that dose provided that the number of patients is not too small, perhaps a minimum of ten patients [E5].

A35. An alternative approach is to apply a height and weight conversion factor to allow for deviation in size and composition from that of reference man [L4]. Correcting for patient size was first proposed by Lindskoug [L4] and has been further developed by Chapple et al. [C1]. It enables reference values to be obtained from large-scale patient dose surveys by correcting each individual dose quantity to what it would have been had the individual corresponded to the size and composition of reference man.

A36. The collective effective dose to the population is the sum, over all types of examinations, of the mean effective dose, E_e, for a specific examination type multiplied by the number of these examinations, n_e. The number of examinations may be deduced from the annual frequency (expressed as number of examimations per 1,000 population) and the estimated population for that country or health-care level.

A37. The per caput effective dose is also used to quantify exposures that result from diagnostic radiology. It is the collective effective dose averaged over the population of both exposed and non-exposed individuals. The weakness of the per caput dose approach is that medical exposures tend to be performed on a subset of the population whose members are ill.

A. Projection radiography

A38. In projection radiography, the assessment of air kerma or dose (with or without backscatter) at the entrance surface of the patient is a common approach to patient dosimetry. This may be achieved by measurement of tube radiation output in mGy/mAs at a given point (without a patient) using an ionization chamber, followed by calculation of the ESD from recorded exposure and geometric data, as well as the use of an appropriate backscatter factor. ESD or ESAK may be measured using thermoluminescent dosimetry (TLD).

A39. A common method for measuring patient doses is to use TLDs. The dosimeters are packaged in plastic sleeves that are sterilizable, and are attached to the patient's skin using surgical tape. Correction factors for the energy dependence of the dosimeters and their sensitivity are applied to the raw TLD data. A background correction is also applied.

A40. In addition to TLDs, glass dosimeters are widely used in Japan to assess medical exposures owing to their superior technical characteristics. Glass dosimeters have been used to assess ESD in intraoral radiography and for endovascular treatments [K31, N14].

A41. Physical phantoms that simulate patient anatomy can be used for dosimetry [C1, M2]. Some phantoms have a fair degree of anatomical accuracy and are a reasonably accurate representation of human anatomy, both in terms of the size and position of the organs and with respect to the attenuation properties. A problem with some anthropomorphic phantoms is that they are not tissue equivalent, which leads to inaccurate dosimetry for diagnostic radiology [S38]. The ICRU has described the requirements for physical dosimetry phantoms [I30].

A42. There are limitations regarding measurements in a physical dosimetry phantom. These relate to the need to use a large number of dosimeters to estimate the dose to physically large organs, the non-uniform distribution of radiation within the phantom and the effect of small uncertainties in the position of the radiation field. As a consequence, this method of patient dosimetry as well as the other methods (measuring ESD with TLDs) are not suitable for routine patient dose assessments.

A43. Monte Carlo computational techniques are also used to estimate organ or tissue doses. These are computer-based methods that employ computational models to simulate the physical processes associated with the interaction of an X-ray beam with the human body. There are two types of computational model: mathematical and voxel phantoms. Monte Carlo calculations are used to deduce energy deposition of X-ray photons in computational models of human anatomy [I30]. Normally, patient dose is assessed by applying suitable Monte Carlo calculated conversion coefficients to a routinely measured quantity such as KAP or ESD. Mathematical phantoms are a three-dimensional representation of a patient. The organs and the whole body are defined as geometric bodies (such as cylinders and ellipsoids). The various phantoms used have been of increasing anatomical accuracy and complexity [C21, I26, J1, K23, S39].

A44. Voxel phantoms are based on either CT or MR images of actual patients. Organ sizes and positions are deduced from the volume elements determined from the imaging data. As a consequence these phantoms are physically more accurate, the only limitation being the size of the voxels used. Various voxel phantoms have been described in references [P15, V13, Z9, Z10].

A45. As mentioned above, there are uncertainties in the estimation of organ doses. For example, relatively small differences in patient build can result in large differences in organ doses depending on whether the organs lie within or outside the primary beam [G21, S40]. In chest radiology the uncertainty in dose to the lower large intestines can be as large as 48% [I46]. Other uncertainties in Monte Carlo calculations arise from uncertainties in attenuation coefficients, the patient phantom and the model of the X-ray source.

A46. If the dose or air kerma at a specified point is known, it is possible to use normalized organ dose data to deduce organ doses for a typical patient, effective dose being calculated

from the organ doses. Normalized organ dose data are available for many examination types, including CT. They are generally based upon Monte Carlo simulations of examinations [D3, D4, D6, H13, J1, J3, R2].

A47. Numerous publications have tabulated backscatter factors for X-rays [B22, C22, G3, G4, G22, H28, H29, I23, K24, K25, M29, P16, S41], which may be required in estimating entrance skin dose. Various handbooks of dose conversion coefficients have been published [D6, H13, H30, H31, H32, J1, J3, K23, R19, R20, R21, R22, S42, S43, V13, Z9, Z11, Z12, Z13].

A48. A computer-based Monte Carlo program for calculating patient doses resulting from medical radiological examinations has been developed by Tapiovaara et al. [T17]. This computer program uses hermaphrodite phantoms for six ages ranging from newborn to adult. There is good agreement between this program and other software [H30, H32, J1] when used to calculate organ dose conversion coefficients.

B. Fluoroscopy

A49. Approaches to patient dosimetry are different for procedures that involve the use of fluoroscopy equipment [B1]. During these examinations an automatic exposure control is used to adjust the generator settings to compensate for changes in attenuation in the X-ray beam. Consequently the tube potential and tube current change continuously as the projection direction changes because of changes in attenuation through the patient. Furthermore, the anatomical area of the patient irradiated by the primary beam varies, and different tissues have different attenuation coefficients. This means that it is difficult to monitor maximum ESD directly, as the anatomical position where this occurs may not be known in advance [W4]. In addition, dosimeters placed on the patient's skin may not be in the primary beam for all projection directions used in some procedures (e.g. interventional cardiology). In these circumstances, dose–area product (DAP) or air KAP may be assessed, depending upon the calibration of the measurement instrument. These are quantities that have the advantages of being easy to measure and to correlate with risk. Additionally they are independent of the distance from the X-ray tube [A13, B21, C23, M31].

A50. In fluoroscopy, large-area transmission ionization chambers are commonly used to assess patient doses [C10]. These instruments measure KAP (Gy cm^2) or DAP (Gy cm^2) [I46], depending on the calibration of the instrument [I46, W26]. These quantities can be used to deduce the total energy imparted to the body or effective dose. It is also possible to derive other dose quantities from the KAP or DAP reading (e.g. ESD and mean organ doses) [I46, W26].

A51. Transmission ionization chambers must be calibrated in situ, because for geometry involving an undercouch X-ray tube and overcouch detector the attenuation of the patient couch must be taken into account [C24]. The uncertainty on DAP or KAP readings is approximately 6% for an overcouch X-ray tube geometry [L25] and up to 20% for an undercouch X-ray tube geometry, depending on how well the DAP meter has been calibrated [C24].

A52. The structure of transmission ionization chambers often includes high-atomic-number elements [I46], which means that their calibration is dependent on the radiation beam energy [B25, L25]. Instrument calibration is therefore particularly important for fluoroscopy equipment on which additional copper filtration is used.

A53. There is increasing concern about skin dose levels in cardiology and interventional radiology [I1]. This is because of the discovery of deterministic injuries in patients who have undergone long procedures using suboptimal equipment and performed by individuals inadequately trained in radiation protection. Assessment of maximum ESD is particularly difficult, as the projection direction and irradiated area change during interventional procedures. Various measurement techniques have been proposed, including slow films [G11], real time software [F12], DAP [V18] and calculation [M12].

A54. Organ doses resulting from fluoroscopy procedures may also be assessed using TLDs loaded into a physical phantom. Dosimeters may be placed in the phantom at positions corresponding to the organs of interest, and a typical fluoroscopy procedure is simulated on the phantom using the appropriate X-ray equipment [C1]. The TLDs are read out and the organ doses deduced. Surface doses during fluoroscopy have also been assessed using glass dosimeters [N14].

A55. Measurement of either air KAP or DAP is probably the method of choice for assessing the doses and effective dose, and hence the potential risks, resulting from interventional procedures. DAP correlates reasonably well with radiation risk by means of conversion factors [H13]. These conversion factors are examination-specific and may be deduced from Monte Carlo organ dose calculations made for simulated interventional procedures. This approach has been used in reporting many of the patient dose data in response to the surveys (sections III and IV of this appendix).

A56. At present there are no established technical approaches that provide a direct indication of maximum ESDs. However, there are four technical approaches that are being developed: *(a)* calculation of entrance dose from the generator settings, assuming a given focus–skin distance; *(b)* directly determining entrance dose from either the air KAP or the DAP and collimator settings, also assuming a given focus–skin distance; *(c)* use of special solid-state detectors placed on the skin surface of the patient; and *(d)* use of a large-area field-sensing ionization chamber, which measures DAP and entrance dose at a given focus distance simultaneously [T2]. Methods *(a)*, *(b)* and *(d)* require an assumption about backscatter radiation, whereas the detector in *(c)* will automatically include it. The use of detectors placed on the skin is a potential problem, in that with different angulations

of the X-ray tube, the dosimeter may not be placed at the position where the maximum skin dose occurs (as this may not be known beforehand). The dosimeters may also be visible on the displayed image. The other approaches inevitably yield an overestimate of maximum ESD.

A57. One design of ionization chamber incorporates an ultrasonic distance ruler at the chamber [T2]. This instrument can therefore deduce ESD. The computer linked to the chamber applies an inverse square law correction based on the measurement of the chamber-to-patient distance made using the ultrasonic ruler. Consequently this instrument design can provide an on-line display of ESD, but if different angulations of the X-ray tube are used, this method will also overestimate the maximum ESD.

C. Mammography

A58. Dosimetry in mammography is particularly difficult, as low-energy X-rays are used to image the breast [N4]. This places particular demands on the instruments used to measure breast dose, as they need to be energy independent down to 15 keV or an appropriate calibration factor should be applied.

A59. Moreover, while simple measurement of ESD on top of an appropriate phantom has been considered as a suitable quantity, this does not take into account the attenuation properties of breast tissue, which vary according to both breast composition and X-ray radiation quality. Depth-dose data are critically dependent upon breast composition and the X-ray spectrum [D3, D4, D12].

A60. It is widely acknowledged that within the breast it is the glandular tissue that is most radiosensitive, rather than fat or connective tissue. Mean glandular dose or average absorbed dose in glandular tissue has been recommended by the ICRP as the relevant dosimetric quantity for mammography [D6, I5, I46, N4]. While the quantity mean glandular dose correlates reasonably well with the associated radiation risk, it cannot be measured directly and therefore has to be inferred from other measurements.

A61. Hammerstein et al. [H9] proposed a model for a standard breast comprising 50% adipose and 50% glandular tissue. The composition of this breast was deduced from the elemental composition of a relatively small number of autopsy sections. Hammerstein et al. also proposed using a conversion factor to be applied to the measured ESD [H9].

A62. Mean glandular dose, D_G, can also be derived from incident air kerma, $K_{a,i}$, to a standard breast phantom; this has a superficial layer of either 0.4 cm of glandular tissue or 0.5 cm of adipose tissue with a varying thickness of 50:50 adipose and glandular tissue between the two superficial layers [D4]. A conversion coefficient is used to deduce D_G [I46]:

$$D_G = c_G K_{a,i} \qquad \text{(Gy)}$$

A63. Many authors have published conversion coefficients for assessing doses in mammography [A14, D4, D12, J11, R23, S43, W27, W28, Z14]. Conversion coefficients are tabulated as a function of half-value layer and compressed breast thickness [D4]. There are variations of up to approximately 15% between different conversion coefficients [I46]. In addition, breast composition also varies with compressed breast thickness [G15, K26, Y11, Y12].

A64. Since this earlier work, a number of authors have used Monte Carlo techniques to model the interaction of low-energy X-ray beams within breast tissue [D3, D4, R2].

D. CT dosimetry

A65. Air kerma–length product, P_{KL}, is recommended by the ICRU for CT dosimetry [I46]. The air kerma–length product is the integral of the air kerma free in air along a line of length parallel to the axis of rotation of the CT scanner and is given by:

$$P_{KL} = \int_L K_a(L)\, \mathrm{d}L \qquad \text{(Gy cm)}$$

This quantity may also be assessed inside a phantom, $P_{KL,CT.}$

A66. The CT air kerma index free in air, $CTDI_{air}$, has also been defined by the ICRU [I46] for dosimetry of fan beam scanners. It is the integral of the CT axial air kerma profile, $K_a(z)$, along the axis of rotation of the CT scanner for a single rotation divided by the nominal beam collimation, T.

$$CTDI_{air} = 1/T \int_{-\infty}^{+\infty} K_a(z)\, \mathrm{d}z$$

$$= P_{KL}/T \qquad \text{(Gy)}$$

A67. For a multislice CT scanner with N slices of collimation T

$$CTDI_{air} = P_{KL}/(NT) \qquad \text{(Gy)}$$

A68. For phantom measurements on CT scanners, a CT air kerma index, $C_{K,PMMA}$, can also be defined [I46].

$$C_{K,PMMA} = \frac{1}{T} \int_{-\infty}^{+\infty} K_{a,PMMA}(z)\, \mathrm{d}z$$

$$= P_{KL,PMMA}/T \qquad \text{(Gy)}$$

A69. Other specialized dosimetric techniques have been used to assess patient radiation dose in CT, as it is difficult to directly determine organ doses [S17, S18]. These techniques have been described in a series of publications [F3, I32, J2, M22, S18, S19, U3, W16]. These dosimetric approaches are based upon the use of three quantities dedicated to CT dosimetry: weighted CT dose index ($CTDI_W$), volume-weighted CT dose index ($CTDI_{vol}$) and dose–length product (DLP).

A70. Dedicated CT dosimetry phantoms are recommended by the ICRU [I30]. The phantom is placed on the CT scanner couch so that the scanner's axis of rotation coincides with the longitudinal axis of the phantom [I46]. The centre of the CT scanner slice or multiple slices is aligned to the centre of the phantom. Measurements are made at the centre and periphery of the CT dosimetry phantom, which is manufactured from polymethylmethacrylate (PMMA).

A71. CT dosimetry is based upon the use of PMMA phantoms with diameters of 16 cm and 32 cm to represent an adult head and body, respectively. Measurements are made, usually with a pencil ionization chamber of 100 mm length, at the centre of the phantom and 1 cm below the surface at four equally spaced locations.

A72. The weighted $CTDI_w$ in either phantom is given by:

$$CTDI_w = 1/3\ CTDI_{100,c} + 2/3\ CTDI_{100,p}$$

where $CTDI_{100,p}$ is the average of the four *CTDI* measurements (see above) made at the periphery of the phantom. $CTDI_{100,c}$ is the measurement made at the centre of the phantom. $CTDI_w$ is measured for a range of technique factors (i.e. tube current, tube voltage, slice collimation) typical of those used clinically.

A73. $CTDI_{100}$ (expressed in mGy) is defined as the integral over 100 mm along a line parallel to the axis of rotation *(z)* of the dose profile *D(z)* for a single rotation, at a fixed tube potential, divided by the nominal collimation of the X-ray beam used by the CT scanner [S18]:

$$CTDI_{100} = 1/NT \int_{-50mm}^{50mm} D(z)\, dz$$

where, for a single rotation, the number of CT slices is *N*, the nominal thickness of each slice is *T*, and *NT* (expressed in cm) is the total detector acquisition width and is equivalent to the nominal beam collimation [S18]. $CTDI_{100}$ is usually measured using a pencil ionization chamber of 100 mm length.

A74. $CTDI_{vol}$ (expressed in mGy) is given by the following equation:

$$CTDI_{vol} = CTDI_w/P$$

where *P* is the CT pitch factor given by:

$$P = \Delta d/NT$$

where Δd is the distance (expressed in cm) moved by the patient table in the *z* direction, between serial scans or per rotation in helical scanning [I32, S19].

A75. $CTDI_w$ may be normalized to the tube current–time product. Normalized $CTDI_w$ may also be given for a standardized nominal beam collimation of 10 mm [S19]. For specific models of CT scanner, relative conversion coefficients are provided for a range of collimation settings. In CT scanners that operate in automatic exposure control mode where the tube current is automatically modulated, average tube current or current–time product is used to take account of the effect of this modulation [K11, K12, L17].

A76. *DLP* (expressed in mGy cm) is given by the following equation:

$$DLP = CTDI_w NT_n$$

where *N* is the number of slices of collimation *T* in centimetres per rotation and *n* is the total number of rotations. Alternatively, *DLP* may be calculated using:

$$DLP = CTDI_{vol} L$$

where *L* is the scan length, determined by the outer margin of the volume irradiated in the CT scan [M22, S19].

A77. The International Electrotechnical Commission (IEC) has recognized the need for a dose display on CT scanners and has recommended that $CTDI_{vol}$ be used [I32]. On some machines, *DLP* is also displayed. These equipment displays mean that patient dosimetry in CT is made easier by using recently manufactured machines. The IEC has also considered developing a standard for the recording of dosimetry data in the DICOM header.

A78. One of the problems associated with performing patient dosimetry measurements using *CTDI* on CT scanners with a large number of rows of detectors is the required integration length. For a nominal beam width of 128 mm, an integration length of 300 mm is required if scattered radiation is to be appropriately assessed [M36]. Conversion factors have been developed to allow a standard *CTDI* phantom and a 100-mm-long ionization chamber to assess *CTDI* on multislice CT scanners [M36].

A79. Effective dose *E* may be inferred from the DLP using appropriate conversion coefficients ($(E_{DLP})_{regime}$). Conversion coefficients have been calculated for different regions of the body at a range of standard ages [J2, J3, K13, S18, S19, S20, S21]. These conversion coefficients are derived from mathematical phantoms [K13] using Monte Carlo modelling. Measured conversion coefficients have been published by Chapple et al. [C13] for paediatric patients. These conversion coefficients were deduced from a series of measurements made using anthropomorphic phantoms that simulate a range of ages from 0 to 15 years, into which TLDs had been placed.

E. Dental panoral tomography

A80. ESD is commonly measured in intraoral dental radiology.

A81. In dental panoral tomography (and also in CT), air kerma–length product is used for dosimetry. Air kerma–length product, P_{KL}, is the integral of the air kerma over a length L [I17].

$$P_{KL} = \int_L K(z)dz$$

F. Dual-energy absorptiometry

A82. In dual-energy absorptiometry it is common to use approaches to patient dosimetry that are similar to those employed for projection radiography (i.e. measurement of ESD or effective dose using anthropomorphic phantoms).

III. METHODOLOGY FOR ANALYSIS OF DOSIMETRY IN NUCLEAR MEDICINE

A. Dosimetric approaches

A83. The MIRD (medical internal radiation dose) system was developed primarily for use in estimating radiation doses received by patients from administered radiopharmaceuticals.

A84. The simplest form of the dose equation is:

$$D = N \times DF$$

where N is the number of disintegrations that occur in a source organ and DF is given by:

$$DF = \frac{k\sum_i n_i E_i \phi_i}{m}$$

where n_i = number of particles with energy E_i emitted per nuclear transition;

E_i = energy of particle emitted (MeV);

ϕ_i = fraction of energy emitted that is absorbed in the target;

m = mass of target region (kg);

k = the proportionality constant used to resolve the units (Gy kg·(MBq s MeV)$^{-1}$).

The equation for absorbed dose in the MIRD system is [T18]:

$$D_{r_k} = \sum_h \tilde{A}_h \, S(r_k \leftarrow r_h)$$

In this equation, r_k represents a target region and r_h represents a source region. The term $\tilde{A}_h$ is the number of disintegrations in a source region h and all other terms must be amalgamated into the factor S, which becomes:

$$S(r_k \leftarrow r_h) = \frac{k\sum_i n_i \, E_i \, \phi_i (r_k \leftarrow r_h)}{m_{r_k}}$$

A85. The ICRP has developed a system for calculating internal doses to radiation workers who inhale or ingest radionuclides. The technical basis is identical to that shown above, but different symbols are used for many of the quantities. Moreover, values of permissible intakes and air concentrations for many radionuclides are derived from dose limits established for workers. The details are not given here, because this report focuses on dosimetry for the purposes of nuclear medicine.

A86. However, the ICRP has also published extensive compendia of dose estimates for radiopharmaceuticals in its Publications 53 [I34] and 80 [I25]. In these documents, the available literature supporting the design of a kinetic model for each of the (over 100) radiopharmaceuticals is reviewed and a kinetic model is given, as well as dose estimates for adult and 15-, 10-, 5- and 1-year-old subjects.

A87. As discussed above, the ICRP has defined the quantity effective dose [I3] for the purpose of gauging stochastic risks from radiation exposure. The discussion above concerning the limitations of the use of effective dose for assessing the exposures due to medical radiology also apply to its use for assessing exposures due to nuclear medicine. Thus, although the quantity has limitations, it is used here as a surrogate to assess patient exposures because of its convenience.

IV. METHODOLOGY FOR ANALYSIS OF DOSIMETRY IN RADIATION THERAPY

A88. Data for analysis of trends and annual frequency of procedures in radiation therapy are derived from published literature, supplied by professional organizations and governments, and/or from the survey forms. The data are typically more difficult to obtain than those for diagnostic radiology or nuclear medicine. There are some inherent difficulties with the definition and comparison of the reported values. Some surveys report the number of patients treated, others report the number of treatment regimens (each of which may have up to 30 treatments) and still others report treatments. For this analysis it has proven valuable to supplement these estimates by considering data on the number and type of installed machines.

A89. The UNSCEAR reports have often presented the intended absorbed or equivalent organ doses for various treatments. However, these are typically of the order of tens of grays. The concept of effective dose strictly applies only to lower dose levels (in the region where only stochastic effects occur), and therefore neither effective dose nor collective effective dose may legitimately be used for the high dose levels of radiation therapy. As a result, no contribution has been calculated for radiation oncology or included in the estimates of worldwide annual per caput effective dose or collective effective dose from medical exposures.

A90. There are risks of stochastic and deterministic effects for patients who undergo radiation therapy resulting from radiation exposure of tissues outside the target radiation field. The risk of a second cancer is particularly important for those radiation oncology patients who survive treatment for malignant disease or receive radiation therapy for benign disease. However, the Committee has been unable to obtain sufficient data to adequately quantify these risks.

APPENDIX B.
LEVELS AND TRENDS OF EXPOSURE IN DIAGNOSTIC RADIOLOGY

I. SUMMARY FROM UNSCEAR 2000 REPORT [U3]

B1. The utilization of X-rays for diagnosis in medicine varied significantly between countries. Information on national practices that had been provided to the Committee by a sample of countries was extrapolated to allow a broad assessment of global practice, although inevitably there were significant uncertainties in many of the calculated results. On the basis of a global model in which countries were stratified into four levels of health care depending on the number of physicians relative to the size of population, the world annual total number of medical radiological examinations for 1991–1996 was estimated to be about 1,900 million, corresponding to an annual frequency of 330 per 1,000 world population (table B1). Estimates of these quantities for 1985–1990 were 1,600 million and 300 per 1,000 population, respectively. The global total of examinations was distributed according to the model among countries with different health-care levels as follows: 74% in countries of level I (at a mean rate of 920 per 1,000 population; 25% in countries of level II (150 per 1,000 population); and 1% in countries of health-care levels III and IV (20 per 1,000 population). In addition to such medical radiological examinations, there was also an estimated global total of about 520 million dental radiological examinations annually, corresponding to an annual frequency of 90 per 1,000 world population. The assumed distribution between health-care levels is: more than 90% occur in level I and less than 0.1% in levels III and IV. Notwithstanding the estimated mean frequencies of examination for each health-care level quoted above, there were also significant variations in the national frequencies between countries in the same health-care level.

B2. Estimated doses to the world population resulting from diagnostic medical and dental radiological examinations are summarized in table B2. For 1991–1996, the global annual collective effective dose due to medical radiological examinations was estimated to be about 2,330,000 man Sv, corresponding to an average annual per caput dose of 0.4 mSv; estimates of these quantities for 1985–1990 were 1,600,000 man Sv and 0.3 mSv, respectively. The distribution of the collective dose among the different health-care levels of the global model was as follows: 80% in countries of level I (giving a mean annual per caput dose of 1.2 mSv); 18% in countries of level II (corresponding to 0.14 mSv per caput); and 2% in countries of health-care levels III and IV (corresponding to 0.02 mSv per caput). Diagnostic dental radiological examinations were estimated to provide a further annual collective dose to the world population of about 14,000 man Sv, equating to about 0.002 mSv per caput. These values were less than the corresponding estimates for 1985–1990 of 18,000 man Sv and 0.003 mSv per caput. However, the uncertainties in all these estimates were considerable and this apparent trend may not be real. Approximately 68% of the global collective dose due to dental radiology arises from countries in health-care level I, with contributions of about 31% and less than 1% from countries in health-care level II and level III/IV, respectively.

B3. The numbers of X-ray generators (excluding dental units) available for diagnostic radiology varied considerably between countries and between the health-care levels of the global model, with estimated averages of 0.5, 0.2 and 0.02 per million population for levels I, II and III/IV, respectively (table B1). The estimated average annual number of medical radiological examinations per medical X-ray generator was lower for countries of health-care levels III and IV (1,100) than for those of level II (2,300) and level I (2,700). The estimated average values of annual collective dose per medical X-ray generator followed a similar global pattern: 1.2 man Sv per unit in health-care levels III and IV; 2.0 man Sv per unit in level II; and 3.6 man Sv per unit in level I. However, there may be an under-reporting of medical and dental equipment in some countries.

B4. The estimated global annual per caput effective dose per medical radiological examination for 1991–1996 was 1.2 mSv, which is comparable to the value of 1.0 mSv estimated for 1985–1990. However, the levels of dose to individual patients varied significantly among the different types of examination and also among countries. The contributions to collective dose provided by the different categories of examination are summarized in table B3 according to health-care level. On a global scale, population exposure due to medical radiology was dominated by the use of CT (which accounted for 34% of the annual collective dose) rather than examinations of the upper gastrointestinal (GI) tract (12%), which had been estimated to be the most important procedure for the period 1985–1990. This new pattern applied principally for countries of health-care level I, where the mean contribution from the use of CT was 41%. However, the dominant practice in health-care level II countries was chest fluoroscopy (50% of collective dose), and in countries of levels III and IV it was examination of the lower GI tract (34%), with CT use providing contributions of only 5% and 2%, respectively.

II. DOSES FOR SPECIFIC X-RAY PROCEDURES

A. Diagnostic radiography

B5. In the United Kingdom of Great Britain and Northern Ireland, the former National Radiological Protection Board (NRPB) (now the Radiation Protection Division of the Health Protection Agency) performed surveys of patient doses for common radiological examinations [S7]. A national database is used to collect data on patient doses from routine examinations according to a national protocol [N1].

B6. The NRPB has published data for common radiological examinations in terms of ESD and DAP [H34].

B7. Table B4 is a summary of patient dose data for conventional diagnostic radiological examinations (adapted from reference [H33]). It has been revised with additional patient dosimetry data. Effective dose estimates are given in the table. These have been calculated by the authors of the NRPB report, by the authors of the cited document or by applying a conversion factor used by the NRPB to the additional dosimetry data assessed in the cited patient dose survey.

B8. Various authors have compared flat panel direct digital detectors with computed radiography (CR) systems [B12, Z4]. For the same image quality, radiation doses were halved using direct digital radiography (DDR) during excretory urography [Z4]. Doses for chest imaging were 2.7 times lower for a direct digital detector compared with film–screen radiography and 1.7 times lower compared with a computed radiography system.

B9. In another study, Ludwig et al. used monkeys as surrogates for paediatric patients in order to deduce the dose saving from the introduction of flat panel detectors for lumbar spine radiography [L11]. Dose savings of 75% without loss in image quality were predicted.

B10. Vañó et al. [V8] have developed a computerized system for dose monitoring in radiology. Technical details for a series of examinations performed on a CT system were deduced from the DICOM header. A computer workstation, linked to the hospital PACS network, calculates ESD and DAP from the technical parameters. The dose monitoring system calculates a running average for ESD and DAP for the most recent ten patients. It then compares this running average with reference levels. A warning signal is given if the running average is higher than the preset reference value.

B11. There is some evidence that the use of "technique factors" suggested by manufacturers can lead to higher doses in projection radiography [P17]. Peters and Brennan [P17] were able to reduce patient doses by optimizing technique factors. Weatherburn et al. [W20] investigated patient dose levels associated with bedside chest radiography following the replacement of a film–screen system with a computed radiography system. They discovered in a randomized controlled trial that ESDs were higher in the computed radiography group.

B12. Vañó et al. [V14] performed a retrospective analysis of patient dose levels in projection radiography using a computed radiography system. They found that immediately following the introduction of computed radiography, doses increased by between 44% and 103% for lumbar spine and chest examinations when compared with the film–screen combination. Since this initial period, patient doses have been reduced. This analysis is based upon relatively large sample sizes of between 1,800 and 23,000.

B13. Radiation doses for standard radiographic examinations in an accident and emergency department were studied by an Italian group [C28]. They concluded that effective doses for direct digital radiography were typically 29% and 43% lower than for film–screen or computed radiography.

B14. Since the previous report, digital imaging has been introduced into many centres worldwide. In summary, the impact of the introduction of digital imaging on patient dose levels in diagnostic radiography is unclear.

B. Mammography

B15. Mammography has also undergone many technological changes. Originally it was performed with conventional X-ray tubes using industrial direct exposure X-ray film to have good image quality. The introduction of dedicated mammography equipment, having a specialized tube with a molybdenum target/molybdenum filtration, combined with the introduction of film–screen cassettes with a rear phosphor screen, substantially reduced radiation doses.

B16. This reduction in dose facilitated consideration of the introduction of mass screening programmes. Given the public health benefits of breast cancer screening, many countries in health-care level I have introduced mass screening programmes. As a consequence, there has been a large increase in the frequency of use of mammography.

B17. The introduction of film–screen mammography coupled with molybdenum target tubes with molybdenum filters has reduced ESD to about 0.01 Gy [G8]. However, a number of individuals have advocated increasing film optical density so that the target optical density coincides with the point on the film–screen characteristic curve with maximum slope and hence contrast amplification [F2]. This has been shown to improve cancer detection rates [Y3].

B18. Compressed breast thickness was analysed by Ogasawara and Date for Japanese women [O5]. The typical compressed breast thickness for Japanese women was under 3.8 cm, comparable to that in the Republic of Korea [O3].

Mean glandular doses are likely to be similar. Typical glandular doses were reported as 1.5 mGy in studies in Japan and in Taiwan Province of China [D8, T6]. While the compressed breast thickness reported in a German study [H22] was 5.57 cm, the mean glandular dose was comparable to that in surveys of Asian women (1.51 mGy). A similar value (1.5 mGy) was reported in a Canadian study [F10].

B19. Young [Y2] surveyed radiation doses in the United Kingdom trial of breast screening in women aged 40–48 years. Doses for 2,296 women were estimated. The average dose was 2.0 mGy for a craniocaudal film and 2.5 mGy for an oblique view. Doses in younger women were approximately 7% higher than in older women (those aged over 50 years).

B20. The Food and Drug Administration in the United States approved the first full-field digital mammography unit in 2000 [C25]. The introduction of digital mammography in the United States has been relatively slow, with digital units comprising 6.4% of the accredited mammography units [L26, M32]. Digital mammography offers potential benefits in the imaging of young women and women with dense breasts [P22, P24]. However, the high cost of digital mammography represents a limitation on its acquisition by screening programmes [T5].

B21. Doses to over 5,000 women were examined on a General Electric 2000D full-field digital mammography system in a two-year period [M6]. Dose information was obtained from the DICOM header. Mean glandular doses for both craniocaudal and mediolateral oblique projections were 1.8 mGy and 1.95 mGy, respectively. Fischmann et al. also found that doses for full-field digital mammography were comparable to those for film–screen systems [F4].

B22. Gennaro et al. [G15] calculated the ESAK for a sample of 800 craniocaudal full-field digital mammograms. Mean glandular doses were in the range 1.27–1.37 mGy and 1.37–1.49 mGy for 50% and 30% glandularity, respectively. These dose levels are lower than for film–screen mammography.

B23. The Digital Mammographic Imaging Screening Trial (DMIST) included 49,528 women from 33 participating academic and community practices in the United States and Canada (25.5 months of enrolment from 2001 to 2003). All women in the trial underwent both film–screen and digital mammography. Mean glandular doses were between 1.7 and 2.5 mGy for the digital systems and between 1.5 and 2 mGy for the film–screen mammography units [P25].

B24. As may be deduced from table B4, the variation in dose is relatively small for mammography. The small range in doses is consistent with the practice of optimized mammography subject to quality control.

C. Fluoroscopy and angiography

B25. *Direct fluoroscopy*. Most regulatory systems internationally have prohibited the use of direct or non-intensified fluoroscopy [I11]. However, direct or non-intensified fluoroscopy is still performed in some countries. The number of dose surveys on non-intensified fluoroscopy systems is somewhat limited. Dosimetry on these systems is important, not least from a historical perspective.

B26. In a study in Brazil, doses for barium enema were reported as 63 Gy cm^2, with a range of 85–316 Gy cm^2. A mean dose of 107 Gy cm^2, with a range of 25–118 Gy cm^2, was reported for hysterosalpingograms [C2]. Most of the DAP arose from direct fluoroscopy and not from radiographic images. Mean DAP for seriography was 167 Gy cm^2 (range 25–118 Gy cm^2) [C2].

B27. Marshall et al. performed a study of chest examinations using non-intensified fluoroscopy in Albania [M3]. They investigated seven direct chest fluoroscopy systems. DAP ranged from 0.34 to 3.64 Gy cm^2, with effective doses in the range 0.06–0.42 mSv. The ESD was typically 17 mGy for a PA chest fluoroscopy, which is nearly 100 times higher than the reference dose for the equivalent examination performed using a film–screen system in the United Kingdom [H34].

B28. *Image intensified fluoroscopy*. In the United Kingdom, the NRPB published data on DAP received by patients for common examinations involving fluoroscopy [H33]. This survey was undertaken in a limited number of centres and may not be representative of national practice.

B29. Average DAP for endoscopic retrograde cholangiopancreatography (ERCP) in Greece was studied by Tsalafoutas et al. [T8]. The average DAP was 13.7 Gy cm^2 for a diagnostic procedure and 41.8 Gy cm^2 for a therapeutic one.

B30. Patient doses for barium meal examinations were measured in three hospitals in Serbia and Montenegro by Ciraj et al. [C14]. A total of 74 patients were monitored in three hospitals with a minimum of 19 in each. All patients weighed within 10 kg of 70 kg. Median values of KAP varied by a factor of 3, from 7.2 to 22.1 Gy cm^2. The authors also calculated effective doses. These ranged from 1.7 to 4.8 mSv [C14], which illustrates the variation between hospitals.

B31. In summary, there are wide variations in dose levels for fluoroscopy procedures, reflecting differences in local practice, equipment and staff. The impact of digital imaging on dose levels is also unclear.

D. Interventional radiology

B32. Interventional radiology procedures have experienced a dramatic increase in frequency in recent years, principally because of the numerous significant benefits. Specifically, it is now possible to perform in a radiology department on an outpatient basis procedures that previously would have

necessitated surgical treatment in hospital. This results in considerably reduced trauma for the patient, and the hospital gains because more patients can be treated as outpatients at a lower cost. Consequently, both hospitals and the public demand access to more interventional radiology. This inevitably leads to an increase in the frequency of interventional radiology procedures.

B33. This growth in demand has implications for population doses [C11, N10, W10]. Specifically, some interventional procedures are very complicated, and often involve extended fluoroscopy times and the operation of fluoroscopy equipment in high-dose-rate mode. This leads to high patient doses. In some patients the procedures are repeated owing to restenosis.

B34. Table B5 is a summary of various sources of patient dose data for interventional radiology procedures; it has been adapted from a table produced by Hart and Wall [H33]. The original table has been revised with the inclusion of additional patient dose survey results in interventional radiology. Effective dose has been included for comparative purposes. Effective dose was calculated by either the NRPB or the original authors of the cited reports. In those instances where the authors of the survey did not deduce the effective dose, the NRPB conversion factor has been applied to the DAP to derive the value quoted.

B35. Data on various fluoroscopy and interventional procedures have been analysed by the NRPB in the United Kingdom [H33, H34]. However, as the NRPB indicates, many of the data were obtained from too small a number of hospitals or X-ray rooms to be indicative of national practice in the United Kingdom.

B36. Results from a large-scale survey of patient doses in interventional radiology have been published by Marshall et al. [M1]. Forty fluoroscopy rooms were monitored using calibrated DAP meters linked to laptop computers. Size-corrected DAP values for seven groups of interventional procedures were published. Size correction was performed using previously published approaches [C1, L4].

B37. It is clear from the data presented in these tables that considerable variations in patient dose exist between centres. Doses are dependent upon factors related to both equipment and procedure, as well as on the skill of the interventionalist and the clinical protocol adopted in a specific centre. In addition, some centres perform more complex procedures, and hence dose levels tend to be higher [P6]. The data presented in these tables should therefore be regarded as indicative of radiation dose levels received by patients.

B38. Lavoie and Rasuli have assessed ESDs for angiographic procedures in Canada [L2]. The mean ESD was 0.16 Gy for a transluminal aortogram, rising to 2.1 Gy for a liver tumour embolization. Uterine embolization had a mean ESD of 1.3 Gy [L2].

B39. The effect of the choice of puncture site on radiation doses in intrainguinal angioplasty has been studied [N9]. The mean DAP was 7.95 Gy cm^2 for a retrograde puncture site and 1.07 mGy cm^2 for antegrade punctures, which illustrates the effect of examination protocol on patient doses.

B40. Doses from cerebral embolization studies were reported by Theodorakou and Horrocks [T9]. The average DAP was 48 Gy cm^2 for a posterior–anterior plane and 58 Gy cm^2 for a lateral plane. Typical doses were 60 mGy to the patient's right eye and 24 mGy to the thyroid gland.

B41. Ropolo et al. have deduced a factor to convert DAP to effective dose (0.15 mSv/(Gy cm^2)) [R7] for abdominal and vascular interventional radiology procedures. They concluded that there was a good correlation between DAP and fluoroscopy time, as well as DAP and number of images.

B42. A large United States study has been reported by Miller et al. [M13]. The Society of Interventional Radiology was asked by the Food and Drug Administration to undertake a survey of dose levels in interventional radiology. Twenty-one interventional procedures were studied over a three-year period. Dose data from 2,142 cases were reported. Dosimetry data were obtained in terms of DAP and cumulative dose (i.e. total air kerma at the interventional reference point). Table B6 (adapted from reference [M13]) summarizes the mean, 95% confidence intervals, minimum and maximum DAP (cGy cm^2), and cumulative dose (mGy).

B43. Vetter et al. [V5] estimated the effective dose resulting from uterine artery embolization of leiomyomata. They observed that the estimated effective dose of 34 mSv for uterine artery embolization (deduced from the DAP) was twice that for an abdominal CT scan.

B44. Bor et al. [B20] performed a series of measurements in Turkey for a range of interventional radiology procedures. DAP and entrance doses were assessed for a series of 162 adult patients. Conversion factors were used to deduce effective dose. Table B7 is a summary of effective doses measured in this study compared with previously published data [C12, H1, M2, M4, M14, S26, T12, Z5]. The effective dose levels assessed in Turkey are comparable to those reported in previous surveys.

B45. Struelens studied patient doses for interventional procedures in seven different hospitals in Belgium [S25]. Average DAPs for angiography of the lower limbs, carotid arteries and cerebral embolizations were 68, 36 and 230 Gy cm^2, respectively. Average skin doses were 77, mGy and 262 mGy, respectively, for the same three procedures [S25].

B46. Bridcut et al. investigated patient doses resulting from 3-D rotational neurovascular studies [B7]. Three-dimensional rotational angiography is a recently introduced technique in which the X-ray tube and detector rotate around the patient during an interventional X-ray procedure. Reconstruction techniques are used to present the radiologist with

3-D volume data. This technique is particularly useful in the treatment of cerebral aneurysms. The average DAP was 48 Gy cm^2 for conventional digital subtraction angiography and 2 Gy cm^2 for 3-D rotational angiograph.

E. Interventional cardiology

B47. Coronary angiography is used in the diagnosis of coronary artery disease [P19]. In these examinations, contrast medium is introduced into the bloodstream using a catheter to provide images of the heart. Coronary angiography is used in the diagnosis of obstructive coronary artery disease to determine whether an angioplasty or coronary artery bypass surgery is appropriate [F6]. Coronary angiography is the most common angiographic procedure and tends to be undertaken in those aged 45 years or over. Angiography may also be performed in other areas of the body, for example to diagnose obstructive disease in the extremities or the head.

B48. A literature search has been performed to deduce typical dose levels for cardiac interventional procedures. Dose data for coronary angiograms are presented in table B8. The reviews of PTCA patient dosimetry studies are summarized in table B9 and data for stent procedures are presented in table B10. Table B11 is a review of the patient dosimetry studies for pacemaker insertions. It may be deduced from this literature review that the typical DAP was 32 Gy cm^2 for a coronary angiogram, 44 Gy cm^2 for a PTCA, 46 Gy cm^2 for a stent procedure and 18 Gy cm^2 for a pacemaker insertion.

B49. Conversion factors may be used to deduce the effective dose from DAP or KAP readings and have been published by various authors for cardiac interventional procedures [B14, M14, M35, R19]. The average conversion factor is 0.17 mSv/(Gy cm^2).

B50. Larrazet et al. studied the effect of various factors on DAP during percutaneous coronary angioplasty [L14]. DAP was 175 Gy cm^2 for a radial technique compared with 138 Gy cm^2 for a femoral technique. Predilation, direct stenting significantly reduced the DAP.

B51. In common with other interventional procedures, dose levels in interventional cardiology are influenced by staff and the clinical protocol used, as well as the type of equipment.

F. Computed tomography

B52. A review of the published literature has been undertaken. Data on DLP and effective dose for head, body, spine, angiography and other types of CT scans on adults are given in tables B12, B13, B14, B15 and B16, respectively. Table B17 summarizes patient doses for CT scanning in paediatric patients.

B53. The annual frequency of CT examinations has exhibited a dramatic increase since CT's introduction [H3]. In the United Kingdom in 1990, 20% of the annual collective dose due to all radiological examinations resulted from CT examinations, even though there were a relatively small number of scanners [S1, S2]. Recent publications have confirmed the upward trend in the contribution of CT to the total collective dose from medical examinations [N16, N17]. In 1998 Shrimpton and Edyvean estimated the contribution to have risen to 40% [S17]. This had increased to 50% in 2003 [H24]. The number of CT scanners had almost doubled in the six years since the original survey, [S3]. However, the number of CT scanners per caput is over 50% higher in the European Union as a whole and over 400% higher in the United States than in the United Kingdom [B3]. The collective effective dose to the citizens of countries that have a higher number of CT scanners per caput is likely to be even higher than that in the United Kingdom.

B54. The NRPB performed a survey of CT practice in the United Kingdom between 2002 and 2003, surveying 126 of the estimated 471 CT scanners in the country. In the period since the previous survey in 1991, all the CT scanners had been replaced and were capable of scanning in the helical mode. Over a third of the CT scanners surveyed were capable of multislice scanning (2–16 slices). A questionnaire was sent to each centre to obtain information on scanning protocols and sequences. Typical doses from CT scanning in the United Kingdom are summarized in tables B12 and B13 [S19].

B55. Huda and Mergo [H5] have investigated the impact of the introduction of multislice or helical CT. Table B14 provides a comparison of effective doses for three regions of the body. It is interesting to compare doses with time from these various surveys of CT practice [H4, J2, S1]. The European data for head CT scanning are comparable to the reported mean effective doses, being in the range 1.6–1.8 mSv. This is particularly remarkable, given that the first paper [S1] preceded the last by nearly a decade [H4]. The introduction of spiral/axial multislice CT has resulted in an increase in effective dose by a factor of over 2.5 for chest CT and of over 2 for abdomen CT (table B14).

B56. A survey of patient doses from CT examinations has been undertaken in Hungary [P1]. The authors estimated an annual total of 623,000 CT examinations in 1999 on 54 operational machines. This equates to 62.3 examinations per 1,000 individuals.

B57. A comparison of the performance of CT scanners in Nordic countries has been undertaken by Torp et al. [T1]. Results for brain, chest and lumbar spine scans are given in tables B15, B16 and B17, respectively. Effective dose was calculated using the method developed by the NRPB [J3].

B58. In two editorials in the American Journal of Roentgenology, Rogers [R13, R14] raised awareness of the need for dose reduction in CT, especially the need to adjust CT exposure factors for paediatric patients [D7, P11]. As a consequence, optimization of CT examinations has become an important topic with a high level of public interest [M26, P12, R15].

B59. In the United States, a nationwide survey of patient doses from CT was undertaken during 2000–2001 as part of the series of NEXT surveys of X-ray trends [S24]. Information on patient workload and CT scanning technique factors was obtained from 263 facilities in 39 states. X-ray output measurements were performed both free in air and in a standard head phantom manufactured from PMMA. From these measurements, CTDI and mean effective dose were deduced.

B60. The NEXT survey estimated that there were 7,800 CT facilities in the United States. The estimated number of CT examinations and procedures (both adult and paediatric) was 58,000,000. The survey revealed that 30% of CT scanners performed axial scanning only. Helical scanners comprised 69% of CT scanners. Of the machines surveyed, 29% were capable of multiple slices. Just 1% of the machines were electron beam CT scanners [S24].

B61. The estimated effective doses for CT scanning in the United States are summarized in table B18.

B62. A nationwide survey of CT examinations was undertaken in 2000 in Japan [N13]. This survey indicated that there were 87.8 CT scanners per million population. The distribution of examinations according to age was 100,000 in children aged up to 14 years, and 3.54 million for persons aged 15 years and older (i.e. 290 examinations per 1,000 population). The most common examination was head scanning, which comprised 80% of the examinations in children and 40% of those in adults. A breakdown of the annual number of CT examinations in Japan is given in table B19.

B63. The effective dose per examination assessed in this Japanese survey was 2.4, 9.1, 12.9 and 10.5 mSv for head, chest, abdomen and pelvis scans, respectively. The trend in the number of CT scanners, examination frequencies, number of CT scans, collective effective dose and effective dose per person in Japan is summarized in table B20 [N13].

B64. A survey of radiation exposure for multislice CT was conducted by Brix et al. [B18] in Germany in 2001. The facilities for each of the 207 multislice CT scanners in Germany were contacted, of which 113 replied. The response rate was slightly higher for public hospitals (60%) than for private practice (43%). All facilities were asked to provide data on scan parameters and annual frequency for 14 standard examinations. Standard CT dosimetry quantities were deduced using formulae that had been experimentally verified. The results of the survey for multislice CT scanners are summarized in table B21. The results of the previous survey are summarized in table B22 [G13] for comparison. (An examination may comprise more than one series.)

B65. Comparison of the results of the two surveys indicated that the scanner annual workload is considerably higher for multislice CT (5,500) than for single-slice CT (3,500), a difference of 63%. Average effective dose for CT examinations was 7.4 mSv for single-slice, 5.5 mSv for dual-slice and 8.1 mSv for quad-slice CT scanners. The increase in dose for quad-slice CT scanners was not as great as reported by Giacomuzzi et al. [G14], probably owing to the optimization of procedures. The authors predicted that improved clinical efficacy and new applications will lead to rising examination frequencies [G14].

B66. Zammit-Maempel et al. studied the radiation dose to the lens of the eye during scanning of the paranasal sinuses [Z1]. TLDs were attached to the patient to measure eye and thyroid doses in the axial and coronal planes on a Siemens CT scanner using 140 kV, 100 mAs and 1 mm collimation. Eye doses of 35.1 mGy for the coronal plane and 24.5 mGy for the axial plane were measured. Thyroid doses were 2.9 mGy and 1.4 mGy, respectively. The use of a low-dose scanning technique resulted in an eye dose of 9.2 mGy and a thyroid dose of 0.4 mGy.

B67. The use of CT in the diagnosis of renal colic has been investigated [K4]. The effective mean dose from low-dose helical scanning was 1.35 mSv for female patients. Low-dose helical CT was considered to be the method of choice.

B68. Multidetector CT (MDCT) has enabled angiographic examinations to be performed on CT scanners. As a consequence, MDCT is being explored as an alternative to conventional angiographic examinations. In another study [K5], doses from conventional and CT angiography of the renal arteries were compared. For conventional renal angiography, effective dose was deduced from the DAP. Two dose reduction strategies in conventional renal angiography were compared with the default factory settings. Effective dose was reduced from 22 mSv to 11 mSv if half the number of digital subtraction angiography images were taken and to 9.1 mSv if the beam filtration was increased. The effective dose from CT angiography was 5.2 mSv, lower than any of the low-dose conventional angiography procedures.

B69. Nickoloff and Alderson measured radiation doses from a 64-slice cardiac CT scanner [N25]. Effective doses for 64-slice CT angiography were in the range 8–25 mSv, compared with 3–6 mSv for a routine chest CT and 14–26 mSv for diagnostic coronary angiography with fluoroscopy [N25]. The main cause for concern was the high equivalent dose to the breast of 30–100 mSv.

B70. Radiation doses from CT and cone beam CT in dentistry were studied by Ludlow et al. [L12]. As might be expected, the effective dose varied depending upon whether the salivary gland was included in the calculation. The effective dose for a cone beam CT mandibular/maxilliary scan was 36 μSv, or 78 μSv if the salivary glands were included in the calculation. For a maxillary scan only, the effective doses were 19 and 42 μSv, respectively. For a mandibular scan, the respective effective doses were 35 and 75 μSv. These doses are less than the effective dose for conventional CT.

B71. Mori et al. compared patient doses for 256-slice CT with those for 16-slice CT [M24]. A prototype 256-slice CT scanner was developed to take dynamic 3-D images of moving organs such as the heart. The estimated effective doses for chest, abdomen and pelvis examinations were 2.2, 2.6 and 3.3 mSv, respectively. Dose profile integrals were between 11% and 47% lower for 256-slice CT than for 16-slice CT [M24].

B72. Van der Molen et al. [V9] have investigated the reductions in effective dose achievable on 16-slice CT scanners compared with 4-slice CT, once the scanning protocol was optimized. Dose reduction was greatest for abdomen and pulmonary CT angiography, the magnitude of the dose reduction depending on the examination. Effective doses for optimized 16-slice CT ranged from 1.9 mSv for head scans to 7.2 mSv for abdomen scans.

B73. Mettler et al. [M41] have reviewed the published literature on radiation doses from CT scanning. These data are presented in table B23.

B74. Effective doses for CT colonography are in the range 1–18 mSv, with a typical effective dose of 8 mSv [I19].

B75. In summary, patient dose levels for CT examinations are higher than for many other types of diagnostic medical exposure. The introduction of multislice CT scanning has shortened examination times and has enabled more examinations to be performed on a single scanner. The increase in workload associated with multislice CT scanning will impact on population doses.

G. Dental radiology

B76. Dental radiological examinations are among the most common medical exposures [H12]. There are two basic techniques: intraoral and dental panoral tomography [G10, H2]. The former involves placing a film inside the mouth and the use of a dedicated dental X-ray tube. In dental panoral tomography both the tube and the film move around the head.

B77. Geist and Katz [G9] surveyed 65 dental schools in the United States and Canada. They found that 86% use E-speed film. Direct digital imaging is used by just over half (58%) for intraoral radiography and by 11% for extraoral. The use of dose reduction techniques was quite high, with 88% using long focus–skin distances, 47% rectangular collimation and 100% rare-earth film–screen systems for intraoral radiography.

B78. The use of digital imaging for intraoral radiography by general dental practitioners in the Netherlands was investigated [B10]. The study indicated that centres using digital imaging devices took more radiographs. Centres using photostimulable storage phosphor plates took an average of 42.8 radiographs weekly, compared with 32.5 for film–screen users and 48.4 for centres with solid-state detectors. The study concluded that, despite the increase in the frequency of use, the introduction of digital imaging would reduce effective doses by about 25%, as digital intraoral radiography requires 50–80% lower doses.

B79. A Chinese study looked at eye doses in full-mouth dental radiography [Z2]. The dose to the lens of the eye was 250 μGy. The dose to the thyroid was 125 μGy, to the pituitary 110 μGy, to the parotid 150 μGy and to the breast 12 μGy.

B80. In panoral tomography, the X-ray tube and film rotate around the patient's head to obtain an image of the entire dentition and jawbones. X-ray manufacturers have introduced panoramic equipment that allows the operator to select the part of the jaw or dentition to be imaged. Effective doses for one machine have been reported as being in the range 6–19 μSv, depending upon which anatomical programme has been selected [L6].

B81. Doses for dental implant imaging were assessed by Lecomber et al. [L10]. Conventional radiography, cephalometry, linear cross-sectional tomography and CT were compared. Doses were measured using thermoluminescent dosimeters in an anthropomorphic phantom. Salivary gland doses were 0.004 mSv for dental panoral tomography and 0.002 mSv for both cephalometric imaging and cross-sectional tomography. CT doses were substantially higher, at 0.31 mSv.

B82. Doses in dental radiology have recently been assessed by Helmrot and Alm Carlsson [H2]. ESAK and DAP for four common intraoral dental examinations in Sweden varied from 1 mGy ESAK for an incisor to 2.5 mGy ESAK for a molar/upper jaw examination. DAP values for panoral tomography were in the range 0.06–0.1 Gy cm^2 for adult examinations and 0.03–0.04 Gy cm^2 for paediatric examinations.

B83. Manufacturers have developed dedicated CT scanners for dental radiology. These devices use cone beams and software specific to maxillodental CT scanning [S12]. They are used for the diagnosis of a wide variety of maxillofacial diseases in addition to dental implant imaging [H38].

B84. Digital volume tomography (DVT) is a recently introduced technique in dental radiology [C5]. It is intended to be a low-dose alternative to CT and panoramic tomography. A study has been performed by Cohnen et al. [C5] to assess DVT. Two types of DVT were compared with CT scanning. Radiation doses were measured using TLDs placed in an Alderson–Rando phantom. The results are given in table B24. DVT acquires an image optimized for the display of bony structures and other high-contrast objects, at the expense of soft-tissue imaging. It operates at a lower dose than either dental CT or sinus CT.

B85. Doyle et al. [D13] assessed dose–width product (DWP) and DAP for 20 panoral tomography dental units and compared their findings with a series of earlier studies [I33, N15, O6, P13, T13, W17] (table B25).

B86. Iwai et al. [I24] have estimated the effective dose for dental cone beam X-ray CT examinations. Effective doses were 7.4 μSv for the maxillary incisor, 6.3 μSv for the maxillary first molar, 12 μSv for the mandibular first molar, 9 μSv for the temporomandibular joint (TMJ) and 14 μSv for the middle ear when assessed using 3-dimensional X-ray multi-image micro-CT. For an ortho-CT machine the effective doses for the mandible, maxilla and TMJ were 13, 22 and 23 μSv, respectively.

B87. Dose levels from dental radiology are, in the main, low compared with other types of diagnostic medical exposure. The impact of dental CT will have to be closely monitored.

H. Bone mineral densitometry and dual-energy X-ray absorptiometry

B88. Bone mineral densitometry is a rapidly growing specialized radiological technique. It is used to deduce bone mass and bone density from X-ray or gamma ray transmission measurements.

B89. Low bone density is associated with a higher fracture risk. Though it affects a small but significant fraction of the male population, low bone mass is a particular problem in post-menopausal women. As a consequence, most bone mineral densitometry scans are performed on post-menopausal women.

B90. Effective doses for pencil beam and for array modes of operation (dual-energy X-ray absorptiometry (DEXA) examinations) are given in table B26 [N5]. There is a clear trend towards more frequent and shorter examinations [L3].

B91. The effective dose for an anterior–posterior (AP) lumbar spine scan was 59 μSv on a Lunar Expert-XL fan beam DEXA scanner [S13]. The effective dose was 56 μSv for an AP femoral neck scan, 71 μSv for lateral spine morphometry and 75 μSv for a whole-body scan.

B92. Effective doses to children from DEXA have been assessed by Njeh et al. [N8]. Patient doses were assessed using lithium borate TLDs in anthropomorphic child phantoms. Effective doses for posterior–anterior (PA) spine procedures were 0.28 μSv for a 5-year-old and 0.20 μSv for a 10-year-old. The effective dose for a whole-body scan was 0.03 μSv to a 5-year-old and 0.02 μSv for a 10-year-old.

B93. In summary, dose levels to patients having DEXA examinations are small compared with those for most other diagnostic medical examinations.

III. DOSES FOR SPECIFIC POPULATIONS

A. Paediatric patients

B94. Data on paediatric doses are very difficult to analyse, because the height and weight of children is very dependent on age [H11]. In addition, it is inappropriate to use effective dose to quantify patient dose levels for paediatric and neonatal radiology. In order to compare centres, an agreement was reached within the European Union to collect data for five standard ages, i.e. for newborn, 1-year-old, 5-year-old, 10-year-old and 15-year-old children.

B95. Some data are available in the United Kingdom for paediatric patients [H34]. These data are summarized in table B27 for five common radiographic examinations in terms of ESD, and in table B28 for three fluoroscopic examinations (DAP). As these data were obtained from a small sample of centres, these values may not be representative of practice nationally.

B96. Compagnone et al. [C15] assessed ESDs and deduced effective doses for various paediatric examinations. Effective doses were 0.005 mSv for chest PA and 0.10 mSv for abdomen AP examinations.

B97. Patient doses from paediatric radiology have been assessed in a large Spanish hospital [V10]. Dose values were obtained for four common projection radiography examinations performed using a photostimulable storage phosphor computed radiography system. The DICOM header was interrogated to provide information on the examination, patient and technique factors. ESD was deduced using knowledge of the measured tube output. Over 3,500 patient dose values were obtained. A summary of the results of this survey is given in table B29.

B98. A multicentre study of patient doses from CT scanning in children has been undertaken in Belgium [P7]. Values of effective dose were in the ranges 0.4–2.3 mSv, 1.1–6.6 mSv and 2.3–19.9 mSv for head, thorax and abdomen scans, respectively.

B99. ESDs in micturating cystourethrography (MCU) examinations in children have been monitored by Fotakis et al. [F11]. Despite its limitations noted earlier, effective dose was evaluated for comparative purposes using the factors published by the ICRP [I3]. The mean effective dose was 0.86 mSv for male patients and 0.76 mSv for female patients.

B100. Skin doses during paediatric cardiac catheterization examinations have been assessed [L13]. The average ESD to infants and children was 870 mGy.

B101. The effective dose during the percutaneous treatment of varicocele in adolescents was 18 mSv [P9]. This compared with the doses from abdominal X-rays (1.31 mSv) and for urography (4.6 mSv).

B102. In another study, Ono et al. [O9] investigated the annual frequency and type of X-ray examinations performed on neonates as a function of birthweight in a neonatal intensive care unit. The radiology records of over 2,400 neonates were investigated. On average, neonates weighing less than 720 g birth weight had 26 films. While the number of ESDs per neonate was dependent on birth weight, the maximum dose was not. For chest examinations the dose varied between 0.02 and 0.17 mGy, depending on birth weight.

B103. Kiljunen et al. have collected a series of patient doses for thorax examinations on paediatric patients in six hospitals in Finland in the years 1994–2001 and in two hospitals in 2004 [K31]. Patient doses correlated exponentially with projection thickness. As a consequence, diagnostic reference levels were specified in terms of both ESD and DAP as a function of patient projection thickness rather than by age band.

B104. Onnasch et al. [O10] evaluated DAP for three different types of angiocardiography system over a period of eight years. Data on 2,859 patients were acquired. Mean effective doses for seven paediatric cardiac interventions are given in table B30 [O10]. Onnasch et al. also investigated the total effective dose for patients with different types of congenital heart disease who underwent multiple examinations over 12 years [O10]. On average a paediatric patient would have four examinations. The mean total effective dose for a child with congenital heart disease who had multiple examinations was 19 mSv (range 0.64–184 mSv).

B. Foetal dosimetry

B105. The risks to the foetus of radiation exposure are well established. Consequently, most X-ray and nuclear medicine departments have mechanisms for avoiding unintended irradiation of the foetus. There are relatively few studies of radiation doses to the foetus, reflecting the effectiveness of these mechanisms.

B106. A retrospective study performed in the Islamic Republic of Iran [A1] involved over 1,300 patients referred to a medical physicist for dose estimation. The average age of the foetus was 31 days and the mean foetal absorbed dose was 6–8 mGy. Most examinations were performed for non-malignant gastrointestinal or urological problems.

B107. Osei and Faulkner studied the foetal dose received by a series of 50 pregnant women in the north of England [O1]. These women had asked their physicians about the risks of ionizing radiation to the foetus. Virtually all the dose estimations were performed retrospectively, as most of the women were unaware that they were pregnant at the time of the examination. Table B31 is a summary of the estimated mean of foetal absorbed dose per examination for this group of women. Also given in table B31 are reported typical means from the published literature. Most of the foetal doses in this table are based upon a United Kingdom survey made in the mid 1980s and may not be representative of current practice.

B108. Most of the foetuses (68%) had a gestational age of less than 8 weeks; a further 26% had a gestational age between 8 and 25 weeks. Five of the foetuses (10%) received a total dose of over 10 mGy. The majority (58%) received doses of below 5 mGy. Estimated doses to the women tended to be higher than would be deduced from average doses for the examination. In addition, the women tended to be older than the norm.

B109. Wagner et al. [W6] have produced a guide to the medical management of pregnant patients and diagnostic irradiation. In their book, a series of case studies are presented. While the majority were diagnostic radiological examinations, some nuclear medicine procedures were performed. Most doses were in the range 20–40 mGy. These doses are higher than those reported by Osei and Faulkner [O1], mainly because many patients in the series reported by Wagner et al. had CT scans [W6].

B110. The estimated foetal dose while patients underwent ERCP procedures was 3.1 mSv in a study in the United States [T7]. Foetal doses were reviewed in a study of the use of double pigtail stents in the treatment of hydronephrosis [H20]. The mean uterus/foetal dose was 0.40 mGy (range 0.03–0.79 mGy).

B111. CT can be used for the detection of pulmonary embolism in pregnant patients [R8]. Doses from helical CT were calculated [W12]. Foetal doses varied with gestational age, being in the range 3.3–20.2 mGy in the first trimester and rising to 51.3–130.8 mGy in the third. Mean foetal doses with helical CT were reported as being lower than with the scintigraphy technique.

B112. TLDs were used to estimate foetal dose from CT in late pregnancy using anthropomorphic phantoms [D10]. The measured foetal dose for abdomen examinations was in the range 30.0–43.6 mGy in the second trimester and 29.1–42 mGy in the third trimester.

B113. Transjugular intrahepatic portosystemic shunts (TIPS) are used in the treatment of recurrent bleeding in liver cirrhosis [W13]. The foetal dose was estimated as below 10 mSv in a German study [W13].

IV. TRENDS

A. Trends in practice

B114. Most radiological examinations are performed on a subgroup of the population who are ill. Patients who are ill tend to be either young or older than the average age of the general population. It is for this reason that the data collection forms ask for the age distribution for the examinations performed. For example, the average age of cancer patients is generally higher than the average age of the general population. Some of these patients are likely to have multiple CT examinations to diagnose and stage their disease. They are also likely to be subject to multiple follow-up CT examinations to check that there is no recurrence of the disease. Consequently their total dose will likely be somewhat higher than the average. In addition to this effect, there is a trend for the increasing use of CT examinations for the early diagnosis of diseases and the screening of asymptomatic individuals (for lung cancer, colorectal cancer, whole-body screening, and calcium scoring).

B115. The introduction of MRI has had an impact on the frequency of diagnostic radiological examinations. For example, in the period 1992–2001 in Canada, the number of MRI spine scans increased by 450%, whereas in the same period the number of CT spine scans increased by 51% and the number of radiographic examinations of the lumbar spine decreased by 11% [C25].

B116. In the main, radiology is performed more frequently on elderly individuals than on the general population. An exception is dental radiology, which tends to be performed more on younger individuals, whose teeth and dentition are still developing. With improvements in dental hygiene, however, individuals are likely to retain their teeth for longer; thus the age distribution of individuals having dental radiology will change with time.

B117. The past four decades have witnessed immense technological advances in radiology. The introduction of image intensification has led to the development of diagnostic procedures such as angiography and interventional radiology. The improvement in image quality associated with the introduction of image intensification and subsequent technical developments such as image digitization have made possible the expanded use of fluoroscopic examinations. Angiographic examinations have become more common and in some instances more complicated.

B118. Digital imaging has had the greatest impact on the conduct of barium studies. Almost overnight, conventional fluoroscopy equipment ceased to represent the state of the art. Digital imaging meant that barium studies could be performed in a shorter period of time, and spot (still) digital images were instantaneously available. This meant that fewer technologists were required to assist the radiologist performing the examination. Also, more examinations could be performed in a given period, inevitably leading to more efficient use of equipment and more examinations being performed. In addition, the introduction of colonoscopy will have an impact on the number of barium studies conducted.

B119. Digital imaging has also proved useful to interventional radiologists and cardiologists. The availability of last image hold or road mapping facilities has made it much easier for the interventionalist to orientate the displayed image with patient anatomy. The planning of procedures has become easier.

B120. The acquisition of images in a digital format permits the use of computer techniques to enhance the images. Thus it is easier to see guidewires, catheters, stents, etc. This facilitates the introduction of more complex interventional procedures. Almost all interventional radiology is performed with digital imaging equipment where it is available, even in countries with health-care levels II to IV.

B121. While digital radiography was originally introduced two decades ago, it is only recently that these systems have started to become widely available in health-care level I countries. With these systems, dose becomes a user-selectable variable. It is therefore important to select a dose sufficient to obtain the image quality required for the clinical objective of the examinations.

B122. Dotter and Judkins described the first percutaneous treatment of arteriosclerotic vascular obliterations in 1964 [D1]. Since then the range of interventional procedures has dramatically increased. This has been accompanied by significant developments in equipment, such as the introduction of digital imaging and more recently direct digital imaging.

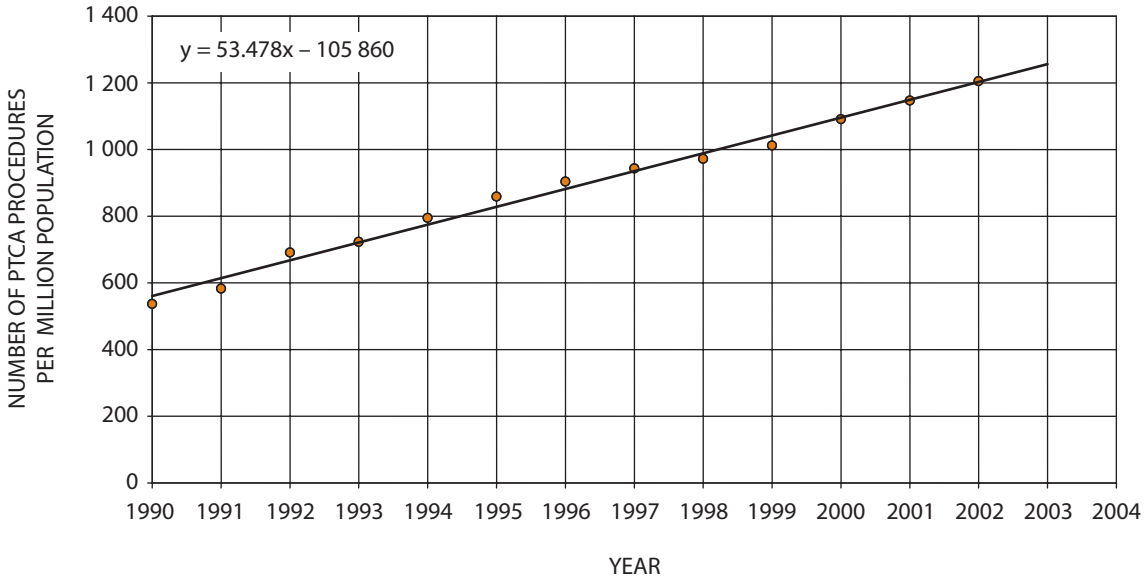
B123. In recent years there has been a dramatic increase in the frequency of both diagnostic cardiological examinations (coronary angiograms) and X-ray-guided coronary treatment procedures, such as PTCA and the insertion of coronary stents and pacemakers. This increase has been motivated by the many benefits of X-ray-guided cardiological procedures. These cardiological procedures, which would previously have required open-heart surgery, can be undertaken on an outpatient basis. The patient benefits from a reduction of the trauma associated with the procedure.

B124. The aspirations of interventionalists to perform more complex procedures have been matched by the desire of manufacturers to design and market systems that meet these perceived requirements [W1]. Initially, interventionalists used equipment intended for diagnostic studies such as barium studies or to use a mobile image intensifier system in a sterile theatre. However, manufacturers nowadays sell equipment with highly differentiated designs. Thus interventional equipment designed specifically for neuroradiology or cardiology has been developed. The design and operation are

thus optimized for a narrow group of procedures. For example, the imaging requirements for embolization in interventional neuroradiology is different from the requirements for barium studies.

B125. The frequency of interventional cardiological procedures has been investigated by Faulkner and Werduch [F19]. On its website [H27] the British Heart Foundation publishes statistical information on the rates of coronary angiograms, PTCA and stents per million population for various European countries for the period 1990–2003. The data are incomplete, the most complete data being for PTCA procedures. It is possible to deduce the frequency of PTCA procedures in 2006 by separately performing a regression analysis on each country's data and then extrapolating to 2006 using the average annual rate of increase. For illustration purposes, the data for the Netherlands are shown in figure B-I. Also shown is the linear regression line fitted to these data. For each country the fitting of a regression line to the PTCA annual frequency data was reasonably good, the worst fit being for Greece with a p-value of 0.047 and an R-value of 0.76. The Finnish data fitted best to a regression analysis for data after 1999, when there appears to be a change in the rate of increase in the annual number of procedures. This general approach was used to analyse the coronary angiography and stent data for those countries where the data were available.

Figure B-I. Frequency of PTCA procedures in the Netherlands for the period 1990–2003
A regression line has been fitted to the data ($p < 0.001$; $R = 0.995$)



B126. For some countries, frequency data on the number of coronary angiograms and stents per million population were not available on the website. In order to estimate the number of coronary angiograms and stents, the ratio of the annual frequency of coronary angiograms to PTCAs and the ratio of the annual frequency of stents to PTCAs were calculated for each country using the data available. The average ratio of coronary angiograms to PTCAs was 3.6, and the average ratio of stents to PTCAs was 0.72. These ratios were used to estimate the number of coronary angiogram and stent procedures for cases where data were not available.

B127. There were limited data available for the number of pacemaker insertions performed for each country where data were available. The ratio of pacemaker insertions to PTCAs for the country in 2000 was used to deduce the number of pacemaker insertions in 2006 from the estimated number of PTCA procedures. If this ratio was not available for a given country, the average ratio across those countries where data were available was used.

B128. Table B32 gives the estimated number of procedures per million population and the total number of procedures in 2006 for various European countries. In the table, data estimated from the annual frequency of PTCAs using the ratio method are given in italics. Data on the population for European countries were obtained from the Central Intelligence Agency website [C26]. The total number of procedures for each country was deduced by multiplying the annual frequency (expressed as number per million population) by the size of the country's population (in millions). For Bulgaria and Ireland, limited data were available on the British Heart Foundation website, which gave only the number of PTCA procedures for years around 2000 and no data for other years. The average annual rate of increase across Europe was used to deduce the number of PTCA procedures in 2006. The ratio method was then used to deduce the estimated number of coronary angiograms per million population and of stents per million population for Bulgaria and Ireland.

B129. It may be deduced from table B32 that in the 29 European countries studied, the estimated average number of coronary angiogram is 5,045 (range 670–11,646) per million population (population-weighted average). The average number of PTCA procedures in Europe is 1,510 (range 186

to 3,704) per million population. The corresponding figures for stent procedures are 836 (range 134 to 2,667) per million and 926 (range 53–2,481) per million for pacemaker insertions. On average there are 3.6 coronary angiogram examinations for every stent procedure. This ratio varies between countries and will reflect the local practice regarding the classification of combined coronary angiogram and PTCA procedures and stent procedures. Data for recent years will be affected by the rate of introduction of drug-eluting stents, as these have an impact on the restenosis rate.

B130. López-Palop et al. [L18] have surveyed interventional cardiology practice in Spain in 2003. Data were acquired from 112 centres (104 adult, 8 paediatric), representing nearly all centres in Spain. Over 40,000 percutaneous coronary interventions were performed; an increase of 14.4% in a year; 92.5% of interventions involved the use of stents. The number of mitral valvuloplasty procedures increased by 23% in 2003 to 433.

B131. The annual frequency of screening mammography varies between countries. For example, the Canadian Cancer Society recommends that women aged 50 years to 69 years have a screening mammogram on a biennial basis [C25], whereas in the United Kingdom's National Health Service Breast Screening Programme, women aged 50 to 69 are offered mammography on a triennial basis [L27]. The number of screening mammography examinations performed in a specific country depends on the health-care level, the eligible population, and the screening interval and uptake.

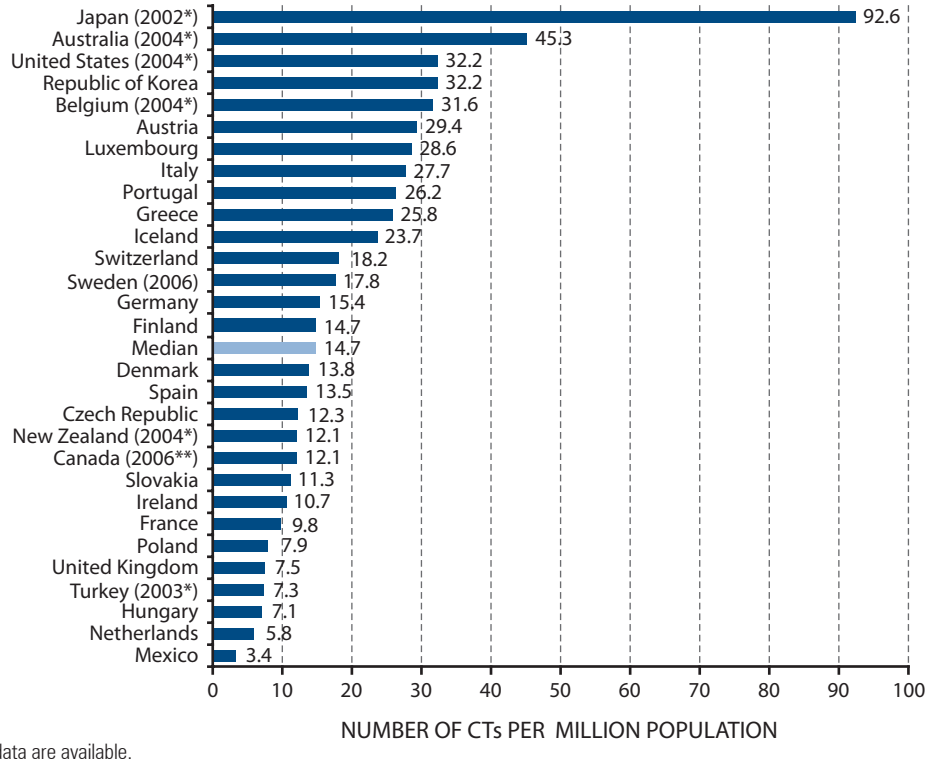
B132. CT scanners were introduced into clinical use in 1972 by EMI in the United Kingdom [H3]. The clinical benefits of these procedures were realized immediately. The use of computers in medical imaging has subsequently revolutionized radiology, with the introduction of digital radiography and the digitization of images produced by image intensifier television systems.

B133. In Canada, the number of CT scanners increased by 82% in the period 1990–2005 [C25]. There was a variation of almost a factor of 4 in the number of CT scanners per million population in different states, yet the variation in the number of angiography suites per million population was less than a factor of 3, and the variation in the number of catheterization laboratories per caput was only a factor of 2. Typically there were 2.1 CT scanners for every MRI machine.

B134. The Organisation for Economic Co-operation and Development (OECD) has reported wider variations in the number of items of medical imaging equipment. Figure B-II summarizes the number of CT scanners per million population. Japan has the largest number of CT scanners per population, approximately 60 times more than Mexico. The median number of CT scanners in the countries studied in the OECD survey [C25] was 14 per million population. However, the data may not be representative of the number of CT scanners in Germany.

Figure B-II. Number of CT scanners per million population in OECD countries [C25]

Sources: OECD Health Data 2007, OECD, for all countries except Sweden and Canada; Belgian Health Care Knowledge Centre, *HTA of Diagnostic Resonance Imaging*, KCE report vol. 37C, 2006, for Sweden; National Survey of Selected Medical Imaging Equipment, Canadian Institute for Health Information, for Canada. Reproduced with permission from the Canadian Institute for Health Information



*Latest year for which data are available.

**As of January 1, 2006.

B135. Temporal changes in the number of CT scanners for three European countries and Canada over the period 1990–2005 are summarized in figure B-III. The largest increase occurred in Italy, where the number of CT scanners increased by a factor of over 3. There was a 68% increase in the number of CT scanners between 1998 and 2002 [C25]. In the period 1991–2005 the number of CT scanners in Canada increased from 200 to 361 [C25].

B136. Mettler et al. [M37] investigated CT practice in the United States. The authors concluded that in the period 1993–2006 the annual growth in the number of CT procedures was over 10% (figure B-IV). The rate of increase has been steeper since 1998 (just under 17%), which is probably associated with the introduction of helical and multislice CT scanning.

Figure B-III. Number of CT scanners per million population in selected G8 countries for which time series were available, 1990–2005 [C25]

Sources: OECD Health Data 2007; National Survey of Selected Medical Imaging Equipment (2003, 2004 and 2005). Reproduced with permission from the Canadian Institute for Health Information

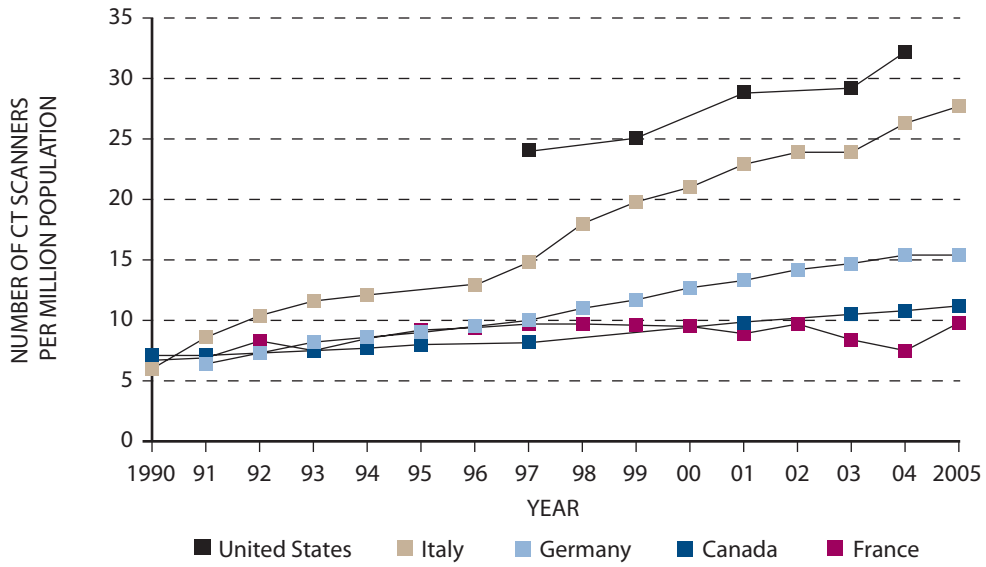
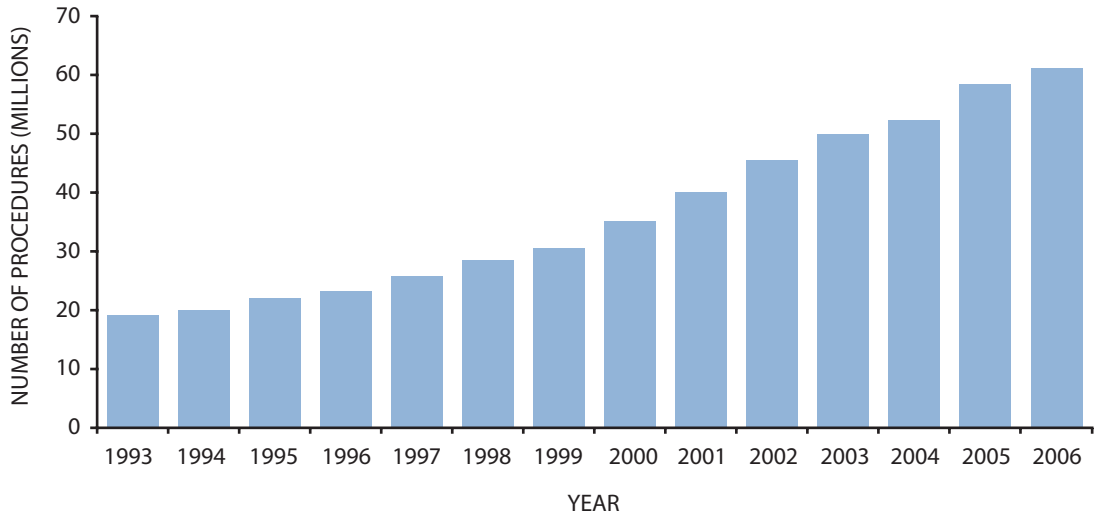


Figure B-IV. Number of CT procedures annually in the United States [M37]



B137. With the advent of helical and multislice scanning together with the associated use of slip ring technology, CT has undergone a renaissance. The shortening of scan times, coupled with the rapid reconstruction of CT images made possible by modern computer processing power, has resulted in an increased demand for CT scanners. Given the relatively high doses associated with these machines, it is likely that CT examinations will make the largest contribution to population dose from man-made exposures in many countries.

B138. The development of multimodality CT scanners will inevitably lead to an increase in the number and annual frequency of CT scans. These machines allow the acquisition of nuclear medicine scans and CT scans using the same machine. They are described in greater detail in appendix C on nuclear medicine.

B. Trends in patient doses

B139. International organizations, regulatory bodies and standards organizations have promoted dose reduction for medical exposures [L8]. Equipment manufacturers have responded to this with a series of technological developments and advances to reduce patient doses. Thus doses for a single examination have tended to decrease because of continuing improvements in equipment design and performance. Doses for diagnostic examinations can be reduced by giving careful consideration to the use of X-ray equipment, its design and how the procedure is performed. Methods of dose reduction in diagnostic radiology have been reviewed elsewhere [F2].

B140. Film–screen systems are used in conjunction with manual film processing in many centres worldwide, whereas in centres of health-care level I countries, automatic processing is almost invariably used. The number of repeat films made necessary because of problems with manual processing may be as high as 50%, whereas for automatic processors this can drop to 6% [R3].

B141. Image intensifiers have replaced direct fluoroscopy systems, because the former have enabled the examinations to be performed in low ambient light rather than under conditions of dark adaptation. In addition, patient and staff doses with the non-intensified equipment were unacceptably high.

B142. Increasing the gain of an image intensifier insert means that less radiation is required to be incident upon the input surface of the insert to produce the same light output. High-gain systems can reduce patient doses [B2]. Inappropriately adjusted control systems may result in unnecessarily high patient doses. Checking image intensifier input dose rates under automatic control usually forms part of a quality assurance programme. Automatic systems can compensate for a loss in image intensifier gain without the operator being aware of the problem. This has led to one overexposure incident in the United Kingdom [G1]. A significant proportion of the population dose from the overexposure arose from the use of automatic control systems with image intensifiers that suffered a rapid loss in gain.

B143. Manufacturers are developing new detectors with higher detective quantum efficiency (DQE) [D2]. The introduction of detectors based on amorphous selenium could reduce patient doses. These detectors have higher DQEs than conventional film–screen combinations or computed radiography systems and require a lower dose to form an image containing an equivalent level of noise.

B144. The detection efficiency of amorphous selenium depends on the thickness of the material and the X-ray energy. The DQE of amorphous selenium is approximately twice that of the thallium-doped caesium iodide typically used in image intensifiers [Y1]. Terbium-activated gadolinium oxysulphate, used as a fluorescent screen for radiographic imaging, has a DQE comparable to that of amorphous selenium [Y1].

B145. In the United Kingdom, the Royal College of Radiologists published a handbook on referral criteria designed to fit in the coat pocket of junior doctors and consultants [R1]. The European Commission has adopted an amended version of this document [E3]. The original handbook has also been subsequently revised and replaced [R26]. These publications are based upon research evidence and a consensus approach. They provide advice to the referring physician when a particular radiological examination is recommended for the assessment of a specific clinical condition; their use is intended to avoid inappropriate or unnecessary radiation exposure.

C. Survey results

B146. Table B33 is a summary of the world population distribution according to the four health-care levels as used in previous UNSCEAR assessments of medical exposures. Countries were allocated to a health-care level according to the number of physicians per caput. Data on the population of each country and the number of physicians per caput were obtained from the WHO website [W2].

B147. Table B34 is a summary of the number of physicians and health-care professionals recorded in the UNSCEAR survey. The data have been stratified according to the four health-care levels described above. Data on the number of radiology technicians, medical physicists and other physicians performing radiology have been solicited in this survey.

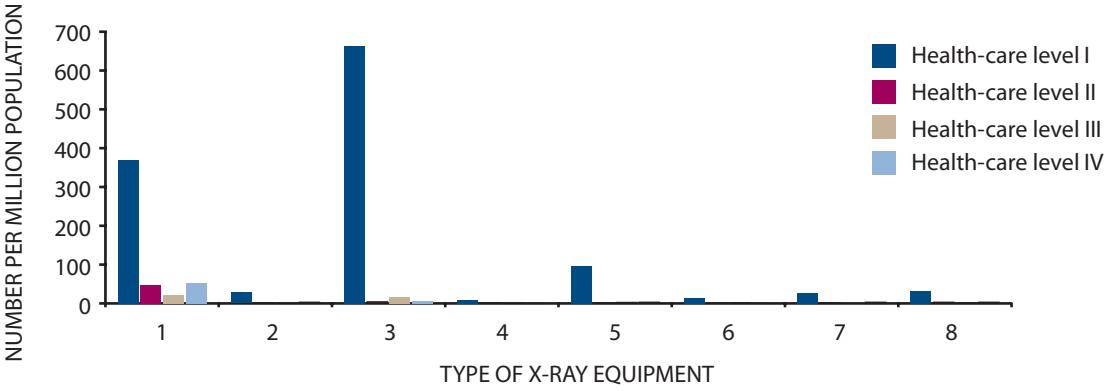
B148. The numbers of physicians and other health-care professionals per million population are summarized in table B35. The weighted average is obtained from the number of physicians in a country weighted according to its population. For health-care level I countries the weighted average number of physicians per million population was 3,530, which represents an increase of just over 600 per million population, or of just under 20%, since the previous survey [U3]. For health-care level II countries the number of physicians per caput has nearly doubled since the previous survey.

There is some uncertainty in the data presented in this table as there are no internationally agreed definitions for some of the professions. The number of physicians per caput in Zimbabwe has decreased over the period of this report; Zimbabwe's inclusion in the health-care level III category may need to be reviewed in the future.

B149. Information on the number of items of diagnostic radiology equipment in each country has been obtained as part of the UNSCEAR survey of practice. Data on digital imaging systems were also requested in this survey. Table B36 summarizes the data returns for various types of conventional diagnostic X-ray generators, bone mineral densitometers and CT scanners, with table B37 summarizing the data received on digital diagnostic equipment.

B150. The data given in tables B36 and B37 have been analysed according to the number of items of equipment, normalized to the size of the population of each country supplying data. This analysis is presented in tables B38 for conventional generators, bone mineral densitometers and CT scanners, and in table B39 for digital equipment. Figure B-V summarizes the number of items of radiological equipment per million population across the four health-care levels.

Figure B-V. Numbers of items of radiological equipment per million population across the four health-care levels
1: general; 2: mammography; 3: dental; 4: interventional; 5: general fluoroscopy; 6: angiography, 7: bone densitometry, 8: CT



B151. For health-care level I countries the number of conventional medical X-ray generators has increased to 370 per million population from 293 per million population in the previous survey [U3]. The number of digital mammography units constitutes just over 25% of the total, whereas for conventional X-ray generators the proportion of digital units is considerably lower for health-care level I countries. The number of CT scanners has nearly doubled to 32 scanners per million population in health-care level I countries.

B152. Trend analysis for health-care level II countries is less robust, owing to the limited number of survey returns. However, it is apparent from the survey that there has been an increase of nearly a factor of 2 in the number of mammography units per caput. Similarly, the number of CT scanners per caput has increased by a third since the previous UNSCEAR survey of practice [U3].

B153. Table B40 contains an analysis of the temporal trends in the average provision for medical radiology.

B154. Temporal trends in the number of conventional X-ray generators, dental X-ray units and CT scanners over the period covered by the various UNSCEAR surveys are summarized in figures B-VI, B-VII and B-VIII, respectively. The estimated number of conventional X-ray generators in health-care level I countries decreased until 1991–1996 and then increased again with this survey.

Figure B-VI. Temporal trends in the provision of conventional X-ray generators

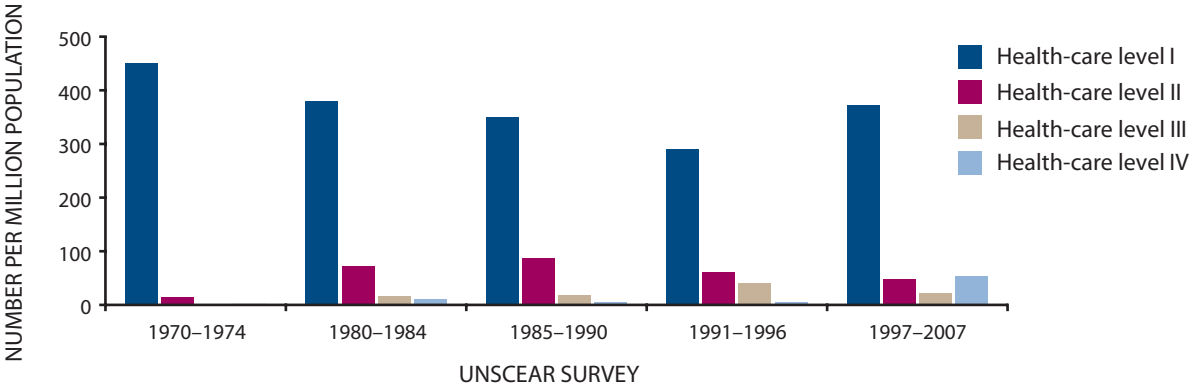


Figure B-VII. Temporal trends in the provision of dental X-ray generators

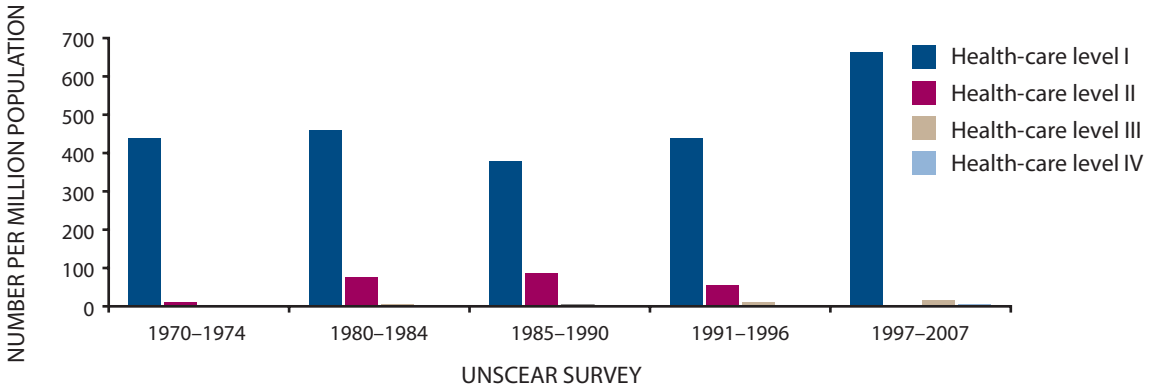
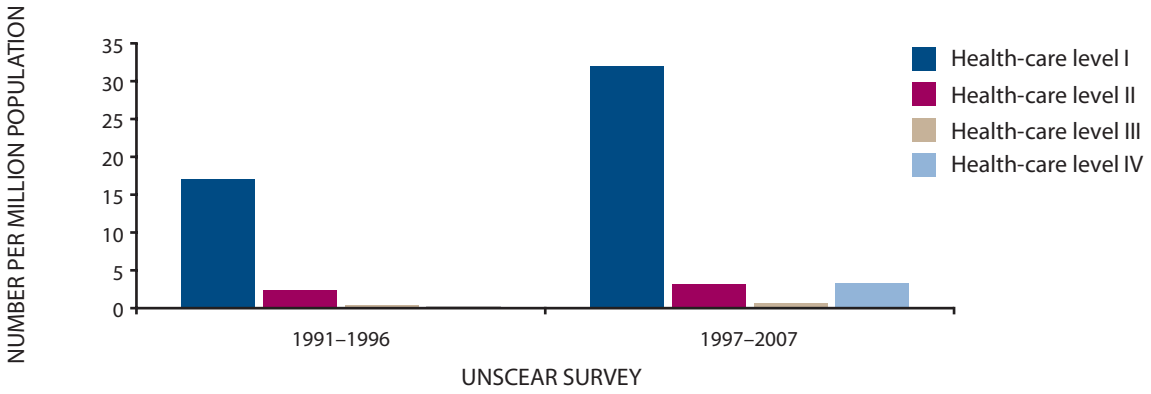


Figure B-VIII. Temporal trends in the provision of CT scanners



B155. The UNSCEAR survey also requested information on the annual number of medical radiological examinations. These data are summarized in tables B41(a–d).

B156. The total number of diagnostic medical and dental examinations performed in various countries obtained from the UNSCEAR survey is summarized in table B42. The survey data in tables B41(a–d) have been analysed according to the number of medical and dental radiological examinations per thousand population performed annually, and this information is presented in tables B43(a–d). The weighted average has been obtained from the number of examinations per caput, weighted according to the size of the country's population. In general, for health-care level II countries the number of examinations has increased for virtually all examination types. There is a large imbalance in the number of procedures per caput across the four health-care levels.

B157. Table B44 is a summary of the total annual number of diagnostic medical and dental examinations performed per thousand population obtained from the UNSCEAR survey. The weighted average total number of diagnostic examinations is approximately 1,180 per thousand population and approximately 350 dental radiological examinations per thousand population, equating to about 1,530 medical and dental examinations per 1,000 population in total in health-care level I countries. For health-care level II countries there were on average just over 410 medical and 15 dental examinations per 1,000 population. The total number of medical and dental examinations was just under 430 per thousand population for health-care level II countries.

B158. Tables B45(a–d) summarize the mean patient dose and variation on the mean for all diagnostic medical and dental radiological examinations included in the UNSCEAR survey. Data in italics are for ESAK. Data in bold are for DAP, whereas CTDI values are underlined. In mammography, mean glandular dose has been used as the dosimetric quantity.

B159. Mean effective doses and variation on the mean value are summarized in tables B46(a–d). Weighted average effective dose has been estimated using the effective dose values given in the UNSCEAR survey of practice for each country, weighted according to population size of that country. Data were available only for level I and level IV countries. The values of effective doses per examination were comparable in these two health-care levels. Mean effective doses for various examinations are given in figures B-IX, B-X and B-XI.

Figure B-IX. Mean effective doses for various interventional procedures in health-care level I countries

1: PTCA cardiac; 2: cerebral; 3: vascular; 4: other; 5: non-cardiac angiography; 6: cardiac angiography

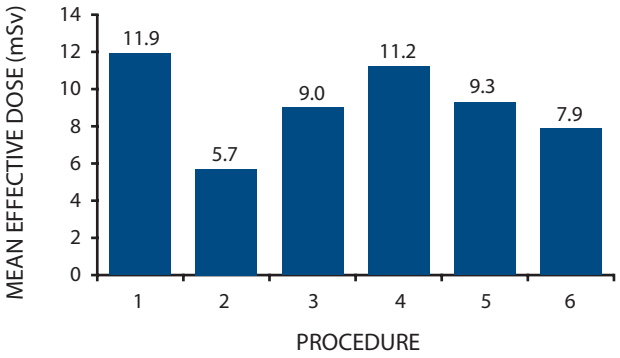


Figure B-X. Mean effective doses for various CT examinations in health-care level I countries

1: head; 2: thorax; 3: abdomen; 4: spine; 5: pelvis; 6: other

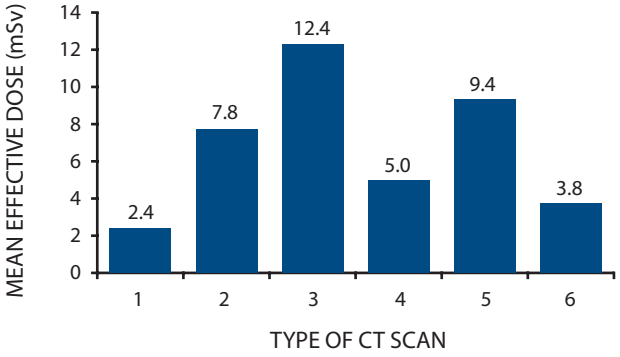
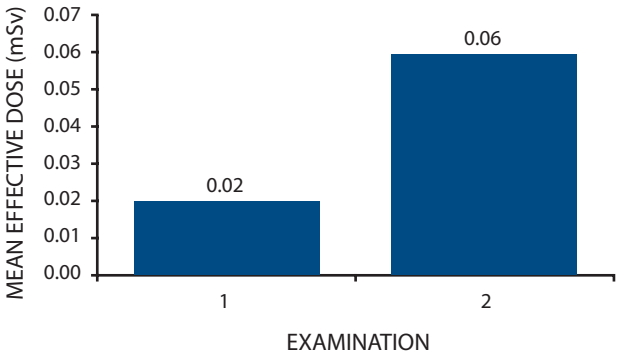


Figure B-XI. Mean effective doses for various dental examinations in health-care level I countries

1: intraoral; 2: panoral tomography



B160. Table B47 is a summary of the distribution by age and sex of patients undergoing medical and dental radiological examinations. The weighted average has been calculated. Most medical examinations are performed on individuals aged over 40 years. There is a fairly even split between medical examinations performed on men and on women; the exceptions are mammography, which is mainly performed on women, and pelvimetry, which is performed only on women, usually aged between 15 and 40 years.

B161. In dental radiology, most examinations are performed on individuals aged between 16 and 40 years. There is an almost equal split of examinations between the two sexes. In general the age and sex distribution of individuals undergoing medical and dental exposures is comparable to that of the previous survey [U3].

B162. The annual collective dose due to diagnostic radiology was estimated by multiplying the number of examinations per thousand population for a health-care level country by the effective dose for that examination and the total population of that country obtained using the health-care model summarized in table B33. Using the data in table B48, the average effective per caput dose from medical exposures was 1.91, 0.32 and 0.03 mSv for health-care levels I, II and III–IV, respectively.

B163. For dental examinations, the total collective dose to the population was estimated as 9,900 man Sv for health-care level I countries, 1,300 man Sv for health-care level II countries and 89 man Sv for health-care level III–IV countries. The total collective dose to the world population from dental exposures estimated on the basis of the survey returns and using the UNSCEAR health-care model is 11,000 man Sv.

B164. The total collective dose from all medical and dental exposures is estimated as 2,900,000 man Sv for health-care level I countries, 1,000,000 man Sv for health-care level II countries and 57,000 man Sv for health-care level III–IV countries. The contribution made by dental exposures to the total is approximately 0.25% for health-care level I countries, 0.03% for level II countries and 0.002% for countries of level III–IV.

B165. The total collective dose to the global population from medical exposures is estimated to be 4,000,000 man Sv and from dental exposures 11,000 man Sv. About 73% of the collective dose to the global population due to medical and dental radiological examinations is received by individuals living in health-care level I countries. The populations of level II receive about 25%, while the populations of level III–IV countries receive only about 1%. This essentially reflects the variation in the frequency of medical and dental radiological examinations between health-care levels.

B166. Vanmarcke et al. [V1] have estimated the collective dose to the population of Belgium in 2001. In this study they used the same approach as was used in the previous UNSCEAR report [U3] and which has been employed here. The estimated annual per caput dose from diagnostic

radiological examinations was 1.8 mSv, with 0.2 mSv from nuclear medicine. Approximately half of the dose (0.9 mSv) arose from CT examinations.

B167. The estimated annual per caput dose to the Belgian population was higher than the average effective per caput dose estimated here for medical and dental procedures in level I countries [V1]. This is consistent with Belgium having a higher annual frequency of medical examinations per caput than the average for level I countries (i.e. 1,255 per 1,000 population annually).

B168. Scanff et al. [S44] have investigated the dose to the French population from diagnostic medical procedures. Data on the frequency of examinations in 2002 were obtained. The estimated annual number of medical examinations was in the range 672–1,001 per 1,000 population, slightly lower than the average for level I countries estimated here. The estimated annual per caput effective dose was in the range 0.66–0.83 mSv, with CT examinations contributing 39% of the collective dose. The per caput effective dose is less than that estimated here. This is consistent with CT examinations making a smaller contribution to the population dose than in other level I countries in this study.

B169. In the United Kingdom, the Health Protection Agency has estimated the dose to the United Kingdom population from medical exposures [H33]. Hart and Wall estimated that there were 700 medical examinations per 1,000 population annually, giving rise to an annual per caput dose of 0.33 mSv, considerably lower than those for France, Belgium and other level I countries estimated in this annex [H33, S44, V1]. The lower per caput dose was attributed to the lower doses per examination and fewer examinations per person in the United Kingdom [H33].

B170. The National Council on Radiation Protection and Measurements (NCRP) [N26] has estimated the dose to the population of the United States due to diagnostic radiology and nuclear medicine (table B49). The annual collective effective dose to the population of the United States was estimated to be 900,000 man Sv, with an annual per caput effective dose of 3 mSv, somewhat higher than that estimated for health-care level I countries here.

B171. Table B50 summarizes the contribution made by the various types of radiological examination to the total number of procedures, stratified according to the UNSCEAR health-care level model. Just over 87% of radiological examinations worldwide are diagnostic, with 13% being dental. Worldwide, CT scanning accounts for just under 6% of all examinations.The percentage contribution to the collective dose for various types of medical and dental examination is summarized in table B51. It may be deduced from table B51 that just under 43% of the total dose to the world population arises from CT scanning.

B172. Temporal trends in the annual frequency of diagnostic medical radiological examinations are summarized in table B52. For health-care level I countries the number of diagnostic medical radiological examinations has increased from 820 to 1,332 per 1,000 population over the period covered by the UNSCEAR surveys, mainly because of the steep increase noted in the current survey. Over the same period, the increase in the annual frequency of diagnostic radiological examinations in health-care level II countries has increased by a factor of over 12. For health-care level III and IV countries the number of diagnostic radiological examinations per caput has remained approximately constant.

B173. Table B53 summarizes the temporal trends in the annual frequency of diagnostic dental radiological examinations since the first UNSCEAR survey in 1970–1979, though the approach to estimating the annual frequency has changed over this period. The annual frequency of diagnostic dental examinations has remained fairly constant in health-care level I countries, while in level II countries it has increased by a factor of 20. The annual frequency of diagnostic dental procedures in health-care level III and IV countries has also dramatically increased.

B174. Table B54 illustrates the temporal trends in the average effective dose for some diagnostic medical radiological examinations in health-care level I countries over the period covered by the various UNSCEAR surveys of medical practice. In general, average effective doses for radiography examinations have decreased in this period (e.g. chest and head).

B175. Effective doses for upper and lower GI examinations that involve the use of fluoroscopy were constant for the first two surveys. Then there was a major decrease to less than half for the third survey period, and those lower doses have been maintained for the present survey. This could reflect the introduction of digital fluoroscopy systems for barium studies and/or the impact of optimization studies in the period 1991–1996.

B176. In the first survey period, the only CT scans were examinations of the head. In the next survey, body scanning was introduced. The change in practice impacts on the average effective doses because the dose for a head CT examination is less than that for a typical body scan.

B177. The estimated dose to the world's population from diagnostic medical and dental radiological examinations in the period 1997–2007, stratified according to the UNSCEAR health-care level model, is given in table B55. The total annual collective dose due to all diagnostic medical radiological examinations estimated using the approach of previous UNSCEAR reports was 4,000,000 man Sv, and 11,000 man Sv due to diagnostic dental examinations. The total annual collective effective dose due to all diagnostic radiology was 4,011,000 man Sv.

B178. Figure B-XII illustrates the variation in per caput effective dose for diagnostic medical exposures with health-care level. The per caput effective dose to individuals living in health-care level I countries is approximately six times that received by individuals in health-care level II countries. By comparison, the per caput effective dose for individuals living in health-care level III and IV countries is less than one-tenth of that in health-care level II countries.

Figure B-XII. Variation in per caput effective dose for diagnostic medical radiological exposures with health-care level

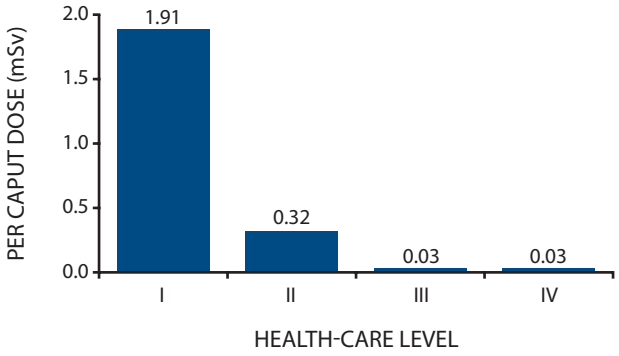
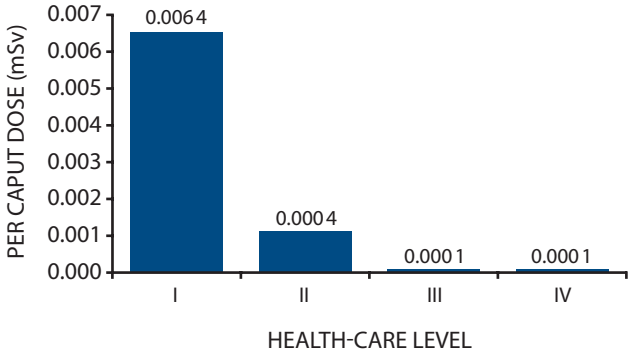


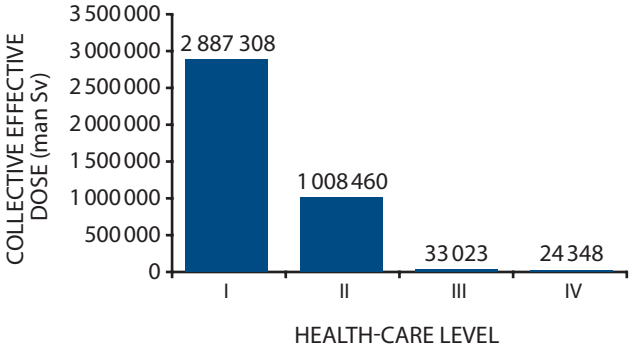
Figure B-XIII illustrates the variation in per caput effective dose with health-care level for diagnostic dental radiological examinations.

Figure B-XIII. Variation in per caput effective dose for diagnostic dental radiological exposures with health-care level



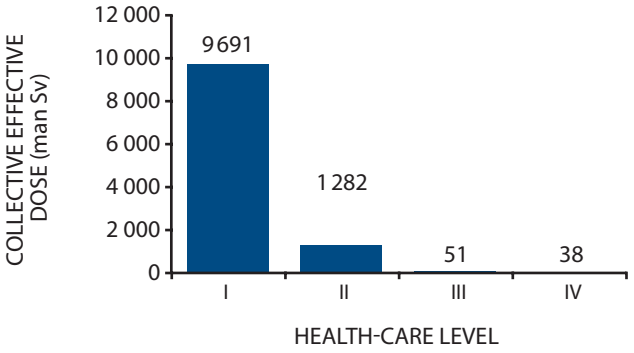
B179. The variation in collective effective dose due to diagnostic medical radiological examinations is given in figure B-XIV. Most of the collective effective dose is received by individuals living in health-care level I countries, where this value is more than twice that for health-care level II countries.

Figure B-XIV. Variation in collective effective dose from diagnostic medical radiological examinations



B180. Figure B-XV illustrates the variation in collective effective dose due to diagnostic dental radiological examinations. Once again the majority of the collective effective dose is received by individuals living in health-care level I countries.

Figure B-XV. Variation in collective effective dose from diagnostic dental radiological examinations



B181. As with previous estimates of the annual collective effective dose to the world's population from diagnostic medical examinations, there are considerable uncertainties in this estimate. This uncertainty arises in part from data limitations in the survey returns at all health-care levels, but particularly for health-care levels II, III and IV. Survey returns submitted by countries in health-care level I represented just under half of the total population in this category. This represents a reasonable level of response. For health-care levels II, III and IV, the survey returns submitted represented only about 1% of the total population in each category. As a consequence there are major uncertainties in the estimates for the annual frequency of each radiological examination, particularly for health-care levels II, III and IV. This is compounded by uncertainties in population estimates and in the effective dose received for specific radiological examinations. Thus the value for the annual collective effective dose given here should be regarded as a reasonable estimate, but one on which there is some considerable uncertainty.

V. SUMMARY

B182. A survey of practice in medical and dental radiology has been undertaken. Responses from various countries have been received. These data have been supplemented by information on medical and dental radiological examinations obtained from a review of the published literature.

B183. A global model, as used in earlier UNSCEAR reports, has been used. In this model, countries are stratified into four health-care levels, depending on the number of physicians per 1,000 members of the population. As with previous UNSCEAR surveys of global exposure, there are considerable uncertainties on the results estimated using this global model.

B184. The uncertainty arises from a number of sources, but primarily in extrapolating from the limited survey data obtained. In addition, patient dose surveys sample the patient dose distribution, which can have a wide range (i.e. the doses received by some individuals may be 100 to 1,000 times those received by others). In addition, the small sample size in the UNSCEAR survey could mean that the annual frequency data are distorted. There is also an uncertainty on the population estimates for the global population, although this uncertainty is much smaller than the others.

B185. According to this global model, the annual frequency of diagnostic medical examinations in health-care level I countries has increased from 820 per 1,000 population in 1970–1979 to 1,332 per 1,000 in this survey. Comparative values for health-care level II countries exhibit an even greater increase, from 26 per 1,000 population in 1970–1979 to 332 per 1,000 in 1997–2007. Between the periods 1970–1979 and 1997–2007, level III and IV countries have shown a slight decrease in the annual frequency of diagnostic medical examinations: from 23 per 1,000 population to 20 per 1,000 population for level III countries and from 27 per 1,000 population to 20 per 1,000 population for level IV countries.

B186. Temporal trends in the annual frequency of diagnostic dental examinations have been obtained. For health-care level I countries, the annual frequency has slightly decreased, from 320 per 1,000 population to 275 per 1,000 between the periods 1970–1979 and 1997–2007, whereas for the countries of other health-care levels, the number of diagnostic dental radiological examinations has increased.

B187. In the period covered by this UNSCEAR report, the estimated annual collective effective dose to the world population due to diagnostic medical and dental radiological examinations is estimated to be 4,000,000 man Sv. This represents an increase in collective dose of approximately 1,700,000 man Sv, or of just over 70% from the previous evaluation. This increase in collective dose has occurred because of two main factors. Firstly, the per caput effective dose has increased from 0.4 mSv to 0.62 mSv, mainly as a result of the increased annual frequency of CT scanning. Secondly, the world population itself has increased.

Table B1. Global use of medical radiology (1991–1996) [U3]
Estimates derived from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

PART A: NORMALIZED VALUES

Quantity		*Number per million population[a] at health-care level*				
		I	*II*	*III*	*IV*	*Globally*
Physicians						
All physicians		2 800	700	210	45	1 100
Physicians conducting radiological procedures		110	80	5	0.1	70
X-ray imaging						
Equipment	Medical	290	60	40	4	110
	Dental	440	60	10	0.1	150
	Mammography	24	0.5	0.2	0.1	7
	CT	17	2	0.4	0.1	6
Annual number of examinations	Medical[b]	920 000	150 000	20 000		330 000
	Dental[c]	310 000	14 000	200		90 000
Radionuclide imaging						
Equipment	Gamma cameras	7.2	0.3	0.1	0.03	2.1
	Rectilinear scanners	0.9	0.3	0.1	0.01	0.4
	PET scanners	0.2	0.002	0	0	0.05
Annual number of examinations[d]		19 000	1 100	280	17	5 600

Quantity		*Number per million population[a] at health-care level*				
		I	*II*	*III*	*IV*	*Globally*
Radionuclide therapy						
Annual number of patients[e]		170	40	20	0.4	65
Teletherapy						
Equipment	X-ray	2.8	0.2	0.03	0.02	0.9
	Radionuclide	1.6	0.5	0.2	0.1	0.7
	Linac	3.0	0.3	0.06	0	0.9
Annual number of patients[f]		1 500	690	470	50	820
Brachytherapy						
Afterloading units		1.7	0.4	0.1	0.1	0.7
Annual number of patients[g]		200	17	15	(15)[h]	70

[a] Extrapolated, with rounding, from limited samples of data.
[b] Based on following population sample sizes for global model: 67% for level I, 50% for level II, 9% for levels III and IV, and 46% overall.
[c] Based on following population sample sizes for global model: 39% for level I, 49% for level II, 4% for levels III and IV, and 37% overall.
[d] Based on following population sample sizes for global model: 68% for level I, 18% for level II, 11% for level III, 16% for level IV and 30% overall.
[e] Based on following population sample sizes in relation to global model: 44% for level I, 16% for level II, 8% for level III, 16% for level IV and 22% overall.
[f] Based on following population sample sizes in relation to global model: 56% for level I, 19% for level II, 17% for level III, 5% for level IV and 27% overall.
[g] Based on following population sample sizes in relation to global model: 38% for level I, 11% for level II, 9% for level III, 0% for level IV and 17% overall.
[h] Assumed value in the absence of survey data.

PART B: ABSOLUTE NUMBERS

Quantity		*Total number (millions) at health-care level[a]*				
		I	*II*	*III*	*IV*	*Globally*
Physicians						
All physicians		4.3	2.1	0.13	0.03	6.6
Physicians conducting radiological procedures		0.16	0.23	0.003	0.000 1	0.4
X-ray imaging						
Equipment	Medical	0.45	0.2	0.02	0.002	0.7
	Dental	0.67	0.2	0.01	<0.000 1	0.9
	Mammography	0.04	0.001	0.000 1	0.000 1	0.04
	CT	0.027	0.007	0.000 3	0.000 1	0.034
Annual number of examinations	Medical[b]	1 410	470	24		1 910
	Dental[c]	475	42	0.24		520
Radionuclide imaging						
Equipment	Gamma cameras	0.011	0.001	0.000 1	0.000 02	0.012
	Rectilinear scanners	0.001	0.001	0.000 1	0.000 01	0.002
	PET scanners	0.000 3	0.000 01	0	0	0.000 31
Annual number of examinations[d]		29	3.5	0.2	0.01	32.5
Radionuclide therapy						
Annual number of patients[e]		0.3	0.1	0.01	0.000 2	0.4
Teletherapy						
Equipment	X-ray	0.004	0.001	0.000 02	0.000 01	0.005
	Radionuclide	0.002	0.002	0.000 1	0.000 04	0.004
	Linac	0.005	0.001	0.000 04	0	0.005
Annual number of patients[f]		2.3	2.1	0.3	0.03	4.7
Brachytherapy						
Afterloading units		0.003	0.001	0.000 1	0.000 04	0.004
Annual number of patients[g]		0.3	0.05	0.01	(0.01)[h]	0.4

Quantity	*Total number (millions) at health-care level*[a]				
	I	*II*	*III*	*IV*	*Globally*
Population					
Total population	1 530	3 070	640	565	5 800

[a] Extrapolated, with rounding, from limited samples of data.
[b] Based on following population sample sizes for global model: 67% for level I, 50% for level II, 9% for levels III and IV, and 46% overall.
[c] Based on following population sample sizes for global model: 39% for level I, 49% for level II, 4% for levels III and IV, and 37% overall.
[d] Based on following population sample sizes for global model: 68% for level I, 18% for level II, 11% for level III, 16% for level IV and 30% overall.
[e] Based on following population sample sizes in relation to global model: 44% for level I, 16% for level II, 8% for level III, 16% for level IV and 22% overall.
[f] Based on following population sample sizes in relation to global model: 56% for level I, 19% for level II, 17% for level III, 5% for level IV and 27% overall.
[g] Based on following population sample sizes in relation to global model: 38% for level I, 11% for level II, 9% for level III, 0% for level IV and 17% overall.
[h] Assumed value in the absence of survey data.

Table B2. Estimated doses to the world population from diagnostic medical and dental radiological examinations[a] (1991–1996) [U3]

Health-care level	*Population (millions)*	*Annual per caput effective dose (mSv)*		*Annual collective effective dose (man Sv)*	
		Medical	*Dental*	*Medical*	*Dental*
I	1 530	1.2	0.01	1 875 000	9 500
II	3 070	0.14	0.001	425 000	4 300
III	640	0.02	<0.000 1	14 000	13
IV	565	0.02	<0.000 1	13 000	11
World	5 800	0.4	0.002	2 330 000	14 000

[a] As was discussed in appendix A, because many of these exposures are received by patients nearing the end of their lives and the doses are not distributed evenly among the population, these dose estimates should not be used for the assessment of detriment.

Table B3. Contributions to frequency and to collective dose from the various types of diagnostic medical (excluding dental) radiological examination assumed for global model (1991–1996) [U3]

Examination	*Contribution (%)*			
	Level I	*Level II*	*Levels III and IV*	*World*
Contribution to total annual frequency				
Chest radiography	31	16	19	27
Chest photofluorography	4	0.1	<0.1	3
Chest fluoroscopy	1	42	<0.1	11
Limbs and joints	18	13	24	17
Lumbar spine	5	3	5	5
Thoracic spine	1	0.8	2	1
Cervical spine	4	2	3	3
Pelvis and hip	4	2	7	3
Head	6	4	14	6
Abdomen	4	8	7	5
Upper GI tract	5	2	4	4
Lower GI tract	0.9	1	6	1
Cholecystography	0.3	0.1	0.4	0.3
Urography	1	0.6	3	1
Mammography	3	0.4	<0.1	2
CT	6	1.0	0.4	5

Examination	*Contribution (%)*			
	Level I	*Level II*	*Levels III and IV*	*World*
Angiography	0.8	0.1	<0.1	0.6
Interventional procedures	0.3	0.1	<0.1	0.3
Other	4	4	4	4
All	100	100	100	100
Contribution to total annual collective dose				
Chest radiography	3	2	3	3
Chest photofluorography	2	<0.1	<0.1	2
Chest fluoroscopy	1	50	<0.1	10
Limbs and joints	0.8	0.8	2	0.8
Lumbar spine	7	6	8	7
Thoracic spine	1	1	3	1
Cervical spine	0.7	0.6	0.9	0.7
Pelvis and hip	2	2	7	2
Head	0.5	0.4	2	0.5
Abdomen	2	5	6	2
Upper GI tract	12	9	15	12
Lower GI tract	5	8	34	5
Cholecystography	0.5	0.3	0.6	0.5
Urography	4	3	11	3
Mammography	1	0.2	<0.1	0.9
CT	41	5	2	34
Angiography	7	0.8	0.4	6
Interventional procedures	5	1	0.6	4
Other	4	4	4	4
All	100	100	100	100

Table B4. Summary of patient dose data for diagnostic medical radiological examinations

Examination	*ESD (mGy)*	*DAP (Gy cm^2)*	*Effective dose (mSv)*	*Patients*	*Reference*
Skull and facial bones					
Nasal bones			0.01		[H33]
Facial bones	1		0.01	3	[H33]
Mastoids			0.06		[H33]
Skull (PA + LAT + 0.75AP)	1.4–2.5		0.06	2 580	[G2, H33]
Skull PA	2.7		0.027		[Z6]
Skull LAT	2.1		0.021		[Z6]
Skull			0.027		[C28]
Skull			0.1		[M41]
Skull (CR)			0.029		[C28]
Skull (DDR)			0.022		[C28]
Cephalometry			0.01	40 000	[N23, S43]
Mandible	1.35		0.014	2	[H33]
TMJ			0.012		[H33]
Sinuses and antra	2.2		0.022	50	[H33]

Examination	*ESD (mGy)*	*DAP (Gy cm²)*	*Effective dose (mSv)*	*Patients*	*Reference*
Head, soft tissue					
Dacryocystography		1.8	0.05	1	[H33]
Pharyngography			0.06		[H33]
Post-nasal space	0.2		0.002	20	[H33]
Salivary glands			0.056		[H33]
Sialography		2	0.056	24	[H33]
Eyes	2.5		0.025		[H33]
Head	1.94		0.019		[V8]
Teeth					
Intraoral			0.005		[L5, N23]
Intraoral			0.005		[M41]
Panoramic			0.01		[N23]
Panoramic			0.01		[M41]
Cerebral angiography					
Carotid/cerebral		48.5	4	90	[M2]
Carotid/cerebral		28	0.78	55	[H33]
Carotid/cerebral		42		57	[K30]
Myelography					
Myelography		12.3	2.46	68	[H33]
Discography			1.3	75	[M34]
Lumbar radiculography			3.5	106	[M34]
Neck, soft tissue					
Soft tissues of neck		0.1	0.003	1	[H33]
Larynx			0.07		[H33]
Laryngography			0.07		[H33]
Cervical spine					
Cervical spine	0.3, 1.7		0.07	83	[H33]
Cervical spine		0.49	0.064	104	[H33]
Cervical spine			0.2		[M41]
Thoracic spine					
Thoracic spine			0.7		[W7]
Thoracic spine	3.9, 10.8		0.64	1 277	[H33]
Thoracic spine		4.2	0.8	38	[H33]
Thoracic spine			1.0		[M41]
Thoracic spine AP	6.5		0.6		[Z6]
Thoracic spine LAT	15		0.39		[Z6]
Lumbar spine					
Lumbar spine AP, LAT	6, 14.5		1	9 892	[H33]
Lumbar spine		5.7	1.2	592	[H33]
Lumbar spine			1.5		[M41]
Lumbar spine AP	10		1.1		[Z6]
Lumbar spine LAT	26		0.65		[Z6]
Lumbar spine AP/PA	4.08		0.44		[V8]
Lumbar spine LAT	17.5		0.44		[V8]
Lumbar spine AP + LAT			0.309		[C28]
Lumbar spine AP + LAT (CR)			0.476		[C28]
Lumbar spine AP + LAT (DDR)			0.179		[C28]

Examination	*ESD (mGy)*	*DAP (Gy cm²)*	*Effective dose (mSv)*	*Patients*	*Reference*
Lumbosacral joint					
Lumbosacral joint			0.3		[W7]
Lumbosacral joint	28.1		0.34	2 210	[H33]
Lumbosacral joint		2.2			[N2]
Sacroilliac			0.17		[H33]
Sacroilliac	5.4		0.06	1	[H33]
Sacrum and coccyx	13.9		0.17	6	[H33]
Whole spine/scoliosis					
Whole spine/scoliosis			0.1		[H33]
Whole spine/scoliosis	0.53, 0.63		0.07	78	[H33]
Whole spine/scoliosis			0.12	7	[H12]
Whole spine/scoliosis			0.14	61	[C29]
Whole spine/scoliosis	0.08			283	[P21]
Shoulder girdle					
Shoulder		0.3	0.011	21	[H33]
Shoulder			0.01		[M41]
Shoulder AP	0.19		0.001	3	[H33]
Shoulder AP/LAT	0.31, 0.98		0.009	4	[H37]
Acrominoclavicular joints			0.01		[H33]
Clavicle/collar bone			0.01		[H33]
Scapula			0.01		[H33]
Sternoclavicular joint			0.01		[H33]
Sternum			0.01		[H33]
Upper arm					
Upper arm	0.15		0.000 8	4	[H37]
Elbow					
Elbow		0.1	0.001	53	[H33]
Forearm, wrist and hand					
Fingers			0.000 5		[H33]
Hand	0.1		0.000 5	6	[H33]
Hand		0.4	0.000 4	1	[H33]
Radius and ulna/forearm			0.001		[H33]
Extremities			0.001		[M41]
Thumb			0.000 5		[H33]
Wrist/scaphoid	0.1		0.000 5	197	[H33]
Pelvis					
Pelvis			0.7		[W7]
Pelvis	4.2		0.67	4 281	[H37]
Pelvis		2.6	0.75	285	[H33]
Pelvis			0.6		[M41]
Pelvis AP		2.2	0.64		[N2]
Pelvis/hip	2.18		0.35		[V8]
Pelvis AP	1.81		0.295		[C28]
Pelvis AP (CR)	1.83		0.326		[C28]
Pelvis AP (DDR)	1.02		0.168		[C28]

Examination	*ESD (mGy)*	*DAP (Gy cm²)*	*Effective dose (mSv)*	*Patients*	*Reference*
Hip					
Hip			0.35		[H33]
Hip	2.7, 3.7		0.18	189	[H33]
Hip		3.1	0.54	10	[H33]
Hip	3.8		0.27	14	[H37]
Hip	7.2		0.43		[Z6]
Hip			0.7		[M41]
Orthopaedic pinning		2.6	0.7	55	[C30]
Femur					
Femur	0.5		0.002 5	18	[H37]
Femur	0.13, 0.14		0.001 4	5	[H33]
Leg length					
Leg length			0.184	13	[R24]
Knee, lower leg, ankle, foot					
Ankle	0.42		0.002	103	[H33]
Ankle		0.1	0.001	12	[H33]
Foot		0.06	0.000 6	116	[H33]
Foot	0.1		0.000 5	1	[H33]
Knee	0.49		0.002 5	404	[H33]
Knee		0.15	0.001 5	52	[H33]
Knee			0.005		[M41]
Calcanaeum/heel		0.09	0.000 9	5	[H33]
Patella			0.002 5		[H33]
Tibia and fibula			0.002		[H33]
Tibia and fibula	0.1		0.000 5	33	[H33]
Toes			0.000 6		[H33]
Skeletal survey					
Skeletal survey		18	1.8	2	[H33]
Chest					
Chest/ribs			0.02		[W7]
Chest/ribs	0.16		0.016	10 361	[H33]
Chest PA	0.5		0.05		[Z6]
Chest PA			0.02		[M41]
Chest PA	0.17		0.017	61 988	[V8]
Chest LAT	0.94		0.094	61 988	[V8]
Chest PA + LAT			0.29		[C28]
Chest PA + LAT			0.1		[M41]
Chest PA + LAT (CR)			0.041		[C28]
Chest PA + LAT (DDR)			0.23		[C28]
Thoracic inlet			0.02		[H33]
Bronchography		1.74	0.21	1	[H33]
Mammography					
Craniocaudal	1.77				[O3]
Lateral	1.88				[O3]
Craniocaudal	1.54				[J5]
Lateral	1.82				[J5]
	1.5				[T6]
	1.5				[D6]

Examination	*ESD (mGy)*	*DAP (Gy cm²)*	*Effective dose (mSv)*	*Patients*	*Reference*
	1.51				[H22]
Craniocaudal	2				[Y2]
Lateral	2.5				[Y2]
	1.5				[F10]
Craniocaudal	1.27–1.37				[G15]
Lateral	1.37–1.49				[G15]
Craniocaudal	1.8				[M11]
Lateral	1.95				[M11]
Symptomatic			0.37		[Y12]
Symptomatic			0.33		[B15, P21]
Symptomatic			0.4		[M41]
Screening (two views)	3.7		0.37	3 035	[Y12]
Screening (two views)	3.3		0.33	4 633	[B15]
Assessment			0.23	50 000	[N23]
Abdomen					
Abdomen			0.7		[W7]
Abdomen	5.4		0.76	5 500	[H33]
Abdomen		3.1	0.81	224	
Abdomen AP	7.5		1.05		[Z6]
Abdomen	2.65		0.37	22 374	[V8]
Abdomen			0.7		[M41]
Abdomen AP	1.88		0.28		[C28]
Abdomen AP (CR)	2.4		0.358		[C28]
Abdomen AP (DDR)	1.64		0.223		[C28]
Kidney and ureter					
Kidneys exposed			2.5		[H33]
Antegrade pyelography		3.5	0.6	8	[H33]
Nephrostogram, post-operative		9	1.6	57	[H33]
Retrograde pyelogram		13	2.3	27	[H33]
Urinary tract AP	2.18		0.168		[C28]
Urinary tract AP (CR)	2.51		0.193		[C28]
Urinary tract AP (DDR)			0.223		[C28]
Intravenous urography					
IVU			2.4	1 141	[H33]
IVU			3.0		[M41]
Bladder and urethra					
Cystourethrography			1.5		[H33]
Cystometrography		7	1.3	70	[H33]
Cystography		10	1.8	197	[H33]
Excretion urography/MCU		6.4	1.2	995	[H33]
Urethrography		6	1.1	19	[H33]
Gynaecology					
Pelvimetry	5.1		0.8	28	[H33]
Pelvimetry		1.4	0.41	1	[H33]
Hysterosalpingogram		4	1.2	201	[H33]
Lymphangiogram					
Lymphangiogram		0.3	0.06	1	[H33]

Examination	*ESD (mGy)*	*DAP (Gy cm²)*	*Effective dose (mSv)*	*Patients*	*Reference*
Tomography					
Tomography	3		0.15		[R15]
Bone mineral densitometry					
Bone mineral densitometry			0.000 5–0.035		[A7]
Bone mineral densitometry			0.000 2–0.01		[N5]
Bone mineral densitometry			0.001		[M41]
Arthrography					
Arthrography		1.7	0.17	82	[H33]
Pulmonary angiography					
Pulmonary arteriography		47	5.6	5	[H33]
Pulmonary angiogram			5		[M41]
Arterial pressures			7		[H33]
Superior venacavography			2.5		[H33]
Venacavogram		21	2.5	22	[H33]
Abdominal angiography					
Inferior venacavography			2.5		
Mesenteric angiography		85	22.1	338	[H33]
Mesenteric angiography		112		108	[K30]
Renal and visceral		92	23.9	56	[K30]
Renal and visceral		91	12.7	29	[R10]
Aortography					
Thoracic		34.5	4.1	287	[H33]
Abdominal		98	25.5	41	[W14]
Abdominal			14	19	[L16]
Abdominal			12		[M41]
Peripheral angiography					
Arteriography		27.2	7.1	759	[H33]
Arteriography		64		571	[K30]
Arteriography		26.3	4	25	[T12]
Phlebography		3.7	0.37	158	[H33]
Phlebography		23		26	[W14]
Barium swallow					
Barium swallow			1.5	4 258	[W7]
Barium meal					
Barium meal			2.6	9 718	[H33]
Barium follow-through					
Barium follow-through			3	886	[W7]
Small bowel enema					
Small bowel enema		30	7.8	176	[H33]
Barium enema					
Barium enema			8		[M41]
Barium enema			7.2	22 586	[H33]
Abdominal investigations					
Endoscopy			0.3		
Fistulogram		6.4	1.7	18	[H33]
Herniography		14	3.6	8	[H33]
Loopogram		5	1.3	4	[H33]
Peritoneogram		12	3.1	26	[H33]

Examination	*ESD (mGy)*	*DAP (Gy cm²)*	*Effective dose (mSv)*	*Patients*	*Reference*
Ileoanal pouchogram		15	3.9	7	[H33]
Sinography		16	4.2	71	[H33]
Biliary system					
Preliminary cholecystogram			2		[H33]
Operative cholangiography			3		[H33]
Infusion cholangiography			9		[H33]
Intravenous cholangiography		34	8.8	25	[H33]
Oral cholecystography		12	3.1	10	[H33]
ERCP		15	3.9	525	[H33]
ERCP		14.5	3.8	1 736	[M1]
ERCP			4.0		[M41]
Percutaneous transhepatic cholangiography		31	8.1	48	[H33]
T-tube choleangiogram		10	2.6	149	[H33]

Table B5. Summary of patient dose data for interventional radiology procedures

Procedure	*DAP (Gy cm²)*	*Effective dose (mSv)*	*Patients*	*Reference*
Biopsy				
Pathological specimen		1.6		[H33]
Biopsy	6	1.6	32	[H33]
Small bowel biopsy	1	0.26	15	[H33]
Venous sampling		0.4		[H33]
Biliary and urinary systems				
Bile duct drainage	38	9.9	8	[H33]
Bile duct drainage	43	11.2	86	[R10]
Bile duct drainage	69	17.9	10	[V2]
Bile duct drainage	150	38	18	[R9]
Bile duct drainage	70.6	18.4	123	[M13]
Bile duct drainage	86.7	22.5	9	[R10]
Bile duct drainage	43	11.2	14	[R10]
Bile duct dilatation/stenting	54	14	15	[H33]
Bile duct dilatation/stenting	51	13.3	74	[W14]
Bile duct dilatation/stenting	43	11.2	30	[M14]
Biliary intervention	54	14	153	[M1]
Bile duct stone extraction	27	7	29	[H33]
Lithotripsy	5	1.3	40	[H33]
Nephrostomy	13	3.4	68	[H33]
Nephrostomy	34.3	8.9	143	[M13]
Nephrostomy	22.7	5.9	14	[R10]
Nephrostomy	43	11.2	35	[M14]
Nephrostomy	8	2.1	21	[V6]
Nephrostomy	56	14.6	54	[R9]
Ureteric stenting	18	4.7	15	[H33]
Kidney stent insertion	49	12.7	5	[H33]

Procedure	*DAP (Gy cm²)*	*Effective dose (mSv)*	*Patients*	*Reference*
Cardiovascular				
Embolization	75	19.5	12	[H33]
Embolization	105	27.3	27	[W14]
Embolization	114	29.6	128	[M1]
Management of varicocele	51	6.4	41	[C31]
Management of varicocele	106	25.7	10	[R10]
Management of varicocele	131	38	1	[H33]
Management of varicocele	75	17	20	[R9]
Management of varicocele	50.8	13.2	14	[M13]
Neuroembolization	202	5.7	1	[H33]
Neuroembolization	122.2	10.6	8	[M2]
Neuroembolization	116	1.7	8	[B13]
Neuroembolization	105	10.5	5	[M14]
Neuroembolization	320.1	9	382	[M13]
Neuroembolization	129	3.6	21	[J4]
Neuroembolization	81	2.3	35	[J4]
Thrombolysis	13.5	3.5	5	[H33]
TIPS	206	53.6	10	[H33]
TIPS	182	47.3	56	[W14]
TIPS	161	18.7	23	[Z3]
TIPS	524	84	4	[M14]
TIPS	335.4	87.2`	135	[M13]
TIPS	226	58.8	13	[Z3]
TIPS	77	20	10	[Z3]
TIPS		70		[M41]
Valvuloplasty	162	29.3	40	[B14]
Vascular stenting	40	10.4	14	[H33]
Vascular stenting	42	5.8	44	[O8]
Pelvic vein embolization		60		[M41]
Insertion of caval filters	48	12.5	4	[H33]
Removal of foreign bodies		7		[H33]
Uterine fibroid embolization				
Uterine fibroid embolization	298.2	77.5	90	[M13]
Uterine fibroid embolization	30.6	8	18	[A4]
Uterine fibroid embolization	211.4	55	16	[A4]
Gastrointestinal				
Feeding tube	13	3.4	16	[H33]
Gastrostomy	13	3.4	15	[H33]
Dilation/stenting oesophagus	15	1.5	96	[H33]
Dilation pyloric stenosis	27	7	4	[H33]
Colonic stent		7		[H33]
Nerve injection	1.7	0.2	22	[C30]

Table B6. Statistics on a variety of interventional radiology and interventional neuroradiology procedures [M13]

Procedure description	*Total cases*	*DAP (cGy cm²)*				*Cumulative dose (mGy)*			
		Mean	*95% CI*	*Min*	*Max*	*Mean*	*95% CI*	*Min*	*Max*
TIPS	135	33 535	29 071, 37 999	1 427	136 443	2 039	1 760, 2 317	104	7 160
Biliary drainage	123	7 064	5 848, 8 281	302	38 631	907	730, 1 083	21	4 831
Nephrostomy, obstruction	79	2 555	1 805, 3 305	41	21 225	257	185, 328	3	2 169
Nephrostomy, stone access	64	4 514	2 859, 6 170	47	41 850	611	364, 857	10	6 178
Pulmonary angiogram, no IVC filter	106	7 731	6 520, 8 942	957	41 416	342	300, 384	34	1 479
Pulmonary angiogram, with IVC filter	17	10 826	8 072, 13 580	2 596	26 514	465	356, 575	76	987
IVC filter placement only	279	4 451	4 079, 4 822	170	20 327	166	152, 181	9	680
Renal/visceral angioplasty, no stent	53	15 749	11 633, 19 866	2 619	104 075	1 183	892, 1 474	157	5 482
Renal/visceral angioplasty, with stent	103	19 004	16 654, 21 355	983	72 420	1 605	1 375, 1 834	104	7 160
Iliac angioplasty, no stent	24	16 356	13 119, 19 592	2 060	30 099	885	729, 1 041	189	1 562
Iliac angioplasty, with stent	93	21 282	18 215, 24 350	1 148	88 650	1 335	1 141, 1 530	211	4 567
Central venous reconstruction, SVC	12	10 089	4 880, 15 298	585	27 695	573	331, 815	34	1 209
Central venous reconstruction, IVC	3	19 549		11 243	35 375	1 247		610	2 316
Aortic fenestration	2	23 358		21 403	25 312	1 178		937	1 419
Bronchial artery embolization	27	13 943	10 119, 17 767	2 821	39 289	1 123	840, 1 406	248	2 764
Hepatic chemoembolization	126	28 232	25 241, 31 224	1 712	90 415	1 406	1 216, 1 596	61	6 198
Pelvic arterial embolization, trauma	18	31 629	23 046, 40 213	9 291	62 358	1 705	1 237, 2 173	455	4 797
Pelvic arterial embolization, tumour	19	30 284	21 128, 39 441	11 002	83 811	1 846	1 338, 2 355	493	4 133
Pelvic arterial embolization, fibroids	90	29 822	25 830, 33 815	416	81 575	2 460	2 141, 2 779	15	6 990
Pelvic arterial embolization, AVM	12	48 425	34 103, 62 748	21 842	98 028	2 818	1 766, 3 871	1 071	6 149
Pelvic arterial embolization, aneurysm	4	22 385		16 497	27 900	2 599		808	3 885
Pelvic vein embolization, ovarian vein	6	41 355		12 217	102 605	2 838		1 628	5 406
Pelvic vein embolization, varicocele	14	5 082	1 753, 8 410	742	19 058	344	168, 520	41	1 007
Other tumour embolization	91	27 487	23 004, 31 970	1 668	152 005	1 579	1 298, 1 860	24	7 986
Peripheral AVM embolization	17	11 911	2 493, 21 329	330	54 129	990	245, 1 735	16	4 606
GI haemorrhage, diagnosis/therapy	94	34 757	30 599, 38 915	2 713	129 465	2 367	2 037, 2 697	105	7 160
Neuroembolization, head, AVM	177	33 976	30 313, 37 640	398	135 111	3 791	3 407, 4 175	43	13 410
Neuroembolization, head, tumour	56	35 776	30 498, 41 054	4 587	95 590	3 865	3 317, 4 414	598	10 907
Neuroembolization, head, aneurysm	149	28 269	26 113, 30 426	6 788	82 515	3 767	3 517, 4 018	1 284	9 809
Neuroembolization, spine, AVM	10	56 039	28 089, 83 989	8 079	103 399	6 288	4 219, 8 356	2 080	10 526
Neuroembolization, spine, aneurysm	1	54 014				4 214			
Neuroembolization, spine, tumour	13	47 062	29 222, 64 902	17 559	126 411	4 935	3 877, 5 993	2 380	7 504
Stroke therapy	9	19 824	11 333, 28 315	7 924	46 171	2 369	1 430, 3 309	992	4 991
Carotid stent	18	16 785	10 762, 22 807	3 193	51 544	1 382	846, 1 917	326	4 405
Vertebroplasty	98	7 813	6 578, 9 048	642	33 533	1 253	1 075, 1 431	146	3 993

Note: IVC = inferior vena cava; SVC = superior vena cava; AVM = arteriovenous malformation.

Table B7. Comparison of effective dose (mSv) for various interventional procedures [B20]

Procedure	*Reference*									
	[B20][a]	*[M14]*	*[S26][b]*	*[T12]*	*[C12]*	*[H1]*	*[M4]*	*[K14]*	*[Z5]*	*[M2]*
Hepatic	8.6/10.5	21.7	23							
Renal	11.7/13.7	6.4–13.6	16			13.6	25	6		
Thoracic	6	11.9				16.3			3.2	
Upper extremity	0.54/0.9	0.3							3.5	
Lower extremity	3.5/4.5	7.4[c]	4	4	3.1	9[d]/2.8[e]				
Carotid	2.5/4.9	4.9								
Cerebral	3.0/3.0	7.4[f]	4						4.4	3.6

a Diagnostic/therapeutic.
b Effective dose equivalent.
c Femoral angiography.
d Digital.
e Analogue.
f Therapeutic.

Table B8. Summary of patient dose data for coronary angiography examinations

DAP (Gy cm^2)	*Effective dose (mSv)*	*Patients*	*Reference*
57.8	9.4	2 174	[B19]
23.4	4.6	126	[B19]
66.5		288	[V2]
111.03		6	[V16]
147.43		3	[V16]
40.72		4	[V16]
60.21		13	[V16]
84.9		27	[D9]
76.6		45	[D9]
46		14	[V17]
60.64		62	[V18]
110.1		15	[V18]
23–79	4.6–15.8	198	[N11]
55.9		76	[P18]
27	9.2	19 215	[A15]
55	6.6	4	[H33]
26	3.1	187	[H33]
26.4		231	[H34]
30.4		8 000	[H34]
13.97	3.1	90	[L16]
63		65	[F18]
30.4	5.6	29	[B11]
18		167	[P20]
42			[H7]
29	5	20	[E6]
23.6		509	[K27]
12.7		473	[K27]
12.8		278	[K28]

DAP (Gy cm²)	*Effective dose (mSv)*	*Patients*	*Reference*
13.2		47	[K28]
47.3		195	[T18]
57		600	[N11]
49		20	[H35]
	2.5		[K29]
	2.1		[K29]
44.25		3 079	[B15]
55.9		39	[Z15]
72.63		30	[W15]

Table B9. Summary of patient dose data for PTCA examinations

DAP (Gy cm²)	*Effective dose (mSv)*	*Patients*	*Reference*
77.9	14.2	214	[B19]
51.6	10.2	11	[B19]
87.5		45	[V2]
113.21		7	[V16]
125.5		33	[D9]
59.8		37	[D9]
82.5		14	[V17]
115.23		13	[V18]
27–205	5.4–41	122	[N22]
101.9		54	[P18]
145		223	[B9]
46		17	[W11]
93		90	[M33]
51		89	[P20]
37.6	6.9	12	[F18]
50.6	9.3	6	[F18]
42			[H7]
75	14	20	[E6]
22.2		233	[K27]
14.4		269	[K27]
68		97	[T18]
63.4		334	[H34]
94		600	[N11]
40		10	[H35]
62.6		401	[B16]
50.8		180	[B16]
69.5		183	[B16]
130.5		58	[B16]
50.8	14.2	98	[B16]
128.3	10.2	121	[B16]
151.05		30	[W15]
33	11	9 692	[A15]
11.8		115	[K28]
15		30	[K28]

Table B10. Summary of patient dose data for stent procedures

DAP (Gy cm²)	*Effective dose (mSv)*	*Patients*	*Reference*
165.95	7	10	[V18]
49.2	9	14	[B11]
70.7	13	7	[B11]
41		479	[P20]
58		58	[P20]

Table B11. Summary of patient dose data for pacemaker insertions

DAP (Gy cm²)	*Effective dose (mSv)*	*Patients*	*Reference*
8.46		101	[B19]
17		627	[H34]
19		3 197	[A15]

Table B12. Summary of patient dose data for head CT examinations

DLP (mGy cm)	*Effective dose (mSv)*	*Reference*
	2.1	[P4]
739–2 130	2.8	[A8]
544	1.2	[T23]
	2.2	[N2]
610–1 684		[N3]
238–1 332	1.7	[O4]
250–1 400	1.8	[O4]
125–1 262	6.1–7.9	[M25]
183–2 173	1.6	[T20]
	1.6–2.8	[M43]
660	1.5	[H10]
36–1 180	1.7	[Y4]
	2.2	[B18]
430–758	1.4	[T19]
	1.9	[V9]
	1.5	[H14]
	1.3	[H15]
	0.9	[H36]
930	1.5	[S19]
	2.8 (neck)	[C16]
	1.4	[T22]
694	1.5	[S6]
	1.7	[C17]
	2.4	[E1]
740	0.9 (spiral)	[H5]
	1.2 (multislice)	[H5]
	1.7	[T1]

Table B13. Summary of patient dose data for body CT examinations

DLP (mGy cm)	*Effective dose (mSv)*	*Reference*
Abdomen		
	7.4	[P4]
	7.7–13.3	[M43]
	12.4–16.1	[C16]
717–1 428		[N3]
	3.1	[H14]
105–2 537	4.9–13.2	[M25]
	15.3	[N2]
470	5.3	[S19]
352	5.3	[S6]
920	10.1	[A8]
	7.2	[V9]
	9.9 (abscess)	[T22]
	14.5 (liver metastases)	[T22]
58–1 898	7.4	[T20]
	7.8	[O4]
	7.9	[O4]
	2.4	[H10]
	3.6 (contrast)	[H10]
549	8.2	[T23]
250–440	7.0	[Y4]
278–582	7.1	[T19]
880	14.9	[I4]
	3.9	[W3]
	9.7	[B18]
	11.7	[E1]
	3.5 (axial)	[H5]
	7.7 (multislice)	[H5]
Chest		
	3.9 (spiral)	[H5]
	10.5 (multislice)	[H5]
420	7.1	[T1]
	7.3	[P4]
348–807	10.9	[T19]
224–1 530	9.3	[A8]
580	5.8	[S19]
402	5.8	[S6]
	5.5	[B18]
50–2 157	8.9	[T20]
	3.8	[V9]
	7.5–12.9	[C16]
	2.3	[T22]
	4.9–7.8	[M43]
195	4.0	[H10]
70–270	3.5	[Y4]
35–240	2.2 (high resolution)	[Y4]
496–992		[N3]

DLP (mGy cm)	*Effective dose (mSv)*	*Reference*
	8.0	[O4]
	7.9	[O4]
215–766	5.5–9.7	[M25]
348	5.9	[T23]
	12.2	[N2]
399	6.8	[I4]
650	11.1	[E1]
Pelvis		
	10.3	[P4]
526–1 302		[N3]
205–910	9	[A8]
286–895	6–15.7	[M25]
67–1 984	7.7	[T20]
	8.9	[O4]
	8.8	[O4]
306–592	9.3	[T19]
	13.4	[N2]
478	8.1	[I4]
570	10.8	[E1]
Chest–abdomen–pelvis		
320–750	10.9	[Y4]
668	9.9	[S6]

Table B14. Summary of patient dose data for spine CT examinations

DLP (mGy cm)	*Effective dose (mSv)*	*Reference*
Lumbar spine		
	7.1	[P4]
455	7.2	[H10]
220–570	6.4	[Y4]
200–382		[N2]
	5.4	[N3]
166–870	4.9–8.1	[M25]
	4.5	[T22]
47–495	4.5	[O4]
49–500	4.6	[O4]
411	6.2	[I4]
800		[E1]
420	7.9	[T1]
Thoracic spine		
	13.1	[P4]
Cervical spine		
	3.4	[P4]
66–708	1.5	[O4]

Table B15. Summary of patient dose data for CT angiography examinations

DLP (mGy cm)	*Effective dose (mSv)*	*Reference*
Coronary angiography		
	7.8–8.8	[S22]
	9–29	[E4]
305	5–7 (aortic)	[H10]
	9.5	[E8]
	11.7 (calcium scoring)	[E8]
	22.8 (16 slices)	[M44]
	27.8 (64 slices)	[M44]
	14.1 (256 slices)	[M44]
	14.7	[C20]
	3.0	[H39]
	6.7–10.9 (male)	[H35]
	8.1–13 (female)	[H35]
	20.6	[N24]
	8.1 (female)	[T21]
	10.9 (male)	[T21]
	6.4 (16 slices)	[H40]
	11.0 (64 slices)	[H40]
	9.8	[D5]
Pulmonary angiography		
165	3.4	[H10]
737	19.9	[H41]
	14.4	[H21]
	4.1	[T22]
	3.0	[V9]
	4.2	[K6]
	21.5 (4 slices)	[C27]
	18.2–19.5 (16 slices)	[C27]
	5.2	[B18]

Table B16. Summary of patient dose data for various other CT examinations

DLP (mGy cm)	*Effective dose (mSv)*	*Reference*
Appendix		
	13.3	[H21]
Renal		
	4.5	[H21]
	4.6	[H10]
Liver–spleen–pancreas		
97–2 876	13	[T20]
	10.2	[V9]
900		[E1]
Kidneys		
47–2 157	11	[T20]
800		[E1]

Table B17. Summary of patient dose data for paediatric CT examinations

DLP (mGy cm)	*Effective dose (mSv)*	*Reference*
Head		
300 (<1 year)		[S21]
600 (5 years)		[S21]
750 (10 years)		[S21]
	1.3–2.3 (8 weeks)	[M43]
	1.5–2.0 (5–7 years)	[M43]
	7.6	[H15]
	6.0 (newborn)	[H14]
	4.9 (1 year)	[H14]
	4.0 (5 years)	[H14]
	2.8 (10 years)	[H14]
	1.7 (15 years)	[H14]
230 (1 year)	2.5 (1 year)	[S6]
383 (5 years)	1.5 (5 years)	[S6]
508 (10 years)	1.6 (10 years)	[S6]
	3.6 (<1 year)	[H36]
	4	[B5]
Chest		
200 (<1 year)		[S21]
400 (5 years)		[S21]
600 (10 years)		[S21]
	1.9–5.1 (8 weeks)	[M43]
	3.1–7.9 (5–7 years)	[M43]
50 (newborn)	1.7 (newborn)	[H19]
100 (1 year)	1.8 (1 year)	[H19]
140 (5 years)	2.1 (5 years)	[H19]
270 (10 years)	3.0 (10 years)	[H19]
430 (15 years)	4.1 (15 years)	[H19]
780 (18 years)	5.4 (18 years)	[H19]
	6.4 (8 weeks)	[M45]
	6.8 (7 years)	[M45]
159 (<1 year)	6.3 (<1 year)	[S6]
198 (5 years)	3.6 (5 years)	[S6]
303 (10 years)	3.9 (10 years)	[S6]
	3	[B5]
Abdomen		
330 (<1 year)		[S21]
360 (5 years)		[S21]
800 (10 years)		[S21]
	6.1 (<10 years)	[W3]
	4.4 (11–18 years)	[W3]
	4.4–9.3 (8 weeks)	[M43]
	9.2–14.1 (5–7 years)	[M43]
	5.3 (newborn)	[H14]
	4.2 (1 year)	[H14]
	3.7 (5 year)	[H14]
	3.7 (10 year)	[H14]

DLP (mGy cm)	*Effective dose (mSv)*	*Reference*
	3.6 (15 year)	[H14]
	5	[B5]
560	11	[H10]

Table B18. Effective dose from routine CT examinations in the United States according to the 2000–2001 NEXT Survey [S24]

Examination	*Percentage*[a]	*Percentage axial*	*Percentage helical*	*Axial scanning*			*Helical scanning*		
				Mean (mSv)	*SD*	*Number*	*Mean (mSv)*	*SD*	*Number*
Head (brain)	27	88	12	2	1	45	1	1	4
Abdomen–pelvis	21	35	65	17	6	16	12	7	21
Chest	11	34	66	9	4	14	6	4	22
Abdomen	10	30	70	8	4	11	6	4	19
Simple sinus	5	79	21						
Chest–abdomen–pelvis	5	34	66	28	11	10	15	10	18
Pelvis	5	31	69	7	4	11	6	4	15
Skull	5	83	17						
Spine	4	66	34						
Kidneys	2	24	76						
Liver	1	27	73						
Pancreas	1	30	70						
Other	1	40	60						

[a] The distribution of adult examinations is based on 56 facilities reporting an average of 3,165 axial and 2,680 helical examinations.

Table B19. Annual number of CT examinations in Japan [N13]

Scan region	*Male*	*Female*	*Total*
Head	8 247 000	7 763 000	16 010 000
Head–chest	203 000	162 000	365 000
Head–abdomen	98 000	69 000	167 000
Head–pelvis	40 000	31 000	71 000
Chest	2 889 000	2 115 000	5 004 000
Chest–abdomen	2 415 000	2 072 000	4 487 000
Chest–pelvis	741 000	569 000	1 310 000
Abdomen	2 963 000	2 184 000	5 147 000
Abdomen–pelvis	17 511 000	1 493 000	3 244 000
Pelvis	262 000	290 000	552 000
Other	99 000	96 000	195 000
Total	19 708 000	16 844 000	36 552 000

Table B20. CT practice in Japan: comparison of surveys [N13]

Survey year	*Number of CT scanners*	*Annual number of examinations*	*Annual number of scans*	*Collective effective dose (man Sv)*	*Per caput effective dose (mSv)*
1979 [N16]	712	1 454 000	14 850 000		
1989 [N17]	5 382	11 904 000	243 700 000	99 000	0.8
2000 [N13]	11 050	36 550 000	906 000 000	295 000	2.3

Table B21. Summary of measurements undertaken on multislice CT scanners in Germany in 2002
Data provided from 113 CT scanners [B18]

Examination	*Relative frequency (%)*	*Number of centres providing data*	*Effective dose/series (mSv)*	*Effective dose/examination (mSv)*
Brain	27.1	104	2.2	2.8
Face and sinuses	4.4	102	0.8	0.8
Face and neck	3.6	99	1.9	2
Chest	15.7	108	5.5	5.7
Abdomen–pelvis	17.6	106	9.7	14.4
Pelvis	2.6	94	6.3	7.2
Liver–kidney	5.9	103	5.5	11.5
Whole trunk	4.1	76	14.5	17.8
Aorta thoracic	1.4	90	6.1	6.7
Aorta abdomen	1.8	91	9	10.3
Pulmonary vessels	1.8	91	5.2	5.4
Pelvis skeleton	1.5	88	8.2	8.2
Cervical spine	3.2	103	2.9	2.9
Lumbar spine	5.9	107	8.1	8.1

Table B22. Summary of measurements undertaken on single-slice spiral CT scanners in Germany
Data provided from 398 CT scanners installed between January 1996 and June 1999 [B18]

Examination	*Number of centres providing data*	*Effective dose/series (mSv)*	*Effective dose/examination (mSv)*
Brain	387	1.9	2.8
Face and sinuses	379	1	1.1
Face and neck	365	1.7	2
Chest	385	5.2	6.2
Abdomen–pelvis	377	10.3	17.2
Pelvis	367	6.9	8.8
Liver–kidney	375	4.6	8.7
Whole trunk	139	14.9	20.5
Aorta thoracic	193	5	5.8
Aorta abdomen	203	6.3	7.6
Pulmonary vessels	180	3.3	3.6
Pelvis skeleton	328	8.6	8.8
Cervical spine	331	2.1	2.1
Lumbar spine	384	2.7	2.7

Table B23. Representative adult effective dose for various CT procedures [M41]

Examination	*Effective dose (mSv)*	*Reported range (mSv)*
Head	2	0.9–4.0
Neck	3	
Chest	7	4.0–18.0
Pulmonary embolism	15	13–40
Abdomen	8	3.5–25
Pelvis	6	3.3–10
Liver (3-phase)	15	5.0–25
Spine	6	1.5–10
Coronary angiogram	16	5.0–32
Calcium scoring	3	1.0–12
Virtual colonoscopy	10	4.0–13.2
Dental	0.2	

Table B24. Comparison of effective dose from various types of dental X-ray equipment [C5]

Equipment	*DVT old, soft tissue*	*DVT new, soft tissue*	*Orthophos CT*	*Dental CT 94 mA*	*Dental CT 60 mA*	*Dental CT 43 mA*	*Dental multislice CT*	*Sinus CT 94 mA*
Effective dose (mSv)	0.1	0.11	0.01	0.61	0.36	0.15	0.74	1.27

Table B25. Comparison of mean DWPs for panoramic dental radiography examinations [D13]

Study	*Sample size*	*Mean DWP (mGy mm)*	*Mean DAP (mGy cm²)*
[D13]	20	65	89
[N15]	387	57	
[I33]	5	74	
[P13]	6		113
[W17]	16	65	113
[O6]	26	69	
[T13] (male)	62		101
[T13] (female)	62		85

Table B26. Effective dose for pencil and fan beam DEXA (premenopausal women) [N5]

Type of machine	*Scan type*	*Effective dose (mSv)*
Pencil beam	Total body	4.6
	AP spine (L1–L4)	0.5
	Lateral spine (L2–L4)	0.6
	Proximal femur	1.4
Fan beam	PA spine (L1–L4)	0.4–2.9
	Lateral spine (L2–L4)	1.2–2.5
	Proximal femur	3.0–5.9
	Total body	3.6

Table B27. Mean ESD per radiograph for paediatric patients [N2]

Examination	*Age (years)*	*Mean ESD (mGy)*
Abdomen AP	0	110
	1	340
	5	590
	10	860
	15	2 010
Chest AP/PA	0	60
	1	80
	5	110
	10	70
	15	110
Pelvis AP	0	170
	1	350
	5	510
	10	650
	15	1 300
Skull AP	1	600
	5	1 250
Skull LAT	1	340
	5	580

Table B28. DAP for common paediatric fluoroscopic examinations [N2]

Examination	*Age (years)*	*Normalized DAP per examination (mGy cm^2)*
MCU	0	430
	1	810
	5	940
	10	1 640
	15	3 410
Barium meal	0	760
	1	1 610
	5	1 620
	10	3 190
	15	5 670
Barium swallow	0	560
	1	1 150
	5	1 010
	10	2 400
	15	3 170

Table B29. Patient dose survey of paediatric radiology in a Madrid hospital [V10]

Examination	*Age (years)*	*Sample size*	*Median ESD (mGy)*
Chest (no bucky)	0–1	1 180	41
	1–5	309	34
	6–10	143	54
	10–15	92	10

Examination	*Age (years)*	*Sample size*	*Median ESD (mGy)*
Chest (with bucky)	1–5	181	87
	6–10	255	105
	11–15	363	170
Abdomen	0–1	93	91
	1–5	30	225
	6–10	69	600
	11–15	150	1 508
Pelvis	0–1	254	48
	1–5	128	314
	6–10	122	702
	11–15	137	1 595

Table B30. Effective dose for seven selected paediatric cardiac interventions [O10]

Procedure	*Number*	*Effective dose (mSv)*
ASD occlusion	259	3.88
PDA occlusion	165	3.21
Balloon dilation	122	4.4
Coil embolization	33	4.58
VSD occlusion	32	12.1
Atrial septostomy	25	3.62
PFO occlusion	21	2.16

ASD = atrial septal defect; PDA = patent ductus; VSD = ventricular septal defect; PFO = patent foramen ovale.

Table B31. Comparison of mean and reported typical mean foetal doses per examination [O1]

Examination	*Mean (from [O1]) (mGy)*	*Reported typical mean from literature (mGy)*
Abdomen AP	2.9	1.9 [S7]
Abdomen PA	1.3	0.53 [S7]
Abdomen	2.6	2.5 [W6]
Chest AP	<0.01	<0.01 [S7]
Chest PA	<0.01	<0.01 [S7]
Chest	<0.01	0.01 [W6]
Lumbar spine AP	7.5	1.9 [S7]
Lumbar spine LAT	0.91	0.41 [S7]
Lumbar spine	4.2	4.0 [W6]
Lumbosacral joint LAT	1.1	0.56 [S7]
Pelvis AP	3.4	2.0 [W6]
Thoracic spine AP	<0.01	<0.01 [S7]
Thoracic spine PA	<0.01	<0.01 [S7]
Thoracic spine	<0.01	<0.1 [W6]

Table B32. Estimated number of procedures per million population and total number of procedures in 2006 for various European countries [F19]

Country	*Number of procedures/million population*				*Population*	*Total number of procedures*			
	CA	*PTCA*	*Stent*	*Pacemaker*		*CA*	*PTCA*	*Stent*	*Pacemaker*
Austria	7 476	2 110	1 561	*1 413*	8 192 880	61 246	17 287	12 792	*11 577*
Belgium	6 842	2 190	1 328	1 222	10 379 067	71 017	22 729	13 779	12 683
Bulgaria	*670*	186[a]	*134*	*124*	7 385 367	*4 948*	1 373	*990*	*916*
Croatia	*3 816*	1 060	*763*	*710*	4 494 749	*17 150*	4 764	*3 430*	*3 191*
Czech Republic	4 642	1 483	1 033	1 041	10 235 455	47 512	15 175	10 568	10 655
Denmark	*6 448*	1 791	*1 290*	*1 199*	5 450 661	*35 143*	9 762	*7 029*	*6 535*
Estonia	2 906	738	449	692	1 324 333	3 849	978	595	916
Finland	7 997	1 926	1 158	1 143	5 231 372	41 834	10 074	6 059	5 979
France	5 955	2 318	2 230	1 185	60 876 136	362 540	141 084	135 772	72 138
Germany	*11 646*	3 235	*2 329*	2 167	82 422 299	*959 987*	266 663	*191 962*	178 609
Greece	2 931	674	569	781	10 688 058	31 325	7 205	6 077	8 347
Hungary	2 535	378	290	559	9 981 334	25 305	3 772	2 893	5 580
Iceland	6 522	2 658	1 975	827	299 388	1 952	796	591	248
Ireland	*2 851*	792[a]	*570*	*530*	4 062 235	*11 581*	3 217	*2 315*	*2 153*
Israel	7 353	3 704	*2 667*	*2 481*	6 352 117	46 704	23 528	*16 940*	*15 760*
Italy	4 556	1 540	*1 109*	*1 032*	58 133 509	264 854	89 548	*64 475*	*59 994*
Latvia	2 550	830	591	576	2 274 735	5 802	1 888	1 345	1 310
Lithuania	3 182	1 027	249	488	3 585 906	11 410	3 684	893	1 750
Netherlands	*5 098*	1 416	*1 020*	*948*	16 491 461	*84 092*	23 359	*16 818*	*15 634*
Poland	2 919	1 012	572	688	38 536 869	112 499	38 992	22 027	26 513
Portugal	3 157	825	703	599	10 605 870	33 487	8 749	7 459	6 353
Romania	1 421	207	200	142	22 303 552	31 698	4 617	4 455	3 167
San Marino	3 243	1 135	1 135	*760*	29 251	95	33	33	*22*
Spain	2 662	939	726	601	40 397 842	107 543	37 950	29 317	24 279
Sweden	*5 278*	1 466	*1 056*	982	9 016 596	*47 570*	13 214	*9 514*	8 854
Switzerland	6 241	2 169	1 583	713	7 523 934	46 958	16 319	11 913	5 365
Turkey	3 026	558	336	53	70 413 958	213 101	39 257	23 640	3 732
The former Yugoslav Republic of Macedonia	1 402	601	559	116	2 050 554	2 876	1 232	1 146	238
United Kingdom	*3 096*	860	722	497	60 609 153	*187 646*	52 124	43 785	30 123
				Total	569 348 641	2 871 726	859 373	648 612	522 621

Note: Data in italics estimated using average ratio of coronary angiograms to PTCAs (3.6), stents to PTCAs (0.72) and pacemakers to PTCAs (0.67) as appropriate.
[a] Estimated from 2000 data using an average rate.

Table B33. Population distribution over the four health-care levels as used in global assessments of medical exposures

Year	*Percentage of population by health-care level*				*Global population (millions)*	*Reference*
	I	*II*	*III*	*IV*		
1977	29	35	23	13	4 200	[U9]
1984	27	50	15	8	5 000	[U7]
1990	25	50	16	9	5 290	[U6]
1996	26	53	11	10	5 800	[U3]
2007	24	49	16	11	6 446	Present

Table B34. Physicians and health-care professionals

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country/area	*Population (thousands)*	*Number*						
		All physicians	*Physicians conducting radiological procedures*	*Radiology-technicians*	*Medical-physicists*	*Interventional cardiologists*	*Other physicians performing radiology*	*Dentists*
Health-care level I								
Albania	3 200		160	120	6	6		
Australia	20 406	59 023	1 201		392			8 800
Austria	8 200	37 000	1 030	2 200	70	200	800	4 500
Belgium	10 300	42 978	1 690		155	888		8 450
Bulgaria	8 149	27 526	815					6 778
Croatia	4 437	12 830	485	947	22	28	97	3 445
Czech Republic	10 290	35 960	1 299	3 257	199	434	522	6 429
Estonia	1 370	4 300	192	371	20	14	44	1 200
Finland	5 250	14 661	770	3 892	88	90		6 113
France	61 700	205 000	7 590	23 380	347	500	13 600	41 250
Germany	82 501	306 435	6 314	31 000	635		19 000	65 000
Greece	11 000	55 000	1 800	2 500	350	2 400		12 000
Hungary	9 981	36 907	1 171	3 000	60	65	500	5 156
Iceland	294	1 120	35	170	10	15	25	350
Japan	127 435	262 687	4 710	41 549	117			92 874
Korea, Rep.	48 497	127 158	2 434	14 291	56	294	24 021	22 366
Latvia	2 295	8 956	277	7 236	393	21		1 415
Lithuania	3 491	14 034	394	1 228	9	36	209	2 446
Luxembourg	452	1 422	54	165	5	12	183	312
Malta	400	1 407	26	164	3	5	16	195
Netherlands	15 638	46 000	730		110			6 344
New Zealand	3 737	8 615	215	1 600	32	74	200	1 591
Norway	4 640	18 404	476	2 350	75	52	756	4 140
Russian Federation	146 700	607 000	14 860	26 880	150		320	42 200
Slovenia	2 003	4 671	300	457	15		50	1 233
Spain	44 109	194 668	3 655	6 093	579	347	3 371	21 055
Sweden	8 861	32 000	1 300	3 000	200			11 000
Switzerland	7 461	28 251	517	5 100	60	205	4 500	4 500
The former Yugoslav Republic of Macedonia	2 033	5 131	113	287	13	24	74	1 602
United Kingdom	59 500	100 000	2 750	19 000	1 100			21 000
Venezuela (Bolivarian Rep. of)	27 031		1 072					208
Health-care level II								
Azerbaijan	7 962			4	3			
Brazil	186 771	466 111			299			56 995
Chile	15 116	15 195	700		10			8 748
China	1 248 100	1 999 521		126 173				
Colombia	41 468	13 471	5 544					20 328
Costa Rica	4 326	6 812	103	386	5	63		2 696
El Salvador	6 500	7 000	60	600	10	8	30	5 000
Malaysia	26 909	14 986	275	1 799	47	35	54	3 989
Mauritius	1 200		18	115	3	12		106
Oman	2 018	3 248	40	334	3		2	262

Country/area	Population (thousands)	Number						
		All physicians	Physicians conducting radiological procedures	Radiology-technicians	Medical-physicists	Interventional cardiologists	Other physicians performing radiology	Dentists
Thailand	60 607	16 569	329	3 885	98	110	860	3 414
Trinidad and Tobago	1 262	2 667	5	125	5	7	187	295
Tunisia	9 650	8 000	178	3 000	15	10		1 180
Turkey	67 800	81 988	3 500	16 000	130			14 226
Health-care level III								
Zimbabwe	12 000	13	15	180	4			200
Health-care level IV								
Maldives	300	18	3	23	0	1	0	10

Table B35. Physicians and health-care professionals per million population
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country/area	Population (thousands)	Number per million population						
		All physicians	Physicians conducting radiological procedures	Radiology-technicians	Medical-physicists	Interventional cardiologists	Other physicians performing radiology	Dentists
Health-care level I								
Albania	3 200			38	2	2		
Australia	20 406	2 892	59		19			431
Austria	8 200	4 512	126	268	9	24	98	549
Belgium	10 300	4 173	164		15	86		820
Bulgaria	8 149	3 378	100					832
Croatia	4 437	2 892	109	213	5	6	22	776
Czech Republic	10 290	3 495	126	317	19	42	51	625
Estonia	1 370	3 139	140	271	15	10	32	876
Finland	5 250	2 793	147	741	17	17		1 164
France	61 700	3 323	123	379	6	8		669
Germany	82 501	3 714	77	376	8		230	788
Greece	11 000	5 000	164	227	32	218		1 091
Hungary	9 981	3 698	117	301	6	7	50	517
Iceland	294	3 810	119	578	34	51	85	1 190
Japan	127 435	2 061	37	326	1			729
Korea, Rep.	48 497	2 622	50	295	1			461
Latvia	2 295	3 902	121	171	(3 153)	9		617
Lithuania	3 491	4 020	113	352	3	10	60	701
Luxembourg	452	3 146	119	365	11	27	405	690
Malta	400	3 518	65	410	8	13	40	488
Netherlands	15 638	2 942	47		7			406
New Zealand	3 737	2 305	58	428	9	20	54	426
Norway	4 640	3 966	103	506	16	11	163	892
Russian Federation	146 700	4 138	101	183	1		2	288
Slovenia	2 003	2 332	150	228	7		25	616
Spain	44 109	4 413	83	138	13	8	76	477

Country/area	*Population (thousands)*	*Number per million population*						
		All physicians	*Physicians conducting radiological procedures*	*Radiology-technicians*	*Medical-physicists*	*Interventional cardiologists*	*Other physicians performing radiology*	*Dentists*
Sweden	8 861	3 611	147	34	23			1 241
Switzerland	7 461	3 786	69	684	8	27	603	603
The former Yugoslav Republic of Macedonia	2 033	2 524	56	141	6	12	36	788
United Kingdom	59 500	1 681	46	319	18			353
Venezuela (Bolivarian Republic of)	27 031		40					8
Weighted average		3 530	77	370	7	40	92	540
Health-care level II								
Azerbaijan	7 962			1	0			
Brazil	186 771	2 496			2			305
Chile	15 116	1 005	46		1			579
China	1 248 100	1 602		101				
Colombia	41 468	325	134	42	0			490
Costa Rica	4 326	1 575	24	89	1	15		623
El Salvador	6 500	1 077	9	92	2	1	5	769
Malaysia	26 909	557	10	67	2	1	2	148
Mauritius	1 200		15	96	3	10		88
Oman	2 018	1 610	20	166	1		1	130
Thailand	60 607	273	5	64	2	2	14	56
Trinidad and Tobago	1 262	2 113	4	99	4	6	148	234
Tunisia	9 650	829	18	311	2	1		122
Turkey	67 800	1 209	52	236	2			210
Weighted average		1 600	45	100	1	2	12	280
Health-care level III								
Zimbabwe	12 000	1.1	1.3	15.0	0.3			16.7
Weighted average		1.1	1.3	15	0.3			17
Health-care level IV								
Maldives	300	60	10	76.7	0	3.3	0	33.3
Weighted average		60	10	77	0	3.3	0	33

Note: Value for Latvia excluded from the calculation of the population-weighted mean.

Table B36. Number of items of diagnostic X-ray equipment in various countries

Country	*X-ray generators*						*Bone densitometry*	*CT scanners*
	Medical	*Mammo-graphy*	*Dental*	*Interventional*	*General fluoroscopy*	*Angiography*		
Health-care level I								
Albania	9	10	100	1	11		1	17
Australia	3 938	400	10 100					500
Austria	2 230	420	10 000		13 000	150	120	250
Belgium	2 241	283	3 914			24	185	204
Bulgaria	1 498	79	455	11			5	32
Croatia	552	137	593	17	3	27	45	65
Czech Republic	1 981	137	4 670		323	63	52	126
Estonia	80	6	588	17	29	5	5	10
Finland	1 079	198	5 200			28	86	80
France	13 061	2 538	33 245					608
Germany	23 000	3 100	72 600		7 000	1 900		2 800
Greece	1 373	433	10 000	180	200	80	396	286
Hungary	1 800	100	2 600	35	300	50	53	60
Iceland	46	5	360		7		3	6
Japan	88 000	2 905	131 300			3 223	9 381	11 803
Korea, Rep.	15 599	1 493	24 592	119	5 939	166	1 734	1 491
Latvia	370	34	610	6	20	3	8	41
Lithuania	797	26	578					23
Luxembourg	61	10	426	6	40	6	1	12
Malta	57	13	149	3	10	3	6	10
New Zealand	665	96	2 228	23			43	45
Norway	830	87	6 400	75	200			124
Romania	1 305	114	634	5	901	24	25	107
Russian Federation	18 564	1 167	5 835	480	11 000	243	30	378
Slovakia	650	102	750	8	350	40	40	94
Slovenia	257	34	376	13		8	34	20
Spain	12 438	1 093	18 486	32	1 253		382	566
Sweden	1 200	180	12 000	30			40	130
Switzerland	5 134	239	9 846	1 337	1 300	37	135	214
The former Yugoslav Republic of Macedonia	140	15	136	66	61	5	2	13
United Kingdom								400
Venezuela (Bolivarian Republic of)	506	90	217		60	10	31	64
Health-care level II								
Azerbaijan	6	2	-					
Brazil	18 229	3 057	20 610		1 402	535	932	2 043
Chile	1 424	279	815	16	69	42	78	161
China	59 000	750	2 450					3 712
Colombia	1 833	98	2 526	5				106
Costa Rica	284	46	648	12	29	29	13	12
El Salvador	113	38	500	5	53	5	4	17
Mauritius	47	2	60	11				2

Country	*X-ray generators*						*Bone densitometry*	*CT scanners*
	Medical	*Mammo-graphy*	*Dental*	*Interventional*	*General fluoroscopy*	*Angiography*		
Oman	159	4	33	2			1	6
Thailand	2 866	100	1 678	1 700				261
Trinidad and Tobago	50	24	90	5	15		4	8
Tunisia	1 128	77	763	21			7	88
Turkey	3 915	433	1 100	181			251	685
Health-care level III								
Zimbabwe	250	2	200	2	30	15		8
Health-care level IV								
Maldives	16	1.0	2.0	0.0	1.0	0.0	1.0	1.0

Note: For some countries, the number of items of conventional equipment also includes the number of digital machines.

Table B37. Number of items of digital diagnostic equipment in various countries

Country	*Digital systems*					
	General	*Mammography*	*Dental*	*Interventional*	*General fluoroscopy*	*Angiography*
Health-care level I						
Albania	92	3		1	50	1
Australia	31					
Bulgaria	28	1	17	8		
Czech Republic				36		
Estonia	26			6	10	1
Finland						81
Hungary	15			3	15	3
Iceland	30					6
Japan	2 082				2 649	
Latvia					7	2
Luxembourg	3	0		2		
New Zealand		0	3			
Romania	59	0	0	2		2
Russian Federation	221		528			
Spain	2 548	400	1 180	273	1 110	
Sweden	400	2	200	20		
Venezuela (Bolivarian Rep. of)			43			
Health-care level II						
Costa Rica						
El Salvador	15					
Mauritius	0	0	0	0	0	0
Oman	2					
Trinidad and Tobago			20		3	4
Tunisia	10					

Note: For some countries, the number of items of conventional equipment also includes the number of digital machines.

Table B38. Number of items of diagnostic X-ray equipment in various countries per million population

Country	*X-ray generators*						*Bone densitometry*	*CT scanners*
	Medical	*Mammography*	*Dental*	*Interventional*	*General fluoroscopy*	*Angiography*		
Health-care level I								
Albania	2.8	3.1	31.3	0.3	3.4		0.3	5.3
Australia	193.0	19.6	495.0					24.5
Austria	272	51	1 220		159	18	15	31
Belgium	217.6	27.5	380.0			2.3	18.0	19.8
Bulgaria	183.8	9.7	55.8	1.3			0.6	3.9
Croatia	124.4	30.9	133.6	3.8	0.7	6.1	10.1	14.6
Czech Republic	192.5	13.3	453.8		31.4	6.1	5.1	12.2
Estonia	58.4	4.4	429.2	12.4	21.2	3.6	3.6	7.3
Finland	205.5	37.7	990.5			5.3	16.4	15.2
France	211.7	41.1	538.8					9.9
Germany	278.8	37.6	880.0		84.8	23.0		33.9
Greece	124.8	39.4	909.1	16.4	18.2	7.3	36.0	26.0
Hungary	180.3	10.0	260.5	3.5	30.1	5.0	5.3	6.0
Iceland	156.5	17.0	1 224.5		23.8		10.2	20.4
Japan	690.5	22.8	1 030.3			25.3	73.6	92.6
Korea, Rep.	321.6	30.8	507.1	2.5	122.5	3.4	35.8	30.7
Latvia	161.2	14.8	265.8	2.6	8.7	1.3	3.5	17.9
Lithuania	228.3	7.4	165.6					6.6
Luxembourg	135.0	22.1	942.5	13.3	88.5	13.3	2.2	26.5
Malta	142.5	32.5	372.5	7.5	25.0	7.5	15.0	25.0
Netherlands	179.1							
New Zealand	178.0	25.7	596.2	6.2			11.5	12.0
Norway	178.9	18.8	1 379.3	16.2	43.1			26.7
Russian Federation	126.5	8.0	39.8	3.3	75.0	1.7	0.2	2.6
Slovakia	119.5							
Slovenia	128.3	17.0	187.7	6.5		4.0	17.0	10.0
Spain	282.0	24.8	419.1	0.7	28.4		8.7	12.8
Sweden	135.4	20.3	1 354.2	3.4			4.5	14.7
Switzerland	688.1	32.0	1 319.7	179.2	174.2	5.0	18.1	28.7
The former Yugoslav Republic of Macedonia	68.9	7.4	66.9	32.5	30.0	2.5	1.0	6.4
United Kingdom								6.7
Venezuela (Bolivarian Republic of)	18.7	3.3	8.0		2.2		1.1	2.4
Weighted average	370	28	660	8.5	96	15	27	32
Health-care level II								
Azerbaijan	0.8	0.3	0.0					0.0
Brazil	97.6	16.4	110.3		7.5	2.9	5.0	10.9
Chile	94.2	18.5	53.9	1.1	4.6	2.8	5.2	10.7
China	47.3	0.6	2.0					3.0
Colombia	44.2	2.4	60.9	0.1				2.6
Costa Rica	65.6	10.6	149.8	2.8	6.7	6.7	3.0	2.8
El Salvador	17.4	5.8	76.9	0.8	8.2	0.8	0.6	2.6
Mauritius	39.2	1.7	50.0	9.2				1.7
Oman	78.8	2.0	16.4	1.0			0.5	3.0

Country	*X-ray generators*						*Bone densitometry*	*CT scanners*
	Medical	*Mammography*	*Dental*	*Interventional*	*General fluoroscopy*	*Angiography*		
Thailand	47.3	1.6	27.7	28.0				4.3
Trinidad and Tobago	39.6	19.0	71.3	4.0	11.9		3.2	6.3
Tunisia	116.9	8.0	79.1	2.2			0.7	9.1
Turkey	57.7	6.4	16.2	2.7			3.7	
Weighted average	47	0.9	4.4	0.6	1.2	0.5	0.7	3.1
Health-care level III								
Zimbabwe	20.8	0.2	16.7	0.2	2.5	1.3		0.7
Average	21	0.2	17	0.2	2.5	1.3		0.7
Health-care level IV								
Maldives	53.3	3.3	6.7	0.0	3.3	0.0	3.3	3.3
Average	53	3.3	6.7	0.0	3.3	0.0	3.3	3.3

Table B39. Number of items of digital diagnostic equipment in various countries per million population

Country	*Digital systems*					
	General	*Mammography*	*Dental*	*Interventional*	*General fluoroscopy*	*Angiography*
Health-care level I						
Albania	28.8	0.9		0.3	15.6	0.3
Australia	1.5					
Bulgaria	3.4	0.1	2.1	1.0		
Czech Republic				3.5		
Estonia	19.0			4.4	7.3	0.7
Finland	0.0					15.4
Hungary	1.5			0.3	1.5	0.3
Iceland	102.0					20.4
Japan	16.3				20.8	
Latvia					3.1	0.9
Luxembourg	6.6	0.0		4.4		
New Zealand		0.0	0.8			
Romania	2.7	0.0	0.0	0.1		0.1
Russian Federation	1.5		3.6			
Spain	57.8	9.1	26.8	6.2	25.2	
Sweden	45.1	0.2	22.6	2.3		
Venezuela (Bolivarian Republic of)	0.0	0.0	1.6			
Weighted average	14	4.5	7.6	3.2	20	2.2
Health-care level II						
El Salvador	2.3					
Mauritius	0.0	0.0	0.0	0.0	0.0	0.0
Trinidad and Tobago			15.8		2.4	3.2
Tunisia	1.0					
Weighted average	1.4	0.0	8.1	0.0	1.2	1.6

Table B40. Trends in average provision of medical radiology per million population
Data from the UNSCEAR Global Surveys of Medical Radiation Usage and Exposures

Resource	*Years*	*Number per million population at health-care level*			
		I	*II*	*III*	*IV*
Physicians	1985–1990	2 600	550	180	53
	1991–1996	2 780	695	210	45
	1997–2007	3 530	1 580	1.1	60
Physicians conducting radiological procedures	1970–1974	62	23		
	1980–1984	76	64	4	
	1985–1990	72	41	6	0.3
	1991–1996	106	76	5	0.1
	1997–2007	77	45	1	10
Dentists	1991–1996	530	87	49	3
	1997–2007	540	280	17	33
Medical physicists	1997–2007	7	1.5	0.3	0
Radiology technicians	1997–2007	370	100	15	77
Diagnostic radiology physicians	1997–2007	77	45	1.3	10
Interventional cardiologists	1997–2007	40	2.2		3.3
Medical X-ray generators, conventional	1970–1974	450	14		0.6
	1980–1984	380	71	16	10
	1985–1990	350	86	18	4
	1991–1996	290	60	40	4
	1997–2007	370	47	21	53
Mammography X-ray generators, conventional	1991–1996	24	0.5	0.2	0.1
	1997–2007	28	0.9	0.2	3.3
Dental X-ray generators, conventional	1970–1974	440	12		0.04
	1980–1984	460	77	5	
	1985–1990	380	86	3	0.4
	1991–1996	440	56	11	0.1
	1997–2007	660	4	17	6.7
Interventional radiology systems, conventional	1997–2007	8.5	0.6	0.2	0.0
CT scanners	1991–1996	17	2.4	0.4	0.1
	1997–2007	32	3.1	0.7	3.3
General X-ray generators, digital	1997–2007	14	1.4		
Mammography, digital	1997–2007	4.5	0.0		
Dental, digital	1997–2007	7.6	8.1		
Interventional radiology, digital	1997–2007	3.2	0.0		
Bone mineral densitometry	1997–2007	27	0.7		3.3

Table B41a. Annual number of medical radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Chest*				*Limbs and joints*	*Spine*					
		Chest PA	*Chest LAT*	*Photo-fluorography*	*Fluoroscopy*		*Lumbar AP/PA*	*Lumbar LAT*	*Thoracic AP*	*Thoracic LAT*	*Cervical AP*	*Cervical LAT*
I	Australia	2 208 100	1 464 300			3 256 400	822 100		455 900		523 200	
	Austria	1 977 000	1 200 000			1 718 000	400 000	392 000	222 000	207 000	332 000	325 000
	Belgium	2 533 800	1 637 700	412		2 811 900	391 400	391 400	195 700	195 700	350 200	350 200
	Bulgaria	569 187	243 937	94 126	33 745	635 511	45 880	107 056	15 746	63 058	30 242	56 165
	Croatia	676 834	378 674		32 381	1 545 721						
	Czech Republic	1 060 106	58 102		43 489	1 572 134	268 128	200 112	16 100	8 414	112 621	143 114
	Finland	1 173 914				1 102 625	156 261		31 310		76 736	
	France	5 600 000				14 000 000	7 900 000					
	Germany	17 134 400				21 195 500	3 940 700		2 055 100		4 491 500	
	Greece	3 400 000				1 500 000	800 000					
	Hungary	4 794 000	463 000	301 000	550 000	2 161 000	14 000	442 000	13 000	244 000	13 000	287 000
	Iceland	47 992				55 062	6 017		2 503		3 540	
	Japan	83 271 000			397 000	20 817 000	10 060 000		2 488 000		6 609 000	
	Korea, Rep.	18 408 379	2 125 281				3 542 052	2 727 445	873 330	875 428	2 101 582	2 083 825
	Latvia	464 404		320 196		734 261						
	Lithuana	440 451		1 142 015	170 753	1 414 331						
	Luxembourg	53 412	21 419			109 353	25 138		7 915		12 812	
	Malta	33 053	574	0	0	23 603	2 962	2 962	732	732	1 666	1 656
	Netherlands	2 600 000										
	Norway	185 256	545 050			886 887	161 058		40 018		92 562	
	Romania	997 265	314 207	1 385 085	1 962 670	1 740 362	183 739	341 123	71 400	144 964	214 543	143 028
	Russian Federation	10 500 000	8 540 000	59 700 000	2 600 000	2 940 000	2 770 000	1 700 000	2 230 000	759 000	2 360 000	1 940 000
	Slovenia	388 000	121 000			452 000	117 000	125 000	51 000	51 000	145 000	151 000
	Spain	14 391 203	6 460 927			1 919 608	1 066 753	787 090	869 715	602 227	1 988 509	628 466
	Sweden	841 000	841 000	0	0	1 338 000	170 000	170 000	76 000	76 000	90 700	90 700
	Switzerland	1 400 000	350 000	51 000	3 200	1 940 000	279 000	279 000	82 000	82 000	195 000	195 000
	The former Yugoslav Republic of Macedonia	4 320				5 760						
	United Kingdom	8 300 000	-	-		7 700 000	825 000		281 000		859 000	

Health-care level	*Country*	*Chest*				*Limbs and joints*	*Spine*					
		Chest PA	*Chest LAT*	*Photo-fluorography*	*Fluoroscopy*		*Lumbar AP/PA*	*Lumbar LAT*	*Thoracic AP*	*Thoracic LAT*	*Cervical AP*	*Cervical LAT*
II	Costa Rica	60 629	45 897	0	6	34 088	7 020	7 020	3 500	3 500	3 516	3 516
	El Salvador	1 823 400	455 800		386	189 800	34 200	34 200	5 700	5 700	17 100	17 100
	Mauritius	64 500	3 200	0	0	163 600	38 760					
	Oman	163 677				216 475				77 169		
	Trinidad and Tobago	65 764	17 764				27 363		13 048		24 514	
III	Zimbabwe	20 000	4 000	10 000	0	3 500	10 000	10 000	8 000	8 000	15 000	15 000
IV	Maldives	494	237			8 456	1 550	1 551	270	269	716	781

Table B41b. Annual number of medical radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Pelvis/hip*	*Head*	*Abdomen*	*Upper GI*	*Lower GI*	*Cholecystography*	*Urography*	*Mammography*	
									Screening	*Clinical diagnosis*
I	Australia	953 300	385 500	242 000			2 790	52 200	800 000	337 000
	Austria	498 000	338 000	156 000	113 000	149 000	20 000	131 000	630 000	410 000
	Belgium	906 400	319 300	494 400	91 670	81 370	7 210	97 850	72 100	947 600
	Bulgaria	123 631	157 725	81 449	105 328	59 267	3 521	31 572	57 066	40 244
	Croatia			68 188	85 611	28 271	1 363	66 464		250 962
	Czech Republic	317 354	417 220	156 953	34 553	52 867	10 954	66 703		248 602
	Finland	180 644	396 993	55 159	5 361	13 625	4 321	7 037	197 712	93 117
	France	4 300 000	2 300 000	2 500 000					5 600 000	
	Germany	6 975 000	3 751 100	2 570 000	302 400	571 800	95 000	1 208 300	5 150 300	
	Greece	320 000	430 000		170 000					195 000
	Hungary	533 000	633 000	471 000	99 000	22 000	1 600	47 000	253 000	1 506 000
	Iceland	2 517	6 297	3 996	1 161	1 437		2 146	14 872	500
	Japan	3 589 000	8 461 000	16 210 000	15 000 000	2 270 000	553 000	1 442 000		844 000
	Korea, Rep.	2 249 892	4 314 452	4 323 800						
	Latvia			277 873	24 969	9 044	754	44 977	85 915	
	Lithuania			264 046				90 888	85 944	

Health-care level	*Country*	*Pelvis/hip*	*Head*	*Abdomen*	*Upper GI*	*Lower GI*	*Cholecystography*	*Urography*	*Mammography*	
									Screening	*Clinical diagnosis*
I	Luxembourg	29 612	9 582	8 880	2 396	1 095	158	6 921	12 252	11 271
	Malta	1 238	3 713	8 473	1 850	1 622	0	1 632	5 059	1 604
	Netherlands								700 000	250 000
	Norway	340 969	31 300	45 808	10 733	28 245		24 628	1 485 263	2 005 303
	Romania	274 433	601 641	70 604	749 516	252 805	19 658	248 250		90 388
	Russian Federation	2 420 000	6 060 000	808 000	1 710 000	855 000	162 000	804 000	239 000	871 000
	Slovenia	219 000	182 000	40 000						60 000
	Spain	981 484	628 316	933 446	446 020	359 087	38 858	272 681	1 368 981	1 473 994
	Sweden	420 000	73 000	63 000	63 600	70 000		75 000	520 000	260 000
	Switzerland	312 000	160 000	92 000	13 000	16 000	6 000	42 000		265 000
	The former Yugoslav Republic of Macedonia			2 880				1 728	8 640	
	United Kingdom	1 773 000	1 118 000	1 217 000	222 000	400 000	68 000	258 000	1 334 000	390 000
II	Costa Rica	5 267	11 456	10 326	891	1 629	251	736	5 250	5 250
	El Salvador	28 500	61 940	61 940	171 000	114 000	142 500	142 500	158 680	68 000
	Mauritius		49 800	20 900	2 320			760	0	253
	Oman	19 064	64 589	47 044	4 761		193	3 817	1 206	
	Trinidad and Tobago	16 673	14 015	24 380	1 990	1 317		1 758	2 196	
III	Zimbabwe	25 000	30 000	20 000	5 000	5 000	0	10 000	10 000	10 000
IV	Maldives	586	1 688	1 333	56	52		19		

Table B41c. Annual number of medical radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*CT*							*Interventional procedures*				*Angiography*	
		Head	*Thorax*	*Abdomen*	*Spine*	*Pelvis*	*Inter-ventional*	*Other*	*PTCA*	*Cerebral*	*Vascular*	*Others*	*Non-cardiac*	*Cardiac*
I	Australia												67 400	31 500
	Austria	218 000	101 000	96 000	40 000	44 000		112 000	30 000	3 000	16 000	23 000	73 000	7 000
	Belgium	432 600	669 500	669 500					19 570		9 270		133 900	19 570
	Bulgaria									5 400	5 488		1 601	
	Croatia	89 444			24 247	105 521			14 800				11 978	

Health-care level	*Country*	*CT*							*Interventional procedures*				*Angiography*	
		Head	*Thorax*	*Abdomen*	*Spine*	*Pelvis*	*Inter-ventional*	*Other*	*PTCA*	*Cerebral*	*Vascular*	*Others*	*Non-cardiac*	*Cardiac*
I	Czech Republic	187 427	44 753	78 114	58 200	44 741			8 030	4 512	3 200	1 203	4 424	92 196
	Finland	136 512	33 078	62 948	14 158	1 177	2 091	17 107	9 854	436	7 276	14 416	12 432	16 556
	France	1 900 000	620 000	930 000	1 300 000			350 000	105 553	12 183	354 000	420 000		
	Germany	3 267 700	1 488 600	2 269 300	1 588 500	372 200		90 800	189 700	137 400			1 047 500	1 280 300
	Greece	210 000	180 000	200 000	85 000	200 000	0	36 000					35 000	35 000
	Hungary	276 000	199 000	225 000	58 000	54 000	1 100	55 000					82 000	
	Iceland	10 718	2 936	6 024	3 229	231	0	1 475	580		193	120	793	2 121
	Japan	16 613 000	11 167 000	12 878 000		3 796 000		195 000					1 102 000	
	Korea, Rep.	881 008	188 804	278 096										
	Latvia	62 497	19 984	28 800	29 271			3 677	2 798	142	124	241	3 913	6 107
	Lithuania	104 650							7 633					
	Luxembourg	19 795	6 035	11 879	16 807			6 378	698	32	634	235	3 163	1 545
	Malta	5 673	1 351	2 707	220	1 036	40	636	578	0	75	290	370	2 051
	Netherlands	300 000	210 000	305 000						19 000			130 000	
	Norway	183 922	49 631	81 279	76 871	51 991		10 457	2 517	357	10 930		28 732	17 032
	Romania	235 723	225 355						15 942				34 162	19 358
	Russian Federation	714 000	102 000	204 000					80 000	60 100	50 000	40 000	130 000	35 000
	Slovakia	30 000	30 000	30 000	30 000				3 600					1 800
	Spain	719 523	247 082	645 489	219 030	149 713	65 404	132 227	28 757	7 419	67 442	132 484	75 158	56 330
	Sweden	324 000	97 000	128 000	12 000	25 000		24 000						
	Switzerland	196 000	84 000	166 000	80 000	120 000		20 000	7 800	650	9 500	3 500	22 000	20 000
	The former Yugoslav Republic of Macedonia	11 520							1 728					
	United Kingdom	618 000	193 000	297 000				8 000	26 000	2 000	65 000	97 000	158 000	163 000
II	Costa Rica	8 868	786	1 770	1 180	590		721					125	
	El Salvador	17 000	7 480	20 400	2 176	9 520		11 424	770	462	77	231	721 772	37 988
	Mauritius	0	0	0					0	0	0	0	0	280
	Oman	14 625											183	1 363
	Trinidad and Tobago	4 143	1 875	1 778	581	1 441		226						
III	Zimbabwe	10 000	8 000	8 000	6 000	4 000	1 000		0	0	0	0	0	0
IV	Maldives	992	98	110	58	76								

Table B41d. Annual number of various medical and dental radiological examinations
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Pelvimetry*	*Other medical*	*Total medical*	*Intraoral*	*Panoramic*	*Dental CT*	*Total dental*
I	Austria			8 770 000	5 500 000	1 350 000	400	6 850 000
	Belgium	6 180	1 050 600	14 887 002				
	Bulgaria	11 808	136 808	3 014 561	260 309	12 265		272 574
	Croatia				314 843	68 944		383 787
	Czech Republic			5 773 618	2 094 778	367 660		2 462 438
	Finland	1 860	25 872	3 583 517	1 656 000	300 000		1 956 000
	France			47 000 000	15 700 000	2 300 000		18 000 000
	Germany		5 873 400	87 046 500				47 925 500
	Greece					22 000		
	Iceland	198	6 561	182 719				
	Japan	60 000	19 524 000	237 346 000	61 443 000	11 975 000		73 418 000
	Korea, Rep.			44 994 733				
	Latvia	100 054	320 215	2 540 216				114 960
	Lithuania							356 199
	Luxembourg	1	2 702	397 239	108 158	21 444		175 767
	Malta	0	0	108 158	42 321	1 146	0	43 467
	Netherlands			8 400 000				8 200 000
	Norway			3 377 606	1 790 000	56 500		1 865 500
	Romania	9 110	61 742	10 555 115	327 406	15 537		342 943
	Russian Federation	16 000	45 700 000	157 800 000	13 300 000	2 100 000		14 100 000
	Slovenia							375 000
	Spain	245 346	56 356	38 055 077	3 753 836	1 181 763	449	4 936 048
	Switzerland		43 600	6 400 000	3 800 000	231 000		4 031 000
	The former Yugoslav Republic of Macedonia			36 576				
	United Kingdom	6 000		29 000 000	9 500 000	3 000 000		12 500 000
II	Costa Rica	0		223 778		5 000		
	El Salvador	5 698		4 367 444	83 300	36 000		119 300
	Mauritius	0	0	383 100				320
	Oman				19 508	5 965		25 473
III	Zimbabwe	0			30 000	1 000		
IV	Maldives			77 580				

Table B42. Total annual number of diagnostic medical and dental radiological examinations
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Diagnostic examinations*	
		Medical	*Dental*
I	Austria	8 770 000	6 850 000
	Belgium	14 887 002	14 887 002
	Bulgaria	3 014 561	272 574
	Croatia		383 787
	Czech Republic	5 773 618	2 462 438
	Finland	3 583 517	1 956 000
	France	47 000 000	18 400 000
	Germany	87 046 500	47 925 500
	Iceland	182 719	
	Japan	237 346 000	73 418 000
	Korea, Rep.	44 994 733	
	Latvia	2 540 216	114 960
	Lithuana		356 199
	Luxembourg	397 239	175 767
	Malta	108 158	43 467
	Netherlands	9 900 000	4 920 000
	Romania	10 555 115	342 943
	Russian Federation	157 800 000	14 100 000
	Slovenia		375 000
	Spain	38 055 077	4 936 048
	Sweden	5 120 000	
	Switzerland	6 400 000	4 031 000
	The former Yugoslav Republic of Macedonia	36 576	
	United Kingdom	29 000 000	12 500 000
II	Costa Rica	223 778	
	El Salvador	4 367 444	119 300
	Mauritius	383 100	320
	Oman		25 473
IV	Maldives	77 580	

Table B43a. Annual number of various medical examinations per 1,000 population

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Chest*				*Limbs and joints*	*Spine*					
		Chest PA	*Chest LAT*	*Photo-fluorography*	*Fluoroscopy*		*Lumbar AP/PA*	*Lumbar LAT*	*Thoracic AP*	*Thoracic LAT*	*Cervical AP*	*Cervical LAT*
I	Australia	108.21	71.76			159.58	40.29		22.34		25.64	
	Austria	241.1	146.34			209.51	48.78	47.80	27.07	25.24	40.49	39.63
	Belgium	246.00	159.00	0.04		271.00	38.00	38.00	19.00	19.00	34.00	34.00
	Bulgaria	69.85	29.93	11.55	4.14	77.99	5.63	13.14	1.93	7.74	3.71	6.89
	Croatia	152.54	85.34		7.30	348.37						
	Czech Republic	103.02	5.65	0.00	4.23	152.78	26.06	19.45	1.56	0.82	10.94	13.91
	Finland	223.60				210.02	29.76		5.96		14.62	
	France	90.76				226.90	128.04					
	Germany	207.69				256.91	47.77		24.91		54.44	
	Greece	309.09				136.36	72.73					
	Hungary	480.31	46.39	30.16	55.10	216.51	1.40	1.30	1.30	24.45	1.30	28.75
	Iceland	163.24				187.29	20.47	8.51	8.51		12.04	
	Japan	653.44			3.12	163.36	78.94		19.52		51.86	
	Korea, Rep.	391.60	45.21				75.35	58.02	18.58	18.62	44.71	44.33
	Latvia	202.35		139.52		319.94						
	Lithuania	126.17		327.13	48.91	405.14						
	Luxembourg	118.17	47.39			241.93	55.62		17.51		28.35	
	Malta	82.63	1.44			59.01	7.41	7.41	1.83	1.83	4.17	4.14
	Netherlands	166.26										
	Norway	39.93	117.47			191.14	34.71		8.62		19.95	
	Romania	45.93	14.47	63.80	90.40	80.16	8.46	15.71	3.	6.68	9.88	6.59
	Russian Federation	71.57	58.21	406.95	17.72	20.04	18.88	11.59	15.20	5.17	16.09	13.22
	Slovenia	193.71	60.41			225.66	58.41	62.41	25.46	25.46	72.39	75.39
	Spain	326.26	146.48			43.52	24.18	17.84	19.72	13.65	45.08	14.25
	Sweden	94.91	94.91			151	19.19	19.19	8.58	8.58	10.24	10.24
	Switzerland	187.64	46.91	6.84	0.43	260.02	37.39	37.39	10.99	10.99	26.14	26.14
	The former Yugoslav Republic of Macedonia	2.12				2.83						
	United Kingdom	139.50				129.41	13.87		4.72		14.44	
	Weighted average	168	70	287	17	140	31	23	16	9.8	32	19

Health-care level	Country	Chest				Limbs and joints	Spine					
		Chest PA	Chest LAT	Photo-fluorography	Fluoroscopy		Lumbar AP/PA	Lumbar LAT	Thoracic AP	Thoracic LAT	Cervical AP	Cervical LAT
II	Azerbaijan	0.48		0.01		0.09	0.01		0.00		0.00	
	Costa Rica	14.02	10.61		0.00	7.88	1.62	1.62	0.81	0.81	0.81	0.81
	El Salvador	280.52	70.12		0.06	29.20	5.26	5.26	0.88	0.88	0.88	2.63
	Mauritius	53.75	2.67			136.33	32.30					
	Oman	81.11				107.27				38.24		
	Trinidad and Tobago	52.11	14.08				21.68		10.34		19.42	
	Weighted average	140	39	0.01	0.03	27	3.8	3.8	0.85	6.7	1.9	1.9
III	Zimbabwe	1.7	0.33	0.83	0.00	0.29		0.83	0.67	0.67	1.3	1.3
	Average	1.7	0.33	0.83	0.00	0.29		0.83	0.67	0.67	1.3	1.3
IV	Maldives	0.04	0.02			0.70	0.13	0.13	0.02	0.02	0.06	0.07
	Average	0.04	0.02			0.70	0.13	0.13	0.02	0.02	0.06	0.07

Table B43b. Annual number of various medical examinations per 1,000 population

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	Country	Pelvis/hip	Head	Abdomen	Upper GI	Lower GI	Cholecystography	Urography	Mammography	
									Screening	Clinical diagnosis
I	Australia	46.72	18.89	11.86			0.14	2.56	39.20	16.51
	Austria	60.73	41.22	19.02	13.78	18.17	2.44	15.98	76.83	50.00
	Belgium	88.00	31.00	48.00	8.90	7.90	0.70	9.50	7.00	92.00
	Bulgaria	15.17	19.36	9.99	12.93	7.27	0.43	3.87	7.00	4.94
	Croatia	0.00		15.37	19.29	6.37	0.31	14.98		56.56
	Czech Republic	30.84	40.55	15.25	3.36	5.14	1.06	6.48		24.16

Health-care level	*Country*	*Pelvis/hip*	*Head*	*Abdomen*	*Upper GI*	*Lower GI*	*Cholecystography*	*Urography*	*Mammography*	
									Screening	*Clinical diagnosis*
I	Finland	34.41	75.62	10.51	1.02	2.60	0.82	1.34	37.66	17.74
	France	69.69	37.28	40.52					90.76	
	Germany	84.54	45.47	31.15	3.67	6.93	1.15	14.65	62.43	
	Greece	29.09	39.09		15.45					17.73
	Hungary	53.40	63.42	47.19	9.92	2.20	0.16	4.71	25.35	150.89
	Iceland	8.56	21.42	13.59	3.95	4.89		7.30	50.59	1.70
	Japan	28.16	66.40	127.20	117.71	17.81	4.34	11.32		6.62
	Korea, Rep.	47.86	91.78	91.98						
	Latvia			121.08	10.88	3.94	0.33	19.60	37.44	
	Lithuania							26.03	24.62	
	Luxembourg	65.51	21.20	19.65	5.30	2.42	0.35	15.31	27.11	24.94
	Malta	3.10	9.28	21.18	4.63	4.06	0.00	4.08	12.65	4.01
	Netherlands								44.76	15.99
	Norway	73.48	6.75	9.87	2.31	6.09		5.31	320.10	432.18
	Romania	12.64	27.71	3.25	34.52	11.64	0.91	11.43		4.16
	Russian Federation	16.50	41.31	5.51	11.66	5.83	1.10	5.48	1.63	5.94
	Slovenia	109.34	90.86	19.97						29.96
	Spain	22.25	14.24	21.16	10.11	8.14	0.88	6.18	31.04	33.42
	Sweden	47.40	8.24	7.11	7.18	7.90		8.46	58.68	29.34
	Switzerland	41.82	21.44	12.33	1.74	2.14	0.80	5.63		35.52
	The former Yugoslav Republic of Macedonia							0.85		
	United Kingdom	29.80	18.79	20.45	3.73	6.72	1.14	4.34	22.42	6.55
	Weighted average	40	44	45	34	9.3	1.7	8.5	23	20
II	Costa Rica	1.22	2.65	2.39					1.21	1.21
	El Salvador	4.38	9.53	9.53	26.31	17.54	21.92	21.92	24.41	10.46
	Mauritius		41.50	17.42	1.93			0.63	0.00	0.21
	Oman	9.45	32.01	23.31	2.36		0.10	1.89	0.60	
	Trinidad and Tobago	13.21	11.11	19.32	1.58	1.04		1.39	1.74	
	Weighted average	4.9	13	11	12	9.7	11	9.8	14	6.1
III	Zimbabwe	2.08	2.50	1.67				0.83	0.83	0.83
	Average	2.1	2.5	1.7				0.83	0.83	0.83
IV	Maldives	1.95	5.63	4.44	0.52	0.17		0.06		
	Average	1.9	5.6	4.4	0.52	0.17		0.06		

Table B43c. Annual number of various medical examinations per 1,000 population

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*CT*							*Interventional procedures*				*Angiography*	
		Head	*Thorax*	*Abdomen*	*Spine*	*Pelvis*	*Interventional*	*Other*	*PTCA*	*Cerebral*	*Vascular*	*Others*	*Non-cardiac*	*Cardiac*
I	Australia												3.30	1.54
	Austria	26.59	12.32	11.71	4.88	5.37		13.66	3.66	0.37	1.95	2.80	8.90	0.85
	Belgium	42.00	65.00	65.00					1.90		0.90		13.00	1.90
	Bulgaria									0.66	0.67		0.20	
	Croatia	20.16	0.00	0.00	5.46	23.78			3.34				2.70	
	Czech Republic	18.21	4.35	7.59	5.66	4.35			0.78	0.44	0.31	0.12	0.43	8.96
	Finland	26.00	6.30	11.99	2.70	0.22	0.40	3.26	1.88	0.08	1.39	2.75	2.37	3.15
	France	30.79	10.05	15.07	21.07			5.67	1.71	0.20	5.74	6.81		
	Germany	39.61	18.04	27.51	19.25	4.51		1.10	2.30	1.67			12.70	15.52
	Greece	19.09	16.36	18.18	7.73	18.18	0.00	3.27					3.18	3.18
	Hungary	27.65	19.94	22.54	5.81	5.41	0.11	5.51						
	Iceland	36.46	9.99	20.49	10.98	0.79	0.00	5.02	1.97		0.66	0.41	2.70	7.21
	Japan	130.36	87.63	101.06		29.79		1.53					8.65	
	Korea, Rep.	18.74	4.02	5.92										
	Latvia	27.23	8.71	12.55	12.75			1.60						
	Lithuania	29.98							2.19					
	Luxembourg	43.79	13.35	26.28	37.18			14.11	1.54	0.07	1.40	0.52	7.00	3.42
	Malta	14.18	3.38	6.77	0.55	2.59	0.10	1.59	1.45	0.00	0.19	0.73	0.93	5.13
	Netherlands	19.18	13.43	19.50						1.21			5.12	
	Norway	39.64	10.70	17.52	16.57	11.20		2.25	0.54	0.08	2.36		6.19	3.67
	Romania	10.86	10.38						0.73				1.57	0.89
	Russian Federation	4.87	0.70	1.39					0.55	0.41	0.34	0.27	0.89	0.24
	Slovenia	14.98	14.98	14.98	14.98				1.80					0.90
	Spain	16.31	5.60	14.63	4.97	3.39	1.48	3.00	0.65	0.17	1.53	3.00	1.70	1.28
	Sweden	36.56	10.95	14.45	1.35	2.82		2.71						
	Switzerland	26.27	11.26	22.25	10.72	16.08		2.68	1.05	0.09	1.27	0.47	2.95	2.68
	United Kingdom	10.39	3.24	4.99				0.13	0.44	0.03	1.09	1.63	2.66	2.74
	Weighted average	40	24	30	11	19	0.97	2.8	0.92	0.31	1.6	1.1	2.6	1.5

Health-care level	*Country*	*CT*							*Interventional procedures*				*Angiography*	
		Head	*Thorax*	*Abdomen*	*Spine*	*Pelvis*	*Interventional*	*Other*	*PTCA*	*Cerebral*	*Vascular*	*Others*	*Non-cardiac*	*Cardiac*
II	Costa Rica	2.05	0.18	0.41	0.27	0.14		0.17					0.03	
	El Salvador	2.62	1.15	3.14	0.33	1.46		1.76	0.12	0.07	0.01	0.04	(111.04)	5.84
	Mauritius	0.00	0.00	0.00					0.00	0.00	0.00	0.00	0.00	0.23
	Oman	7.25												
	Trinidad and Tobago	3.28	1.49	1.41	0.46	1.14		0.18						
	Weighted average	2. 3	0.76	1.8	0.33	0.96		1.0	0.10	0.06	0.01	0.03	0.02	5.0
III	Zimbabwe	0.83	0.67	0.67	0.50	0.33	0.08		0.00	0.00	0.00	0.00	0.00	0.00
	Average	0.83	0.67	0.67	0.50	0.33	0.08		0.00	0.00	0.00	0.00	0.00	0.00
IV	Maldives	3.31	0.33	0.37	0.19	0.25								
	Average	3.3	0.33	0.37	0.19	0.25								

Note: Data for El Salvador in parentheses were excluded from the calculation of the weighted average for non-cardiac angiography.

Table B43d. Annual number of various medical and dental radiological examinations per 1,000 population
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Pelvimetry*	*Other medical*	*Total medical*	*Intraoral*	*Panoramic*	*Dental CT*	*Total dental*
	Austria			1 069.51	670.73	164.63	0.05	835.37
	Belgium	0.60	102.00	1 445.34				
	Bulgaria	1.45	16.79	369.93	31.94	1.51		33.45
	Croatia				70.96	15.54		86.50
	Czech Republic			561.09	203.57	35.73		239.30
	Finland	0.35	4.93	682.57	315.43	57.14		372.57
	France			761.75	254.46	37.28		291.73
	Germany		71.19	1 055.1				580.91
	Greece					2.00		
	Iceland	0.67	22.32	621.49				
	Japan	0.47	153.21	1 862.49	482.07	93.97		576.12
	Korea, Rep.			957.17				
I	Latvia	43.60	139.53	1 106.85				50.09
	Lithuania							102.03
	Luxembourg	0.00	5.98	878.85	239.29	47.44		388.87
	Malta	0.00	0.00	270.40	105.80	2.87	0.00	108.67
	Netherlands			633.07	306.94	7.67		314.62
	Norway			727.93	385.78	12.18		402.05
	Romania	0.42	2.84	486.16	15.08	0.72		15.80
	Russian Federation	0.11	311.52	1 075.66	90.66	14.31		96.11
	Slovenia							187.22
	Spain	5.56	1.28	862.75	85.10	26.79	0.01	111.91
	Switzerland		5.84	857.79	509.32	30.96		540.28
	United Kingdom	0.10		487.39	159.66	50.42		210.08
	Weighted average	1.1	159	1 176	230	49	0.02	316
	Costa Rica	0.00		51.73		1.16		
	El Salvador	0.88		671.91	12.82	5.54		18.35
II	Mauritius	0.00	0.00	319.25				0.27
	Oman				9.67	2.96		12.62
	Weighted average	0.47	0.00	410	12	3.6		15
III	Zimbabwe	0.00			2.50	0.08		
	Average	0.00			2.5	0.08		
IV	Maldives			258.60				
	Average			260				

Table B44. Total annual numbers of medical and dental radiological examinations per 1,000 population
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Total medical*	*Total dental*	*Total diagnostic*
I	Austria	1 069.51	835.37	1 904.88
	Belgium	1 445.34		1 445.34
	Bulgaria	369.93	33.45	403.38
	Croatia		86.50	
	Czech Republic	561.09	239.30	800.39
	Finland	682.57	372.57	1 055.15
	France	761.75	291.73	1 053.48
	Germany	1 055.1	580.91	1 636.01
	Iceland	621.49		
	Japan	1 862.49	576.12	2 438.61
	Korea, Rep.	957.17		
	Latvia	1 106.85	50.09	1 156.94
	Lithuania		102.03	
	Luxembourg	878.85	388.87	1 267.71
	Malta	270.40	108.67	379.06
	Netherlands	537.15	314.62	851.77
	Norway	727.93	402.05	1 129.98
	Romania	486.16	15.80	501.96
	Russian Federation	1 075.66	96.11	1 171.78
	Slovenia		187.22	
	Spain	862.75	111.91	974.66
	Sweden	566		
	Switzerland	857.79	540.28	1 398.07
	United Kingdom	487.39	210.08	697.48
	Weighted average	1 176.38	351.62	1 492.80
II	Costa Rica	51.73		
	El Salvador	671.91	18.35	690.27
	Mauritius	319.25	0.27	319.52
	Oman		12.62	
	Weighted average	410	15	430
IV	Maldives	258.60		
	Average	260		

Table B45a. Mean patient dose[a] for various medical and dental radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Chest*				*Limbs and joints*	*Spine*					
		Chest PA	*Chest LAT*	*Photo-fluorography*	*Fluoroscopy*		*Lumbar AP/PA*	*Lumbar LAT*	*Thoracic AP*	*Thoracic LAT*	*Cervical AP*	*Cervical LAT*
I	Australia	0.16	0.73				4.60	13.10	3.10	7.80	0.71	0.55
	Belgium	0.15	1.23				6.10	10.50				
	Czech Republic	0.40	1.20				11.10	15.00	7.00	11.00	6.90	7.20
	Germany	**0.13**	0.46				2.31	4.76	1.46	1.64	0.39	0.20
	Greece	0.50					10.00	30.00			1.30	
	Hungary	0.52	0.91	4.18			5.86	12.40	4.14	6.05	1.48	1.45
	Iceland	**0.57**					**9.60**		**4.20**		**0.90**	
	Japan	0.33	0.44		22.00	0.33	2.70	15.89	2.37	3.80	0.45	
	Lithuania	0.44	1.60	4.40			9.20	27.00	3.30	9.00	1.40	1.00
	Malta	0.20	0.45				5.07	5.80	2.50	5.80	0.25	0.22
	Netherlands	0.04										
	Norway	**0.64**	**0.82**				**4.20**		**3.79**		**1.49**	
	Romania	1.30	3.50	7.20	**5.40**	4.50	17.40	37.40	15.50	26.90	5.90	7.10
	Slovenia	0.29	0.96				6.06	15.52	5.75	6.43	1.40	1.40
	Spain	0.17	0.49			0.13	4.40	10.80	3.10	1.96	1.50	1.40
	Sweden	**0.40**	**0.40**				**6.5**	**6.5**				
	Switzerland	0.10	0.20	0.40	**11.00**	1.00	4.40	17.00	3.00	14.00	1.60	1.80
	United Kingdom	0.16				0.10	6.00	14.00	4.00	11.00	1.70	0.30
II	Chile	0.20	0.70									
	Mauritius	0.40	1.50				AP 10; LAT 30					
	Oman	0.44					16.59					
	Thailand	0.20										
	Tunisia	0.20	11.00				6.30	15.90				
	Turkey	0.38	1.68				4.35	17.60	2.85	11.20		
IV	Maldives	0.20	0.20			0.01	1.30		0.70		0.08	

[a] Values in regular type are for entrance air kerma in mGy; values in bold type are for DAP in Gy cm^2.

Table B45b. Mean patient dose[a] for various medical and dental radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Pelvis/hip*	*Head*	*Abdomen*	*Upper GI*	*Lower GI*	*Cholecystography*	*Urography*	*Mammography (mean glandular dose)*	
									Screening	*Clinical diagnosis*
I	Australia								2.00	2.00
	Belgium			*8.25*					*1.54*	
	Czech Republic	9.90	5.10	9.30	10.20	**19.00**	**12.00**	**11.00**		2.00
	Germany	**1.96**	**0.44**	**2.64**	**23.53**	**57.43**				5.00
	Greece		3.00							7.00
	Hungary	4.78	2.27	3.36						
	Iceland	**2.40**	**1.20**	**7.80**	**31.90**	**89.00**		**19.40**		
	Japan	3.16	2.37	2.37	2.90	2.90	2.84			
	Lithuania	6.10	2.40	7.50						
	Malta	2.65	0.67	2.65	1.87	2.03			3.04	4.17
	Netherlands				**21.00**	**29.00**				
	Norway	**5.17**								
	Romania	15.60	16.30	16.70	**21.50**	**36.80**	32.10	51.60		44.80
	Slovenia	3.95	1.98	4.43						1.27
	Spain	7.00	2.70	5.40	**19.00**	**38.00**	**1.41**	**33.20**	*6*[b]	*6.7*[b]
	Sweden	**1.60**				**30.00**		**15.00**	2.1	2.7
	Switzerland	10.00	3.30	3.30	20.00	20.00	33.00	24.00		
	United Kingdom	4.00	2.00	5.00	**9.00**	**20.00**	**15.00**	**10.00**		
II	Chile	4.00	4.30							10.00
	Mauritius	10.00	5.00	10.00			10.00	10.00		
	Oman		17.50							
	Thailand			2.20						7.80
	Tunisia			7.60						
	Turkey	3.10	4.00							1.65
IV	Maldives	0.70	0.07	0.70	3.00	7.00		2.50		

[a] Values in regular type are for entrance air kerma in mGy; values in bold type are for DAP in Gy cm^2; values in italic type are for ESD.

[b] ESD in mammography.

Table B45c. Mean patient dose[a] for various medical and dental radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*CT*							*Interventional procedures*				*Angiography*	
		Head	*Thorax*	*Abdomen*	*Spine*	*Pelvis*	*Interventional*	*Other*	*PTCA*	*Cerebral*	*Vascular*	*Others*	*Non-cardiac*	*Cardiac*
I	Czech Republic	39.00	22.00	28.00	36.00	39.00			**120.00**	**52.00**	**29.00**		**38.00**	**68.00**
	Germany	**980**	**508**	**1 239**	**248**								**77.46**	
	Greece	90.00	65.00	72.00	90.00	70.00		170.00						
	Iceland								**78.10**					**298.00**
	Japan	145.00	18.80	25.60		23.50							2.72	
	Malta	1 036.53	256.40	410.00	170.57	201.56	85.70		**57.20**		**6.00**	**10.00**	**58.10**	**26.50**
	Netherlands	71.00	22.00	27.00										
	Romania												**29.00**	
	Slovenia	348.40	349.50	700.90										
	Spain	560.00	238.00	290.00	372.00	451.00			**67.80**	**77.40**	**113.40**	**63.60**	**47.30**	**30.30**
	Sweden	**1 000.00**	**390**	**670**	**510**									**44**
	Switzerland	1 200.00	400.00	800.00					**85.00**	**50.00**	**170.00**	**70.00**	**85.00**	**85.00**
II	Chile								80.00	`				36.00
IV	Maldives	2.00	8.00	10.00	8.00	6.00								

[a] Values in regular type are for entrance air kerma in mGy; values in bold type are for DAP in Gy cm^2; values underlined are for CTDI in mGy cm; values underlined and in bold type are for DLP in mGy cm.

Table B45d. Mean patient dose[a] for various medical and dental radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Pelvimetry*	*Other medical*	*Intraoral*	*Panoramic*	*Dental CT*
I	Finland			2.50	**0.09**	
	Japan	3.98				
	Malta			2.17	3.90	
	Romania	36.20	19.40	7.90		
	Spain			3.10	1.6	
	Switzerland		0.20	3.00	**0.10**	

[a] Values in regular type are for entrance air kerma in mGy; values in bold type are for DAP in Gy cm^2.

Table B46a. Mean effective dose and variation on the mean for various medical and dental radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Chest*				*Limbs and joints*	*Spine*					
		Chest PA	*Chest LAT*	*Photofluorography*	*Fluoroscopy*		*Lumbar AP/PA*	*Lumbar LAT*	*Thoracic AP*	*Thoracic LAT*	*Cervical AP*	*Cervical LAT*
Mean effective dose (mSv)												
I	Australia	0.03	0.07			0.10	0.43	0.31	0.29	0.20	0.04	0.01
	Austria	0.06	0.07			0.003	0.32	0.36	0.18	0.22	0.02	0.02
	Belgium	0.03	0.12				0.69	0.28				
	Bulgaria	0.02	0.05									
	Czech Republic	0.06	0.09				1.70	1.00	0.80	0.90	0.40	0.30
	France	0.05				0.02						
	Germany	0.03	0.08			0.05	0.60	0.60	0.40	0.20	0.11	0.07
	Japan	0.09			3.60	0.00	0.75		0.37		0.07	
	Korea, Rep.	0.02	0.13				0.27	0.40	0.18	0.18	0.06	0.00
	Malta	0.03	0.05									
	Netherlands	0.02				<0.001	0.40		0.20		0.02	
	Norway	0.12	0.15			0.02	1.73		0.72		0.18	
	Romania	0.14	0.28	0.84	0.76	0.04	2.10	1.23	1.43	0.81	0.25	0.04
	Russian Federation	0.11	0.37	0.80	0.91	0.10	1.92	1.40	0.69	0.47	0.14	0.31
	Spain	0.09	0.14			0.12	1.20	0.90	0.60	0.60	0.40	0.01
	Sweden	0.07	0.07				1.4	1.4				
	Switzerland	0.04	0.11	0.11	2.60	0.02	1.60	3.30	0.80	2.90	0.20	0.10
	United Kingdom	0.02				0.00	1.00		0.70		0.07	
	Weighted average	0.07	0.20	0.78	2.1	0.05	1.2	1.0	0.51	0.35	0.13	0.13
IV	Maldives	0.02	0.02			0.01	1.30	1.80	0.70		0.08	
	Average	0.02	0.02			0.01	1.30	1.80	0.70		0.08	
Standard deviation or range of mean effective dose (mSv)												
I	Australia	0.04	0.10			0.10	0.40	0.30	0.38	0.26	0.03	0.02
	Belgium	0.01	0.09				0.34	0.16				
	Bulgaria	0.012–0.026	0.042–0.055									
	Germany	0.02–0.05	0.04–0.1			0.001–0.1	0.3–1	0.4–1	0.2–0.5	0.1–0.4	0.05–0.15	0.05–0.1
	Korea, Rep.	0.02	0.13				0.13	0.18	0.08	0.08	0.03	0.00
	Netherlands	0.005–0.137					0.12–0.73		0.07–0.3		0.01–0.02	
	Romania	0.09	0.12	0.41	0.40	0.03	1.18	0.53	0.80	0.53	0.16	0.02
	Spain	0.03–0.2	0.05–0.26			0.01–0.1	0.5–1.3	0.3–1.3	0.3–0.7	0.5–0.7	0.04–0.7	

Health-care level	*Country*	*Chest*				*Limbs and joints*	*Spine*					
		Chest PA	*Chest LAT*	*Photofluorography*	*Fluoroscopy*		*Lumbar AP/PA*	*Lumbar LAT*	*Thoracic AP*	*Thoracic LAT*	*Cervical AP*	*Cervical LAT*
I	Sweden	0.02–0.27	0.02–0.27				0.27–4.4	0.27–4.4				
	Switzerland	0.03	0.05	0.05	2.00	0.02	1.00	2.00	0.50	2.00	0.10	0.05
IV	Maldives	0.01	0.01			0.00	0.01	0.02	0.02		0.01	

Table B46b. Mean effective dose and variation on the mean for various medical and dental radiological examinations
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Pelvis/hip*	*Head*	*Abdomen*	*Upper GI*	*Lower GI*	*Cholecystography*	*Urography*	*Mammography*	
									Screening	*Clinical diagnosis*
Mean effective dose (mSv)										
I	Australia	0.58	0.03	1.00			1.32	3.97	0.40	
	Austria	0.52	0.02	0.31	4.10	5.35	14.85	4.8	0.35	0.35
	Belgium			0.99						
	Czech Republic	1.40	0.20	1.10	1.90	3.50	2.90	2.90		1.20
	France	0.60	0.07							
	Germany	0.50	0.04	0.60	6.00					0.50
	Japan	0.77	0.04	0.58	0.31	0.40	0.15			
	Korea, Rep.	0.28	0.02	0.25						
	Malta	0.45	0.01	0.39						
	Netherlands	0.20			7.00	5.00			0.21	0.40
	Norway	0.60	0.03	3.62	5.17	12.57		3.81	0.13	0.13
	Romania	2.68	0.17	2.39	4.32	10.30	2.86	7.00		0.52
	Russian Federation	2.23/1.47	0.14	0.90	3.80	8.50	1.00	0.60	0.15	0.30
	Spain	0.80	0.07	0.80	7.80	7.80			0.70	0.40
	Sweden	0.46				8.4		2.7	0.1	0.14
	Switzerland	1.60	0.40	2.10	13.00	14.00	12.00	5.30		
	United Kingdom	0.50	0.06	0.70	2.00	7.00	4.00	2.00	0.20	0.30
	Weighted average	1.2	0.08	0.82	3.4	7.4	2.0	2.6	0.26	0.39

Health-care level	*Country*	*Pelvis/hip*	*Head*	*Abdomen*	*Upper GI*	*Lower GI*	*Cholecystography*	*Urography*	*Mammography*	
									Screening	*Clinical diagnosis*
IV	Maldives	0.70	0.07	0.70	3.00	7.00		2.50		
	Average	0.70	0.07	0.70	3.00	7.00		2.50		
Standard deviation or range of mean effective dose (mSv)										
I	Australia	0.60	0.03	1.50			1.19	3.57		
	Belgium			1.56						
	Germany	0.4–1.0	0.02–0.06	0.5–1	2.0–12					0.2–0.8
	Korea, Rep.	0.12	0.01	0.10						
	Netherlands	0.1–0.32			3.0–19	3.0–8				
	Romania	1.68	0.11	1.35	2.14	4.00	1.25	4.80		0.18
	Spain			0.5–1	3–12.7	7–16.7				
	Sweden	0.06–2.3				1.9–20		0.7–8.5	0.03–0.16	0.05–0.3
	Switzerland	1.00	0.20	1.00	5.00	5.00	2.00	2.00		
IV	Maldives	0.01	0.00	0.02	0.10	0.30		0.50		

Table B46c. Mean effective dose and variation on the mean for various medical and dental radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*CT*							*Interventional procedures*				*Angiography*	
		Head	*Thorax*	*Abdomen*	*Spine*	*Pelvis*	*Interventional*	*Other*	*PTCA*	*Cerebral*	*Vascular*	*Others*	*Non-cardiac*	*Cardiac*
Mean effective dose (mSv)														
	Australia	2	10	20.00										
	Austria	2.22	1.72	14.7	4.99	8.02		4.95	5.67		15.85	21.44	8	5
	Belgium		4.14	11.30										
	Czech Republic	2.1	8.8	8.9	8.1	8.5								
	France	2	5	6.7	4				9	5.7	9	9		
	Germany	2.7	7.7	21.4	2.7								15	
	Greece	7.8	7.2	7										
	Hungary	0.83	6.64	3.73		6.98		2.88						
	Iceland								14.3					5.5
I	Japan	2.4	9.1	12.9		10.5								
	Korea, Rep.	0.81	7.4	6.6										
	Netherlands	3	10	16										
	Norway	1.83	11.50	12.7	4.32	9.29			10.8	3.31	13.8		5.38	9.3
	Romania												0.32	
	Spain	1.8	6.6	8.5	5	7.2								
	Sweden	2.2	6.6	10	8.5									8
	Switzerland	5	10	14					19	5	15	18	10	17
	United Kingdom	2	8	10					15	6	7		5	7
	Weighted average	2.4	7.8	12	5.0	9.4	0.0	3.8	12	5.7	9.0	11	9.3	7.9
Standard deviation or range of mean effective dose (mSv)														
	Belgium		1.21	7.8										
	Germany	2.0–4.0	6.0–10	10.0–25	2.0-5.0								10.0–20.0	
	Greece	0.6	3.5	3.5										
	Iceland								7.8					3.4
I	Netherlands	1.0–5	4.0–19	7.0–26										
	Romania												0.12	
	Spain	1.1–2.3	2.6–8	6.5–10		4.4–10								
	Sweden	1.0–4.0	2.1–19	4–21	2.2–21									2.7–20
	Switzerland	1	4	5					5	2	4	5	3	5

Table B46d. Mean effective dose and variation on the mean for various medical and dental radiological examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Pelvimetry*	*Other medical*	*Total medical*	*Intraoral*	*Panoramic*	*Dental CT*	*Total dental*
Mean effective dose (mSv)								
I	Austria				0.01	0.026	0.32	
	Czech Republic				0.10			
	France			0.97	0.01	0.01		0.01
	Germany			1.75	0.01			0.01
	Japan	0.83			0.02	0.01		
	Netherlands			0.87	0.00	0.01		0.00
	Norway			1.47				
	Romania	6.20	3.33	1.25	0.03			0.03
	Russian Federation			0.86	0.02	0.15		0.03
	Switzerland			1.30	0.01	0.05		0.01
	United Kingdom	0.80		0.70	0.01	0.01		0.01
	Weighted average	1.4	3.3	1.0	0.02	0.06	0.32	0.02
IV	Maldives					0.01		
	Average					0.01		
Standard deviation or range of mean effective dose								
I	Germany							0.001–1
	Romania	2.40	2.10	0.65	0.02			0.02
	Switzerland		0.00	0.20	0.01	0.02		0.01

Table B47. Distribution by age and sex of patients undergoing various types of diagnostic radiological examination (1997–2007)

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Chest PA						
I	Australia	7	20	73	50	50
	Bulgaria	19	34	46	51	49
	Czech Republic	7	17	76	50	50
	Iceland	12	10	78	53	47
	Japan	6	18	86	55	45
	Korea, Rep.	20	34	46	54	47
	Luxembourg	6	14	80	54	46
	Romania	22	24	54	56	44
	Russian Federation	7	49	44	48	52
	Spain	10	10	80	51	49
	Switzerland	5	15	80	53	47
	Weighted average	9.0	30	64	51	49
II	Trinidad and Tobago	23	28	49	59	41
	Tunisia	7	35	58	44	56
	Turkey	2	14	84	45	55
	Weighted average	3	17	80	45	55
III	Zimbabwe	50	40	10	50	50
	Average	50	40	10	50	50
IV	Maldives	9	38	54	50	50
	Average	9	38	54	50	50
Chest LAT						
I	Australia	7	20	73	50	50
	Bulgaria	19	34	46	51	49
	Iceland	12	10	78	53	47
	Japan	6	18	76	55	45
	Korea, Rep.	17	29	55	56	44
	Luxembourg	2	16	82	52	48
	Romania	22	24	54	56	44
	Spain	10	11	80	55	45
	Switzerland	5	15	80	53	47
	Weighted average	10	20	71	55	46
II	Trinidad and Tobago	12	34	54	55	45
	Tunisia	0	0	100	100	0
	Weighted average	1	4	95	95	5
III	Zimbabwe	0	100	0	50	50
	Average	0	100	0	50	50
IV	Maldives	3	43	55	71	29
	Average	3	43	55	71	29
Chest photofluorography						
I	Bulgaria	14	46	42	31	69
	Romania	4	55	41	52	48
	Russian Federation	0	41	59	52	48
	Weighted average	1	43	56	51	49

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
III	Zimbabwe	0	100	0	50	50
	Average	0	100	0	50	50
Chest fluoroscopy						
I	Bulgaria	5	46	49	44	56
	Czech Republic	0	29	71	50	50
	Japan	11	17	72	63	37
	Romania	7	35	58	50	50
	Russian Federation	1	28	71	56	44
	Weighted average	6	25	70	58	43
Limbs and joints						
I	Australia	14	32	54	46	54
	Bulgaria	21	32	46	49	51
	Czech Republic	19	30	51	50	50
	Iceland	32	18	51	47	53
	Japan	14	23	63	43	57
	Luxembourg	11	31	58	49	51
	Romania	20	33	47	55	45
	Russian Federation	15	30	55	39	61
	Spain	14	22	64	44	56
	Switzerland	16	30	54	50	50
	Weighted average	15	27	58	43	57
III	Zimbabwe	43	29	28	51	49
	Average	43	29	28	51	49
IV	Maldives	22	29	49	48	52
	Average	22	29	49	48	52
Lumbar spine AP/PA						
I	Australia	2	29	69	42	58
	Czech Republic	6	32	62	50	50
	Iceland	7	15	78	41	59
	Japan	3	18	79	43	57
	Korea, Rep.	10	36	54	51	49
	Luxembourg	5	31	64	44	56
	Romania	6	33	62	49	51
	Russian Federation	11	36	53	58	42
	Spain	6	13	91	42	58
	Switzerland	2	29	69	47	53
	Weighted average	7	28	67	49	51
II	Trinidad and Tobago	6	47	47	50	50
	Tunisia	0	18	82	18	82
	Turkey	3	17	80	45	55
	Weighted average	3	18	80	42	58
III	Zimbabwe	0	50	50	60	40
	Average	0	50	50	60	40
IV	Maldives	5	25	70	57	43
	Average	5	25	70	57	43

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Lumbar spine LAT						
I	Australia	2	29	69	42	58
	Iceland	7	15	78	41	59
	Japan	3	18	79	43	57
	Korea, Rep.	9	53	38	66	34
	Romania	6	33	53	49	51
	Spain	2	13	85	42	58
	Switzerland	2	29	69	47	53
	Weighted average	4	26	70	47	53
II	Trinidad and Tobago	6	47	47	50	50
	Tunisia	0	18	82	18	82
	Turkey	3	17	80	45	55
	Weighted average	3	18	80	42	58
III	Zimbabwe	0	50	50	60	40
	Average	0	50	50	60	40
IV	Maldives	5	25	70	57	43
	Average	5	25	70	57	43
Thoracic spine AP						
I	Australia	4	21	74	31	69
	Czech Republic	0	14	86	50	50
	Iceland	11	15	74	44	56
	Japan	9	23	68	56	44
	Korea, Rep.	14	34	52	51	49
	Luxembourg	4	34	62	43	57
	Romania	12	37	51	49	51
	Russian Federation	13	37	50	60	40
	Spain	10	23	68	44	56
	Switzerland	6	36	58	42	58
	Weighted average	12	32	57	53	47
II	Trinidad and Tobago	15	47	38	47	53
	Turkey	3	17	80	45	55
	Weighted average	4	21	75	45	55
III	Zimbabwe	0	50	50	50	50
	Average	0	50	50	50	50
IV	Maldives	4	25	71	54	46
	Average	4	25	71	54	46
Thoracic spine LAT						
I	Australia	4	21	74	31	69
	Iceland	11	15	74	44	56
	Korea, Rep.	12	33	54	50	50
	Romania	12	37	51	49	51
	Spain	13	21	65	44	56
	Switzerland	6	36	58	42	58
	Weighted average	12	30	58	47	53
II	Trinidad and Tobago	15	47	38	47	53
	Turkey	3	17	80	45	55
	Weighted average	4	21	75	45	55

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
III	Zimbabwe	0	50	50	50	50
	Average	0	50	50	50	50
IV	Maldives	4	25	71	54	46
	Average	4	25	71	54	46
Cervical spine AP						
I	Australia	3	31	66	44	56
	Czech Republic	7	31	63	50	50
	Iceland	15	20	65	42	58
	Japan	4	26	70	47	53
	Korea, Rep.	12	39	48	55	45
	Luxembourg	2	35	63	43	57
	Romania	4	27	69	53	47
	Russian Federation	15	32	53	47	53
	Spain	7	18	75	39	61
	Switzerland	4	32	64	42	58
	Weighted average	9	29	62	47	53
II	Trinidad and Tobago	6	51	43	35	65
	Turkey	3	17	80	45	55
	Weighted average	3	21	76	44	56
III	Zimbabwe	0	53	47	50	50
	Average	0	53	47	50	50
IV	Maldives	6	45	49	51	49
	Average	6	45	49	51	49
Cervical spine LAT						
I	Australia	3	31	66	44	56
	Iceland	15	20	65	42	58
	Korea, Rep.	12	40	48	54	46
	Romania	4	27	69	53	47
	Spain	13	15	72	41	59
	Switzerland	4	32	64	42	58
	Weighted average	11	33	54	50	50
II	Trinidad and Tobago	6	51	43	35	65
	Turkey	3	17	80	45	55
	Weighted average	3	21	76	44	56
III	Zimbabwe	0	53	47	50	50
	Average	0	53	47	50	50
IV	Maldives	6	45	49	51	49
	Average	6	45	49	51	49
Pelvis/hip						
I	Australia	7	22	71	44	56
	Bulgaria	18	29	53	42	58
	Czech Republic	14	12	74	50	50
	Iceland	5	12	83	39	61
	Japan	6	19	75	44	56
	Korea, Rep.	10	21	69	55	46
	Luxembourg	4	15	81	38	62
	Romania	23	24	53	52	48

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Russian Federation	16	17	53	44	56
	Spain	9	9	82	41	59
	Switzerland	5	16	79	44	56
	Weighted average	9	19	73	45	55
II	Trinidad and Tobago	14	40	46	49	51
	Turkey	3	17	80	45	55
	Weighted average	4	20	76	46	55
III	Zimbabwe	0	50	50	48	52
	Average	0	50	50	48	52
IV	Maldives	8	27	65	50	50
	Average	8	27	65	50	50
Head						
I	Bulgaria	24	33	43	45	55
	Czech Republic	27	36	38	50	50
	Iceland	33	24	43	42	58
	Japan	17	29	53	51	49
	Korea, Rep.	24	35	41	58	42
	Luxembourg	23	36	41	50	50
	Romania	21	37	42	57	43
	Russian Federation	16	44	40	52	48
	Spain	20	20	60	46	54
	Switzerland	21	40	39	54	46
	Weighted average	19	35	46	52	48
II	Trinidad and Tobago	19	39	42	50	50
	Turkey	3	17	80	45	55
	Weighted average	5	20	76	46	54
III	Zimbabwe	33	33	34	50	50
	Average	33	33	34	50	50
IV	Maldives	10	35	55	48	52
	Average	10	35	55	48	52
Abdomen						
I	Australia	18	24	58	46	54
	Bulgaria	11	31	58	36	64
	Czech Republic	4	17	79	50	50
	Iceland	19	12	70	47	53
	Japan	6	14	80	57	43
	Korea, Rep.	23	31	47	52	48
	Luxembourg	10	23	67	48	52
	Romania	13	25	63	51	49
	Russian Federation	19	21	60	43	57
	Spain	7	13	80	51	49
	Switzerland	7	22	71	47	53
	Weighted average	13	20	67	50	51
II	Trinidad and Tobago	21	29	50	51	49
	Tunisia	6	25	69	75	25
	Turkey	3	17	80	45	55
	Weighted average	4	18	78	49	51

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
III	Zimbabwe	25	50	25	50	50
	Average	25	50	25	50	50
IV	Maldives	30	36	34	52	48
	Average	30	36	34	52	48
Upper gastrointestinal tract						
I	Bulgaria	9	31	60	35	66
	Czech Republic	3	23	75	50	50
	Iceland	20	20	60	43	57
	Japan	0	17	83	65	35
	Luxembourg	3	25	73	42	58
	Romania	8	32	61	50	50
	Russian Federation	3	29	68	42	58
	Spain	9	19	82	43	57
	Switzerland	4	12	84	43	57
	Weighted average	3	23	75	51	50
II	Trinidad and Tobago	7	39	54	53	47
	Turkey	1	22	77	47	53
	Weighted average	2	24	74	48	52
III	Zimbabwe	0	29	71	50	50
	Average	0	29	71	50	50
IV	Maldives	18	27	55	52	48
	Average	18	27	55	52	48
Lower gastrointestinal tract						
I	Bulgaria	7	30	64	34	65
	Czech Republic	3	15	82	50	50
	Iceland	4	10	86	43	57
	Japan	2	11	88	61	39
	Luxembourg	2	10	88	39	61
	Romania	10	17	73	49	51
	Russian Federation	3	31	66	40	60
	Spain	1	16	83	40	61
	Switzerland	2	13	85	42	58
	Weighted average	3	20	77	48	52
II	Trinidad and Tobago	5	32	63	49	51
	Tunisia	1	22	77	47	53
	Weighted average	2	23	75	47	53
III	Zimbabwe	0	29	71	50	50
	Average	0	29	71	50	50
IV	Maldives	20	29	51	54	46
	Average	20	29	51	54	46
Cholecystography						
I	Bulgaria	6	27	68	31	69
	Czech Republic	6	12	82	50	50
	Japan	0	6	94	64	36
	Luxembourg	1	15	84	35	65
	Romania	0	23	76	62	38
	Russian Federation	3	20	77	44	56

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Spain	0	9	90	54	46
	Switzerland	0	13	87	37	63
	Weighted average	2	14	85	53	47
Urography						
I	Bulgaria	14	30	54	40	60
	Czech Republic	8	18	74	50	50
	Iceland	4	27	79	59	41
	Japan	3	18	80	62	39
	Luxembourg	7	24	69	54	46
	Romania	9	25	67	59	41
	Russian Federation	9	31	60	46	54
	Spain	6	18	77	49	51
	Switzerland	16	25	59	51	49
	Weighted average	7	24	70	53	48
II	Trinidad and Tobago	5	47	48	52	48
	Turkey	3	28	69	50	50
	Weighted average	3	30	67	50	50
IV	Maldives	5	35	60	48	52
	Average	5	35	60	48	52
Mammography screening						
I	Australia	0	0	100	0	100
	Bulgaria	3	43	54	7	93
	Luxembourg	0	0	100	0	100
	Russian Federation	0	30	70	0	100
	Spain				0	100
	Weighted average	0	27	73	0	100
II	Trinidad and Tobago	0	8	92	0	100
	Turkey	0	50	50	0	100
	Weighted Average	0	45	55	0	100
IV	Maldives	0	10	90	0	100
	Average	0	10	90	0	100
Mammography clinical diagnosis						
I	Australia	0	30	70	0	100
	Bulgaria	0	45	55	0	100
	Czech Republic	0	2	98		
	Japan	0	13	88	0	100
	Luxembourg	0	15	85	1	99
	Romania	5	40	55	21	79
	Russian Federation	0	20	80	0	100
	Spain	0	28	72	1	99
	Weighted average	0	20	80	2	99
II	Turkey	0	50	50	0	100
	Average	0	50	50	0	100
CT head						
I	Australia	5	32	63	42	58
	Bulgaria	10	37	53	53	47
	Czech Republic	5	18	77	50	50
	Iceland	15	13	73	46	54

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Japan	6	94		52	48
	Korea, Rep.	17	33	50	52	48
	Luxembourg	4	27	70	46	54
	Romania	12	25	63	53	47
	Russian Federation	5	25	70	52	48
	Spain	8	18	74	49	51
	Switzerland	4	23	73	51	49
	Weighted average	8	26	66	51	49
II	Trinidad and Tobago	23	33	44	51	49
	Turkey	7	29	64	49	51
	Weighted average	9	30	62	49	51
III	Zimbabwe	10	30	60	53	47
	Average	10	30	60	53	47
IV	Maldives	8	40	52	48	52
	Average	8	40	52	48	52
CT abdomen						
I	Australia	0	19	81	46	54
	Bulgaria	5	41	55	49	51
	Czech Republic	5	15	80	50	50
	Iceland	3	12	85	47	53
	Japan	1	99		55	45
	Korea, Rep.	8	23	69	58	42
	Luxembourg	1	17	83	49	52
	Russian Federation	3	25	72	52	48
	Spain	5	10	85	57	43
	Switzerland	1	17	82	55	46
	Weighted average	4	22	74	54	46
II	Trinidad and Tobago	4	38	58	48	52
	Turkey	7	29	64	49	51
	Weighted average	7	30	63	49	51
III	Zimbabwe	25	63	12	44	56
	Average	25	63	12	44	56
IV	Maldives	5	25	70	54	46
	Average	5	25	70	54	46
CT thorax						
I	Australia	0	13	87	55	45
	Bulgaria	11	41	49	49	51
	Czech Republic	3	16	81	50	50
	Iceland	4	13	84	53	47
	Japan	1	99		56	44
	Korea, Rep.	11	27	62	61	39
	Luxembourg	1	13	86	58	42
	Romania	11	21	68	57	43
	Russian Federation	3	25	72	52	48
	Spain	5	11	84	62	38
	Switzerland	2	20	78	51	49
	Weighted average	5	22	73	55	45

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
II	Trinidad and Tobago	2	39	59	56	44
	Turkey	7	29	64	49	51
	Weighted average	6	30	63	50	50
III	Zimbabwe	12	76	12	65	35
	Average	12	76	12	65	35
IV	Maldives	5	20	75	52	48
	Average	5	20	75	52	48
CT spine						
I	Bulgaria	5	41	55	49	51
	Czech Republic	1	21	78	50	50
	Luxembourg	0	27	73	48	52
	Spain	3	22	75	54	46
	Switzerland	0	24	76	50	50
	Weighted average	3	24	73	52	48
II	Trinidad and Tobago	8	53	39	66	34
	Average	8	53	39	66	34
III	Zimbabwe	17	66	17	66	34
	Average	17	66	17	66	34
IV	Maldives	4	35	61	50	50
	Average	4	35	61	50	50
CT pelvis						
I	Bulgaria	5	41	55	49	51
	Czech Republic	2	20	78	50	50
	Japan	1	99		53	47
	Spain	6	12	82	55	45
	Switzerland	4	32	64	47	53
	Weighted average	5	18	78	53	47
II	Trinidad and Tobago	6	34	60	46	54
	Average	6	34	60	46	54
III	Zimbabwe	0	50	50	75	25
	Average	0	50	50	75	25
IV	Maldives	3	23	74	57	43
	Average	3	23	74	57	43
CT interventional						
I	Bulgaria	5	41	55	49	51
	Spain	0	6	94	70	30
	Weighted average	1	11	88	66	34
III	Zimbabwe	0	100	0	50	50
	Average	0	100	0	50	50
CT other						
I	Bulgaria	5	41	55	49	51
	Iceland	5	13	82	49	51
	Japan	5	95		51	49
	Luxembourg	2	26	72	53	47
	Spain	2	18	81	59	41
	Weighted average	2	21	77	53	47

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Non-cardiac angiography						
I	Czech Republic	1	11	88	50	50
	Japan	0	0	100	60	40
	Luxembourg	0	9	91	53	47
	Romania	3	22	75	69	31
	Russian Federation	4	11	85	56	44
	Spain	0	7	93	62	38
	Switzerland	2	26	72	50	50
	Weighted average	2	8	91	59	41
Cardiac angiography						
I	Czech Republic	1	8	92	50	50
	Iceland	0	2	99	69	32
	Luxembourg	0	3	97	65	35
	Romania	4	11	85	63	37
	Russian Federation	6	5	89	56	44
	Spain	0	6	94	44	56
	Switzerland	1	11	88	62	38
	Weighted average	4	6	90	54	46
Cardiac PTCA						
I	Czech Republic	0	4	96	50	50
	Iceland	0	1	99	79	21
	Luxembourg	0	3	97	73	28
	Romania	0	28	71	44	56
	Spain	0	6	94	44	56
	Switzerland	0	3	97	79	21
	Weighted average	0	11	89	48	52
Cerebral angiography						
I	Czech Republic	1	18	81	50	50
	Luxembourg	0	0	100	66	34
	Spain	2	18	80	67	33
	Switzerland	4	38	58	50	50
	Weighted average	2	20	78	62	38
Vascular angiography (non-cardiac)						
I	Czech Republic	19	13	69	50	50
	Luxembourg	0	2	98	69	31
	Spain	0	7	93	62	39
	Switzerland	4	10	86	50	50
	Weighted average	4	8	88	56	42
Other interventional						
I	Luxembourg	0	8	92	46	54
	Spain	0	11	89	56	44
	Switzerland	4	10	86	50	50
	Weighted average	1	11	89	55	45
Pelvimetry						
I	Bulgaria	7	40	54	0	100
	Iceland	3	97	0	0	100
	Japan	0	98	2	0	100
	Luxembourg	0	100	0	0	100
	Romania	14	20	66	0	100
	Spain	0	60	40	0	100
	Weighted average	2	79	19	0	100

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Other diagnostic						
I	Bulgaria	7	38	55	0	100
	Japan	15	24	61	51	49
	Luxembourg	0	3	97	12	88
	Romania	1	41	58	56	44
	Spain	10	11	80	28	72
	Weighted average	12	23	65	44	56
Intraoral dental						
I	Bulgaria	10	50	40	46	54
	Czech Republic	22	37	42	50	50
	Japan	9	28	63	45	56
	Luxembourg	5	48	47	47	53
	Romania	15	43	43	46	54
	Spain	20	40	41	51	49
	Switzerland	5	38	57	45	55
	Weighted average	12	32	55	46	54
III	Zimbabwe	7	73	20	50	50
	Average	77.0	73	20	50	50
Panoramic dental radiology						
I	Bulgaria	20	45	35	49	51
	Czech Republic	22	37	42	50	50
	Japan	6	36	58	45	55
	Luxembourg	36	37	28	47	53
	Romania	28	34	37	50	50
	Spain	16	51	33	62	38
	Switzerland	21	39	40	44	56
	Weighted average	12	39	49	49	51
III	Zimbabwe	80	14	6	50	50
	Average	80	14	6	50	50
IV	Maldives	15	50	35	20	80
	Average	15	50	35	20	80
Dental CT						
I	Luxembourg	3	38	59	42	59
	Average	3	38	59	42	59

Table B48. Frequencies, population-weighted average effective doses and collective doses assumed in the global model for diagnostic practice with medical and dental radiological examinations (1997–2007)

Examinations	*Number of examinations per 1 000 population*				*Effective dose per examination (mSv)*				*Annual collective dose (man Sv)*			
	Level I	*Level II*	*Levels III–IV*	*World*	*Level I*	*Level II*	*Levels III–IV*	*World*	*Level I*	*Level II*	*Levels III–IV*	*World*
Chest PA	168	142	1.6	110	0.1	*0.1*	0.02	0.05	17 000	30 000	57	48 000
Chest LAT	70	39	0.3	36	0.2	*0.2*	0.02	0.2	22 000	25 000	11	47 000
Chest photofluorography	287	0.0	0.8	69	0.8	*0.8*	0.8	0.8	340 000	19	1 100	340 000
Chest fluoroscopy	17	0.0	0.0	4.0	2.1	*2.1*	*2.1*	2.1	53 000	210	0.0	53 000
Limbs and joints	140	28	0.3	47	0.0	*0.0*	*0.01*	0.04	10 000	4 100	5.3	14 000
Lumbar spine AP/PA	31	3.8	0.1	9.2	1.2	*1.2*	1.3	1.2	58 000	15 000	300	73 000
Lumbar spine LAT	23	3.8	0.8	7.6	1.0	*1.0*	1.8	1.2	35 000	12 000	2 600	50 000
Thoracic spine AP/PA	16	0.8	0.7	4.5	0.5	*0.5*	0.7	0.6	13 000	1 400	800	15 000
Thoracic spine LAT	9.8	6.7	0.7	5.8	0.3	*0.3*	*0.3*	0.3	5 200	7 400	400	13 000
Cervical spine AP/PA	32	1.9	1.2	8.9	0.1	*0.1*	0.1	0.1	6 600	810	170	7 500
Cervical spine LAT	19	1.9	1.2	5.9	0.1	*0.1*	*0.1*	0.1	3 900	800	290	5 000
Pelvis/hip	40	4.9	2.1	13	1.1	*1.1*	0.7	1.0	70 000	18 000	2 500	91 000
Head	44	13	2.6	18	0.1	*0.1*	0.1	0.1	5 700	3 500	320	9 600
Abdomen	45	11	1.7	17	0.8	*0.8*	0.7	0.8	56 000	28 000	2 100	86 000
Upper GI tract	34	12	0.5	14	3.4	*3.4*	3.0	3.3	180 000	130 000	2 700	310 000
Lower GI tract	9.3	9.7	0.2	7.0	7.4	*7.4*	7.0	7.3	110 000	230 000	2 100	340 000
Cholecystography	1.7	11	0.0	5.9	2.0	*2.0*	*2.0*	2.0	5 400	71 000	0.0	76 000
Urography	8.5	9.8	0.8	7.1	2.6	*2.6*	2.5	2.6	34 000	80 000	3 600	120 000
Mammography screening	23	14	0.8	12	0.3	*0.3*	*0.3*	0.3	9 100	13 000	380	22 000
Mammography clinical diagnosis	20	6.1	0.8	8.0	0.4	*0.4*	*0.4*	0.4	12 000	7 400	560	20 000
CT head	40	2.3	0.9	11	2.4	*2.4*	*2.4*	2.4	150 000	17 000	3 800	170 000
CT thorax	24	0.8	0.7	6.3	7.8	*7.8*	*7.8*	7.8	290 000	19 000	9 000	310 000
CT abdomen	30	1.8	0.7	8.2	12.4	*12.4*	*12.4*	12.4	570 000	70 000	14 000	650 000

Examinations	*Number of examinations per 1 000 population*				*Effective dose per examination (mSv)*				*Annual collective dose (man Sv)*			
	Level I	*Level II*	*Levels III–IV*	*World*	*Level I*	*Level II*	*Levels III–IV*	*World*	*Level I*	*Level II*	*Levels III–IV*	*World*
CT spine	11	0.3	0.5	3.0	5.0	*5.0*	*5.0*	5.0	87 000	5 100	4 300	96 000
CT pelvis	19	1.0	0.3	5.1	9.4	*9.4*	*9.4*	9.4	270 000	28 000	5 400	310 000
CT interventional	1.0	0.0	0.1	0.3	3.8	*3.8*	*3.8*	3.8	5 700	0.0	530	6 200
CT other	2.8	1.0	0.0	1.2	3.8	*3.8*	*3.8*	3.8	16 000	12 000	0.0	29 000
Non-cardiac angiography	2.6	0.0	0.0	0.6	9.3	*9.3*	*9.3*	9.3	38 000	660	0	38 000
Cardiac angiography	1.5	5.0	0.0	2.8	11.2	*11.2*	*11.2*	11.2	26 000	180 000	0	200 000
Cardiac PTCA	0.9	0.1	0.0	0.3	11.9	*11.9*	*11.9*	11.9	17 000	3 800	0	21 000
Cerebral angiography	0.3	0.1	0.0	0.1	5.7	*5.7*	*5.7*	5.7	2 700	1 100	0	3 800
Vascular angiography (non-cardiac)	1.6	0.0	0.0	0.4	9.0	*9.0*	*9.0*	9.0	23 000	280	0	23 000
Other interventional	1.1	0.0	0.0	0.3	11.2	*11.2*	*11.2*	11.2	19 000	1 100	0.0	20 000
Pelvimetry	1.1	0.5	0.0	0.5	1.4	*1.4*	*1.4*	1.4	2 300	2 100	0.0	4 300
Other diagnostic	159	0.0		38	1.6	*1.6*	*1.6*	1.6	390 000	0.0	0.0	390 000
Total diagnostic	1 332	332	20	488					2 900 000	1 000 000	57 000	4 000 000
Intraoral dental	227	12	2.5	61	0.02	*0.02*	*0.02*	0.02	5 500	600	88	6 200
Panoramic dental	49	3.7	0.08	13	0.06	*0.06*	0.01	0.05	4 500	690	1.5	5 100
Dental CT	0.02	0.00		0.00				0.00	0.00	0.00	0.00	0.00
Total dental	275	16	3	74					9 900	1 300	89	11 000
Average effective dose per caput from medical radiological examinations (mSv)									1.91	0.32	0.03	0.62
Average effective dose per caput from dental radiological examinations (mSv)									0.006 4	0.004	5.1×10^{-5}	0.001 8
Average effective dose per medical radiological examination (mSv)									1.44	0.96	1.60	1.28
Average effective dose per dental radiological examination (mSv)									0.023	0.026	0.020	0.024

Note: Values in italics have been estimated in the absence of data from the UNSCEAR survey.

Table B49. Estimated global number of procedures, collective effective dose and per caput effective dose for various categories of radiographic (excluding dental) nuclear medicine procedures using ionizing radiation in the United States [N26]

Type of procedure	*Number of procedures (millions)*	*Collective effective dose (man Sv)*	*Per caput effective dose (mSv)*
Conventional radiography and fluoroscopy	293	100 000	0.3
Interventional	17	128 000	0.4
CT	67	440 000	1.5
Nuclear medicine	18	231 000	0.8
Total	395	899 000	3.0

Table B50. Contribution to the frequency of various types of diagnostic medical and dental radiological examination

Examinations	*Contribution (%)*			
	Level I	*Level II*	*Levels III–IV*	*World*
Chest PA	10	41	7.1	20
Chest LAT	4.3	11	1.4	6.4
Chest photofluorography	18	0.00	3.6	12
Chest fluoroscopy	1.0	0.01	0.00	0.71
Limbs and joints	8.7	7.9	1.3	8.4
Lumbar spine AP/PA	1.9	1.1	0.56	1.6
Lumbar spine LAT	1.4	1.1	3.5	1.4
Thoracic spine AP/PA	1.0	0.24	2.8	0.79
Thoracic spine LAT	0.6	1.9	2.8	1.0
Cervical spine AP/PA	2.0	0.55	5.3	1.6
Cervical spine LAT	1.2	0.55	5.3	1.0
Pelvis/hip	2.5	1.4	9.0	2.2
Head	2.7	3.8	11	3.2
Abdomen	2.8	3.1	7.6	3.0
Upper GI tract	2.1	3.4	2.3	2.5
Lower GI tract	0.6	2.8	0.74	1.3
Cholecystography	0.1	3.2	0.00	1.0
Urography	0.5	2.8	3.5	1.3
Mammography screening	1.4	3.9	3.6	2.2
Mammography clinical diagnosis	1.2	1.8	3.6	1.4
CT head	2.5	0.65	3.9	2.0
CT thorax	1.5	0.22	2.9	1.1
CT abdomen	1.8	0.52	2.9	1.5
CT spine	0.7	0.09	2.2	0.53
CT pelvis	1.2	0.27	1.4	0.91
CT interventional	0.1	0.00	0.35	0.05
CT other	0.2	0.29	0.00	0.21
Non-cardiac angiography	0.1	0.1	0.00	0.1
Cardiac angiography	0.1	1.4	0.00	0.5
Cardiac PTCA	0.1	0.03	0.00	0.05
Cerebral	0.0	0.02	0.00	0.02
Vascular angiography (non-cardiac)	0.1	0.00	0.00	0.07
Other interventional	0.1	0.01	0.00	0.05
Pelvimetry	0.1	0.14	0.00	0.09
Other medical	9.9	0.00	0.00	6.8
Total medical	83	96	89	87

Examinations	*Contribution (%)*			
	Level I	*Level II*	*Levels III–IV*	*World*
Intraoral dental	14	3.5	11	11
Panoramic dental	3.0	1.1	0.36	2.4
Dental CT	0.00	0.00	0.00	0.00
Total dental	17	4.5	11	13
Total diagnostic examinations	100.00	100.00	100.00	100.00

Table B51. Contribution to the collective effective dose of various types of diagnostic medical and dental radiological examination

Examinations	*Contribution (%)*			
	Level I	*Level II*	*Levels III–IV*	*World*
Chest PA	0.59	3.0	0.10	0.93
Chest LAT	0.74	2.5	0.02	0.98
Chest photofluorography	12	0.00	2.0	9.9
Chest fluoroscopy	1.8	0.02	0.00	1.5
Limbs and joints	0.35	0.41	0.01	0.35
Lumbar spine AP/PA	2.0	1.5	0.52	1.9
Lumbar spine LAT	1.2	1.2	4.5	1.3
Thoracic spine AP/PA	0.43	0.14	1.4	0.40
Thoracic spine LAT	0.18	0.73	0.69	0.26
Cervical spine AP/PA	0.22	0.08	0.30	0.20
Cervical spine LAT	0.13	0.08	0.50	0.13
Pelvis/hip	2.4	1.8	4.4	2.3
Head	0.20	0.35	0.55	0.22
Abdomen	1.9	2.7	3.7	2.1
Upper GI tract	6.0	13	4.8	7.0
Lower GI tract	3.6	22	3.6	6.3
Cholecystography	0.18	7.1	0.00	1.2
Urography	1.2	7.9	6.2	2.2
Mammography screening	0.31	1.3	0.66	0.45
Mammography clinical diagnosis	0.40	0.74	0.98	0.46
CT head	5.0	1.7	6.6	4.6
CT thorax	9.7	1.9	16	8.7
CT abdomen	19	7.0	25	18
CT spine	2.9	0.51	7.5	2.7
CT pelvis	9.3	2.8	9.4	8.4
CT interventional	0.19	0.00	0.93	0.18
CT other	0.55	1.2	0.00	0.64
Non-cardiac angiography	1.28	0.07	0.00	1.1
Cardiac angiography	0.87	17	0.00	3.2
Cardiac PTCA	0.57	0.37	0.00	0.53
Cerebral	0.09	0.11	0.00	0.09
Vascular angiography (non-cardiac)	0.77	0.03	0.00	0.65
Other interventional	0.69	0.10	0.00	0.56
Pelvimetry	0.08	0.20	0.00	0.09
Other medical[a]	13	0.00	0.00	11
Total medical	100.00	100.00	100.00	100.00

Examinations	*Contribution (%)*			
	Level I	*Level II*	*Levels III–IV*	*World*
Intraoral dental	60	47	98	59
Panoramic dental	40	53	2	41
Dental CT	0.00	0.00	0.00	0.00
Total dental	100.00	100.00	100.00	100.00

[a] As there was only one return giving an effective dose for "other medical" examinations, a value of 1.6 mSv has been used, which is an average across all examinations when the data for "other medical" are included. This represents an estimate of the typical effective dose for "other diagnostic" examinations.

Table B52. Trends in the annual frequency of diagnostic medical radiological examinations expressed as number per 1,000 population

Level	*1970–1979*	*1980–1984*	*1985–1990*	*1991–1996*	*1997–2007*
I	820	810	890	920	1 332
II	26	140	120	154	332
III	23	75	67	17	20
IV	27		8.8	29	20

Table B53. Trends in the annual frequency of diagnostic dental radiological examinations expressed as number per 1,000 population

Level	*1970–1979*	*1980–1984*	*1985–1990*	*1991–1996*	*1997–2007*
I	320	390	350	310	275
II		0.8	2.5	14	16
III		0.8	1.7	0.3	2.6
IV				0.1	2.6

Table B54. Trends in average effective dose from diagnostic medical radiological examinations for countries in health-care level I

Examination	*Average effective dose per examination (mSv)*			
	1970–1979	*1980–1990*	*1991–1996*	*1997–2007*
Chest radiography	0.25	0.14	0.14	0.07
Chest photofluoroscopy	0.52	0.52	0.65	0.78
Chest fluoroscopy	0.72	0.98	1.1	2.1
Limbs and joints	0.02	0.06	0.06	0.05
Pelvis and hip	2.2	1.7	1.8	1.1
Head	2.1	1.2	0.83	0.08
Abdomen	1.9	1.1	0.53	0.82
Upper GI	8.9	7.2	3.6	3.4
Lower GI	9.8	4.1	6.4	7.4
Cholecystography	1.9	1.5	2.3	2.0
Urography	3	3.1	3.7	2.6
Mammography	1.8	1	0.51	0.26
CT	1.3	4.4	8.8	7.4
PTCA			22	11.9

Table B55. Estimated doses to the world population from medical and dental radiological examinations 1997–2007

Health-care level	*Population (millions)*	*Per caput effective dose (mSv)*		*Collective effective dose (man Sv)*	
		Medical	*Dental*	*Medical*	*Dental*
I	1 540	1.91	0.006 4	2 900 000	9 900
II	3 153	0.32	0.000 4	1 000 000	1 300
III	1 009	0.03	0.000 051	33 000	51
IV	744	0.03	0.000 051	24 000	38
World	6 446	0.62	0.002	4 000 000	11 000

APPENDIX C:
LEVELS AND TRENDS OF EXPOSURE IN NUCLEAR MEDICINE

I. INTRODUCTION

C1. A radiopharmaceutical is a compound whose molecular structure causes it to concentrate primarily in a specific region of the body and which also contains a radioactive species that allows: *(a)* external imaging of the body (diagnosis) to evaluate the structure and/or function of the region, or *(b)* delivery of a large radiation dose (therapy) to the region to control a specific disease. Most medical imaging or therapy procedures rely on external sources of ionizing or non-ionizing radiation to achieve their aims; nuclear medicine studies employ the unique approach of introducing a radiolabelled substance into the body of the subject, with devices external to the body being able to detect, and in some cases quantify, the activity in different regions of the subject. This thus permits not only the study of the configuration of internal structures, but the evaluation of internal physiological processes. In the case of therapy, the concentration of the material in the target tissue of interest allows the delivery of lethal doses of radiation to the undesirable tissues, with the aim of maintaining lower concentrations in other body tissues so as to minimize unwanted deleterious effects.

C2. In most nuclear medicine imaging procedures, the goal for the physician is diagnosis of disease or improper organ function via study of the distribution of radioactivity inside specific structures within the body. Many imaging procedures evaluate organ structure, size and shape, or may evaluate the presence of cancerous or otherwise deleterious lesions. Dynamic studies are also widely used to provide information on organ or system function through the measurement of the rate of accumulation and subsequent removal of the radiopharmaceutical by an organ of interest. Two examples of dynamic imaging include the study of dynamic cardiac function and of renal clearance of radiolabelled substances [M27].

C3. Nuclear medicine practice depends firstly on the availability of radioactive substances (radionuclides). Radionuclides are generally produced from [W18]:

- Nuclear reactors;
- Particle accelerators; or
- Radionuclide generator systems (devices that contain a longer-lived "parent" radionuclide that continuously produces a shorter-lived "progeny" that can be readily separated from the system for delivery to patients).

The reliable delivery of high-quality radionuclides directly to nuclear medicine centres, or more commonly, to radiopharmacies that produce radiopharmaceuticals and deliver them to nuclear medicine centres, is essential to the routine practice of nuclear medicine. Many hospitals and clinics are very busy, and depend on an uninterrupted supply of high-quality radiopharmaceuticals to function. The amount of a radiopharmaceutical product administered, in terms of mass, is generally quite small, as the specific activity (amount of activity per unit mass, e.g. Bq/g) is kept high. This allows the compound to act as a tracer within the system without perturbing the normal system kinetics or introducing toxicity concerns.

C4. The creation and dissemination of the labelled drug products (radiopharmaceuticals or radiotracers) is the next essential step to successful nuclear medicine practice.

- The large majority of radiopharmaceutical products are labelled with ^{99m}Tc, which has a half-life of approximately 6 hours and is supported in a generator system by its parent ^{99}Mo ($T_{1/2}$ = 66 h).
- Another large general class of radiopharmaceuticals is that of the radioiodinated compounds—tracers labelled with ^{131}I, ^{123}I, ^{125}I and possibly other isotopes of iodine.
- The other significant class of radiolabelled products are those designed for use with positron emission tomography (PET) systems. The principal radionuclides are ^{18}F, ^{11}C, ^{15}O and ^{13}N. The ^{18}F and ^{11}C labels are bound to a number of tracers of interest for the study of myocardial or cerebral function, cancer detection and other processes. The isotope ^{15}O as labelled O_2 or H_2O is used in a number of applications; ^{13}N as NH_3 is used for myocardial imaging.

C5. The equipment for imaging nuclear medicine studies is quite specialized and highly technical. These imaging systems and their associated electronic and computer components have evolved over the past five decades or so. The gamma camera is the main device used for imaging radionuclides. The main detecting medium is a large sodium iodide (NaI (Tl)) crystal, usually in a circular or square configuration. Radiation absorbed by the detector crystal is converted into light, which is detected by a large array of photomultiplier tubes (PMTs). Electronic circuits analyse the PMT

signals to ensure that the energy of the pulses is within a preset tolerance for the nuclide's principal decay energy, to determine the position of the gamma ray interaction and to record acceptable events in a two-dimensional projection field. This information is then displayed and possibly analysed further using computer software provided with the imaging system. Regions of interest may be drawn over different portions of the image and the numbers of counts in different regions determined at various times. Nuclear medicine cameras employ a range of different types of collimator for nuclides of different energies and for particular types of study. Typically, cameras employ low-, medium- and high-energy collimators for large-area viewing, and pinhole or other specialized collimators may be used for particular studies. The majority of commercial cameras today contain more than one head (i.e. imaging system comprised of a NaI (Tl) crystal, PMTs and electronic circuitry). Dual-headed systems are the most common (these permit simultaneous acquisition of data on two sides of the subject, typically anterior and posterior, as well as rapid acquisition of tomographic data in single-photon-emission computed tomography (SPECT)), but some triple-headed systems have also been developed.

C6. Some simpler imaging systems are also routinely used, e.g. small NaI (Tl) crystals for studies of thyroid uptake and function. Simple gamma probes may be used to assist surgeons in identifying and resecting lymph nodes that take up ^{99m}Tc-labelled colloids. Some other studies using in vitro analysis of patient tissue or fluid samples may also be performed; for example, vitamin B12 absorption from the gastrointestinal tract may be evaluated by measuring the fraction of orally administered vitamin B12 labelled with radioactive cobalt (^{57}Co and/or ^{58}Co) that is excreted in urine. Other non-imaging uses of radiopharmaceuticals involve the in vitro studies of thyroid function [P8] and labelled blood cells [S5], and radioimmunoassay [Y13].

C7. The nuclear medicine camera may be used in a number of different data acquisition modes:

- A static image may be obtained by simply placing the camera near the region of the patient to be imaged and leaving it in place during data acquisition. The camera may be placed, for example, over the abdomen, near the chest (for cardiac imaging) or over the head (for cerebral imaging). In addition, the camera may be used to obtain images of the whole body of the subject for bone imaging, quantitative studies and other purposes. This requires the use of special collimators or large subject-to-camera distances. Multiple static images of parts of the body may also be pieced together to create whole-body images.
- Dynamic imaging studies may be performed in which the gamma camera is positioned over the organ to be imaged and images are acquired in a time series possibly before, and certainly after, the injection of the radiopharmaceutical. For example, in a renogram, which is used to assess kidney function, a radiopharmaceutical that is preferentially taken up by the kidney is administered to the patient, usually intravenously. The movement of the radiopharmaceutical through the body, its accumulation in the kidney and its subsequent excretion are imaged. Kidney function is assessed on the basis of the time it takes for the radiopharmaceutical to reach peak concentration and how long it takes for this activity to be cleared from the body. Many dynamic studies of cardiac function are also routinely performed.
- Tomographic data may be taken (SPECT) in a procedure whereby the camera is rotated around the subject and data are gathered from many different angles, with the collected data subsequently analysed to develop three-dimensional images of the radionuclide distribution in the patient. Static or dynamic gamma camera images provide a two-dimensional projection image of the activity within the body. A dual-headed camera provides two projection images, typically 180° apart from each other, although the camera heads can be manipulated to provide other configurations. With correction for scatter and attenuation, these two-dimensional projections can yield quantitative information about the radionuclide content of an identified region. If a three-dimensional representation is obtained using tomography, one may obtain images and quantitative estimates of activity constructed from millions of "voxels" (volume elements, corresponding to the "pixels", or picture elements, that constitute a two-dimensional electronic image). This allows a more detailed evaluation of the radionuclide distribution within the body. The procedures for correcting all of the many projection images taken around the body for attenuation, scatter and other effects are quite involved. Most camera systems provide some standard software for performing these evaluations; the science of these analyses, however, continues to be an area of active investigation and constant improvement.

C8. Properties of many radionuclides commonly used for in vivo imaging are shown in table C1. Many different radionuclides have been employed for imaging, but the most popular for most studies (except for PET) is ^{99m}Tc. This radionuclide has a short half-life (6 hours). It emits a gamma ray at 140 keV with about 89% abundance, which is ideally suited for typical gamma cameras. In addition, as noted above, it is readily available from commercially available molybdenum–technetium generator systems. Table C2 provides a summary of many important radiopharmaceuticals used in nuclear medicine [K15]. The radiopharmaceuticals in use change periodically, of course, as new agents are added or others fall out of use. Particularly in radiation therapy with internal emitters, new radionuclides and agents are continually being proposed and tested. In addition, studies that are popular in some parts of the world are not popular, or approved for use, in others, so practice varies widely.

C9. Improved spatial resolution in tomographic nuclear medicine studies can be achieved with PET. Radionuclides that emit a positron provide the unique advantage that after the positron interacts with an electron in the environment and both are annihilated, two photons of energy 0.511 MeV are emitted simultaneously at a 180º orientation to each other. A PET imaging device exploits this fact and detects pairs of photons in spatially opposed detectors, thereby permitting identification of the location at which the positron annihilation occurred. Table C3 lists some common PET radionuclides and studies [L19].

C10. PET offers another advantage in that small quantities of radiopharmaceutical can be used to measure metabolic function rates, receptor densities, blood flow and changes in function. The main disadvantage of PET scanning is that positron-emitting radionuclides (e.g. ^{11}C, ^{13}N, ^{15}O and ^{18}F) have relatively short half-lives. As a consequence, PET scanners need to be located within short travelling times of the facility that produces the radiopharmaceuticals.

C11. Some advantages of PET studies are that:

- The sensitivity and resolution of PET scanners are better than those of SPECT systems. The attenuation correction algorithms are more accurate.
- Many unique radiopharmaceuticals have been developed to image particular biological or physiological processes, such as general cardiac uptake, tumour imaging and neuroreceptor imaging.
- The use of short-half-life radionuclides may result in lower patient doses.

C12. In PET scanning, a number of radiopharmaceuticals are used for various diagnostic studies. One example is ^{18}F-labelled fluorodeoxyglucose (^{18}F FDG), which is a labelled sugar compound administered to the patient. FDG is thus a marker for sugar metabolism and is used for a number of useful studies.

- In cardiology, PET measures both blood flow (perfusion) and metabolic rate within the heart. PET imaging can identify areas of decreased blood flow as well as muscle damage in the heart. This information is particularly important in patients who have had a myocardial infarction and who are being considered for a revascularization procedure.
- PET studies may be used in neurological studies to diagnose Alzheimer's disease, Parkinson's disease, epilepsy and other neurological conditions.
- Cancer cells tend to have a higher metabolic rate than normal cells. As a consequence, ^{18}F FDG accumulates preferentially in cancer cells, which appear as an area of higher activity on a PET scan.

C13. PET is considered to be particularly effective for imaging a number of common cancers, such as lung cancer, colorectal cancer, lymphoma, melanoma and breast cancer. The nuclear medicine physician is able to identify whether cancer is present or if it has spread. PET is particularly useful in assessing response to treatment and to confirm whether a patient is cancer-free after treatment. PET is also used for cancer staging and for assessing the effectiveness of different kinds of therapy (e.g. chemotherapy).

C14. PET imaging studies have been of high interest to the nuclear medicine community for many years. Interest grew steadily, as did the general use of radiopharmaceuticals. In 1953, Gordon Brownell and H.H. Sweet built a positron detector based on the detection of annihilation photons by means of coincidence counting. Clinical use has been increasing in the last decade owing to increases in the availability of equipment and health-care reimbursement for PET procedures. Patient doses for PET studies are on the high end for diagnostic nuclear medicine procedures, as will be shown in detail below, and the 511 keV photon from the annihilation radiation contributes to staff radiation doses.

C15. Combined SPECT–CT and PET–CT scanners are in widespread use in many countries. In these devices, images from the two modalities may be obtained from a patient without the patient moving between scans. This enables images obtained from the two imaging approaches to be easily co-registered and combined to provide a three-dimensional activity map that is tied directly to the subject's anatomical map.

II. ANALYSIS OF PRACTICE

C16. A wide variety of radiopharmaceuticals are administered diagnostically to patients to study tissue physiology and organ function. The practice of diagnostic nuclear medicine varies significantly between countries; broad estimates of worldwide practice have been made from the available national survey data using a global model, although the uncertainties in this approach are likely to be significant. There was particularly poor reporting from level III and level IV countries in this period, and some discrepancies in reporting caused difficulties in the data analysis. For example, many countries reported individual results for cardiac examinations using either ^{99m}Tc or ^{201}Tl. These examinations have markedly different values for the average dose per procedure (8.0 and 41 mSv, respectively). However, other countries that probably used both nuclides simply reported a "total" number of cardiac studies, without differentiating between ^{99m}Tc and ^{201}Tl. Only the data from the countries that reported these examinations separately were used to develop average numbers of procedures and values for dose per procedure. Also, none of the countries of levels II, III and IV reported values for dose per procedure. The values reported by level I countries were considered to be reliable, and the

population-weighted average values were assumed to apply to the other levels and were used in the dosimetric analysis. The worldwide total number of procedures for 1997–2007 is estimated to be about 32.7 million annually, corresponding to an annual frequency of 5.1 per 1,000 population. Estimates of the worldwide total number of procedures for 1985–1990 and 1991–1996 were 24 and 32.5 million, respectively, corresponding to frequencies of 4.5 and 5.6 per 1,000 population. The present global total of procedures is distributed among the health-care levels of the model as follows: 89% in countries of level I (at a mean rate of 19 per 1,000 population); 10% in countries of level II (1.1 per 1,000 population); and <1% collectively in countries of health-care levels III and IV (<0.05 per 1,000 population). Notwithstanding the estimated mean frequencies of examination for each health-care level quoted above, there are also significant variations in the national frequencies between countries in the same health-care level (table C4). The overall decrease in the average value for level I countries is likely to be due to under-reporting during this survey period. Several cases are seen of clear increases in the numbers of studies in individual countries, and some countries (e.g. the United States and Canada) that previously reported high values did not report during this survey.

C17. The estimated doses to the world population from diagnostic nuclear medicine procedures are summarized in table C5. The global annual collective effective dose for 1997–2007 is estimated to be about 202,000 man Sv, which equates with an average per caput dose of 0.031 mSv. These estimates are comparable to the figures for 1991–1996 (150,000 man Sv and 0.03 mSv) and 1985–1990 (160,000 man Sv and 0.03 mSv). The distribution of collective dose among the health-care levels of the global model is currently as follows: 92% in countries of level I (giving a mean per caput dose of 0.12 mSv), 8% in countries of level II (corresponding to <0.01 mSv per caput) and <1% in countries of level III (0.000 05 mSv per caput). Globally, practice is dominated by bone scans, cardiovascular studies and thyroid studies, with the last being particularly important in countries of health-care levels III and IV.

C18. Overall, the use of diagnostic practices with radiopharmaceuticals remains small in comparison with the use of X-rays. The annual numbers of nuclear medicine procedures and their associated collective doses are only 0.9% and 5.1%, respectively, of the corresponding values for medical X-rays. However, the mean dose per (diagnostic) procedure is larger for nuclear medicine (6.0 mSv) than for medical X-rays (1.3 mSv).

C19. Radiopharmaceuticals are administered systemically or regionally to patients in order to deliver therapeutic radiation absorbed doses to particular target tissues, in particular the thyroid, for the treatment of benign disease and cancer. The utilization of such therapy varies significantly between countries (table C6). Global annual numbers of radiopharmaceutical therapeutic treatments have been broadly estimated from the limited national survey data available using a global model, and the results are summarized in table C7. The uncertainties in these data are likely to be significant. The worldwide total number of treatments for 1997–2007 is estimated to be about 0.87 million annually, corresponding to an average annual frequency of 0.14 treatment per 1,000 population. Estimates of the total number of treatments annually for 1991–1996 and 1985–1990 were 0.4 million and 0.2 million, respectively, and for the same two periods the average annual frequency of treatments per 1,000 population was 0.065 and 0.04, respectively. However, this is surely an underestimate, because no level II, III or IV countries reported a frequency for therapy studies, when surely many occurred. The present global total of treatments is distributed among the health-care levels of the model as follows: 83% in countries of level I (at a mean rate of 0.47 per 1,000 population), 16% in countries of level II (0.043 per 1,000 population), 0.9% in countries of level III/IV (0.004 per 1,000 population). In comparison with the practices assessed for the other modes of radiotherapy, radionuclide therapy is much less common than teletherapy (annual global total of 4.7 million treatments), but is similar in number of treatments to brachytherapy (total of 0.43 million).

III. DOSES FOR SPECIFIC NUCLEAR MEDICINE PROCEDURES

A. Diagnostic uses

C20. A nationwide survey of nuclear medicine practice in Japan in 2002 had the following findings [K16]:

- A total of 1,697 gamma cameras were installed in 1,160 facilities; 50% of these were dual-headed cameras.
- The estimated total annual number of examinations performed was 1.60 million, similar to that of an earlier survey in 1997.
- The annual frequency of SPECT studies increased to 40%, from 30% in the earlier survey.
- The most commonly performed procedure was bone scintigraphy (35%), followed by myocardial perfusion (24%) and brain perfusion (12%) studies. The annual frequency of all of these types of study has increased steadily over the past 20 years.
- Tumour imaging studies, however, fell from third to fourth place in terms of annual procedure frequency.
- The most commonly used radiopharmaceuticals were ^{99m}Tc HMDP for bone studies, ^{201}Tl chloride for myocardial studies, ^{67}Ga citrate for tumour imaging and ^{123}I IMP for brain studies.

- A total of 29,376 PET studies were performed in 2002. The use of ^{18}F FDG increased by a factor of 3.7 over previously reported results.
- There were 1,647 and 3,347 ^{131}I therapies for thyroid cancer and hyperthyroidism, respectively.
- A total of 31.35 million in vitro radioassays were reported; the number of in vitro radioassays has been decreasing continuously since 1992.

C21. A nationwide survey of nuclear medicine practice in the United Kingdom in 2003–2004 [H25] had the following findings:

- A total of 380 gamma cameras were installed in 240 facilities; an average of approximately 1,580 procedures are performed annually on these cameras.
- The total number of procedures performed annually increased by 36% over the last ten years. An estimated 670,000 procedures were performed, approximately 11 procedures per 1,000 population, which is up from 6.8 per 1,000 in 1982 and 7.6 per 1,000 in 1989.
- Planar imaging constitutes 73% of all nuclear medicine studies; SPECT and PET constitute 16% and 2% of all studies, respectively.
- Non-imaging diagnostic procedures represent 7% of all nuclear medicine studies, and therapy procedures account for the remaining 2% of studies.
- The most frequently performed procedures are bone scans, which constitute 29% of all procedures, followed by lung perfusion scans (14%) and myocardial perfusion studies (14%).
- The most frequently performed therapeutic scan is the use of ^{131}I for thyrotoxicosis, which accounts for 75% of all therapy procedures.
- The annual collective effective dose in the United Kingdom from diagnostic nuclear medicine is around 1,600 man Sv (corresponding to an annual per caput effective dose of about 0.03 mSv). Bone scans are the largest contributor to collective dose.
- Planar imaging comprises 61% of the total collective effective dose due to diagnostic nuclear medicine studies in the United Kingdom; SPECT, PET and non-imaging studies account for 33%, 6% and 0.3%, respectively.

C22. Effective doses for many typical radiopharmaceutical procedures for adults are shown in table C8. Most of these data are taken directly from the dose estimates given in ICRP Publication 80 [I25]. Doses for ^{201}Tl chloride and ^{99m}Tc Neurolite were taken from NUREG/CR-6345 [S27]. The doses for ^{153}Sm and ^{99m}Tc Apcitide and Depreotide came from the Radiation Internal Dose Information Center in Oak Ridge, Tennessee, United States [R5]. The survey form used for submitting data for this report asked the countries to report mean patient effective doses per examination. These doses will depend on the amount of activity administered and the assumed values of effective dose per unit activity administered. Data supplied by the respondents were taken as reported, without checking which source may have been used to estimate these doses.

C23. At the time of writing, a significant change is under way in the frequency of use of PET procedures, as well as in the use of combined PET–CT and SPECT–CT imaging systems. One study of four university hospitals in Germany [B4] revealed an average effective dose per PET–CT procedure of 25 mSv, with the majority coming from the CT scans. Ideas for reducing patient dose per procedure have been discussed by a number of authors [B4, C6, C19, T16, W3]. A study based in the United States [F7] concluded that data for CT-based attenuation corrections can be obtained with very-low-dose CT scans, and that for CT scans of diagnostic quality, the dose reduction ideas proposed by Donnelly et al. [D7] and Huda et al. [H6] can be helpful.

B. Therapeutic uses

C24. Therapeutic procedures using radiopharmaceuticals are considerably less frequent than diagnostic procedures. Many therapeutic procedures are for the treatment of thyroid disease using ^{131}I, which is particularly useful in the treatment of differentiated thyroid carcinoma and hyperthyroidism.

C25. Routine therapeutic applications of radiopharmaceuticals also include the use of a number of radiolabelled biological agents against various forms of cancer. Two monoclonal antibody products were recently approved in the United States (^{131}I Tositumomab and ^{90}Y Ibritumomab tiuxetan) for the treatment of non-Hodgkin's lymphoma (The use of ^{90}Y Ibritumomab tiuxetan is also approved in the European Union.). A number of other compounds and nuclides are of current interest in radioimmunotherapy [G16] (tables C9 and C10).

C26. The general concept of "molecular targeting" has been used for both imaging and diagnosis in nuclear medicine therapy. It may be defined as "the specific concentration of a diagnostic tracer or therapeutic agent by virtue of its interaction with a molecular species that is distinctly present or absent in a disease state" [B23]. Specific molecular targets have been attacked with antisense molecules, aptamers, antibodies and antibody fragments. Other cellular physiological activities, including metabolism, hypoxia, proliferation, apoptosis, angiogenesis, response to infection and multiple drug resistance, have also been studied by means of molecular targeting [B23].

C27. A number of radionuclides are used in the palliation of bone pain [L20]. The characteristics and treatment modes are shown in tables C11 and C12.

C28. Another form of radiopharmaceutical therapy involves administration of compounds directly into intracavitary spaces to treat diffuse tumours or arthritis and synovitis.

Direct injection of sodium or chromic phosphate labelled with ^{32}P or ^{198}Au colloids or of ^{131}I- or ^{90}Y-labelled antibodies is made into confined anatomical spaces such as the pleural space or the peritoneal cavity. Treatment of arthritis and synovitis has also been performed using ^{90}Y ferric hydroxide macroaggregate (FHMA), ^{165}Dy FHMA or ^{169}Er colloid into joint spaces.

C29. Polycythemia vera is a relatively rare disease that is characterized by overproduction of red and white blood cells by the bone marrow. ^{32}P phosphate given intravenously will localize in bone, and the radiation dose delivered results in mild bone marrow suppression and management of this disease.

C30. ^{131}I-labelled oil contrast and ^{90}Y glass or resin microspheres have been used to perform intra-arterial therapy for highly vascularized tumours that may not be amenable to surgery or chemotherapy. These radiolabelled compounds are injected and lodge in the arterioles and capillaries of the tumour, providing a highly localized radiation dose.

C31. There are significant advantages in combining PET and CT images for radiation treatment planning [T18]. This technology provides the ability to acquire accurately aligned anatomical and functional images for subjects in a single imaging session. This aids in accurate identification of pathology and accurate localization of abnormal foci. This technology is currently undergoing rapid growth. Some PET–CT design features in 2004 are shown in table C13. The radionuclides and techniques employed here are not used directly in the therapeutic procedures, but are used to diagnose and stage disease.

IV. DOSES FOR SPECIFIC POPULATIONS

A. Paediatric patients

C32. When paediatric patients undergo nuclear medicine procedures, it is accepted practice that lower activities of radionuclide are administered. In general, administered activities of radionuclide are adjusted to body surface area or body weight. If the second approach is adopted, then the effective dose to paediatric patients will be comparable to that of an adult. Effective doses to paediatric patients from diagnostic nuclear medicine procedures are given in table C14 [H16, I25, I34, S27]. The references are the same as those for the adult procedures described above.

B. Foetal dosimetry

C33. Doses to the embryo and foetus arise from the uptake of radionuclides by the mother and the transfer of radionuclides across the placenta, and depend on the types and distribution of radionuclides in foetal tissue. Radiation doses to the embryo and foetus resulting from intakes of radionuclides by the mother also depend on a number of other factors:

- Their transfer through maternal blood and placenta after deposition in the tissues of the mother;
- Their distribution and retention in foetal tissues;
- Growth of the embryo/foetus;
- Irradiation from deposits in the placenta and maternal tissue;
- Direct transfer to the embryo and foetus from maternal blood.

C34. The processes involved in transfer from maternal to foetal blood through the placenta include simple diffusion, facilitated transport and active transport, movement through pores and channels, and pinocytosis [I37]. A radioisotopes follows the same pathways of uptake to maternal blood as the stable element. If data on a particular element are unavailable, then radionuclides will have similar pathways to elements that are chemically similar. For many elements, the rate of transfer depends on the chemical affinity for the different transport systems in various tissues and the placenta [I37].

C35. A comprehensive treatment of radiation doses for radiopharmaceuticals has been given in a document of the American National Standards Institute/Health Physics Society [S23]; the values are shown in table C15.

C36. An area of particular concern in foetal dosimetry is the dose to the foetal thyroid, principally from administration of radioiodines. Radiation doses to the foetal thyroid at various stages of gestation were estimated by Watson [W19] and are shown in table C16.

C. The breast-feeding infant

C37. Another population of concern in nuclear medicine is that of infants who ingest radioactive material excreted in the breast milk of lactating women who undergo nuclear medicine examinations. Several review articles on the subject have been produced, with varying recommendations about cessation times for breastfeeding after administration of various radiopharmaceuticals. Data on such exposures to the population are sparse, as reporting of these events is irregular [M46, M47, R25, S4].

V. SURVEY

C38. The nuclear medicine questionnaires are given in Form 3 of the UNSCEAR Global Survey of Medical Radiation Usage and Exposures.

C39. Tables C17 and C18 summarize the current status of diagnostic nuclear medicine equipment in each country, according to health-care level, obtained from the latest UNSCEAR survey. The number of examinations, number of examinations per million population and effective dose for various diagnostic nuclear medicine procedures are given in tables C19 (a–b), C20 (a-b) and C21 (a–b).

C40. The results of the UNSCEAR survey of practice in therapeutic nuclear medicine are given in tables C22, C23 and C24. The number of procedures, the number of procedures per million population, and the mean and variance on effective dose are recorded in these tables.

C41. Numbers of diagnostic examinations per 1,000 population, effective dose per examination and annual collective dose for diagnostic nuclear medicine examinations are given in table C25.

VI. SUMMARY

C42. A survey of practice in nuclear medicine has been undertaken. Responses from various countries have been received. These data have been supplemented by information on nuclear medicine procedures and treatments obtained from a review of the published literature.

C43. A global model, as used in earlier UNSCEAR reports, has been used. In this model, countries are stratified into four health-care levels, depending on the number of physicians per 1,000 members of the population. As with previous UNSCEAR surveys of global exposure, there are considerable uncertainties on the results estimated using this global model.

C44. The uncertainty arises from a number of sources, but primarily in extrapolating from the limited survey data obtained. For example, the small sample size in the UNSCEAR survey could mean that the annual frequency data are distorted. There is also an uncertainty on the population estimates for the global population.

C45. According to this global model, the annual frequency of diagnostic nuclear medicine examinations per 1,000 population in health-care level I countries has increased from 11 in 1970–1979 to 19 in the present survey. Comparative values for health-care level II countries also exhibit an increase, from 0.9 per 1,000 in 1970–1979 to 1.1 per 1,000 in 1997–2007.

C46. By comparison, for therapeutic nuclear medicine procedures, according to this global model, the annual frequency of nuclear medicine treatments in health-care level I countries has increased from 0.17 per 1,000 population in 1991–1996 to 0.47 per 1,000 population in this survey. Comparative values for health-care level II countries exhibit an even greater increase, from 0.036 per 1,000 population in 1991–1996 to 0.043 per 1,000 population in 1997–2007. In the period covered by this UNSCEAR report, the estimated dose to the world population due to diagnostic nuclear medicine procedures is estimated to be 202,000 man Sv. This represents an increase in collective dose of 52,000 man Sv, a rise of just over a third. This rise in collective dose occurs because of two factors. Firstly, the average effective dose per procedure has increased from 4.6 mSv to 6.0 mSv. Secondly, there has been an increase in the annual number of diagnostic nuclear medicine examinations to the world population.

Table C1. Properties of some radionuclides used for in vivo imaging

Radionuclide	*Half-life*	*Principal emissions*	*Examples of uses*
^{11}C	20 min	Positrons + 511 keV photons	Cerebral perfusion studies
^{13}N	10 min	Positrons + 511 keV photons	Myocardial perfusion studies
^{15}O	2 min	Positrons + 511 keV photons	Oxygen or water flow studies
^{18}F	110 min	Positrons + 511 keV photons	Glucose metabolism
^{67}Ga	78 h	92 keV, 182 keV photons	Detection of soft tissue malignancies, infection
^{99m}Tc	6 h	140 keV photons	Many
^{111}In	2.8 d	173 keV, 247 keV photons	Blood element imaging
^{123}I	13 h	160 keV photons	Thyroid imaging
^{125}I	60 d	25–35 keV X-rays and photons	Blood volume determination
^{131}I	8 d	365 keV photons	Thyroid imaging, therapy of cancer and hyperthyroidism
^{133}Xe	5.3 d	81 keV photons	Lung ventilation studies
^{201}Tl	73 h	80 keV X-rays	Myocardial perfusion studies

Table C2. Radiopharmaceuticals used in nuclear medicine [K15]

Radionuclide	*Form*	*Use*	*Typical administered activity (adult subjects) (MBq)*	*Route*
^{11}C	Carbon monoxide	Cardiac, blood volume	2 200–3 700	Inhalation
^{11}C	Flumazenil injection	Brain, benzodiazepine receptor	740–1 110	IV
^{11}C	Methionine injection	Neoplastic brain disease	370–740	IV
^{11}C	Raclopride injection	Dopamine receptor	370–555	IV
^{11}C	Sodium acetate	Cardiac	444–1 480	IV
^{14}C	Urea	Helicobacter pylori diagnosis	0.037	PO
^{51}Cr	Sodium chromate	Red blood cells	0.37–2.96	IV
^{57}Co	Cyanoalbain capsules	Pernicious anaemia	0.019	PO
^{18}F	Fludeoxyglucose injection	Glucose utilization	370–555	IV
^{18}F	Fluorodopa	Dopamine neuronal	148–220	IV
^{18}F	Sodium fluoride injection	Bone imaging	370	IV
^{67}Ga	Gallium citrate	Hodgkin's lymphoma	296–370	IV
^{67}Ga	Gallium citrate	Acute inflammatory lesions	185	IV
^{111}In	Capromab pendetide injection	Metastases	185	IV
^{111}In	Indium chloride solution	Radiolabelling		
^{111}In	Indium oxide solution	Labelling autologous leucocytes	18.5	IV
^{111}In	Pentetate injection	Cisternography	18.5	Intrathecal
^{111}In	Pentetreotide	Neuroendocrine tumours	111	IV
^{111}In	Pentetreotide	Neuroendocrine tumours (SPECT)	220	IV
^{111}In	Ibritumomab tiuxetan	Biodistribution	185	IV
^{123}I	Iobenguane injection	Pheochromocytoma	5.18/kg (child)	IV
^{123}I	Sodium iodide	Thyroid imaging	14.8–22	PO
^{123}I	Sodium iodide	Thyroid metastases	74	PO
^{125}I	Albumin injection	Plasma volume	0.19–0.37	IV
^{125}I	Iothalamate sodium injection	Glomerular filtration rate	1.11	IV
^{131}I	Iobenguane injection	Pheochromocytoma	18.5/1.7 m^2	IV
^{131}I	Sodium iodide	Thyroid function	0.19–0.37	PO
^{131}I	Sodium iodide	Thyroid imaging	1.9–3.7	PO
^{131}I	Sodium iodide	Thyroid imaging (substernal)	3.7	PO
^{131}I	Sodium iodide	Thyroid metastases	74	PO
^{131}I	Sodium iodide	Hyperthyroidism	185–1 221	PO
^{131}I	Sodium iodide	Carcinoma	5 550–7 400	PO
^{131}I	Iodohippurate sodium	Recoverable renal function	2.775–7.4	IV
^{131}I	Tositumomab	Treatment of non-Hodgkin's lymphoma	$<$0.75 Gy	IV
^{13}N	Ammonia injection	Myocardial perfusion	370–740	IV
^{15}O	Water injection	Cardiac perfusion	1.11–3.7	IV
^{32}P	Chromic phosphate	Peritoneal and pleural effusions	370–740	Intraperitoneal
^{32}P	Sodium phosphate	Polycythemia	37–296	IV
^{82}Rb	Rubidium chloride	Myocardial perfusion	1.11–2.22	IV
^{153}Sm	Lexidronam	Bone palliation	37/kg	IV
^{89}Sr	Strontium chloride	Bone palliation	148	IV
^{99m}Tc	Albumin injection	Heart blood pool	740	IV
^{99m}Tc	Albumin aggregated	Lung perfusion	111	IV
^{99m}Tc	Bicisate	Stroke	740	IV
^{99m}Tc	Disofenin	Hepatobiliary	185	IV
^{99m}Tc	Exametazime	Cerebral perfusion	370–740	IV

Radionuclide	*Form*	*Use*	*Typical administered activity (adult subjects) (MBq)*	*Route*
^{99m}Tc	Gluceptate	Brain	740	IV
^{99m}Tc	Gluceptate	Renal perfusion	370	IV
^{99m}Tc	Mebrofenin	Hepatobiliary	185	IV
^{99m}Tc	Medronate	Bone	740–1 110	IV
^{99m}Tc	Mertiatide	Kidney imaging	185	IV
^{99m}Tc	Mertiatide	Renogram, renal transplant	37–111	IV
^{99m}Tc	Mertiatide	Renogram	37–111	IV
^{99m}Tc	Oxidronate	Bone	740–1 110	IV
^{99m}Tc	Pentetate injection	Glomerular filtration rate (quantitative)	111	IV
^{99m}Tc	Pentetate injection	Renogram	111	IV
^{99m}Tc	Pentetate injection	Renal perfusion	370	IV
^{99m}Tc	Pyrophosphate	Infarct-avid	555	IV
^{99m}Tc	Red blood cells	Gastrointestinal bleeding	555	IV
^{99m}Tc	Sestamibi	Myocardial perfusion	296–1 480	IV
^{99m}Tc	Sodium pertechnetate	Brain	740	IV
^{99m}Tc	Sodium pertechnetate	Thyroid imaging	370	IV
^{99m}Tc	Sodium pertechnetate	Ventriculogram	740	IV
^{99m}Tc	Sodium pertechnetate	Cystography	37	Urethral
^{99m}Tc	Sodium pertechnetate	Dacrocystography	3.7	Eye drops
^{99m}Tc	Sodium pertechnetate	Meckel's diverticulum	185	IV
^{99m}Tc	Succimer	Renal scan, renal function	185	IV
^{99m}Tc	Succimer	Renal scan, cortical anatomy	185	IV
^{99m}Tc	Sulphur colloid	Liver–spleen	185	IV
^{99m}Tc	Sulphur colloid	Lymphoscintigraphy, breast	14.8–22	Interstitial
^{99m}Tc	Sulphur colloid	Lymphoscintigraphy, melanoma	18.5–29.6	Intradermal
^{99m}Tc	Sulphur colloid	Gastric emptying	37	PO
^{99m}Tc	Sulphur colloid	Gastrointestinal bleeding	370	IV
^{99m}Tc	Sulphur colloid	Lung aspiration	185	PO
^{99m}Tc	Sulphur colloid	Gastroesophageal reflux	7.4	PO
^{99m}Tc	Tetrofosomin	Myocardial perfusion	296–1 480	IV
^{201}Tl	Thallium chloride	Myocardial perfusion	111–148	IV
^{133}Xe	Xenon	Lung ventilation	370–740	Inhalation
^{90}Y	Ibritumomab tiuxetan	Treatment of non-Hodgkin's lymphoma	11.1–14.8/kg	IV

Table C3. Radiopharmaceuticals used for clinical PET studies (adapted from reference [L19])

Radionuclide and compound	*Types of study performed*
^{15}O	
Carbon dioxide	Cerebral blood flow
Oxygen	Quantification of myocardial oxygen consumption and oxygen extraction fraction, measurement of tumour necrosis
Water	Quantification of myocardial oxygen consumption and oxygen extraction fraction, tracer for myocardial blood perfusion
^{13}N	
Ammonia	Myocardial blood flow
^{11}C	
Acetate	Oxidative metabolism
Carfentanil	Opiate receptors in the brain

Radionuclide and compound	*Types of study performed*
Cocaine	Identification and characterization of drug binding sites in the brain
Deprenyl	Distribution of monoamine oxidase (MAO) type B, the isoenzyme that catabolizes dopamine
Leucine	Amino acid uptake and protein synthesis, providing an indicator of tumour viability
Methionine	Amino acid uptake and protein synthesis, providing an indicator of tumour viability
N-methylspiperone	Neurochemical effects of various substances on dopaminergic function
Raclopride	Function of dopaminergic synapses
^{18}F	
Haloperidol	Binding sites of haloperidol, a widely used antipsychotic and anxiety-reducing drug
Fluorine ion	Clinical bone scanning
Fluorodeoxyglucose (FDG)	Neurology, cardiology and oncology to study glucose metabolism
Fluorodopa	Metabolism, neurotransmission and cell processes
Fluoroethylspiperone	Metabolism, neurotransmission and cell processes
Fluorouracil	Delivery of chemotherapeutic agents in the treatment of cancer
^{82}Rb	
^{82}Rb	Myocardial perfusion

Table C4. Trends in annual number of diagnostic nuclear medicine procedures per 1,000 population [U3]
Data from the UNSCEAR Global Surveys of Medical Radiation Usage and Exposures

Country/area	*1970–1979*	*1980–1984*	*1985–1990*	*1991–1996*	*1997–2007*
Health-care level I					
Argentina			11.5	11.1	
Australia	3.8	8.9	8.3	12.0	19.0
Austria	18.0				41.9
Belarus				0.5	0.4
Belgium			36.8		52.8
Bulgaria		13.0		3.3	
Canada			12.6	64.6	
Cayman Islands				0	
China - Taiwan				6.6	
Croatia				2.4	8.6
Cuba[a]	(0.8)				
Cyprus				6.6	
Czechoslovakia[b]	13.6	18.3	22.9		
Czech Republic				28.3	12.6
Denmark	14.0	14.2	13.4	15.2	
Ecuador[a]	(0.5)		(0.8)	0.8	
Estonia				8.0	2.0
Finland	12.6	17.7		10.0	7.7
France		9.0	6.9		14.0
Germany[c]	31.1	39.7	39.8	34.1	46.7
Greece					16.7
Hungary				15.3	17.9
Iceland					14.1
Ireland				6.1	
Italy	6.0		7.3	11.0	
Japan			8.3	11.7	10.2
Kuwait			13.1	12.7	

Country/area	*1970–1979*	*1980–1984*	*1985–1990*	*1991–1996*	*1997–2007*
Latvia					6.8
Lithuania				10.6	
Luxembourg			23.5	52.2	34.5
Netherlands			11.6	15.7	24.3
New Zealand	5.6	7.3	7.5	8.3	6.7
Norway	3.9		9.3		10.9
Panama				3.4	
Poland					3.0
Portugal				4.0	
Qatar				4.7	
Romania		3.0	3.5	3.0	2.8
Russian Federation[d]	(9)	(11)	(15)	12.6	
Slovakia[d]			(4.9)	9.4	
Slovenia				11.2	10.4
Spain					16.9
Sweden	9.8		12.6	13.6	10.8
The former Yugoslav Republic of Macedonia					4.0
Switzerland	44.9			9.5	11.7
Ukraine				5.0	
United Arab Emirates				7.2	
United Kingdom		6.8		8.2	
United States			25.7	31.5	
Yugoslavia			6.1		
Average	11	6.9	16	19	22.1
Health-care level II					
Antigua and Barbuda				0	
Barbados			1.0		
Brazil			1.7	1.1	
China			0.6		
Costa Rica					1.73
Dominica				0	
El Salvador					0.61
Grenada				0	
India		0.1	0.2		
Iran (Islamic Rep. of)				1.9	
Iraq			1.2		
Jordan				1.6	
Mexico				1.1	
Oman				0.6	
Pakistan				0.6	
Peru			0.2	0.6	
Saint Kitts and Nevis				0	
Saint Lucia				0	
Saint Vincent and the Grenadines				0	0
Trinidad and Tobago					0.17
Tunisia			1.0	0.8	
Turkey			2.5	2.1	
Average	0.9	0.1	0.5	1.1	1.0

Country/area	*1970–1979*	*1980–1984*	*1985–1990*	*1991–1996*	*1997–2007*
Health-care level III					
Egypt	0.07	0.21	0.48		
Ghana				0.05	
Indonesia					0.01
Jamaica[a]	(2.8)		(2.0)		
Morocco				0.62	
Myanmar	0.54	0.36	0.11		0.06
Sudan	0.12	0.28	0.28	0.09	
Thailand	0.25	0.18	0.26		
Zimbabwe					0.02
Average	0.25	0.25	0.30	0.28	0.02
Health-care level IV					
Ethiopia		0.014	0.10	0.014	
United Rep. of Tanzania				0.024	
Average				0.02	

[a] Categorized in health-care level II in previous analyses.
[b] Historical data.
[c] Historical data for 1970-1979, 1980-1984 and 1985-1990 refer to Federal Republic of Germany.
[d] Historical data were not included in previous analyses.

Table C5. Estimated dose to the world population from diagnostic nuclear medicine procedures (1997–2007) [U3]

Health-care level	*Population (millions)*	*Annual per caput effective dose (mSv)*	*Annual collective effective dose (man Sv)*
I	1 540	0.12	186 000
II	3 153	0.005 1	16 000
III-IV	1 752	0.000 047	82
World	6 446	0.031	202 000

Table C6. Annual number of therapeutic treatments with radiopharmaceuticals per million population (1997–2007)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures [U3]

Country/area	*Thyroid malignancy*	*Hyperthyroidism*	*Polycythemia vera*	*Bone metastases*	*Synovitis*	*Other, e.g. ^{90}YCl*	*Total*
Health-care level I							
Austria	134	415	1.2	12.2	183.2	17.1	763
Croatia	81.8	203	0.0	1.4	0.7	0.0	287
Czech Republic	27.7	117	0.0	77.6	50.5		272
Estonia	117	252	3.6	36.5	3.6	1.5	414
Finland	106	242	70.9	10.7	8.8	1.5	440
Greece	103			16.8			120
Hungary	45.1	260		11.5	12.0		329
Iceland	91.8	252		3.4			347
Japan	17.3	17.3					34.5
Luxembourg	102			4.4	2.2		108
Malta	100	60.0	25.0				185
Norway	59.3	138	0.9	5.0	1.9	3.9	209
Poland	41.5	272		15.6	5.2	1.3	336
Slovenia	105	559		1.5	3.0	15.0	684
Spain	611	1 267	21.8	72.3	63.3	5.6	2 040
Sweden	11.7	259.2	32.8	38.4	1.6	1.1	345

Country/area	*Thyroid malignancy*	*Hyperthyroidism*	*Polycythemia vera*	*Bone metastases*	*Synovitis*	*Other, e.g. ^{90}YCl*	*Total*
Switzerland		201.0			37.9	70.1	309
The former Yugoslav Republic of Macedonia	130	34.4					164
United Kingdom	19.3	193.3	11.9	9.1	6.7	3.4	244
Average	106	279	16.8	21.1	27.2	10.9	401
Health-care level II							
Costa Rica	23.1	34.7					57.8
El Salvador	19.7	13.2					32.9
Average	21.4	24.0					45.4
Health-care levels III and IV							
Indonesia	0.5	0.7		0.06			1.3
Myanmar	1.6	18.6					20.2
Zimbabwe	1.7	0.8			0.0	0.0	2.5
Average	1.3	6.7		0.06	0.0	0.0	8.0

Table C7. Estimated annual number of therapeutic treatments with radiopharmaceuticals in the world (1997–2007) [U3]

Health-care level	*Population (millions)*	*Annual number of treatments*	
		Millions	*Per 1 000 population*
I	1 540	0.73	0.47
II	3 153	0.14	0.043
III–IV	1 752	0.007 5	0.004 3
World	6 446	0.87	0.14

Table C8. Effective dose (adult subjects) from typical nuclear medicine procedures [H29, I25, I34, S27]

Procedure	*mSv/MBq*	*MBq*	*mSv*
^{14}C urea (normal)	3.10×10^{-2}	0.037	1.15×10^{-3}
^{14}C urea (Heliobacter positive)	8.10×10^{-2}	0.037	3.00×10^{-3}
^{57}Co cyanocobalamin (IV, no carrier)	4.40×10^{0}	0.037	1.63×10^{-1}
^{57}Co cyanocobalamin (IV, with carrier)	4.60×10^{-1}	0.037	1.7×10^{-2}
^{57}Co cyanocobalamin (oral, no flushing)	3.1×10^{0}	0.037	1.15×10^{-1}
^{57}Co-7 cyanocobalamin (oral, with flushing)	2.1×10^{0}	0.037	7.77×10^{-2}
^{51}Cr sodium chromate RBCs	1.7×10^{-1}	5.6	9.5×10^{-1}
^{18}F FDG	1.90×10^{-2}	370	7.0×10^{0}
^{67}Ga citrate	1.00×10^{-1}	185	1.85×10^{1}
^{123}I hippuran	1.20×10^{-2}	14.8	1.78×10^{-1}
^{123}I MIBG	1.30×10^{-2}	14.8	1.92×10^{-1}
^{123}I sodium iodide (0% uptake)	1.10×10^{-2}	14.8	1.63×10^{-1}
^{123}I sodium iodide (35% uptake)	2.20×10^{-1}	14.8	3.26×10^{0}
^{125}I albumin	2.20×10^{-1}	0.74	1.63×10^{-1}
^{131}I hippuran	5.20×10^{-2}	0.74	3.85×10^{-2}
^{131}I MIBG	1.40×10^{-1}	0.74	1.0×10^{-1}
^{131}I sodium iodide (0% uptake)	6.10×10^{-2}	3 700	n.a.
^{131}I sodium iodide (35% uptake)	2.40×10^{2}	3 700	n.a.
^{111}In pentetreotide, also known as Octreoscan	5.40×10^{-2}	222	1.20×10^{1}
^{111}In white blood cells	3.6×10^{-1}	18.5	6.66×10^{0}
^{81m}Kr krypton gas	2.70×10^{-5}	370	9.99×10^{-3}

Procedure	*mSv/MBq*	*MBq*	*mSv*
^{15}O water	9.30×10^{-4}	370	3.44×10^{-1}
^{32}P phosphate	2.40×10^{0}	148	3.55×10^{2}
^{153}Sm lexidronam, also known as Quadramet	1.97×10^{-1}	2 590	n.a.
^{89}Sr chloride, also known as Metastron	3.10×10^{0}	148	n.a.
^{99m}Tc apcitide, also known as AcuTect	9.30×10^{-3}	740	6.88×10^{0}
^{99m}Tc depreotide, also known as NeoTect	2.30×10^{-2}	740	1.70×10^{1}
^{99m}Tc disofenin, also known as HIDA (iminodiacetic acid)	1.70×10^{-2}	185	3.15×10^{0}
^{99m}Tc DMSA (dimercaptosuccinic acid), also known as Succimer	8.80×10^{-3}	185	1.63×10^{0}
^{99m}Tc exametazime, also known as Ceretec and HMPAO	9.30×10^{-3}	740	6.88×10^{0}
^{99m}Tc macroaggregated albumin (MAA)	1.10×10^{-2}	148	1.63×10^{0}
^{99m}Tc medronate, also known as Tc-99m Methyenedi-phosphonate (MDP)	5.70×10^{-3}	740	4.22×10^{0}
^{99m}Tc mertiatide, also known as MAG3 (normal renal function)	7.00×10^{-3}	740	5.18×10^{0}
^{99m}Tc mertiatide, also known as MAG3 (abnormal renal function)	6.10×10^{-3}	740	4.51×10^{0}
^{99m}Tc mertiatide, also known as MAG3 (acute unilateral renal blockage)	1.00×10^{-2}	740	7.40×10^{0}
^{99m}Tc Neurolite, also known as ECD and Bicisate	1.10×10^{-2}	740	8.14×10^{0}
^{99m}Tc pentetate, also known as Tc-99m DTPA	4.90×10^{-3}	370	1.81×10^{0}
^{99m}Tc pyrophosphate	5.70×10^{-3}	555	3.16×10^{0}
^{99m}Tc red blood cells	7.00×10^{-3}	740	5.18×10^{0}
^{99m}Tc sestamibi, also known as Cardiolite (rest)	9.00×10^{-3}	740	6.66×10^{0}
^{99m}Tc sestamibi, also known as Cardiolite (stress)	7.90×10^{-3}	740	5.85×10^{0}
^{99m}Tc sodium pertechnetate	1.30×10^{-2}	370	4.81×10^{0}
^{99m}Tc sulphur colloid	9.40×10^{-3}	296	2.78×10^{0}
^{99m}Tc Technegas	1.50×10^{-2}	740	1.11×10^{1}
^{99m}Tc tetrofosmin, also known as Myoview (rest)	7.60×10^{-3}	740	5.62×10^{0}
^{99m}Tc tetrofosmin, also known as Myoview (stress)	7.00×10^{-3}	740	5.18×10^{0}
^{201}Tl thallous chloride (with contaminants)	1.60×10^{-1}	74	1.18×10^{1}
^{133}Xe xenon gas (rebreathing for 5 minutes)	8.00×10^{-4}	555	4.44×10^{-1}

Note: n.a. = not applicable.

Table C9. Radionuclides of current interest in radioimmunotherapy [G16]

Isotope	*$t_{½}$ (h)*	*Emission (for therapy)*	*Maximum energy (keV)*	*Maximum particle range (mm)*
^{131}I	193	β	610	2.0
^{90}Y	64	β	2 280	12.0
^{177}Lu	161	β	496	1.5
^{67}Cu	62	β	577	1.8
^{186}Re	91	β	1 080	5.0
^{188}Re	17	β	2 120	11.0
^{212}Bi	1	α	8 780	0.09
^{213}Bi	0.77	α	>6 000	<0.1
^{211}At	7.2	α	7 450	0.08

Table C10. Recent clinical studies of radioimmunotherapy in haematological tumours [G16]

Tumour type	*Target antigen*	*Antibody*	*Radiolabels*
Non-Hodgkin's lymphoma	CD20	B1	^{131}I
	CD20	Y2B8	^{90}Y
	CD22	hLL2	^{131}I, ^{90}Y
	HLA-DR	Lym-1	^{131}I, ^{67}Cu
Hodgkin's disease	Ferritin	Rabbit	^{131}I, ^{90}Y
Myelocytic leukemia	CD33	HuM195	^{131}I, ^{213}Bi
	NCA95	BW250/183	^{188}Re

Table C11. Physical characteristics of therapeutic radionuclides for bone pain palliation [L20]

Radionuclide	*Half-life*	*Maximum energy (MeV)*	*Mean energy (MeV)*	*Maximum range*	*γ emission (keV)*
^{32}P	14.3 d	1.7 (ß)	0.695 (ß)	8.5 mm	None
^{89}Sr	50.5 d	1.4 (ß)	0.583 (ß)	7 mm	None
^{186}Re	3.7 d	1.07 (ß)	0.362 (ß)	5 mm	137
^{188}Re	16.9 h	2.1 (ß)	0.764 (ß)	10 mm	155
^{153}Sm	1.9 d	0.81 (ß)	0.229 (ß)	4 mm	103
^{117m}Sn	13.6 d	0.13 and 0.16 conversion electrons		$<1\,\mu$m	159
^{223}Ra	11.4 d	5.78 (α) (average)		$<10\,\mu$m	154

Table C12. Administered activity, typical response time and duration, and re-treatment interval for bone-seeking radionuclides [L20]

Radiopharmaceutical	*Usual administered activity*	*Typical response time (days)*	*Typical response duration (weeks)*	*Re-treatment interval (months)*
^{32}P	444 MBq (fractionated)	14	10	>3
$^{89}SrCl_2$	148 MBq	14–28	12–26	>3
^{186}Re-HEDP	1.3 GBq	2–7	8–10	>2
^{188}Re-HEDP	1.3–4.4 GBq	2–7	8	n.e.
^{153}Sm-EDTMP	37 MBq/kg	2–7	8	>2
^{117m}Sn-DTPA	2–10 MBq/kg	5–19	12–16	>2
$^{223}RaCl_2$	50–200 kBq/kg	<10	n.e.	n.e.

Note: n.e. = not established.

Table C13. CT and PET parameters in PET–CT designs (2004) [L20]

CT parameters		*PET parameters*	
Detectors	Ceramic	Scintillator	BGO, GSO, LSO
Slices	1, 2, 4, 8, 16	Detector size	4 × 4 mm, 6 × 6 mm
Rotation speed	0.4–2.0 s	Axial FOV	15–18 cm
Tube current	80–280 mA	Septa	2-D/3-D, 3-D only
Heat capacity	3.5–6.5 MHU	Attenuation	Rod, point, CT only
Transaxial FOV	45–50 cm	Transaxial FOV	55–60 cm
Time/100 cm	13–90 s	Time/bed	1–5 min
Slice width	0.6–10 mm	Resolution	4–6 mm
Patient port	70 cm	Patient port	60–70 cm

Note: BGO = bismuth germanate; GSO = gadolinium oxyorthosilicate; LSO = lutetium oxyorthosilicate; FOV = field of view; MHU = mega Hounsfield units.

Table C14. Radiation dose (paediatric subjects) from typical nuclear medicine procedures [H16, I34, I35, S27]

Procedure	*15-year-old (mSv/MBq)*	*10-year-old (mSv/MBq)*	*5-year-old (mSv/MBq)*	*1-year-old (mSv/MBq)*
^{18}F FDG	0.025	0.036	0.050	0.095
^{67}Ga citrate	0.130	0.200	0.330	0.640
^{123}I sodium iodide (0% uptake)	0.016	0.024	0.037	0.037
^{123}I sodium iodide (5% uptake)	0.053	0.080	0.150	0.290
^{123}I sodium iodide (15% uptake)	0.110	0.170	0.350	0.650
^{123}I sodium iodide (25% uptake)	0.170	0.260	0.540	1.000
^{123}I sodium iodide (35% uptake)	0.230	0.350	0.740	1.400
^{123}I sodium iodide (45% uptake)	0.290	0.440	0.940	1.800
^{123}I sodium iodide (55% uptake)	0.350	0.530	1.100	2.100
^{111}In pentatreotide, also known as Octreoscan	0.071	0.100	0.160	0.280
^{111}In white blood cells	0.836	1.240	1.910	3.380
^{99m}Tc disofenin, also known as HIDA (iminodiacetic acid)	0.021	0.029	0.045	0.100
^{99m}Tc DMSA (dimercaptosuccinic acid), also known as Succimer	0.011	0.015	0.021	0.037
^{99m}Tc exametazime, also known as Ceretec and HMPAO	0.011	0.017	0.027	0.049
^{99m}Tc macroaggregated albumin (MAA)	0.016	0.023	0.034	0.063
^{99m}Tc medronate, also known as Tc-99m methylene diphosphonate (MDP)	0.007	0.011	0.014	0.027
^{99m}Tc mertiatide, also known as MAG3	0.009	0.012	0.012	0.022
^{99m}Tc Bicisate, also known as ECD and Neurolite	0.014	0.021	0.032	0.060
^{99m}Tc pentetate, also known as Tc-99m DTPA	0.006	0.008	0.009	0.016
^{99m}Tc pyrophosphate	0.007	0.011	0.014	0.027
^{99m}Tc red blood cells	0.009	0.014	0.021	0.039
^{99m}Tc sestamibi, also known as Cardiolite (rest)	0.012	0.018	0.028	0.053
^{99m}Tc sestamibi, also known as Cardiolite (stress)	0.010	0.016	0.023	0.045
^{99m}Tc sodium pertechnetate	0.017	0.026	0.042	0.079
^{99m}Tc sulphur colloid	0.012	0.018	0.028	0.050
^{99m}Tc tetrofosmin, also known as Myoview (rest)	0.010	0.013	0.022	0.043
^{99m}Tc tetrofosmin, also known as Myoview (stress)	0.008	0.012	0.018	0.035
^{201}Tl thallous chloride	0.293	1.160	1.500	2.280

Table C15. Estimated foetal dose from various nuclear medicine procedures [S23]
(shading indicates maternal and foetal self-dose contributions)

Radiopharmaceutical	*Activity administered (MBq)*	*Dose to foetus at different ages*			
		Early (mGy)	*3 months (mGy)*	*6 months (mGy)*	*9 months (mGy)*
^{57}Co vitamin B12					
Normal, flushing	0.04	4.0×10^{-2}	2.7×10^{-2}	3.4×10^{-2}	3.5×10^{-2}
Normal, no flushing	0.04	6.0×10^{-2}	4.0×10^{-2}	4.8×10^{-2}	5.2×10^{-2}
Pernicious anaemia, flushing	0.04	8.4×10^{-3}	6.8×10^{-3}	6.8×10^{-3}	6.0×10^{-3}
Pernicious anaemia, no flushing	0.04	1.1×10^{-2}	8.4×10^{-3}	8.8×10^{-3}	8.0×10^{-3}
^{58}Co vitamin B12					
Normal, flushing	0.03	7.5×10^{-2}	5.7×10^{-2}	6.3×10^{-2}	6.3×10^{-2}
Normal, no flushing	0.03	1.1×10^{-1}	8.4×10^{-2}	9.3×10^{-2}	9.3×10^{-2}
Pernicious anaemia, flushing	0.03	2.5×10^{-2}	2.2×10^{-2}	1.9×10^{-2}	1.4×10^{-2}
Pernicious anaemia, no flushing	0.03	2.9×10^{-2}	2.6×10^{-2}	2.3×10^{-2}	1.8×10^{-2}

Radiopharmaceutical	*Activity administered (MBq)*	*Dose to foetus at different ages*			
		Early (mGy)	*3 months (mGy)*	*6 months (mGy)*	*9 months (mGy)*
^{18}F FDG	370	8.1×10^{0}	8.1×10^{0}	6.3×10^{0}	6.3×10^{0}
^{67}Ga citrate	190	1.8×10^{1}	3.8×10^{1}	3.4×10^{1}	2.5×10^{1}
^{197}Hg chlormerodrin	4	4.4×10^{-2}	3.0×10^{-2}	2.7×10^{-2}	2.8×10^{-2}
^{123}I hippuran	75	2.3×10^{0}	1.8×10^{0}	6.3×10^{-1}	5.9×10^{-1}
^{123}I IMP	200	3.8×10^{0}	2.2×10^{0}	1.4×10^{0}	1.2×10^{0}
^{123}I MIBG					
Phaeochromocytoma	350	6.3×10^{0}	4.2×10^{0}	2.4×10^{0}	2.2×10^{0}
Cecholamine tumour	80	1.4×10^{0}	9.6×10^{-1}	5.4×10^{-1}	5.0×10^{-1}
^{123}I sodium iodide					
Thyroid uptake study	30	6.0×10^{-1}	4.2×10^{-1}	3.3×10^{-1}	2.9×10^{-1}
Thyroid imaging	15	3.0×10^{-1}	2.1×10^{-1}	1.7×10^{-1}	1.4×10^{-2}
^{125}I HSA	2	5.0×10^{-1}	1.6×10^{-1}	7.6×10^{-2}	5.2×10^{-2}
^{125}I NaI	1	1.8×10^{-2}	9.5×10^{-3}	3.5×10^{-3}	2.3×10^{-3}
^{131}I hippuran					
Renal function	1.3	8.3×10^{-2}	6.5×10^{-2}	2.5×10^{-2}	2.3×10^{-2}
Renal imaging	1.3	8.3×10^{-2}	6.5×10^{-2}	2.5×10^{-2}	2.3×10^{-2}
^{131}I HSA	0.5	2.6×10^{-1}	9.0×10^{-2}	8.0×10^{-2}	6.5×10^{-2}
^{131}I MAA	55	3.7×10^{0}	2.3×10^{0}	2.2×10^{0}	2.3×10^{0}
^{131}I MIBG	20	2.2×10^{0}	1.1×10^{0}	7.6×10^{-1}	7.0×10^{-1}
^{131}I NaI (diagnostic)					
Thyroid uptake	0.55	4.0×10^{-2}	3.7×10^{-2}	1.3×10^{-1}	1.5×10^{-1}
Scintiscanning	4	2.9×10^{-1}	2.7×10^{-1}	9.2×10^{-1}	1.1×10^{0}
Localization of extra-thyroid metastases	40	2.9×10^{0}	2.7×10^{0}	9.2×10^{0}	1.1×10^{1}
^{131}I NaI (therapeutic)					
Hyperthyroidism	350	2.5×10^{1}	2.3×10^{1}	8.1×10^{1}	9.5×10^{1}
Ablation of normal thyroid tissue	1 900	1.4×10^{2}	1.3×10^{2}	4.4×10^{2}	5.1×10^{2}
^{131}I rose bengal	0.04	8.8×10^{-3}	8.8×10^{-3}	6.4×10^{-3}	3.6×10^{-3}
^{111}In DTPA	20	1.3×10^{0}	9.6×10^{-1}	4.0×10^{-1}	3.6×10^{-1}
^{111}In pentetreotide					
Planar imaging	110	9.0×10^{0}	6.6×10^{0}	3.8×10^{0}	3.4×10^{0}
SPECT imaging	230	1.9×10^{1}	1.4×10^{1}	8.0×10^{0}	7.0×10^{0}
^{111}In platelets	10	1.7×10^{0}	1×10^{0}	9.9×10^{-1}	8.9×10^{-1}
^{111}In white blood cells	20	2.6×10^{0}	1.9×10^{0}	1.9×10^{0}	1.9×10^{0}
^{81m}Kr gas	600	1.1×10^{-4}	1.0×10^{-4}	1.6×10^{-4}	2.0×10^{-4}
^{99m}Tc disofenin	350	6.0×10^{0}	5.2×10^{0}	4.2×10^{0}	2.3×10^{0}
^{99m}Tc DMSA	220	1.1×10^{0}	1.0×10^{0}	8.8×10^{-1}	7.5×10^{-1}
^{99m}Tc DTPA					
Kidney imaging and glomular filtration	750	9.0×10^{0}	6.5×10^{0}	3.1×10^{0}	3.5×10^{0}
Brain imaging and renal perfusion	750	9.0×10^{0}	6.5×10^{0}	3.1×10^{0}	3.5×10^{0}
First pass	350	4.2×10^{0}	3.0×10^{0}	1.4×10^{0}	1.6×10^{0}
Gastric reflux	10	1.2×10^{-1}	8.7×10^{-2}	4.1×10^{-2}	4.7×10^{-2}
Hypertension	800	9.6×10^{0}	7.0×10^{0}	3.3×10^{0}	3.8×10^{0}
Residual urine determination	350	4.2×10^{0}	3.0×10^{0}	1.4×10^{0}	1.6×10^{0}
^{99m}Tc DTPA aerosol	40	2.3×10^{-1}	1.7×10^{-1}	9.2×10^{-2}	1.2×10^{-1}

Radiopharmaceutical	*Activity administered (MBq)*	*Dose to foetus at different ages*			
		Early (mGy)	*3 months (mGy)*	*6 months (mGy)*	*9 months (mGy)*
^{99m}Tc glucoheptonate					
Renal imaging	750	9.0×10^{0}	8.2×10^{0}	4.0×10^{0}	3.4×10^{0}
Brain imaging	750	9.0×10^{0}	8.2×10^{0}	4.0×10^{0}	3.4×10^{0}
^{99m}Tc HDP	750	3.9×10^{0}	4.10×10^{0}	2.3×10^{0}	1.9×10^{0}
^{99m}Tc HMPAO	750	6.5×10^{0}	5.0×10^{0}	3.6×10^{0}	2.7×10^{0}
^{99m}Tc HSA	200	1.0×10^{0}	6.0×10^{-1}	5.2×10^{-1}	4.4×10^{-1}
^{99m}Tc MAA					
Hepatic artery perfusion	150	4.2×10^{-1}	6.0×10^{-1}	7.5×10^{-1}	6.0×10^{-1}
Lung imaging	200	5.6×10^{-1}	8.0×10^{-1}	1.0×10^{0}	8.0×10^{-1}
Isotopic venography	220	6.2×10^{-1}	8.8×10^{-1}	1.1×10^{0}	8.0×10^{-1}
LeVeen shunt patency	110	3.1×10^{-1}	4.4×10^{-1}	5.5×10^{-1}	4.4×10^{-1}
^{99m}Tc MAG3	750	1.4×10^{1}	1.0×10^{1}	4.1×10^{0}	3.9×10^{0}
^{99m}Tc MDP	750	4.6×10^{0}	4.0×10^{0}	2.0×10^{0}	1.8×10^{0}
^{99m}Tc MIBI, rest	1 100	1.7×10^{1}	1.3×10^{1}	9.2×10^{0}	5.9×10^{0}
^{99m}Tc MIBI, stress	1 100	1.3×10^{1}	1.0×10^{1}	7.6×10^{0}	4.8×10^{0}
^{99m}Tc pertechnetate					
Brain imaging	1 100	1.2×10^{1}	2.4×10^{1}	1.5×10^{1}	1.0×10^{1}
Thyroid imaging	400	4.4×10^{0}	8.8×10^{0}	5.6×10^{0}	3.7×10^{0}
Salivary gland imaging	200	2.2×10^{0}	4.4×10^{0}	2.8×10^{0}	1.9×10^{0}
Placental localization	110	1.1×10^{0}	2.4×10^{0}	1.5×10^{0}	1.0×10^{0}
Blood pool imaging	1 100	1.1×10^{1}	2.4×10^{1}	1.4×10^{1}	1.0×10^{1}
Cardiovascular shunt detection	550	6.0×10^{0}	1.2×10^{1}	7.7×10^{0}	5.1×10^{0}
First pass	550	6.0×10^{0}	1.2×10^{1}	7.7×10^{0}	5.1×10^{0}
^{99m}Tc PYP					
Skeletal imaging	550	3.3×10^{0}	3.6×10^{0}	2.0×10^{0}	1.6×10^{0}
Cardiac imaging	700	4.2×10^{0}	4.6×10^{0}	2.5×10^{0}	2.0×10^{0}
^{99m}Tc red blood cell in vitro labelling	930	6.3×10^{0}	4.4×10^{0}	3.2×10^{0}	2.6×10^{0}
^{99m}Tc red blood cell in vivo labelling					
Rest	550	3.5×10^{0}	2.4×10^{0}	1.8×10^{0}	1.5×10^{0}
Exercise	930	6.0×10^{0}	4.0×10^{0}	3.1×10^{0}	2.5×10^{0}
Lower GI bleeding	930	6.0×10^{0}	4.0×10^{0}	3.1×10^{0}	2.5×10^{0}
^{99m}Tc sulphur colloid, normal					
Liver–spleen imaging	300	5.4×10^{-1}	6.3×10^{-1}	9.6×10^{-1}	1.1×10^{0}
Bone marrow imaging	450	8.1×10^{-1}	9.5×10^{-1}	1.4×10^{0}	1.7×10^{0}
Pulmonary aspiration	20	3.6×10^{-2}	4.2×10^{-2}	6.4×10^{-2}	7.4×10^{-2}
LeVeen shunt patency	110	2.0×10^{-1}	2.3×10^{-1}	3.5×10^{-1}	4.1×10^{-1}
^{99m}Tc white blood cells	200	7.6×10^{-1}	5.6×10^{-1}	5.8×10^{-1}	5.6×10^{-1}
^{201}Tl chloride					
Planar imaging	150	1.5×10^{1}	8.7×10^{0}	7.0×10^{0}	4.0×10^{0}
SPECT imaging	110	1.1×10^{1}	6.4×10^{0}	5.2×10^{0}	3.0×10^{0}
Myocardial perfusion	55	5.3×10^{0}	3.2×10^{0}	2.6×10^{0}	1.5×10^{0}
Thyroid imaging	80	7.8×10^{0}	4.6×10^{0}	3.8×10^{0}	2.2×10^{0}
^{133}Xe, injection					
Muscle blood flow	20	9.8×10^{-5}	2.0×10^{-5}	2.8×10^{-5}	3.2×10^{-5}
Pulmonary function with imaging	1 100	5.4×10^{-3}	1.1×10^{-3}	1.5×10^{-3}	1.8×10^{-3}

Table C16. Absorbed dose to the foetal thyroid per unit activity administered to the mother (mGy/MBq) [W19]

Gestational age (months)	^{123}I	^{124}I	^{125}I	^{131}I
3	2.7	24	290	230
4	2.6	27	240	260
5	6.4	76	280	580
6	6.4	100	210	550
7	4.1	96	160	390
8	4.0	110	150	350
9	2.9	99	120	270

Table C17. Number of items of nuclear medicine equipment and of sites, physicians and examinations
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Number of items of equipment*					*Number of sites, physicians and examinations*			
	Planar gamma camera	*SPECT gamma camera*	*PET or PET–CT scanner*	*Rectilinear scanner*	*Static gamma detector*	*Sites*	*Physicians*	*Diagnostic examinations*	*Therapeutic treatments*
Health-care level I									
Albania		1			1	2			
Argentina	212	145	1	118					
Australia			4				145	504 000	
Austria	70	53	23			90	170	343 000	6 250
Belarus	13	9				1 500	48	3 838	
Belgium			18				153	570 900	
Croatia	13	15	2		6	9	67	38 102	1 274
Czech Republic	51	61	3			19	159		
Estonia	2	1	1			3	5	2 708	567
Finland	14	42	4		5		45	45 693	2 026
France		550	10			220			
Germany			60				904	3 831 000	
Greece	20	120	1	6	20	155	210	183 239	1 315
Hungary			3				106	143 500	3 285
Iceland	1	4			2	4	<10	4 133	102
Japan	1 570	1 252	56			1 265		1 560 000	4 400
Korea, Rep.	79	205	66						
Latvia	1	3				4		14 714	
Lithuania	4			11					
Luxembourg	3	5	1			5	7	17 246	49
Malta	0	2	0	0	0	2	1	2 305	74
Netherlands	180		4				60	247 000	5 000
New Zealand	1	20	2			14	8	26 895	
Norway	15	36	2	0	4	25	44	50 438	971
Poland	60	22	2	24	50		150	114 000	12 950
Romania	51					25		71 650	
Russian Federation							2 106		
Slovakia	22	14	4	0	20	11			
Slovenia	14	3	1			7	30	22 830	1 360

Country	Number of items of equipment					Number of sites, physicians and examinations			
	Planar gamma camera	SPECT gamma camera	PET or PET–CT scanner	Rectilinear scanner	Static gamma detector	Sites	Physicians	Diagnostic examinations	Therapeutic treatments
Spain	89	181	21	2		176	356	810 000	90 000
Sweden	70	30	10	0	30		200	110 000	3 496
Switzerland	80	20	16			67	57	97 827	2 306
The former Yugoslav Republic of Macedonia	2	2				2	15	7 937	334
United Kingdom							1 200	650 000	14 500
Venezuela (Bolivarian Republic of)	21		4						
Health-care level II									
Brazil	95	342	9				314		
Chile						30			
China	100	230	13	170	840			725 088	74 880
Costa Rica	1	6			1	4	5	7 500	250
El Salvador	1	2				3	5	3 977	214
Iraq	7						10		
Trinidad and Tobago	1	4				2		1 130	
Health-care level III									
Indonesia		17			15	17	28	3 522	310
Myanmar	3	2			4	5	9	2 796	956
Zimbabwe	2	2				3	1	206	30
Health-care level IV									
Maldives	0	0	0	0	0	0	0	0	0

Table C18. Number of items of nuclear medicine equipment and of physicians per million population
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	Number of items of equipment					
	Planar gamma camera	SPECT gamma camera	PET or PET–CT scanner	Rectilinear scanner	Static gamma detector	Number of physicians
Health-care level I						
Albania		0.31			0.31	
Argentina	5.88	4.02	0.03	3.28		
Australia			0.20			7.11
Austria	8.55	6.47	2.81			21
Belarus	1.26	0.87	0.00			4.7
Belgium			1.75			15
Croatia	2.93	3.38	0.45		1.35	15
Czech Republic	4.96	5.93	0.29			15
Estonia	1.46	0.73	0.73			3.7
Finland	2.67	8.00	0.76		0.95	8.6
France		8.91	0.16			
Germany			0.73			11
Greece	1.82	10.9	0.09	0.55	1.82	19
Hungary			0.30			11
Iceland	3.40	13.61			6.80	
Japan	12.32	9.82	0.44			

Country	*Number of items of equipment*					
	Planar gamma camera	*SPECT gamma camera*	*PET or PET–CT scanner*	*Rectilinear scanner*	*Static gamma detector*	*Number of physicians*
Korea, Rep.	1.68	4.36	1.40			
Latvia	0.44	1.31				
Lithuania	1.15			3.15		
Luxembourg	6.64	11.1	2.21			15
Malta	0.00	5.00	0.00	0.00	0.00	2.5
Netherlands	11.5		0.26			3.8
New Zealand	0.27	5.35	0.54			2.1
Norway	3.23	7.76	0.43	0.00	0.86	9.5
Poland	1.56	0.57	0.05	0.62	1.30	3.9
Romania	2.29					
Russian Federation						14
Slovakia	4.04	2.57	0.74	0.00	3.68	
Slovenia	6.99	1.50	0.50			15
Spain	2.02	4.10	0.48	0.05		8.1
Sweden	7.90	3.39	1.13		3.39	23
Switzerland	10.7	2.68	2.14			7.6
The former Yugoslav Republic of Macedonia	0.98	0.98				7.4
United Kingdom						20
Venezuela (Bolivarian Rep. of)	0.78		0.15			
Health-care level II						
Brazil	0.51	1.83	0.05			1.7
Chile						
China	0.080	0.18	0.01	0.14	0.67	
Costa Rica	0.23	1.39			0.23	1.2
El Salvador	0.15	0.31				0.77
Iraq	0.26					0.37
Trinidad and Tobago	0.79	3.17				
Health-care level III						
Indonesia		0.069			0.061	0.11
Myanmar	0.063	0.042			0.084	0.19
Zimbabwe	0.17	0.17				0.08
Health-care level IV						
Maldives	0	0	0	0	0	0

Table C19a. Annual number of various nuclear medicine examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Bone (^{99m}Tc)*	*Cardiovascular*			*Lung perfusion (^{99m}Tc)*	*Lung ventilation*				*Thyroid scan*		
			^{99m}Tc	*^{201}Tl*	*Total*		*^{99m}Tc*	*^{81m}Rb*	*^{133}Xe*	*Total*	*^{99m}Tc*	*^{131}I/^{123}I*	*Total*
I	Australia	196 200	38 900	38 000	76 900	26 800	26 600			26 600	26 200		26 200
	Austria	52 000		40 000	40 000	14 000	10 000			10 000	200 000		200 000
	Belarus	2 485	38		38	27	4			4	4		4
	Belgium	251 874	99 619		99 619	29 377	20 752			20 752	100 631		100 631
	Croatia	11 992			4 191	1 687	128			128	12 238		12 238
	Czech Republic	49 685	2 822		2 822	29 143	4 740			4 740	7 223		7 223
	Estonia	850	400		400	120	80			80	550		550
	Finland	17 190	5 209	979	6 188	4 389	2 847			2 847	152	103	255
	France	423 000			212 000					127 000			101 000
	Germany	954 000			499 000					294 000			1 435 000
	Greece	73 000		55 000	55 000	7 400	1 900			1 900	30 000		30 000
	Hungary	57 000	18 500		18 500	10 500	2 700			2 700	58 000		58 000
	Iceland	2 631	84		84	81	51			51		290	290
	Japan	471 000	396 000		396 000	33 000	33 000			33 000	87 000		87 000
	Latvia	4 251	1 832		1 832	1 344	1 344			1 344	4 603		4 603
	Luxembourg	5 575	2 518		2 518	414	403			403	4 893		4 893
	Malta	830	481		481	261	46			46	252		252
	Netherlands	122 000			125 000	34 000				14 000			35 000
	New Zealand	13 945	4 579		4 579	1 094	958			958	1 675		1 675
	Norway	17 375	11 148		11 148	2 758	1 757			1 757	5 930		5 930
	Poland	24 740	12 540		12 540	4 200	700			700	30 883	18 137	49 020
	Romania	10 607	1 555		1 555	347				0	21 350	22 432	43 782
	Slovenia	9 225	2 750	450	3 200	1 300				0	3 500	250	3 750
	Spain	341 376	101 976		101 976	66 664	54 933			54 933	89 432		89 432
	Sweden	28 650	10 039	2 851	12 890	8 808	5 464		144	5 608	8 386	5 037	13 423
	Switzerland	39 500	16 700	5 500	22 200	4 800	1 280		1 200	2 480	3 860	1 740	5 600
	The former Yugoslav Republic of Macedonia	1 530	830		830	370	255			255	2 793		2 793
II	Costa Rica	2 544	384		384	144	144			144			2 900
	El Salvador	523	64		64	52	51			51		2 901	2 901
	Trinidad and Tobago	660	120		120	50							

Health-care level	Country	Bone (^{99m}Tc)	Cardiovascular			Lung perfusion (^{99m}Tc)	Lung ventilation				Thyroid scan		
			^{99m}Tc	^{201}Tl	Total		^{99m}Tc	^{81m}Rb	^{133}Xe	Total	^{99m}Tc	^{131}I/^{123}I	Total
	Indonesia	374	240		240	17	17			17	2 010		2 010
III	Myanmar	490	160		160					0	1 528		1 528
	Zimbabwe	150			0	10				0	15		15

Table C19b. Annual number of various nuclear medicine examinations

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	Country	Renal	Gastroenterology	Brain	Liver	PET	PET–CT combined	Other gastric emptying	Other ^{67}Ga scan	Total
	Australia	20 400	3 200	2 900	9 200					
	Austria	11 000		5 000		10 000	1 000			
	Belarus	1 271	13							
	Belgium	12 349		14 151				9 297	6 016	
	Croatia	6 437	911	4 34		84	0			
	Czech Republic	16 820	11 214	5 862		2 265				
	Estonia	550	30	60		31	37			
	Finland	5 690	423	1 633		1 930				
	Germany	295 000	67 000	57 000		230 000				
	Greece	14 500	1 200				239			
	Hungary	15 000	7 800	5 200		1 300	2 500			
I	Iceland	336	232	428		0	0			
	Japan	65 000	5 600	199 000		12 000				
	Latvia	2 148								
	Luxembourg	346	136	252			1 039			
	Malta	307	87	41						
	Netherlands	16 000	5 800	5 200		21 000			2 500	
	New Zealand	2 558	229	57						
	Norway	5 116	166	2 352		318	3 518			
	Poland	16 600	1 000	2 600			2 600			
	Romania	6 750	266						114	
	Slovenia	2 900	160	350		40				
	Spain	40 929	14 327	21 579		1 817	14 546			

Health-care level	Country	Renal	Gastroenterology	Brain	Liver	PET	PET–CT combined	Other gastric emptying	Other ^{67}Ga scan	Total
I	Sweden	13 781	2 041	7 831	846	1 545		439	50	
	Switzerland	4 220		470		7 970				
	The former Yugoslav Republic of Macedonia	2 085	267							
	United Kingdom									650 000
II	Costa Rica	1 000		240	144					
	El Salvador	178	180	27						
	Trinidad and Tobago	170	50							
III	Indonesia	821	52	8						
	Myanmar	521	41	58						
	Zimbabwe	25	6	0		0	0			

Table C20a. Number of various diagnostic nuclear medicine examinations per million population

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	Country	Bone (^{99m}Tc)	Cardiovascular			Lung perfusion (^{99m}Tc)	Lung ventilation				Thyroid scan		
			^{99m}Tc	^{201}Tl	Total		^{99m}Tc	^{81m}Rb	^{133}Xe	Total	^{99m}Tc	^{131}I/^{123}I	Total
I	Australia	9 615	1 906	1 862	3 768	1 313	1 304			1 304	1 284		1 284
	Austria	6 349		4 884	4 884	1 709	1 221			1 221	24 420		24 420
	Belarus	241	3.7		3.7	2.6	0.4			0.4	0.4		0.4
	Belgium	24 454	9 672		9 672	2 852	2 015			2 015	9 770		9 770
	Croatia	2 703			945	380	28.8			28.8	2 758		2 758
	Czech Republic	4 828	274		274	2 832	461			461	702		702
	Estonia	620	292		292	87.6	58.4			58.4	402		402
	Finland	3 274	992	186	1 179	836	542			542	29	20	49
	France	6 656			3 436					2 058			1 637
	Germany	11 627			6 082					3 583			17 489
	Greece	6 636		5 000	5 000	673	173			173	2 727		2 727
	Hungary	57 11	1 854		1 854	1 052	271			270	5 811		5 811
	Iceland	8 949	286		286	276	174			174		986.4	986
	Japan	3 696	3 108		3 108	259	259			259	683		683
	Latvia	18 52	798		798	586	586			586	2 006		2 006
	Luxembourg	12 334	5 571		5 571	916	892			892	10 825		10 825

Health-care level	Country	Bone (^{99m}Tc)	Cardiovascular			Lung perfusion (^{99m}Tc)	Lung ventilation				Thyroid scan		
			^{99m}Tc	^{201}Tl	Total		^{99m}Tc	^{81m}Rb	^{133}Xe	Total	^{99m}Tc	^{131}I/^{123}I	Total
	Malta	2 075	1 202		1 202	652	115.0			115	630		630
	Netherlands	7 802			7 993	2 174				895			2 238
	New Zealand	3 732	1 225		1 225	293	256			256	448		448
	Norway	3 745	2 403		2 403	594	379			378	1 278		1 278
	Poland	642	325		325	109	18.2			18.2	801	471	1 272
I	Romania	476	69.7		69.7	15.6				0.0	957	1 006	1 963
	Slovenia	4 606	1 373	225	1 598	649				0.0	1 747	125	1 872
	Spain	7 739	2 312		2 312	1 511	1 245			1 245	2 028		2 028
	Sweden	3 233	1 133	322	1 455	994	617		16.3	633	946	568	1 515
	Switzerland	5 294	2 238	737	2 976	643	172		160.8	332	517	233	750
	The former Yugoslav Republic of Macedonia	753	408		408	182	125			125	1 374		1 374
	Costa Rica	588	88.8		88.8	33.3	33.3			33.3			670
II	El Salvador	80	9.8		9.8	8.0	7.8			7.8		446	446
	Trinidad and Tobago	523	95.1		95.1	39.6							
	Indonesia	1.5	1.0		1.0	0.1	0.1			0.1	8.2		8.2
III	Myanmar	10.3	3.4		3.4					0.0	32.2		32.2
	Zimbabwe	12.5			0.0	0.8				0.0	1.3		1.3

Table C20b. Number of various diagnostic nuclear medicine examinations per million population

Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	Country	Renal	Gastroenterology	Brain	Liver	PET	PET–CT combined	Other gastric emptying	Other ^{67}Ga scan	Total
	Australia	1 000	157	142	451					
	Austria	1 343		611		1 221	122			
	Belarus	123	1.3							
	Belgium	1 199		1 374				903	584	
I	Croatia	1 451	205	97.8		18.9				
	Czech Republic	1 635	1 090	570		220				
	Estonia	402	21.9	43.8		22.6	27.0			
	Finland	1 084	81	311		368				
	Germany	3 595	817	695		2 803				

Health-care level	*Country*	*Renal*	*Gastroenterology*	*Brain*	*Liver*	*PET*	*PET–CT combined*	*Other gastric emptying*	*Other ^{67}Ga scan*	*Total*
I	Greece	1 318	109				21.7			
	Hungary	1 503	781	521		130	250			
	Iceland	1 143	789	1 456		0	0			
	Japan	510	43.9	1 562		94.2				
	Latvia	936								
	Luxembourg	765	301	558			2 299			
	Malta	768	218	103						
	Netherlands	1 023	371	333		1 343			160	
	New Zealand	685	61.3	15.3						
	Norway	1 103	35.8	507		68.5	758			
	Poland	431	25.9	67.5			67.5			
	Romania	303	11.9						5.1	
	Slovenia	1 448	79.9	174.7		20.0				
	Spain	928	325	489		41.2	330			
	Sweden	1 555	230	884	95	174.4		50	6	
	Switzerland	566		63		1 068				
	The former Yugoslav Republic of Macedonia	1 026	131							
	United Kingdom									10 924
II	Costa Rica	231		55.5	33.3					
	El Salvador	27.4	27.7	4.2						
	Trinidad and Tobago	135	39.6							
III	Indonesia	3.3	0.2							
	Myanmar	11.0	0.9	1.2						
	Zimbabwe	2.1	0.5							

Table C21a. Mean patient effective dose (mSv) for various nuclear medicine diagnostic examinations
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Bone (^{99m}Tc)*	*Cardiovascular*			*Lung perfusion (^{99m}Tc)*	*Lung ventilation*				*Thyroid scan*		
		^{99m}Tc	*^{201}Tl*	*Total*		*^{99m}Tc*	*^{81m}Rb*	*^{133}Xe*	*Total*	*^{99m}Tc*	*^{131}I/^{123}I*	*Total*
Health-care level I												
Australia	5.6	14.1	21.3		2.3	0.7				2.8		
Austria	4.0		23		1.2	2.4				1.0		
Belarus	9	5			38					18		
Belgium	4.1	8.4			2.1					1.8		
Croatia	4.7			7.9	1.8					0.84		
Czech Republic	4	9.9			2.3				0.6	1.8		
Estonia	4.8	7.5			1.2	1.2				1.1		
Finland	3.6	7.5	22.8		1.4	0.6				1.6		
Germany	3.5			7.4	1.2				1.2			0.7
Japan	5.1		46.1		4	4				3.5		
Malta	4.0	5.1			1.2	1.3				2.6		
Netherlands	3.1			6.8	1.1				0.1			3.2
Norway	3.9	4.7			2.1	2.9				2		
Poland		4.9										
Romania	7.2	8.6			1.8					2.4	32.4	
Spain	5.1	9.9			2.4	2.9				2.8		
Sweden	2.9	8.5	15		1.2	1.5				1.3	8	
Switzerland	4.2	5.8	20		2.1	0.28		0.068		1.7	25	
Health-care level III												
Myanmar	3	5.3								0.36		

Table C21b. Mean patient effective dose (mSv) for various nuclear medicine diagnostic examinations
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Renal*	*Gastro-enterology*	*Brain*	*Liver*	*PET*	*PET-CT combined*	*Other gastric emptying*	*Other ^{67}Ga scan*	*Total*
	Australia	2	2.4	7.5	4.1					
	Austria	0.9		6.5		10.8	10.8			
	Belarus	0.02	1.4							
	Belgium	1.4		7.5				1	14.5	
	Croatia	1.1	4.6	3.5		6.3				
	Czech Republic	1.2	0.9	4.2		6.9				
	Estonia	2.2	7	4.4		6	6			
I	Germany	1.5	4.5	5.6		5.6				2.7
	Japan	2.5	5.7	6.8		6.4				
	Malta	1.0	3.4	6						
	Netherlands	0.6		5.7		7.4			6.8	
	Norway	1	0.1	2		6.4				
	Romania	3.8	2.6	4.9					2	
	Spain	1.8	1	5.8			7.4			
	Switzerland	0.4		6.4		6.0				
III	Myanmar	0.6	1.1	2.5						

Table C22. Number of various therapeutic nuclear medicine examinations
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Thyroid malignancy*	*Hyper-thyroidism*	*Polycythemia vera*	*Bone metastases*	*Synovitis*	*Other, e.g. ^{90}YCl*	*Total*
I	Austria	1 100	3 400	10	100	1 500	140	6 250
	Croatia	363	902	0	6	3	0	1 274
	Czech Republic	285	1 200	0	799	520		2 804
	Estonia	160	345	5	50	5	2	567
	Finland	556	1 273	372	56	46	8	2 311
	Greece	1 130			185			1 315
	Hungary	450	2 600		115	120		3 285
	Iceland	27	74		1			102
	Japan	2 200	2 200					4 400
	Luxembourg	46			2	1		49
	Malta	40	24	10				74
	Netherlands							6 000
	Norway	275	642	4	23	9	18	971
	Poland	1 600	10 500		600	200	50	12 950
	Slovenia	210	1 120		3	6	30	1 369
	Spain	26 951	55 863	960	3 191	2 790	245	90 000
	Sweden	104	2 297	291	340	14	10	3 056
	Switzerland		1 500			283	523	2 306
	The former Yugoslav Republic of Macedonia	264	70					334
	United Kingdom	1 150	11 500	710	540	400	200	14 500
II	Costa Rica	100	150					250
	El Salvador	128	86					214
III	Indonesia	132	163		15			310
	Myanmar	77	879					956
	Zimbabwe	20	10	0	0	0	0	30

Table C23. Number of various therapeutic nuclear medicine examinations per million population
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Thyroid malignancy*	*Hyper-thyroidism*	*Polycythemia vera*	*Bone metastases*	*Synovitis*	*Other, e.g. ^{90}YCl*	*Total*
I	Austria	134	415	1.2	12.2	183	17.1	763
	Croatia	81.8	203	0.0	1.4	0.7		287
	Czech Republic	27.7	117	0.0	77.6	50.5		272
	Estonia	117	252	3.6	36.5	3.6	1.5	414
	Finland	106	242	70.9	10.7	8.8	1.5	440
	Greece	103			16.8			120
	Hungary	45.1	261		11.5	12.0		329
	Iceland	91.8	252		3.4			347
	Japan	17.3	17.3					34.5
	Luxembourg	102			4.4	2.2		108
	Malta	100	60.0	25.0				185
	Netherlands							384
	Norway	59.3	138	0.9	5.0	1.9	3.9	209
	Poland	41.5	272		15.6	5.2	1.3	336
	Slovenia	105	559		1.5	3.0	15.0	683
	Spain	611	1 266	21.8	72.3	63.3	5.6	2 040
	Sweden	11.7	259	32.8	38.4	1.6	1.1	345
	Switzerland		201			37.9	70.1	309
	The former Yugoslav Republic of Macedonia	130	34.4					164
	United Kingdom	19.3	193	11.9	9.1	6.7	3.4	244
II	Costa Rica	23.1	34.7					57.8
	El Salvador	19.7	13.2					32.9
III	Indonesia	0.5	0.7		0.1			1.3
	Myanmar	1.6	18.6					20.2
	Zimbabwe	1.7	0.8	0.0		0.0	0.0	2.5

Table C24. Reported mean patient dose (mSv) for various nuclear medicine therapeutic examinations
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Thyroid malignancy*	*Hyperthyroidism*	*Polycythemia vera*	*Bone metastases*	*Synovitis*	*Other, e.g. ^{90}YCl*
I	Austria				380		
	Estonia			400	435		
	Spain	9 356	7 511		615	130	2 220
III	Myanmar	390 000	98 000				

Table C25. Frequency, population-weighted average effective dose and collective dose for nuclear medicine diagnostic examinations (1997–2007)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Examination	*Number of examinations per 1 000 population*				*Effective dose per examination (mSv)*				*Annual collective dose (man Sv)*			
	Level I	*Level II*	*Levels III–IV*	*World*	*Level I*	*Level II*	*Levels III–IV*	*World*	*Level I*	*Level II*	*Levels III–IV*	*World*
Bone ^{99m}Tc	6.17×10^{0}	3.08×10^{-1}	3.33×10^{-3}	1.6×10^{0}	4.74	4.74	4.74	4.74	29 263	1 461	15.8	30 741
Cardiovascular ^{99m}Tc	2.19×10^{0}	4.70×10^{-2}	1.37×10^{-3}	5.5×10^{-1}	7.97	7.97	7.97	8.0	17 476	375	10.9	17 861
Cardiovascular ^{201}Tl	2.26×10^{0}			5.4×10^{-1}	40.7	40.7	40.7	40.7	91 892	0.0	0.0	91 892
Lung perfusion ^{99m}Tc	7.61×10^{-1}	2.04×10^{-2}	1.05×10^{-4}	1.9×10^{-1}	3.52	3.52	3.52	3.52	2 681	71.7	0.4	2 753
Lung ventilation ^{99m}Tc	5.12×10^{-1}	1.80×10^{-2}	6.93×10^{-5}	1.3×10^{-1}	2.66	2.66	2.66	2.66	1 363	47.9	0.2	1 411
Lung ventilation ^{81m}Rb								0.0	0.0	0.0	0.0	0.0
Lung ventilation ^{133}Xe	8.23×10^{-2}			2.0×10^{-2}	0.07	0.07	0.07	0.07	5.6	0.0	0.0	5.6
Thyroid scan ^{99m}Tc	1.97×10^{0}		1.17×10^{-2}	4.8×10^{-1}	3.75	3.75	3.75	3.8	7 374	0.0	43.7	7 418
Thyroid scan ^{131}I/^{123}I	5.67×10^{-1}	4.46×10^{-1}		3.5×10^{-1}	30.5	30.5	30.5	30.5	17 304	13 632	0.0	30 937
Renal	1.27×10^{0}	1.12×10^{-1}	4.48×10^{-3}	3.6×10^{-1}	1.89	1.89	1.89	1.89	2 403	210	8.5	2 622
Gastroenterology	2.87×10^{-1}	2.96×10^{-2}	3.25×10^{-4}	8.3×10^{-2}	3.97	3.97	3.97	3.97	1 140	118	1.3	1 259
Brain	8.19×10^{-1}	2.47×10^{-2}	2.17×10^{-4}	2.1×10^{-1}	6.09	6.09	6.09	6.09	4 984	150	1.3	5 135
Liver	3.43×10^{-1}	3.33×10^{-2}		9.9×10^{-2}	4.10	4.10	4.10	4.10	1 407	136	0.0	1 544
PET	8.74×10^{-1}			2.1×10^{-1}	6.42	6.42	6.42	6.42	5 612	0.0	0.0	5 612
PET–CT combined	2.07×10^{-1}			5.0×10^{-2}	7.88	7.88	7.88	7.9	1 632	0.0	0.0	1 633
Other gastric emptying	5.08×10^{-1}			1.2×10^{-1}	1.00	1.00	1.00	1.0	508	0.0	0.0	508
Other ^{67}Ga scan	1.52×10^{-1}			3.6×10^{-2}	7.26	7.26	7.26	7.3	1 104	0.0	0.0	1 104
Thyroid malignancy	1.09×10^{-1}	2.11×10^{-2}	3.45×10^{-3}	3.7×10^{-2}								
Hyperthyroidism	2.85×10^{-1}	2.18×10^{-2}	3.45×10^{-3}	8.0×10^{-2}								
Polycythemia vera	1.61×10^{-2}	1.68×10^{-2}		3.9×10^{-3}								
PET												
Bone metastases	2.88×10^{-2}			6.9×10^{-3}								
Synovitis	2.88×10^{-2}			6.9×10^{-3}								
Other, e.g. ^{90}YCl	6.65×10^{-3}			1.6×10^{-3}								
Total diagnostic	1.9×10^{1}	1.09×10^{0}	2.15×10^{-2}	5.07×10^{0}					186 000	16 000	82	202 437
Average effective dose per caput from diagnostic nuclear medicine examinations (mSv)									0.121	0.005 1	0.000 047	0.031 4

APPENDIX D: LEVELS AND TRENDS IN THE USE OF RADIATION THERAPY

I. INTRODUCTION

D1. Radiation therapy, often referred to as "radiotherapy", is the collection of treatment options available in the medical specialty known as clinical radiation oncology. Nowadays radiation therapy is used for the treatment of many types of cancer [C18, P14, U3, U4]. The goal of radiation therapy is to achieve cytotoxic levels of irradiation to a well-defined target volume (the volume of tissue that must be treated to assure that the tumour receives the prescribed dose) of the patient, while as far as possible avoiding the exposure of surrounding healthy tissues. Treatments generally involve multiple exposures (fractions) spaced over a period of time for maximum therapeutic effect. Radiation therapy is an important treatment modality for malignant disease, and is most often delivered in combination with surgery or chemotherapy, or both [C18, M28, S10, S11, W22]. The utilization of radiation treatment in oncology varies significantly among the different sites of disease and also between countries. In the United States, for example, 37% of women diagnosed with early stage breast cancer in 2002 received radiation treatment [N7]. In contrast, the radiation therapy utilization rate for breast cancer patients in the Russian Federation in 1995 was 2% [U3]. Less commonly, radiation is also used in the treatment of benign disease [O7]. In 2000, external beam radiation therapy utilization varied considerably among countries. In level I countries, Hungary and the Czech Republic reported 3.5 or more patients treated per 1,000 population, while the United States and the United Kingdom reported approximately 2.0 to 2.5 patients per 1,000 population, and Ecuador, Kuwait and the United Arab Emirates reported fewer than 0.3 patient per 1,000 population. In level II countries, 0.7 patient per 1,000 population received radiation therapy, and in level III countries, only 0.5 patient per 1,000 population received treatment [U3]. The clinical goal in radiation therapy is either the eradication of cancer (curative treatment) or the relief of symptoms associated with the disease (palliative treatment) [C18]. In level I and II countries, the majority of treatments are considered curative. In level III and IV countries, where tumours are less likely to be diagnosed early and where equipment and techniques are generally less advanced than in level I and II countries, a larger proportion of treatments are palliative.

D2. Radiation therapy is delivered by one of two methods: teletherapy, in which a beam of radiation is directed to the target tissue from outside the body; or brachytherapy, in which radioactive sources are placed in a body cavity or placed directly in the tissue. For some tumours, such as cancers of the uterine cervix and the prostate, teletherapy and brachytherapy often are used sequentially or even concomitantly, as is described in more detail below. Unsealed sources of radiation are sometimes used for treatment of metastatic or widespread disease. Such therapy with unsealed sources (radiopharmaceuticals) or with monoclonal antibodies (radioimmunotherapy) is discussed in appendix C. Beams of radiation for therapeutic purposes are produced by machines that fall into four general types: X-ray machines are quite commonly used for therapy, and produce beams of radiation generated between about 50 and 300 kVp. Cobalt teletherapy units contain large sources of radioactive ^{60}Co, with a mechanism that moves the source from a shielded location to a position that permits the gamma rays to pass through an opening of adjustable size, called a collimator. In one type of cobalt unit, multiple sources are arranged in a spherical shield, into which a patient's head is positioned for treatment. Caesium-137 sources have been used in the past, but these have largely been replaced by more modern machines. Megavoltage X-rays can be produced by electron linear accelerators, which are now commonly used throughout the developed world and are becoming more widely used in developing countries. A small number of radiation therapy centres operate cyclotrons or synchrotrons that accelerate beams of protons or heavier charged particles that are used for treatment. At present, 31 centres operate such machines, most of them in Europe, Japan and the United States. Another six are under construction and at least eight more have been proposed [F14, P23].

D3. Radiation therapy involves the use of intense radiation beams and high-activity sources. Treatments are often complex, requiring the delivery of conformally shaped beams from multiple directions, or the use of sophisticated beam modifiers. Properly trained staff are required, and they must follow carefully developed procedures. The equipment must be properly maintained. Failure to adhere to recommended quality assurance procedures and the use of inadequately prepared staff can contribute to a significant potential for accidents. Such events have resulted in serious consequences for the health of both patients and staff; such incidents are discussed further in section VII of this appendix.

II. TECHNIQUES

D4. The objectives of radiation protection in radiation therapy are to minimize the radiation dose to the patient outside the target volume, and to maintain the doses to staff and members of the public as low as reasonably achievable [P14]. Radiation therapy is becoming increasingly sophisticated in the pursuit of these objectives. Achieving the first objective requires that the extent of the tumour be established precisely and that nearby sensitive structures be identified. This requires the use of state-of-the-art diagnostic techniques to distinguish tissues involved with tumours from healthy tissues. The use of CT and MRI for radiation therapy treatment planning is becoming more common. Treatment planning involves the use of a computer to calculate the radiation dose distribution within the body. With advances in computing and the availability of inexpensive fast computer processors, it has become practical to plan radiation therapy treatments in three dimensions (3-D), thereby more closely matching or "conforming" the treated volume to the tumour. Optimized treatments may require multiple beam angles, different beam weights, complex field shapes, wedge filters or other modifiers, or the use of intensity-modulated techniques. The second goal is addressed through improvements in the design and operation of equipment and facilities to provide greater protection for staff and members of the public.

D5. External beam radiation therapy (also called teletherapy) can be delivered with several classes of treatment machines. These can be grouped as: *(a)* kilovoltage X-ray generators, *(b)* radionuclide teletherapy units, *(c)* megavoltage X-ray machines such as linear accelerators, and *(d)* proton and heavy particle accelerators.

D6. Kilovoltage X-ray machines can be of three main types: (1) Contact therapy machines, though rare today, produce X-rays at energies of 25 to 40 kVp. (2) Superficial therapy machines produce X-rays in the range 40–120 kVp, with a typical source–skin distance (SSD) of 30 cm or less, and are used to treat small epithelial lesions. The beam quality of superficial X-ray therapy is usually specified in terms of its half-value layer and lies in the range 0.5–8 mm aluminium [H17, I21]. Lesions of the skin and of the oral, vaginal or rectal mucosa are sometimes treated with this technique [L23]. (3) Orthovoltage therapy machines generate X-ray beams in the range 150–300 kVp. Orthovoltage units have been used to treat skin lesions and bone metastases. The beam size is limited by either an applicator or a diaphragm. SSDs in the range 30–60 cm are used. Orthovoltage therapy units have half-value layers in the range 0.2–5 mm copper [I21].

D7. Many centres worldwide use radiation therapy units containing a high-activity source of radioactive cobalt (^{60}Co). The isotope ^{60}Co decays with a half-life of 5.26 years to ^{60}Ni, producing two gamma rays of 1.17 MeV and 1.33 MeV. Consequently, the radiation from this source is referred to as megavoltage radiation. The activity of the source must be high enough to allow an SSD of 80–100 cm. This means that isocentric treatments are possible. As the source size is relatively large, there is a wide penumbra associated with these radiation sources [H17]. Satellite collimators, or "penumbra trimmers", were introduced to reduce the width of the penumbra, but in comparison with linear accelerator beams, the penumbra of a cobalt beam is still large [H17, J10].

D8. Megavoltage radiation therapy may also be delivered using medical accelerators, usually electron linear accelerators (linacs). These machines use radiofrequency radiation to accelerate electrons to energies of between 4 and 25 MeV. The accelerated narrow electron beam can be passed through a scattering foil to produce a broad uniform electron beam that is directed towards the patient and is defined by a cone or applicator that typically extends to within 5 cm of the patient surface. Electrons lose energy at the rate of about 2 MeV/cm in tissue and are useful for treating superficial tissues quite uniformly while sparing deeper-seated structures. When using sterile intraoperative techniques, electrons can be used to treat a tumour or the tumour bed once it has been exposed through surgery.

D9. Alternatively, the accelerated electron beam can be steered into a metal target, producing bremsstrahlung and characteristic X-rays whose energies fall in a spectrum with a maximum energy equal to the energy of the accelerated electrons. Similar to kilovoltage X-rays, accelerator-produced megavoltage photon beams are commonly described by a potential corresponding to the maximum electron energy, e.g. 4 MV to 25 MV. A collimator consisting of several parts limits and shapes the X-ray beam. A primary collimator is placed near the target and limits the beam to some maximum size, generally 56 cm diameter at the normal treatment distance. A secondary collimator consists of two pairs of heavy moveable jaws that can shape the beam to any rectangle up to the maximum size. Some accelerators are equipped with multileaf collimators (MLCs) that can produce an irregular-shaped beam. The MLC either replaces one pair of collimator jaws or is mounted below the jaws. High-energy photon beams are more penetrating than superficial or orthovoltage X-rays and have a skin-sparing effect. Consequently, these beams are very useful for treating deep-seated tumours, as well as shallower structures such as the breast, for which beams can be directed tangentially.

D10. Worldwide in 1991–1996, approximately equal numbers of radiation therapy patients were treated using X-ray machines, radionuclide units and linear accelerators (table B1 in appendix B) [U3]. Insufficient data were received in 1997–2007 to estimate numbers of patients treated with each type of treatment device. However, the relative availability of linear accelerators worldwide was about 1.6 machines per million population. X-ray machines and cobalt units were each found at a frequency of 0.4 per

million population. In level I countries, however, the availability of treatment equipment was considerably greater, and linear accelerators were reported at a frequency of 5.4 per million population (table D1). The total number of treatment machines also varied from one health-care level to another (table D2). The numbers of patients treated in different countries varied in relation to the availability of treatment equipment. In level I countries, the number of courses of treatment given was 2.4 per 1,000 population, while smaller numbers were reported by level II and III countries (table D3).

D11. The characteristics of a radiation beam are often described through the use of isodose curves. These curves represent a map of the radiation dose distribution, in which each curve corresponds to the locus of points at which the dose is a selected value, such as 20 Gy, or a relative value, such as 70% of the dose at a reference point. Patient dose distributions are generally displayed by superimposing isodose curves on a CT image or other representation of the patient. Several examples of isodose distributions are shown in figures D-I, D-II, D-III and D-IV.

Figure D-I. Representative isodose distributions: A 3-dimensional conformal treatment plan for the prostate, showing significant dose to the rectum

Isodose levels (in Gy) are shown by solid lines, while structures are contoured in dashed lines. Red dashed line – prostate; purple dashed line – prostate PTV (see paragraphs D28-D31); pink dashed line – rectum

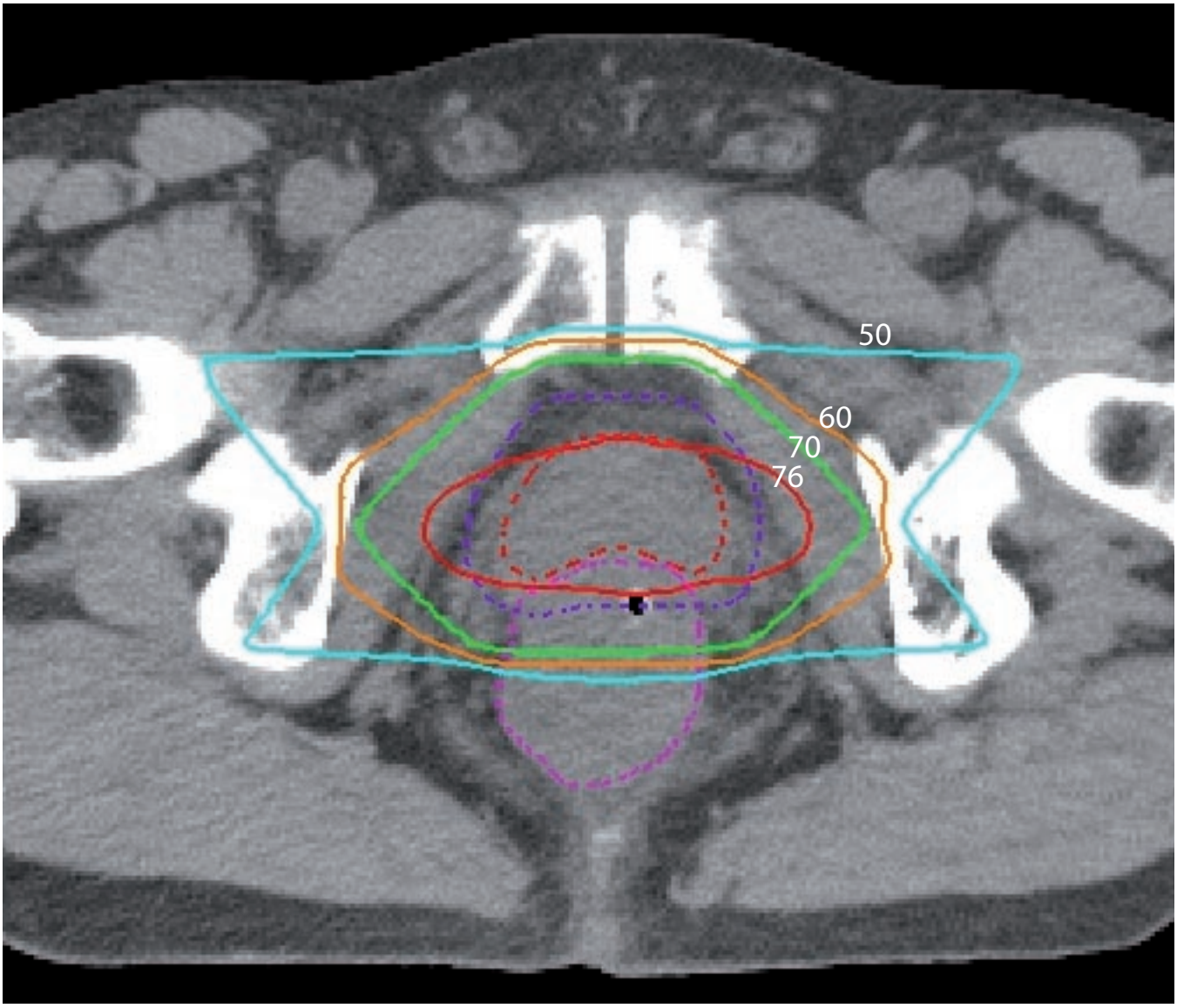


Figure D-II. Representative isodose distributions: Intensity-modulated radiation therapy plan for a gynaecological tumour, showing superior conformation of the 50 Gy isodose line to the planning target volume

Isodose levels (in gray) are shown by solid lines, while structures are contoured in dashed lines. Blue dashed line – prostate; dark red dashed line – prostate PTV (see paragraphs D28-D31); yellow dashed line – bladder; pink dashed line – rectum

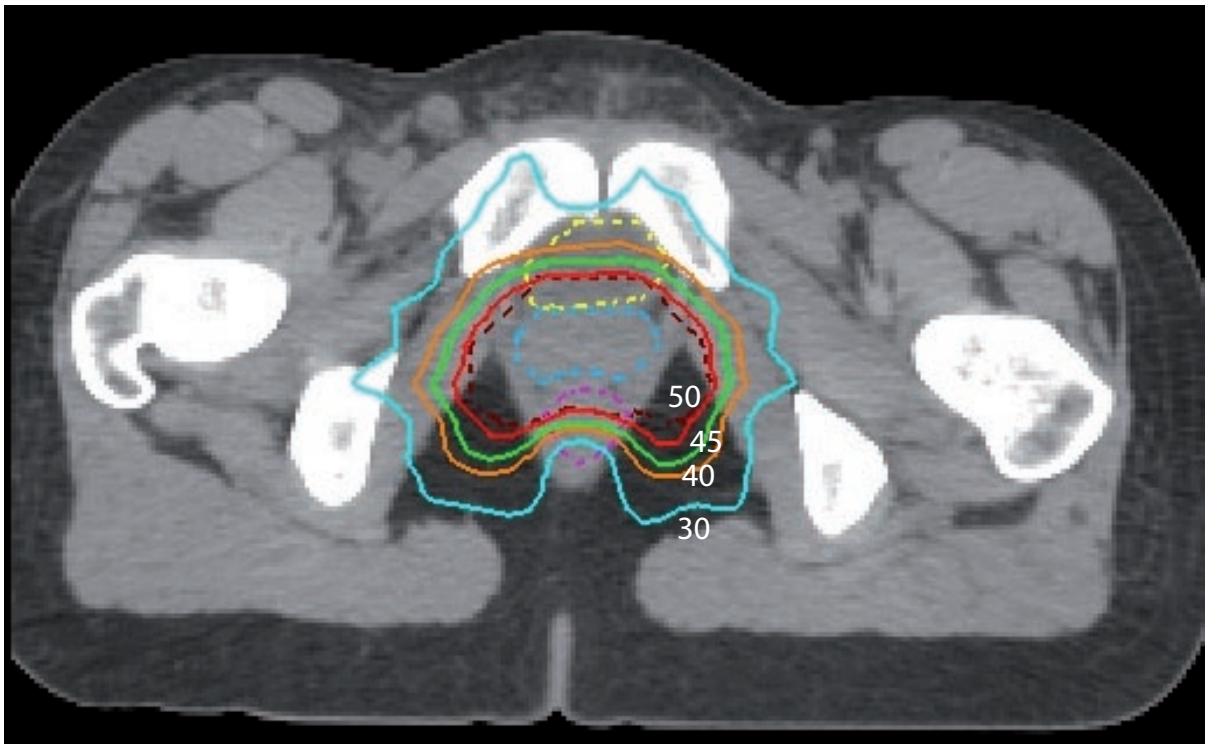


Figure D-III. Representative isodose distributions: Treatment plan showing the use of stereotactic body radiation therapy for a lung tumour

Isodose levels (in gray) are shown by solid lines, while structures are contoured in dashed lines. Red dashed line – lung tumour CTV (see paragraphs D28-D31); purple dashed line – PTV; yellow dashed line – spinal cord

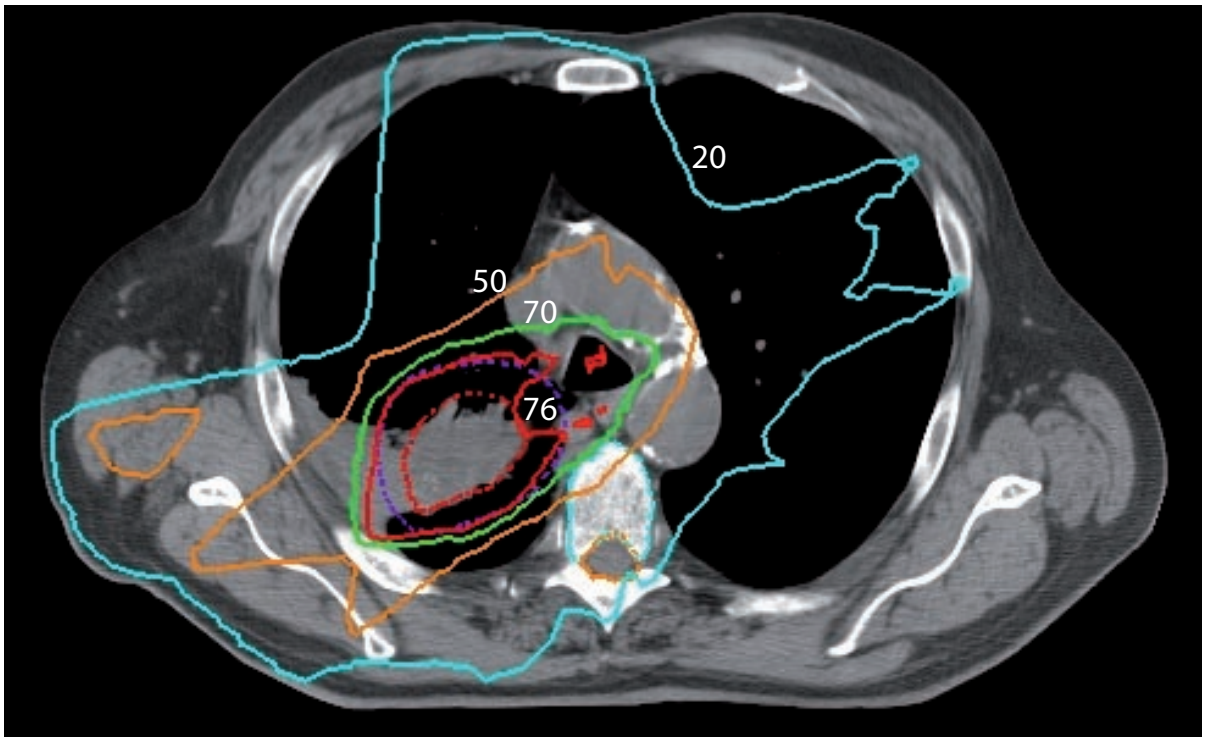
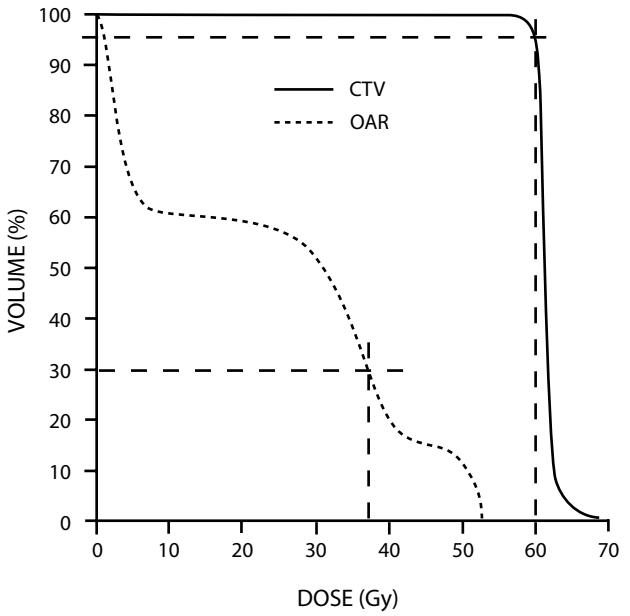


Figure D-IV. Representative isodose distributions: Dose–volume histograms for a clinical target volume (CTV) and an organ at risk (OAR)



D12. The fluence distribution of a teletherapy beam can be adjusted by several means. A simple method of modulating the beam is through the use of a metal wedge filter, which differentially attenuates the beam, producing a sloping intensity profile. The angle through which the isodose curves are tilted is termed the wedge angle. Modern treatment machines use programmable wedges, meaning that one jaw is moved across the field while the beam is on, to differentially modulate the beam and produce wedge-shaped dose distributions.

D13. MLCs can be used to shape the field to the projection of the target volume and to protect normal tissue. This obviates the need for heavy metal alloy shielding blocks and can result in reduced set-up time for treatment. MLCs also can be programmed to modulate the intensity of the treatment beam to create highly conformal dose distributions. This procedure is known as intensity-modulated radiation therapy (IMRT) [B26]. IMRT can be delivered in several ways: *(a)* in step-and-shoot IMRT, at each of several gantry angles the MLC is programmed to several different shapes. A selected number of monitor units is delivered through each MLC setting, creating a non-uniform intensity distribution. When combined with the non-uniform intensity distributions produced at the other gantry angles, a dose distribution is produced that conforms to the target volume; *(b)* in sliding window IMRT, a non-uniform intensity distribution is created by moving pairs of leaves across the field while the beam is on. The width of the field created by each pair of leaves is changed, resulting in an increased or decreased dose at each location. Again, this is done for each of several gantry angles; *(c)* serial tomotherapy is delivered through the use of a "binary MLC" [C3]. This device, first marketed in the 1990s as the Peacock system, uses a 40-cm-wide by 2-cm-long field, which can be blocked by an MLC consisting of 40 pairs of leaves of 1 cm width. Regions 1 cm wide by 2 cm long can be effectively switched on and off, as the gantry is rotated continuously, delivering an IMRT treatment to a 2-cm-thick transverse section of the patient. Following each gantry arc, the patient support couch must be moved precisely 2 cm and the process repeated as necessary to treat the entire length of the target volume; *(d)* helical tomotherapy is a similar process, but rather than delivering an IMRT treatment to a single transverse slice of the patient, the patient couch is moved continuously as the gantry rotates, in exactly the same manner that helical CT is performed. A dedicated treatment machine has been developed for this type of treatment [M5]; *(e)* intensity-modulated arc therapy (IMAT) is delivered by adjusting the MLC to a specific shape, then rotating the accelerator gantry through a range of angles with the beam on. The arc is then repeated, but with the MLC set to a different shape, to increase the dose only to selected regions of the target volume. This process may be repeated several times [Y9].

D14. Radiation therapy is generally delivered to specific, well-defined volumes of tissue, although large-field techniques are also used: whole-body photon beam irradiation in conjunction with bone marrow transplantation for the treatment of leukaemia, hemibody irradiation for the palliation of painful bone metastases, mantle irradiation in the treatment of lymphomas, and irradiation of the entire central nervous system in the treatment of medulloblastoma [S28, W22]. Total-skin electron therapy is used for the treatment of widespread skin diseases such as cutaneous T-cell lymphoma, or Kaposi's sarcoma [B27].

D15. Stereotactic radiosurgery (SRS) refers to the use of narrow, well-defined beams of ionizing radiation for the precise ablation of a well-defined intracranial or extracranial target volume at the focus of a stereotactic guiding device, without significant damage to adjacent (healthy) tissues. SRS is typically given through a single fraction of radiation, with the intention of obliterating the target [C4, F13, G5].

D16. A related treatment called stereotactic radiation therapy (SRT) refers to the use of stereotactic techniques for multifraction radiation therapy. When delivered to extracranial targets, this technique is often referred to as stereotactic body radiation therapy (SBRT) [K9]. An example of an SBRT treatment to a lung tumour is shown in figure D-III. Since the introduction of the technique in 1951, clinical studies have been undertaken with high-energy photons from linear accelerators [F13, G12, K3, K9] and ^{60}Co sources, with protons and with heavy particles.

D17. Brachytherapy involves the placement of an encapsulated source or a group of such sources on or in the patient by application to a surface, within a cavity or directly into the tissue to deliver gamma or beta radiation at a distance of up to a few centimetres [D22]. Radium-226 sources, on the basis of which many brachytherapy techniques were developed, have a number of undesirable characteristics, including the

risk of contamination through leakage or breaking, and have been replaced almost completely by a variety of artificial radionuclides, principally ^{137}Cs, ^{192}Ir and specially designed small ^{60}Co sources [T4].

D18. A novel electronic brachytherapy source has been described recently [R16]. The device consists of a miniature X-ray tube having outer dimensions of approximately 3 mm by 3 mm. The tube operates at either 40 or 50 kVp and is designed to emit X-rays essentially isotropically. Preliminary data indicate that the device can be used quite successfully to simulate an ^{192}Ir brachytherapy source [R27]. Dose rates of as much as 1 Gy/min at 1 cm can be delivered.

D19. When brachytherapy is practical, it offers several advantages over other types of radiation therapy: the radiation source can be placed within or adjacent to the target tissue; the radiation usually does not have to traverse healthy tissue to reach the target tissue; and in the case of low-dose-rate (LDR) brachytherapy, the low dose rate and continuous irradiation offer radiobiological advantages.

D20. Permanent interstitial brachytherapy implants are generally used for deep-seated tumours and today are principally used for treatment of the prostate [S29]. The most commonly used sources are ^{125}I and ^{103}Pd, either as individual miniature sources (seeds) or loaded in dissolvable sutures. Temporary interstitial implants also are used for superficial and easily accessible tumours such as those of the breast, head and neck, and base of the tongue.

D21. The intracavitary implant technique consists of the placement of an applicator containing radioactive sources into a natural body cavity to irradiate an adjacent tumour. It is routinely used in the treatment of carcinomas of the cervix, vagina and endometrium. Intraluminal implants, using a special applicator or catheter, are used in the treatment of carcinomas of the oesophagus, bronchus and bile ducts [S30]. Ophthalmic applicators are used for treating malignant melanoma of the uvea and other malignant and benign tumours of the eye [H26]; medium-sized and large tumours are usually treated with ^{103}Pd or ^{125}I plaques, and small tumours with beta ray applicators incorporating ^{106}Ru or ^{90}Sr.

D22. A number of multicentre studies were completed to investigate the efficacy of endovascular brachytherapy treatment for the inhibition of restenosis after angioplasty [W21]. These have shown that, while brachytherapy is successful in delaying restenosis, newer drug-eluting stents provide equivalent results. Initial concerns about increases in the rate of stent thrombosis leading to increases in the risk of death and myocardial infarction following the use of drug-eluting stents have recently been retracted. In a revised statement, the United States Food and Drug Administration reported that the small increased risk of stent thrombosis with drug-eluting stents was not associated with an increased risk of death or myocardial infarction compared bare metal stents [F8]. Consequently, intravascular brachytherapy has been abandoned at most centres.

D23. Brachytherapy can be used alone but is more often used in combination with external beam therapy [W22]. For example, in the management of cancer of the cervix, teletherapy is used to treat the entire target volume, including the parametrial and pelvic lymph nodes. Intracavitary brachytherapy is used to deliver an additional dose to the primary tumour volume, thus sparing normal tissues and organs at risk from doses above tolerance levels. Tumours of the tongue and breast are often given preliminary treatment by teletherapy, with brachytherapy providing a boost in the dose to the primary tumour. Prostate tumours are often treated with external beam therapy followed by a brachytherapy boost, although it is also common to use brachytherapy alone (monotherapy).

D24. Conventional LDR brachytherapy using ^{137}Cs sources involves dose rates at the prescribed point or surface in the range 0.4–2.0 Gy/h, with most treatments given over a period of several days in one fraction, or more often two; higher-activity ^{137}Cs sources can provide medium dose rates (MDR) of up to 12 Gy/h. High-dose-rate (HDR) brachytherapy utilizes ^{192}Ir sources to provide even higher dose rates, generally 2–5 Gy/min, with treatment times reduced to minutes or less and the treatment generally delivered through several fractions [P10, T11]. Sources having a nominal activity of 3,700 GBq (10 Ci) are generally used, and are driven through coupling tubes into the implanted applicator by a machine called a remote afterloader [S29]. The source is programmed to stop (“dwell”) at selected locations within the applicator, most often in a pattern that simulates the source placement used in conventional LDR brachytherapy. In some countries, sources of ^{60}Co are increasingly being used for HDR brachytherapy; worldwide in 2006, the use of 103 such devices was reported, with most in the Russian Federation and China. Pulsed-dose-rate (PDR) brachytherapy has recently become popular and allows pulses of HDR radiation to be delivered over a time period comparable to that used for LDR brachytherapy. This method uses a high-activity source (typically 370 GBq or 1 Ci) and a remote afterloading machine to deliver the radiation in fractions of a few minutes; these are repeated at intervals of 1 or 1.5 h. Remote afterloading offers significant radiation protection benefits, in that the source is returned to the shielded storage container periodically to allow other persons to be present, for example to give the patinet medical attention. The source can be retracted at any time in the event of an emergency. From a radiological protection point of view, remote afterloading is essential, for HDR, PDR and MDR techniques. Other developments in radiation therapy are discussed in section VI.A in relation to trends in the practice.

III. SUMMARY FROM THE UNSCEAR 2000 REPORT

D25. Radiation therapy involves the delivery to patients of high absorbed doses to target volumes for the treatment of malignant or benign conditions. Resources for radiation therapy were distributed unevenly around the world, with significant variations in radiation therapy practice both among and often within individual countries. 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 are likely to be significant. The world annual total number of treatments for 1991–1996 was estimated to be about 5.1 million, with teletherapy accounting for over 90% of the treatments. The corresponding average annual frequency of 0.9 treatment per 1,000 population was similar to the level quoted for 1985–1990 [U6] on the basis of an estimated total number of 4.0 million treatments.

IV. DOSIMETRIC APPROACHES

D26. Successful treatment of cancer with radiation is dependent upon the accurate and consistent delivery of high doses of radiation to specified volumes of the patient, while minimizing the irradiation of healthy tissues. Detailed assessment of the dose for individual patients is critical to this aim, and techniques for dosimetry and treatment planning are well-documented; see, for example, publications from the ICRU [I9, I10, I13, I14, I15], the IAEA [I12, I42, I43, I44, I45] and others [A12, B28, B29], as well as various codes of practice (e.g. [A2, I45, K10, M29, N18, N21, R17]). Special treatment and dosimetry techniques are required for pregnant patients to minimize potential risks to the foetus from exposure in utero [A3, M20, M21, S31]. Approximately 4,000 pregnant patients required treatment for malignancy in the United States in 1995. The radiofrequency radiation from radiation therapy treatment machines can cause permanently implanted cardiac pacemakers to malfunction, and special techniques have been recommended for the planning and administration of treatment to such patients [L21, M30]. Quality assurance measures and dosimetry intercomparisons are widely recommended to ensure continuing performance to accepted standards [D14, D21, I7, K17, K18, N12, N19, W9].

D27. The delivery of clinical radiation therapy requires assessment of the extent of the disease (staging); identification of the appropriate treatment modality; specification of a prescription defining the treatment volume (encompassing the tumour volume and tissues at risk for microscopic spread), intended tumour doses, consideration of critical normal tissues, number of treatment fractions, dose per fraction, frequency of treatment and overall treatment period; preparation of a treatment plan to provide an optimal dose distribution; and delivery of treatment and follow-up. Radiological imaging, frequently involving CT but also including radiography, MRI and PET when appropriate, is widely used throughout this process; applications include the assessment of extent of disease, preparation of the treatment plan, verifying the location of brachytherapy sources and confirming correct patient set-up for external beam therapy. Because radiation therapy practice is largely empirical, significant variations are apparent in the dose/time schedules used in the treatment of specific clinical problems [D11, D19, G17, N19, P5, U17]. However, the publication of results of clinical trials, both from single-institution practice and from cooperative cancer study groups, has helped to bring a certain degree of conformity to treatment practice among cancer centres. [I16, K19, M23, S32, V11].

D28. The ICRU has promoted a uniform approach to the specification and reporting of dose distributions. ICRU Reports 50 and 62 [I9, I31] have updated Report 29 [I10] and introduce several clinical volumes: gross tumour volume (GTV); clinical target volume (CTV); planning target volume (PTV); organ at risk (OAR); planning organ-at-risk volume (PRV); treated volume (TV); and irradiated volume (IV) [I9, I10, I31]. The failure to accurately define the tumour, its spread into adjacent tissue and its movement relative to landmarks during a course of treatment can result in inadequate dose being delivered to part or all of the tumour. The consequence of such inadequate treatment can be a recurrence of the tumour. Consequently, the systematic identification of the volumes described above can aid in achieving the goal of designing and delivering a successful treatment.

D29. The GTV defines the extent of a demonstrable tumour. This is determined from clinical examination, surgical resection or findings from imaging.

D30. The CTV extends beyond the GTV by a certain margin to take into account the possible microscopic spread of the tumour [S9]. The CTV also can be defined to include local lymph nodes, and sometimes encompasses several GTVs. For gynaecological brachytherapy, MRI is most useful to demonstrate the anatomy, although its use is largely limited to a few centres in level I countries. A recent publication suggests that the tumour identified at the time of diagnosis be termed the intermediate-risk CTV and be prescribed a moderate dose, say 15 Gy, following 45 Gy of external beam radiation. The volume at risk visible on MRI at the time of brachytherapy plus a margin is considered the high-risk CTV and is prescribed a higher dose, typically 35 Gy, following external beam radiation [P3].

D31. With very few exceptions (such as possibly tumours of the brain), there will inevitably be movement of the CTV

relative to external landmarks during a course of treatment involving a number of fractions. To accommodate this inter-fraction motion, as well as the uncertainty in reproducing the patient position from one fraction to the next, the ICRU specifies an additional margin to the CTV to create the PTV. The PTV is equivalent to the previous concept of target volume [I10, S9]. Dose planning, specification and reporting are based upon the PTV, although reporting of doses to the CTV is appropriate under some circumstances [S9].

D32. Healthy tissues that are sensitive to radiation are defined as organs at risk (OAR) and are spared as much as possible during radiation therapy. To accommodate any movement of an OAR during a course of therapy and to take into account the uncertainty of delineating an OAR, a margin can be drawn around the OAR to produce a planning organ-at-risk volume (PRV), which is analogous to the PTV drawn around a CTV.

D33. The doses to healthy tissues from radiation therapy can be estimated from isodose distributions such as those shown in figures D-I, D-II, D-III and D-IV. For example, figure D-I indicates that the dose to the rectum from this prostate treatment plan varies from below 50 Gy to more than 76 Gy. However, it is clear that the distribution shown in figure D-I represents the dose only in a single transverse plane. To understand the dose to the entire rectal volume (or that of another organ), multiple transverse planes must be examined. Alternatively, a dose–volume histogram (DVH) can be valuable to indicate the dose to an organ. A DVH is a graph of the fractional volume of an organ or structure receiving a selected dose or greater. Figure D-IV shows typical DVHs for a target organ (CTV) and an OAR. The figure shows that about 95% of the CTV is receiving at least 60 Gy, while 30% of the OAR is receiving about 37 Gy or more.

D34. Brachytherapy treatments for carcinoma of the uterine cervix have evolved little from the early Stockholm and Paris techniques developed in the 1920s and 1930s [H23, P10, R11]. For example, the Manchester system was evolved from the Paris technique and is still used in a number of centres. Similar treatment applicators are used. In the Manchester system, doses are specified at point A and point B. Point A is defined as being 2 cm lateral to the centre of the uterine canal and 2 cm from the mucous membrane of the lateral fornix in the plane of the uterus. Point B is 5 cm from the midline of the uterus.

D35. In the past several years, significant efforts have been made to develop protocols for image-guided brachytherapy [N19, P3]. The ICRU terminology for defining target volumes has been adapted for brachytherapy, with modifications that make it possible to distinguish between the masses of tumour present before and after surgery. Such protocols allow the treatment to be tailored to the patient's precise condition, rather than relying on simplistic prescriptions based on surrogate non-anatomical reference markers such as point A.

D36. In many treatment centres today, radiation therapy considers the location and shape of the CTV in three dimensions, and the treatment planning process attempts to conform the dose distribution to the PTV and to avoid PRVs. Such 3-D conformal radiation therapy (3-D CRT) uses custom-designed beam blocking or MLCs to shape the field to the projection of the PTV, and allows the display of patient anatomy and dose distributions using 3-D techniques. Modern treatment planning systems also perform dose calculations that consider the effects of tissue densities in three dimensions.

D37. The 3-D CRT technique is capable of shaping dose distributions only to relatively simple convex shapes (figure D-I). In a number of common treatment situations, the PTV exhibits concavities or invaginations produced by the presence or pressure of another structure. A common example is the prostate, which frequently partially wraps around the rectum. Tumours of the posterior nasopharynx can wrap partly around the spinal cord. It is possible with IMRT to generate dose distributions that conform to complex and convoluted PTVs, with the primary goal of minimizing the dose to nearby PRVs, to allow the delivery of high doses to the PTV [B26]. The IMRT technique can achieve uniform dose delivery to the PTV, but generally uniformity of dose is considered of secondary importance to the sparing of organs at risk. Figure D-II provides an example of the use of IMRT.

D38. A principal objective of radiation therapy dosimetry is to measure or predict the absorbed dose in various tissues [H17, I15]. Radiation therapy dosimetry is typically conducted in two stages.

D39. Firstly, the radiation beam from the treatment unit must be fully characterized in a manner that allows a treatment planning computer to reproduce the dose distribution under a range of clinical circumstances. This is done through measurements made in a uniform tissue-simulating medium. Water is most often used, as it is very nearly tissue-equivalent and is easily obtained. It has the further important advantage of allowing an ionization chamber or another radiation detector to be moved to positions within and near the radiation beam to determine the dose distribution. These depth-dose data describe the variation of dose with depth, field size and shape, and distance from the source.

D40. In addition to the depth-dose measurements, it is important to know how radiation output at a reference point changes with various important parameters, including the field size and shape and the distance from the source, and the attenuation of field-shaping and field-modulating devices. It is impractical to measure all conceivable variations, so a sufficient number of representative measurements must be made to allow accurate estimations for clinical treatment situations [H17, I15]. For example, wedge factors are measured to deduce the impact of the wedge on patient field sizes and depth doses.

D41. In many situations, ionization chambers or similar detectors used in water phantoms are inadequate to describe the dose distribution in regions of steep dose gradient, as is found near brachytherapy sources or in very small fields such as are used for SRS. Radiochromic film can be used for quantitative planar dosimetry to map dose distributions under these circumstances as well as for proton beam therapy, and beta ray ophthalmic plaque therapy [N6, V12, Z7]. Radiochromic film offers advantages over radiographic film: it does not require processing, and as it has no high-atomic-number components, it shows very little energy dependence.

D42. The data obtained to characterize the beam are either stored in the treatment planning system or are used to create a mathematical model to simulate dose distributions. Data characterizing the patient are also entered, and the dose distribution is calculated taking into account the beam arrangement, the location of the tumour and the anatomy of the patient.

D43. Radiation therapy equipment is calibrated to determine the relationship between the dose delivered at a reference point and time (in the case of isotope units) and the signal from a monitor chamber (in a linear accelerator). Various protocols exist that explicitly describe each stage of the calibration process [A2, I45]. A quality assurance programme is necessary to ensure that the treatment unit performs consistently from one treatment fraction to the next and from one patient to the next. Recommendations for quality assurance programmes have been published [F15, K17].

D44. In vivo dosimetry is conducted to monitor the actual dose received by the patient during treatment to check the accuracy of delivery and as a means of determining the dose to critical organs, such as the lens of the eye and the spinal cord [E7, M15]. TLDs [D18, K20, K21] and several types of solid-state detector [A9, B30, C7, S8, V7, W23] are used. In vivo dosimetry is particularly useful during 3-D conformal radiation therapy [L24].

D45. Quality assurance of IMRT treatments requires the measurement of dose and dose distribution in a phantom to ensure that the patient will be treated correctly [B26]. This is most often done by simulating a simple water or water-equivalent phantom (generally rectangular or cylindrical) with the treatment planning computer and imposing on it the fluence distributions determined for patient treatment [L15, L22, T14, W24]. The shape of the hybrid phantom, as it is often called, will distort the dose distribution from that intended for the patient, but it allows the placement of ion chambers and film or other detectors to compare the calculated distribution with measurements. Agreement in the hybrid phantom provides assurance that the intended dose and dose distribution will be delivered to the patient [L1].

D46. Independent quality audits of radiation therapy facilities are conducted to help provide assurance that patient treatments are delivered consistently from one facility to another. Several groups, including the IAEA, the European Society for Therapeutic Radiology and Oncology (ESTRO) Quality Assurance Programme (EQUAL) and the Radiological Physics Center (RPC), among others, perform periodic audits of megavoltage treatment machine calibration using mailed TLDs [F5, H8, I20, I29, K32]. These programmes identify, at relatively low cost, errors in treatment machine calibration, often resulting from misinterpretation of a calibration protocol, incorrect use of the dosimetry equipment or the failure of a component of the treatment machine itself. Audits also have been conducted of complex treatment procedures through the use of anthropomorphic phantoms [I35, I40, M42]. These audits permit evaluation of the entire radiation therapy process, from imaging, through treatment planning and quality assurance, to treatment delivery. The experience of the RPC indicates that, in an evaluation of IMRT, roughly one third of the institutions surveyed failed to deliver the intended dose distribution to within 7% and 4 mm distance to agreement [I35].

V. ANALYSIS OF PRACTICE

A. Frequency of treatments

D47. Differences in the resources available for radiation therapy lead to wide variations in national practice, with many smaller countries or less developed countries having no treatment facilities, or only a few. Even in countries with treatment facilities, the type of equipment available varies considerably, and this affects the numbers of patients treated as well as the types of treatment given. The number of treatment centres available to residents, by country, is shown in table D4. The data demonstrate an average in level I countries of 3.4 radiation therapy centres per million population. The number of centres also varies within level I. Monaco has only one radiation therapy centre, but with its small population, the relative value is over 30 per million residents. Excluding Monaco, the United States and Japan have the highest values, with 9.2 and 5.7 centres per million population, respectively. In level II countries, the average falls to 0.56 centre per million population, with a range of from 0.1 (for example for Algeria, Pakistan and Uganda) to more than 6 (for example for Barbados and the Bahamas, both countries with small populations). In level III countries, there were fewer than 0.2 centre per million population, while in level IV, there were fewer than 0.1 centre per million. Annual numbers of treatments reported by different countries from 2000 to 2006 are summarized in tables D5(a–c) and D6(a–b) for teletherapy procedures and in table D7 for brachytherapy procedures.

D48. Patterns of practice vary significantly from country to country, even within a single health-care level. For comparison, countries in health-care level I reported 5.41 linear accelerators per million population (table D4). The number dropped to 0.34 per million population for level II countries, to 0.06 per million for level III countries and to 0.53 per million for Botswana, the only level IV country reporting these data. These numbers show a significant increase for level II and III countries over data from 1991–1996. In contrast, the number of cobalt units reported by health-care level was 0.78 per million population for level I, 0.43 per million for level II, 0.19 per million for level III and 0.05 per million for level IV. These numbers have increased for all levels except level I. Within level I, the number of accelerators varied from less than 0.1 per million population in countries such as the Republic of Korea and Ukraine to 9 per million in Denmark and 16 per million in the United States. Annual frequencies of teletherapy treatments differed by a factor of over 6 within the sample of 18 countries in health-care level I, where the average was 2.4 courses of treatment per 1,000 population (see tables D3, D5 (a–c) and D6 (a–b)). Disregarding countries reporting zero practice, similarly large variations existed in level II countries, where the average was 0.4 course per 1,000 population. Insufficient data were available from level III and IV countries.

D49. Brachytherapy practice was difficult to ascertain for several reasons. Firstly, limited data were obtained through the UNSCEAR surveys. Secondly, the surveys did not distinguish clearly between remote and manual afterloading procedures. Consequently, the analyses discussed here are based on limited data from a small number of countries. Additional data were obtained from a survey of brachytherapy use in European installations [G7].

D50. The average annual frequency of brachytherapy treatments in level I countries (0.12 treatment per 1,000 population) is about 1/18 of that for teletherapy. In level II, practice in brachytherapy is lower by a factor of about 2 compared with level I.

D51. Regardless of the differences between the individual countries, some broad patterns of practice in radiation therapy are apparent from the average frequencies of use for the different health-care levels. In general, teletherapy is widely used in the treatment of breast and gynaecological tumours, although there is also significant use for treatments of the prostate and lung/thorax in countries of level I, and for treatments of the head/neck in level II. Brachytherapy practice is universally dominated by treatments of gynaecological tumours. Some interesting variations among countries are evident from tables D5 (a–c) and D6 (a–b). Luxembourg reports that a large fraction of teletherapy treatments are used for breast cancer, while more than 50% of teletherapy treatments in El Salvador are for gynaecological disease. Japan reports a high annual treatment frequency for head and neck cancer as well as for digestive tumours other than colorectal. Both Hungary and Norway use teletherapy frequently for palliative treatments, but the Czech Republic reports that 40% of teletherapy is used for benign disease. Temporal trends in the annual frequency of examinations are discussed elsewhere.

B. Exposed populations

D52. The distributions reported by different countries of the age and sex of patients undergoing teletherapy treatments for selected diseases in 1997–2007 are presented in table D8. As was done for previous analyses of exposed populations, three ranges of patient age have been used, and the countries are listed by health-care level. As might be expected, since radiation therapy is primarily employed in the treatment of cancer, therapeutic exposures are largely conducted on older patients (>40 years old), with the skew in ages being even more pronounced than for the populations of patients undergoing diagnostic examinations with X-rays or radiopharmaceuticals. Countries in the lower health-care levels exhibit a shift towards the younger age ranges for most treatments, relative to level I countries, probably as a result of underlying differences in national population age structures [U3].

D53. For certain teletherapy and brachytherapy procedures, for example the treatment of breast and gynaecological tumours in females and of prostate tumours in males, there are obvious links to patient sex. However, there are some surprising exceptions in the reported data. For example, Hungary reported that, of the patients treated with external beam therapy for head and neck cancer, 84% were female. For other treatments, there is a general bias towards males in the populations of patients. In a few cases, the bias towards females appears extreme; for example, several countries report the use of brachytherapy almost exclusively in females, evidently for gynaecological disease.

C. Doses from treatments

D54. The doses received by patients from radiation therapy are summarized in tables D9 (a–c) and D10 (a–c) in terms of the prescribed doses to target volumes for complete courses of treatment, as discussed previously. The average doses for each type of treatment and health-care level are weighted by the numbers of treatments in each country. Prescribed doses are typically in the range 40–60 Gy for most treatments, with somewhat lower doses being used in radiation therapy for leukaemia, testis tumours, benign disease and some paediatric tumours. Other variations in the reported data are apparent, although these might have resulted from misinterpretation of the data requested by the survey forms.

D55. In teletherapy with photon beams, the doses to tissues at large distances from the target volume arise from several sources: (1) radiation scattered in the patient; (2) leakage through the treatment head of the machine; (3) scatter from the collimator and its accessories; and (4) radiation scattered from the floor, walls or ceiling [N20, V4]. The first and fourth contributions depend on field size, distance and

photon energy, and can be measured and applied generally. The second and third contributions are machine-specific and in principle require measurement for individual machines. Collimator scatter varies according to specific design, although levels of leakage radiation are rather similar for all modern equipment, corresponding to an average value of 0.03 ± 0.01% (relative to the central axis dose maximum) in the patient plane at a distance of 50 cm from the beam axis [K22, S34]. When evaluating the deleterious effects of out-of-field doses, the gonads are generally considered the limiting organ, although organs such as the thyroid and the breasts of young women must also be considered. When the distance between the organ being considered (for example the gonads) and the primary beam is large (around 40 cm, for example, in the treatment of breast cancer), gonad dose is primarily determined by the leakage radiation. Collimator scatter can be influenced by the presence of accessories, in particular wedge filters, which increase the out-of-field dose significantly [F16]. Specific data have also been reported in relation to the peripheral dose during therapy using a linear accelerator equipped with multileaf collimation [S34]. Leakage radiation might not be insignificant during high-energy electron treatments, although the associated risks to patients should be judged in the context of the therapy and the patient's age and medical condition [M16].

D56. Measurements in a patient population have demonstrated a broad range of gonad doses from photon teletherapy treatments for some specific treatment sites [V4]. The minimum and maximum values are determined not only by the range of tumour doses considered but also by the range of field sizes and distances encountered in clinical practice, with due account taken of the variation between men and women in the distance to the gonads. For treatments in the pelvic region, gonad doses can range from tens of milligrays to several grays, depending on the exact distance from the centre of the treatment volume to the gonads. These data are also relevant for estimating the dose to a foetus carried by a pregnant woman.

D57. The risk to patients of a second malignancy as a result of out-of-field radiation has been estimated [S31]. With IMRT, these risk estimates are increased. An IMRT treatment requires that the MLC be adjusted to create small field segments for much of the treatment, while different regions of the target volume are irradiated to different doses. This makes IMRT delivery considerably less efficient than 3-D conformal therapy. It is not unusual for the number of monitor units used for IMRT to be from four to ten times as great as for 3-D conformal therapy. As a result, the leakage radiation emitted by the accelerator head during IMRT is proportionally greater [K22].

D58. In brachytherapy, where radiation sources are inserted directly into the body, the dose to peripheral organs is determined primarily by their distance from the target volume. The decrease in dose with distance from a brachytherapy point source can be described by the inverse square law, modified by a factor to account for scatter and absorption in tissue, and experimental data have been reported to allow the estimation of dose in the range 10–60 cm from ^{60}Co, ^{137}Cs and ^{192}Ir sources [V4].

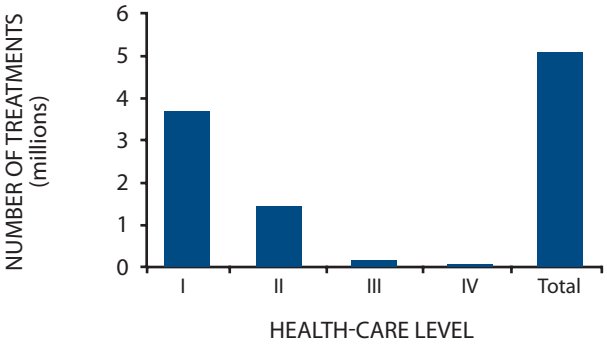
D59. The skin-sparing advantage and clinical efficacy of high-energy photon beams can be compromised by electron contamination arising from the treatment head of the machine and the intervening air volume, and comprehensive dosimetric assessment requires taking into consideration the effect of this component on the depth-dose distribution [H18, S35, Z8]. Electrons and photons with energies of above 8 MeV can produce neutrons through interactions with various materials in the target, the flattening filter and the collimation system of the linear accelerator, as well as in the patient [K7]. For a typical treatment of 50 Gy to the target volume using a four-field box irradiation technique with 25 MV X-rays, the additional average dose over the irradiated volume from such photoneutrons is estimated to be less than 2 mGy and is quite negligible in comparison with the therapeutic dose delivered by the photons [A10]. The average photoneutron dose outside the target volume would be about 0.5 mGy under the same circumstances, and for peripheral doses this component could be similar in magnitude to the contribution from photons [V4]. High-energy X-ray beams will also undergo photonuclear reactions in tissue to produce protons and alpha particles [S36], with total charged particle emissions exceeding neutron emissions above 11 MeV [A11]. However, these charged particles have a short range, so any additional dose to the patient will mostly be imparted within the treatment volume and will be insignificant.

D. Assessment of global practice

D60. The data in table D3 for the period 1997–2007 provide estimates of the annual total numbers of teletherapy and brachytherapy patients per 1,000 population within each health-care level. The frequencies of teletherapy in levels II and III may have been overestimated as it appears that some of the national data used refer to numbers of treatments rather than cancer patients, although these sources of uncertainty are reduced when considering global practice. Data broken down by disease category and by patient age were provided by too few countries for 1997–2007 to permit an in-depth evaluation. Consequently, the mean values shown in table D8 for the individual types of treatment within each health-care level were averaged over different populations because of the lack of comprehensive information for all countries listed and so do not represent a self-consistent set of data. Analyses are presented separately for both teletherapy and brachytherapy. The estimates of world practice have been calculated using the global model of population described above. The uncertainties inherent in the estimates of mean frequencies provided by the global model are difficult to quantify but will be significant, particularly when extrapolations have been made on the basis of small samples of data.

D61. According to the model developed, the global annual frequencies assessed for radiation therapy treatments during 1997–2007 are dominated by the national practices in health-care level I countries, which provide contributions of about 73% and 42% to the total numbers of teletherapy and brachytherapy treatments, respectively, in the world (table D2). The most important uses of teletherapy are for treatments of breast, lung, genitourinary and gynaecological tumours, while practice in brachytherapy is principally concerned with the treatment of gynaecological and genitourinary tumours, although some differences are apparent between the mean frequencies for the different health-care levels. The global average annual frequency assessed for brachytherapy treatments (0.07 per 1,000 population) is about one-tenth that for teletherapy treatments (0.7 per 1,000 population) (see table D3). Figure D-V shows the estimated annual number of all radiotherapy (both teletherapy and brachytherapy) treatments (in millions) for the four health-care levels.

Figure D-V. Estimated total annual number of radiotherapy treatments (both teletherapy and brachytherapy)



D62. While radiation therapy is most often used for treatment of malignant diseases, a significant number of patients are treated with radiation for benign conditions. The use of radiation to treat conditions such as bursitis and acne, while common in the 1950s, has essentially disappeared today. However, as shown in tables D5 and D6, the use of radiation for treatment of benign conditions, such as arteriovenous malformations, trigeminal neuralgias and acoustic neuromas, today is quite common in some countries [C4].

VI. TRENDS IN RADIATION THERAPY

A. Teletherapy

D63. Over the last 50 years, there have been continuing advances in engineering, the planning and delivery of treatment, and clinical radiation therapy practice, all with the aim of improving performance [B31]. In developed countries, at least, there has been growing use of high-energy linear accelerators for the effective treatment of deep-seated tumours. It has been suggested that the energy ranges 4–15 MV for photons and 4–20 MeV for electrons are those optimally suited to the treatment of cancer in humans [D23]. Units with ^{60}Co sources remain important for developing countries in view of their lower initial and maintenance costs and their simpler dosimetry in comparison with linear accelerators.

D64. Chemotherapy has been used in combination with radiation therapy for many years. The delivery of certain chemotherapeutic agents in close temporal proximity to radiation therapy can enhance the effectiveness of the radiation against cancer cells. The synergistic effects of combined therapy will continue to be pursued as new drugs are developed.

D65. Developments in diagnostic imaging, such as CT and MRI, have benefited the assessment of disease and also the planning and delivery of therapy [C8, R18]. Treatment plans are calculated using sophisticated computer algorithms to provide 3-D dose distributions, including so-called beam's-eye views. Monte Carlo simulation techniques are beginning to be used in selected cases for comparison [M17, S37]. Computer control of the linear accelerator has facilitated the development of new treatment techniques. MLCs can not only replace the use of individual shielding blocks in routine treatments with static fields as a tool for sparing healthy tissues, but can also allow the achievement of computer-controlled conformal radiation therapy [G20]. This type of therapy seeks to provide optimal shaping of the dose distribution in three dimensions so as to fit the target volume [D16, F17]. Developments include: tomotherapy, which uses slit beams provided by dynamic control of MLCs coupled with movement of the gantry during treatment [Y7]; IMAT, which combines spatial and temporal intensity modulation [Y9]; and adaptive radiation therapy, in which treatment plans for individual patients are automatically reoptimized during the course of therapy on the basis of systematic monitoring of treatment variations [Y5]. The success of such therapies is compromised by intrafraction organ

motion [Y6], and synchronous gating or tracking of the radiation beam with respiration is being evaluated in a number of centres [K8].

D66. Tumours of the lung, breast and liver can move as a result of normal respiration. Such intrafraction motion is difficult to estimate, much less accommodate in treatment planning without sophisticated imaging procedures. Four-dimensional computed tomography (4-DCT) is being evaluated at a number of centres to demonstrate the respiratory motion of some tumours. The 4-DCT technique requires the use of a fast multidetector helical CT scanner, and either gating of imaging with respiratory motion, or continuous imaging during free breathing, with subsequent binning of the images according to the stage of the respiratory cycle at the time of each scan. From 4-DCT images, an internal target volume can be drawn that contains the full range of motion of the CTV.

D67. The use of a novel 3-D gel dosimeter for evaluating IMRT dose distributions has been described recently [G19, I22, I38, I39]. The dosimeter, composed of acrylic monomers stabilized in a gelatin matrix, responds to irradiation by polymerizing. The distribution of polymer microparticles is proportional to the absorbed dose, and a map of the distribution can be obtained either by MRI or by optical CT scanning [I39].

D68. Portal films and digital imaging devices visualizing exit fields are used to verify the positional accuracy of external beams during treatment, and increasingly to provide quantitative dosimetric information [A5, S33, T10]. Some treatment machines are equipped with on-board X-ray imaging devices, and use is beginning to be made of these systems to image patients on the treatment table, so that adjustments to patient position can be made immediately before treatment [G18].

D69. A technique called volumetric modulated arc therapy (VMAT) has been described recently [T15]. This technique combines sliding-window MLC control simultaneously with gantry rotation to eliminate the requirement for couch movement. Commercialization of this technique began at the end of 2007.

D70. Patients undergoing radiation therapy should have available to them the necessary facilities and staff to provide safe and effective treatment. Many radiation therapy centres in level II, III and IV countries do not have sufficient numbers of linear accelerators, simulators or remote afterloading brachytherapy units, and the level of availability significantly compromises their ability to deliver radiation therapy [B6].

B. Brachytherapy

D71. Intracavitary brachytherapy for gynaecological cancer using radium (^{226}Ra) was one of the first radiotherapeutic techniques to be developed. This radionuclide has now largely been replaced throughout the world by ^{137}Cs. The remote afterloading technique is standard practice in most countries for the treatment of carcinoma of the cervix and is increasingly being used for interstitial implants in relation to the bronchus, breast and prostate [S29]. HDR brachytherapy offers advantages over the manual LDR technique, for example in terms of improved geometrical stability during the shorter treatment times and reduced staff exposures. However, the relative loss of therapeutic ratio requires modified treatment schedules to avoid late normal tissue damage and so allow cost-effective therapy [J6, J7, T11]. PDR brachytherapy has been developed in the hope of combining the advantages of the two techniques, while avoiding their disadvantages [B32, M18]. In essence, a continuous LDR interstitial treatment lasting several days is replaced with a series of short HDR irradiations, each about 10 minutes long, for example, and given on an hourly basis, so as to deliver the same average dose. Each pulse involves the stepping of a single high-activity source through all catheters of an implant, with computer-controlled dwell times in each position to reflect the required dose distribution.

D72. Endovascular brachytherapy treatments to inhibit restenosis after angioplasty enjoyed a brief popularity during the 1990s and early 2000s, but they have now largely been replaced by the use of drug-eluting stents. Patients who are not candidates for these stents are occasionally treated with intravenous brachytherapy using catheters for the temporary implantation of radioactive seeds and wires (^{192}Ir or ^{90}Sr/^{90}Y) and also for the permanent implantation of radioactive stents (^{32}P) [C9, J8, T3].

C. Other modalities

D73. A continuing obstacle to definitive radiation therapy is the difficulty of delivering lethal doses to tumours while minimizing the doses to adjacent critical organs. Various special techniques have been developed to overcome this limitation, although such modalities are less common practice than the techniques discussed above. Intraoperative radiation therapy (IORT) involves surgery to expose the tumour or tumour bed for subsequent irradiation, usually with a beam of electrons in the energy range 6–17 MeV, while normal organs are shifted from the field [D15, M19]. The entire dose is delivered as a single fraction in a complex configuration, which makes dose control and measurement particularly critical [B24]. A total of approximately 3,000 patients are estimated to have been treated with IORT worldwide by 1989, mostly in Japan and the United States. A recent development for the treatment of primary bone sarcomas is extracorporeal radiation therapy, in which the afflicted bone is temporarily excised surgically so that it can undergo high-level irradiation in isolation before immediate reimplanting [W25]. Studies have also been made of the potential enhancement of dose to the target volume using the technique of photon activation, in which increased photoelectric absorption is achieved by loading the tissue with an appropriate element prior to irradiation. Modelling has

been reported for therapeutic applications of iodine contrast agents in association with a CT scanner modified for rotation X-ray therapy [M7, S14] and for a silver metalloporphyrin for use in interstitial brachytherapy with ^{125}I seeds [Y8].

D74. There were at least 451 dedicated stereotactic devices in use worldwide in 2008, of which 247 were in the United States. Of the 451 devices worldwide, at least 247 were units containing multiple ^{60}Co sources called a Leksell Gammaknife (LGK). Data from the manufacturer indicate a total of 46 gamma knives in Japan and 16 in China; additional information is given in table D11 [E2]. Data from the 2000 UNSCEAR Global Survey of Medical Radiation Usage and Exposures indicated a total of 20 gamma knives in Japan and 36 in China. The reason for the difference in numbers in Japan is not known. The difference in numbers in China may reflect the use of a similar device sold by a Chinese manufacturer. The Leksell Society reported that 350,000 treatments had been delivered with the LGK worldwide up to the end of 2005 [L7]. Doses to extracranial sites during LGK treatments have been reported to be relatively low, with the eyes receiving about 0.7% of the maximum target dose and doses to other sites decreasing exponentially with increasing distance from the isocentre of the LGK unit [G5]. A frameless robotic radiosurgery system has been developed in which real-time X-ray imaging of the patient locates and tracks the treatment site during exposure and so provides automatic targeting of a 6 MV photon beam [M8, M9]. Data from the manufacturer indicate that there were 98 of these devices in use worldwide in 2006, of which 62 were in the United States and 17 were in Japan [A6]. At least 72 conventional linear accelerators were used for SRS in 2006; these were modified by adding a micro-MLC. Trials are also in progress with a novel miniature X-ray source for stereotactic interstitial radiosurgery, in which a needle-like probe is used to deliver relatively low-energy photons directly into a lesion. The intensity and peak energy are adjustable for optimal tumour dose while minimizing damage to surrounding healthy tissue [B9, B25, D17, Y10].

D75. There are potential advantages in conducting radiation therapy with high-energy, heavy charged particles such as protons and heavier charged particles [W5]. Such beams of charged particles can provide superior localization of dose at depth within target volumes [L9, M10, N21]. Furthermore, ions with high-linear-energy-transfer (LET) components can damage cells in locally advanced radioresistant tumours more effectively than low-LET radiations such as photons and electrons [B17]. During proton therapy, secondary neutrons and photons make small contributions to the patient dose [A10]. However, the dose received by non-target tissues is low, and is considered comparable to the neutron dose received during treatments with high-energy photon beams.

D76. Proton beams have been used therapeutically since 1955 and represent the treatment of choice for ocular melanoma [B17, I41]. Protons are currently also being used to treat deep-seated tumours, including those of the prostate, brain and lung. As of early 2007, there had been more than 53,000 patient treatments worldwide with protons and heavier ions. The largest numbers of patients have been treated in the United States. There are currently 31 facilities actively engaged in proton or ion therapy. Another 20 facilities are in various stages of planning and construction in several European countries, the United States, Africa and Asia [M10, N21, P23, S15, S16].

D77. Light ions (e.g. helium or carbon) are attractive owing to their favourable physical and radiobiological characteristics, such as high relative biological effectiveness, small oxygen effect and small cell-cycle dependence [K1, P23]. In 1996, only two heavy-ion facilities were operational in the world: HIMAC in Japan and GSI in Germany. A third facility opened in 2002 at the HIBMC facility in Japan. However, developments for the establishment of ion therapy centres in Europe have gained momentum and at present are in a very dynamic phase. In Heidelberg, Germany, a new facility has just initiated patient treatments. In Pavia, Italy, and in Wiener Neustadt, Austria, similar facilities are scheduled to become operational before 2009. The ENLIGHT cooperation, coordinated by ESTRO and supported by the European Commission, has been instrumental in networking all these projects and in creating for them a common platform for research and a concerted clinical approach between European radiation oncologists. More than 2,800 patients with various types of tumour located in various organs have been treated with a carbon beam at the HIMAC facility alone since 1994 [K2]. As of early 2007, more than 3,300 patients had been treated worldwide. In addition, about 1,100 patients were treated with negative pi mesons between 1974 and 1994, although with no active facilities since 1996, this is not a significant modality.

D78. Fast neutron radiation therapy was first used as a cancer treatment tool in 1938 in the United States, but it was not successful, because the radiobiology was not fully understood [G6]. Later, in the 1960s. studies in the United Kingdom with appropriate fractionation paved the way for clinical trials at various centres around the world. In particular, a 20-year multiphase project was begun in the United States in 1971; the project has involved ten separate neutron facilities and several thousand patients to establish the efficacy of neutron therapy. Clinical experience over two decades with neutron therapy for pancreatic cancer has demonstrated high complication rates and overall survival rates that are no better than those achieved with conventional radiation therapy [D20, R6, R12]. Neutron brachytherapy using ^{252}Cf sources is being carried out at one medical centre in the United States [M11]. Boron neutron capture therapy is currently being evaluated at a few reactor facilities. This technique is predicated on the supposition that pharmaceuticals containing boron can be designed that will be deposited preferentially in a tumour. If a patient whose tumour contained an adequate concentration of boron were irradiated with a beam of neutrons from a reactor, the tumour would receive a significantly higher dose than the surrounding tissue. The technique is proposed for treatment of brain tumours, specifically glioblastoma multiforme. However, to date, the results have been disappointing owing to the lack of selectivity of the boron carriers [V3].

VII. ACCIDENTS IN RADIATION THERAPY

D79. The practice of radiation therapy involves the use of large doses of radiation, which if applied incorrectly can cause serious harm or death to the irradiated individual. The delivery of radiation doses that exceed the tolerance of normal tissues can result in unintended adverse effects, referred to as complications of treatment. It should be emphasized that such complications are distinct from radiation therapy accidents; the risk of complications is well known and understood, and most radiation therapy treatments are prescribed with the full knowledge of an attendant small risk of significant complications.

D80. While radiation therapy accidents are rare, a number of serious mistakes have resulted in unfortunate consequences for patients and members of the public. A summary of nearly 100 radiation therapy accidents has been published by the IAEA [I18] and a similar number have been reported by the ICRP [I27]. These accidents have been examined in detail and categorized to indicate their educational value to practitioners. Annex C to the present report, "Radiation exposures in accidents", also discusses radiation therapy accidents in the context of other radiation accidents.

D81. The IAEA grouped the accidents into the following categories: radiation measurement systems; external beam therapy machine commissioning and calibration; external beam therapy treatment planning, patient set-up and treatment; decommissioning of teletherapy equipment; mechanical and electrical malfunctions; LDR brachytherapy sources and applicators; HDR brachytherapy; and unsealed sources.

D82. The accidents include events such as the failure to correctly interpret the treatment time setting during calibration, resulting in overdoses of 50% to patients. Other accidents have resulted in doses significantly below what was needed; when such accidents occur under circumstances from which recovery is not possible, they can result in progression of the patient's tumour. Accidents caused by misinterpretation of the physician's prescription are also reported.

D83. Accidents involving SRS have been reported, including errors caused by misinterpretation of the coordinates of the target volume [N22]. In one reported case, a patient was positioned in a CT scanner feet-first rather than the more common head-first position. This change was not recognized by the treatment staff, who mistakenly irradiated the wrong side of the patient's head. Calibration errors have also been reported, including one in which a linear accelerator used for SRS was calibrated in error by 50% [J9]. According to news reports, 77 patients were treated before the error was discovered and received 50% greater doses than had been prescribed.

D84. The use of modern technology, including dynamic MLCs and programmable wedge distributions, has been involved in several accidents resulting in patient injury. In one case, 23 patients received doses that were 7% to 34% greater than prescribed. The error was due to a misinterpretation of treatment planning software in which the operators confused dynamic wedge treatments with the use of mechanical (metal) wedge filters. Information displayed by the software was in English rather than the operators' native language, apparently contributing to the confusion. The result was that, on some occasions, the monitor unit setting for the accelerator was calculated as if a mechanical wedge filter was to be used, when in fact a programmable wedge distribution was created by moving one collimator jaw across the field to modulate the intensity [P2].

D85. Accidents involving IMRT have been reported, including several in which patients received lethal doses of radiation. In at least one case, a treatment plan was corrupted in the process of transferring it from the treatment-planning computer to the treatment machine. Reportedly, the treatment staff overlooked or ignored a warning message indicating that the treatment plan had not been transferred correctly. As a result, the treatment was delivered through open fields, rather than with the MLC modulating the beam intensity. The patient was believed to have received approximately seven times the intended dose [V15].

D86. Accidents involving brachytherapy also have been reported. One in which a patient received an extremely large dose, causing her death, was reported in November 1992 in Indiana, Pennsylvania. The accident involved a female patient scheduled for an HDR brachytherapy procedure using a 159 GBq ^{192}Ir source. The treatment was to be given in three fractions of 6 Gy each. Part-way through the first fraction, the source broke off the guidewire and remained inside one of the catheters that had been surgically implanted into the patient's tumour. The patient was returned to a local nursing home without a radiological survey being performed. The catheter containing the source became dislodged four days later and was discarded in the biohazard waste. It was discovered soon afterwards when a waste truck passed through a radiation detector installed at an incinerator facility. The estimated dose at 1 cm in tissue was 16,000 Gy. Ninety-four additional individuals, including staff, visitors, family members and other nursing home residents were exposed, although the doses were not medically significant [M38].

D87. A website has been established by a group called the Radiation Oncology Safety Information System (ROSIS), to which individuals can post a description of radiation therapy errors or accidents, with the goal of providing education to others [R4]. The website lists over 700 such events, ranging from typographical errors in a verification system discovered at the time of the first treatment, to the failure to use a wedge filter for an entire course of treatment, resulting in a dose delivery error approaching a factor of 2.

VIII. SUMMARY

D88. Cancer is likely to be an increasingly important disease in populations with increasing lifespan, and this will probably cause radiation therapy practice to grow in most countries. WHO estimates that, worldwide, by the year 2015 the annual number of new cancer cases will have risen to about 15 million, from 9 million in 1995, with about two thirds of these cases occurring in developing countries [W8]. If half of these cases are treated with radiation, at least 10,000 external beam therapy machines will be required at that time in developing countries, in addition to a large number of brachytherapy units.

D89. In the period 1997–2007, the global use of radiation therapy increased to 5.1 million treatments, from 4.7 million treatments 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, from about 5,000 in the previous period. A large increase was seen in level I countries. Level II countries appeared to show a decrease, but this is likely to be an artefact of the limited data received from the survey. At the same time, the number of brachytherapy treatments and the number of afterloading brachytherapy units appeared to have changed very little.

D90. Radiation therapy involves the delivery of high doses to patients and accordingly there is an attendant potential for accidents with serious consequences for the health of patients (arising from over- or under-exposure relative to prescription) and also of staff. Quality assurance programmes help ensure high and consistent standards of practice so as to minimize the risks of such accidents. Effective programmes comprehensively address all aspects of radiation therapy, including, inter alia: the evaluation of patients during and after treatment; the education and training of physicians, technologists and physicists; the commissioning, calibration and maintenance of equipment; independent audits for dosimetry and treatment planning; and protocols for treatment procedures and the supervision of delivery [D14, D21, K17].

Table D1. Global use of radiotherapy (1997–2007): normalized values
Data from United Nations Survey of Nations and IAEA/WHO Directory (DIRAC)

Quantity		*Number per million population at health-care level*				
		I	*II*	*III*	*IV*	*Globally*
Teletherapy						
Equipment	X-ray	1.3	0.2	—[a]	—[a]	0.4
	Radionuclide	0.8	0.4	0.2	0.0	0.4
	Linac	5.4	0.3	0.1	0.5	1.6
Annual number of patients		2 241.1	370.0	55.4	—[a]	729.7
Brachytherapy						
Afterloading units		1.4	0.2	0.07	0.02	0.5
Annual number of patients		115.7	61.9	—[a]	—[a]	67.2

[a] No data submitted.

Table D2. Global use of radiotherapy (1997–2007): total values
Data from United Nations Survey of Nations and IAEA/WHO Directory (DIRAC)

Quantity		*Total number (millions) at health-care level*				
		I	*II*	*III*	*IV*	*Globally*
Teletherapy						
Equipment	X-ray	0.002	0.000 6	—[a]	—[a]	0.002
	Radionuclide	0.001	0.001	0.000 19	0.000 04	0.003
	Linac	0.008	0.001	0.000 06	—[a]	0.009
Annual number of patients		3.45	1.17	0.06	(0.03)[b]	4.7
Brachytherapy						
Afterloading units		0.002	0.001	0.000 1	0.000 0	0.003
Annual number of patients		0.18	0.20	(0.05)[b]	(0.01)[b]	0.43

[a] No data submitted.
[b] Assumed value in the absence of data.

Table D3. Estimated annual number of radiotherapy treatments[a] in the world (1997–2007)
Data from United Nations Survey of Nations and United Nations World Population Database

Health-care level	*Population (millions)*	*Annual number of teletherapy treatments*		*Annual number of brachytherapy treatments[b]*		*Annual number of all radiotherapy treatments*	
		Millions	*Per 1 000 population*	*Millions*	*Per 1 000 population*	*Millions*	*Per 1 000 population*
I	1 540	3.5	2.2	0.18	0.12	3.6	2.4
II	3 153	1.2	0.4	0.20	0.06	1.4	0.4
III	1 009	0.1	0.1	(<0.05)[c]	(<0.01)[c]	0.1	0.06
IV	744	(0.03)[c]	(<0.01)[c]	(<0.01)[c]	(<0.005)[c]	(0.03)[c]	(0.01)[c]
World	6 446	4.7	0.73	0.43	0.067	5.1	0.8

[a] Complete courses of treatment.
[b] Excluding treatments with radiopharmaceuticals.
[c] Assumed value in the absence of data.

Table D4. Number of radiotherapy centres and of items of radiotherapy equipment per million population (1997–2007)
Data from IAEA/WHO Directory (DIRAC), United Nations Survey of Nations, United Nations World Population Database and Radiological Physics Center

Country/area	*Radiotherapy centres*	*Teletherapy units*			*Brachytherapy afterloading units*
		X-ray	*Radionuclide*	*Linear accelerator*	
Health-care level I					
Albania	0.3		0.63		
Argentina	2.3		2.25	1.29	0.10
Armenia	0.7		1.00	0.33	0.33
Australia	1.6	0.96		5.40	1.30
Austria	1.6		0.36	4.66	1.83
Azerbaijan	0.2				
Belarus	1.3		2.17	0.52	0.72
Belgium	2.4	1.91	0.38	4.11	0.86
Bulgaria	1.7		1.57	0.26	0.13
Canada	1.0		1.06	3.19	0.82
China - Hong Kong SAR	1.2		0.28	2.91	0.14
China - Taiwan	0.4				
Croatia	1.5	0.88	1.54	1.54	1.76
Cuba	0.8		0.89	0.18	0.44
Cyprus	2.3		2.34	2.34	1.17
Czech Republic	3.7	2.26	1.57	2.06	2.75
Democratic People's Republic of Korea	0.0		0.04	0.04	
Denmark	1.1		0.18	8.82	0.74
Ecuador	0.6		0.52	0.37	0.30
Estonia	1.5		0.75	1.50	3.00
Finland	1.9	0.38		5.69	2.08
France	3.4		1.65	5.43	0.41
Georgia	0.9		0.91		
Germany	3.0	1.03	0.24	4.72	2.49
Greece	2.2	0.27	1.26	2.96	0.99
Hungary	1.2	2.09	0.90	2.29	2.29
Iceland	3.3	3.32		6.64	3.32
Ireland	1.9		0.93	2.09	0.23
Israel	2.0		1.15	3.61	0.43

Country/area	*Radiotherapy centres*	*Teletherapy units*			*Brachytherapy afterloading units*
		X-ray	*Radionuclide*	*Linear accelerator*	
Italy	2.6		1.56	4.48	0.46
Japan	5.7		0.33	5.81	2.70
Kazakhstan	1.2		1.95	0.13	0.84
Kuwait	0.7		0.70	0.35	
Kyrgyzstan	0.2		0.38	0.19	
Latvia	1.8	0.44	0.88	3.07	0.88
Lebanon	1.5		0.98	2.20	
Lithuania	1.5	4.13	5.31	0.59	2.06
Luxembourg	2.1			4.28	2.14
Malta	2.5	2.46	2.46	2.46	
Monaco	30.3				
Netherlands	1.3		0.06	4.39	2.74
New Zealand	1.4	1.68	0.24	4.55	0.48
Norway	1.9	2.55		7.02	1.06
Panama	0.9		0.60	1.20	
Poland	0.6	0.11	0.37	1.68	1.10
Portugal	1.5		0.66	2.45	0.85
Qatar	2.4				
Republic of Korea	1.1		0.12	1.43	0.64
Republic of Moldova	0.3		1.05		0.53
Romania	2.1	1.63	0.79	0.23	0.19
Russian Federation	0.9		1.43	0.26	0.47
Singapore	0.7		0.23	2.25	0.68
Slovakia	3.0	0.37	3.53	2.60	5.01
Slovenia	0.5	1.00	1.00	3.00	
South Africa	0.4		0.43	0.54	0.16
Spain	2.6	0.54	1.08	4.00	1.56
Sri Lanka	0.2		0.36		0.10
Sweden	2.1	5.04	0.11	6.58	2.41
Switzerland	3.5	6.41	0.27	6.28	4.41
The former Yugoslav Republic of Macedonia	0.5		0.49	0.98	1.47
Ukraine	1.0		1.93	0.04	0.13
United Arab Emirates	0.5		0.46	0.91	0.46
United Kingdom	1.0		0.35	3.11	0.31
United States	9.2		0.32	15.50	2.49
Uruguay	4.2		2.69	1.50	
Uzbekistan	0.5		0.55		
Venezuela (Bolivarian Rep. of)	1.7		0.51	0.58	0.14
Average[a]	3.4	1.26	0.78	5.41	1.37
Health-care level II					
Algeria	0.1		0.27	0.18	
Bahamas	6.0			3.02	
Barbados	6.8		6.80		3.40
Bolivia	0.6		0.52	0.10	
Bosnia and Herzegovina	0.3		0.25	0.51	0.25
Brazil	0.8	0.31	0.58	0.82	0.26
Chile	1.3		0.90	0.96	0.12
China	0.6	0.16	0.41	0.32	0.30

Country/area	*Radiotherapy centres*	*Teletherapy units*			*Brachytherapy afterloading units*
		X-ray	*Radionuclide*	*Linear accelerator*	
Colombia	0.8		0.84	0.37	0.02
Costa Rica	0.7	0.22	0.67	0.67	0.45
Dominican Republic	0.3		0.31	0.10	0.20
El Salvador	0.4		0.44	0.15	0.73
Iran	0.3		0.37	0.01	
Jordan	0.7		0.68	1.01	0.17
Libyan Arab Jamahiriya	1.1		0.97		0.32
Malaysia	1.2		0.26	0.49	0.04
Mauritius	0.8		1.58	0.79	
Mexico	0.7		0.77	0.19	0.04
Mongolia	0.4		1.14		0.38
Montenegro	1.7				1.67
Nicaragua	0.2		0.18		
Pakistan	0.1		0.10	0.04	0.02
Paraguay	0.5		0.33	0.65	
Peru	0.4		0.32	0.29	
Philippines	0.3		0.28	0.18	0.07
Puerto Rico	1.5		0.75	2.00	
Serbia	0.7		0.20	1.52	0.30
Syrian Arab Republic	0.1		0.20		0.05
Tajikistan	0.1		0.30		
Thailand	0.4		0.38	0.25	0.19
Trinidad and Tobago	0.8	0.75	1.50		
Tunisia	0.6		0.68	0.19	0.39
Turkey	0.8		0.67	0.61	0.15
Uganda	0.1		0.03		
Average[a]	0.56	0.18	0.43	0.34	0.23
Health-care level III					
Congo, Rep.	0.1				
Egypt	0.4		0.26	0.28	0.03
Gabon	0.8		0.75		
Ghana	0.1		0.09		0.09
Guatemala	0.4		0.45	0.15	
Haiti	0.1		0.10		
Honduras	0.6		0.99	0.14	
India	0.2		0.22	0.03	0.07
Iraq	0.1		0.07		
Jamaica	1.1		0.74	0.37	
Madagascar	0.1		0.05		
Morocco	0.2		0.16	0.13	0.51
Namibia	0.5		0.48		
Nigeria	0.0		0.02	0.01	0.01
Saudi Arabia	0.3		0.08	0.73	0.08
Sudan	0.1		0.08	0.05	0.03
Viet Nam	0.1		0.13	0.01	0.03
Zimbabwe	0.1			0.22	0.15
Average[a]	0.16		0.19	0.06	0.07

Country/area	*Radiotherapy centres*	*Teletherapy units*			*Brachytherapy afterloading units*
		X-ray	*Radionuclide*	*Linear accelerator*	
Health-care level IV					
Angola	0.1				
Bangladesh	0.1		0.06		
Botswana	0.5			0.53	
Cambodia	0.1				
Cameroon	0.1		0.11		0.05
Ethiopia	0.0		0.01		0.01
Indonesia	0.0		0.02		
Kenya	0.1		0.08		0.03
Myanmar	0.1		0.16		
Nepal	0.0		0.04		
Papua New Guinea	0.2		0.16		
Senegal	0.1		0.08		
United Rep. of Tanzania	0.0		0.05		
Yemen	0.0		0.04		
Zambia	0.1				
Average[a]	0.06		0.05	0.53	0.02

[a] Averages are based on data submitted by surveyed countries, weighted by the population sizes of those countries.

Table D5a. Number of patients treated annually with various teletherapy procedures (2000–2006)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Leukaemia*	*Lymphoma*		*Breast tumour*	*Lung/thorax tumour*	*Gynaecological tumour*	*Head/neck tumour*	*Brain tumour*
		Hodgkin's	*Non-Hodgkin's*					
Health-care level I								
Croatia	8	27	40	1 556	1 062	570	582	354
Czech Republic	249	451	596	4 927	2 989	2 856	1 774	653
Hungary	22	34	88	851	494	318	438	80
Japan	1 590	570	10 080	36 450	49 660	14 830	35 860	14 420
Latvia	1	12	23	616	139	503	9	39
Lithuania	5	82	61	1 035	608	1 074	533	159
Luxembourg	1	6	10	263	56	50	52	28
Malta		9	21	306	20	42	61	4
Netherlands				9 000	7 000			
Norway	8		255	1 875	253	251	363	59
Poland	420	420	420	5 460	5 040	2 940	2 940	2 100
Slovenia	10	26	163	1 099	325	212	526	86
South Africa	16	9	19	340	200	693	369	34
Spain	394	1 076	1 506	17 170	8 268	5 393	7 146	4 369
Switzerland	269	154	329	3 512	1 111	674	851	544
The former Yugoslav Republic of Macedonia		15	10	403	285	345	189	57
Total	2 933	2 891	13 621	84 863	77 510	30 751	51 693	22 986

Country	*Leukaemia*	*Lymphoma*		*Breast tumour*	*Lung/thorax tumour*	*Gynaecological tumour*	*Head/neck tumour*	*Brain tumour*
		Hodgkin's	*Non-Hodgkin's*					
Health-care level II								
Costa Rica	15	15	11	79	2	40	28	42
El Salvador	6	11	19	139	21	564	100	19
Trinidad and Tobago				189	33	165	61	
Total	21	26	30	407	56	769	189	61
Health-care level III								
Zimbabwe	22	75	104	13	295	19		19
Total	22	75	104	13	295	19	0	19

Table D5b. Number of patients treated annually with various teletherapy procedures (2000–2006)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Testis*	*Other urological tumours*	*Tumour of colon and rectum*	*Other digestive tumours*
Health-care level I							
Croatia	85	104	305	30	35	406	134
Czech Republic	792	337	1 298	224	471	2 120	618
Hungary	182	48	145	13	29	299	100
Japan	2 410	4 040	6 070	500	1 850	7 070	25 840
Latvia	462	89	171	144	91	176	78
Lithuania	682	188	234	14	76	384	176
Luxembourg	15	3	50	9	3	48	20
Malta	436	33	96			63	
Netherlands			4 000				
Norway	337	54	802	56	5	320	41
Poland	420	420	1 680	420	420	1 680	420
Slovenia	309	11	128	3	26	245	128
South Africa	156	21	53	4	6	67	316
Spain	1 998	1 093	11 255	628	186	4 812	2 031
Switzerland	353	106	1 695	146	152	665	400
The former Yugoslav Republic of Macedonia	2	55	18	23	8	161	
Total	8 639	6 602	28 000	2 214	3 358	18 516	30 302
Health-care level II							
Costa Rica	12		145	23		11	20
El Salvador	4	11	13		8	20	10
Trinidad and Tobago	9	11	60	2	8	52	2
Total	25	22	218	25	16	83	32
Health-care level III							
Zimbabwe	49	22	37			33	12
Total	49	22	37	0	0	33	12

Table D5c. Number of patients treated annually with various teletherapy procedures (2000–2006)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Bone and soft tissue sarcomas*	*Palliative treatments*	*Benign diseases*	*Other*	*Total of all patients treated*
Health-care level I					
Croatia	128	1 659	9	98	7 249
Czech Republic	230	7 965	21 845	894	51 399
Finland					12 803
Germany					240 000
Hungary	42	2 310	582	545	4 310
Japan	20 310		1 190	7 800	242 510
Latvia	18	104	14	16	2 705
Lithuania	165	506	333	295	6 626
Luxembourg	9	112	10	40	787
Malta					1 091
Netherlands					38 000
Norway	62	3 598	192	453	8 984
Poland	420	13 020	420	420	42 000
Slovenia	51	1 569	26	47	4 990
South Africa	63	1 000	722	37	4 186
Spain	1 211	11 325	1 570	285	81 756
Switzerland	306	3 648	937	1 264	14 881
The former Yugoslav Republic of Macedonia	3		22		1 596
United States					840 000[a]
Total	23 018	46 816	27 872	12 194	1 605 873
Health-care level II					
China					494 208
Costa Rica	11	30		50	551
El Salvador	19		6	11	981
Trinidad and Tobago		36		77	705
Total	30	66	6	138	496 445
Health-care level III					
Zimbabwe	10				739
Total	10	0	0	0	739

[a] Estimate from the Radiological Physics Center, United States.

Table D6a. Number of paediatric patients treated annually with teletherapy (2000–2006)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Brain*	*Lymphoma*	*Neuroblastoma*	*Rhabdomyosarcoma*	*Wilm's tumour*	*Other tumour*
Health-care level I						
Croatia	22	5	3	4	2	21
Czech Republic	33	14	8	8	9	38
Hungary	17	5	3		3	8
Japan	700	80		60		1 150
Lithuania	15					1
Luxembourg	1	1				
Poland	420	420	420	420	420	420

Country	*Brain*	*Lymphoma*	*Neuroblastoma*	*Rhabdomyosarcoma*	*Wilm's tumour*	*Other tumour*
Slovenia	11	2				4
South Africa	34	1		14	8	4
Spain	56		42	21	42	77
Switzerland	7	4	3	9	4	7
Total	1 316	532	479	536	488	1 730
Health-care level II						
Costa Rica	6	11		2	1	8
Total	6	11	0	2	1	8
Health-care level III						
Zimbabwe				5	2	22
Total	0	0	0	5	2	22

Table D6b. Number of patients treated annually with special teletherapy procedures (2000–2006)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Intraoperative radiotherapy*	*Whole-body irradiation*	*Total lymphoid irradiation*	*Stereotactic irradiation*	
				Intracranial	*Extracranial*
Health-care level I					
Croatia			4		
Czech Republic		30	5	823	
Hungary		16		170	
Netherlands	200			70	
Norway		7	6	208	
Poland	150	50	20	765	110
Slovenia		15			
Spain	113	211	1	1 099	296
Switzerland	7	108		127	
Total	470	437	36	3 262	406

Table D7. Number of patients treated annually with brachytherapy (2000–2006)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Head/neck tumour*	*Breast tumour*	*Gynaecological tumour*	*Prostate tumour*	*Intravascular brachytherapy*	*Other*	*Total*
Health-care level I							
Croatia	1		369			138	508
Czech Republic	71	345	1 160			681	2 257
Finland							774
Hungary	14	13	230	47		89	393
Japan	3 940		7 850			1 560	13 350
Latvia			660				660
Lithuania			431			16	447
Luxembourg			31				31
Malta			5				5
Netherlands							2 000
Norway			148		21	19	188
Poland	120	130	5 850	240	110	1 950	8 400

Country	*Head/neck tumour*	*Breast tumour*	*Gynaecological tumour*	*Prostate tumour*	*Intravascular brachytherapy*	*Other*	*Total*
Slovenia	2		212			28	242
South Africa	6		600			250	856
Spain	417	1 655	4 017	986		90	7 165
Sweden							1 900
Switzerland	2	12	238	113	97	12	498
The former Yugoslav Republic of Macedonia			185			4	189
United States							0[a]
Total	4 573	2 155	21 986	1 386	228	4 837	37 963
Health-care level II							
China							0
Costa Rica			244				244
El Salvador			400				400
Trinidad and Tobago			80	60			140
Total	0	0	724	60	0	0	784
Health-care level III							
Zimbabwe							0
Total	0	0	0	0	0	0	0

[a] Data from the Radiological Physics Center, United States.

Table D8. Distribution by age and sex of patients undergoing teletherapy for a range of conditions (1997–2007)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
Head and neck tumour						
I	Croatia	0	5	95	86	14
	Czech Republic	0	1	99	82	18
	Hungary	0	4	97	16	84
	Japan	0	3	97	73	27
	Lithuania	0	5	95	87	13
	Luxembourg	0	0	100	84	16
	Malta	0	9	91	66	34
	Poland	0	9	91	78	22
	Slovenia	0	2	98	81	19
	South Africa	0	9	91	82	18
	Spain	0	0	100	45	55
	Switzerland	0	3	97	73	27
	Average	0	4	96	71	29
II	Costa Rica	18	11	71	79	21
	El Salvador	0	6	94	51	49
	Average	9	8	83	65	35
Breast tumour						
I	Croatia	0	7	93	1	99
	Czech Republic	0	4	96	0	100
	Hungary	0	5	95	3	97

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
I	Japan	0	10	90	1	99
	Latvia	0	7	93	0	100
	Lithuania	0	12	88	0	100
	Luxembourg	0	7	93	0	100
	Malta	0	1	99	2	98
	Poland	0	8	92	2	98
	Slovenia	0	7	93	0	100
	South Africa	0	20	80	6	94
	Spain	0	11	89	1	99
	Switzerland	0	7	93	1	99
	Average	0	8	92	1	99
II	Costa Rica	0	14	86	0	100
	El Salvador	0	13	87	1	99
	Average	0	13	87	0	100
Gynaecological tumour						
I	Croatia	0	11	89	0	100
	Czech Republic	0	3	97	0	100
	Hungary	0	9	91	0	100
	Japan	0	7	93	0	100
	Latvia	0	5	95	0	100
	Lithuania	0	11	89	0	100
	Luxembourg	0	0	100	0	100
	Malta	0	0	100	0	100
	Poland	0	10	90	0	100
	Slovenia	0	12	88	0	100
	South Africa	0	6	94	0	100
	Spain	0	8	92	0	100
	Switzerland	0	6	94	0	100
	Average	0	7	93	0	100
II	Costa Rica	0	25	75	0	100
	El Salvador	0	17	83	0	100
	Average	0	21	79	0	100
Prostate tumour						
I	Croatia	0	1	99	100	0
	Czech Republic	0	0	100	100	0
	Hungary	0	0	100	100	0
	Japan	0	0	100	100	0
	Latvia	0	0	100	100	0
	Lithuania	0	1	99	100	0
	Luxembourg	0	0	100	100	0
	Malta	0	0	100	100	0
	Poland	0	2	98	100	0
	Slovenia	0	0	100	100	0
	South Africa	0	0	100	100	0
	Spain	0	0	100	100	0
	Switzerland	0	0	100	100	0
	Average	0	0	100	100	0

Health-care level	*Country*	*Age distribution (%)*			*Sex distribution (%)*	
		0–15 years	*16–40 years*	*>40 years*	*Male*	*Female*
II	Costa Rica	0	2	98	100	0
	El Salvador	0	0	100	100	0
	Average	0	1	99	100	0
Brachytherapy treatments						
I	Czech Republic	0	6	94	40	60
	Hungary	0	1	99	38	62
	Japan	0	5	95	11	89
	Latvia	0	6	94	2	98
	Lithuania	0	7	93	0	100
	Luxembourg	0	0	100	0	100
	Malta	0	0	100	0	100
	Poland	0	10	90	24	76
	Slovenia	0	9	91	8	92
	Switzerland	0	2	98	33	67
	Average	0	5	95	16	84

Table D9a. Typical patient teletherapy doses (Gy)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Leukaemia*	*Lymphoma*		*Breast tumour*	*Lung/ thorax tumour*	*Gynaecological tumour*	*Head/neck tumour*	*Brain tumour*
		Hodgkin's	*Non-Hodgkin's*					
Health-care level I								
Croatia	45	42	40	50	42	50	64	60
Czech Republic	24	35	40	60	64	70		64
Hungary	12		36	66	50	46	66	60
Japan	12	30	40	50	60	50		50
Latvia	6	36	40	60	50	28	68	60
Lithuania	26	35	37	45	50	45	60	50
Luxembourg	20	36	36	60	60	50.4	70	60
Norway	30		30	50	60	50	70	60
Poland	20	40	40	50	60	50	60	60
Slovenia	12	30.6	30	45	50.6	50.4	60	56
South Africa	36		60	45	50	60	54	45
Spain	12	30	40	50	60	45	60	55
Switzerland	25	30	35	60	60	50	65	60
The former Yugoslav Republic of Macedonia				50		50		60
Average	16	33	40	51	60	51	61	53
Health-care level II								
Costa Rica	27	36	40	50.4	45	45	70	54
El Salvador		40	40	100	40	45		20
Trinidad and Tobago				50		45	60	
Average	27	38	40	67	40	45	63	43

Table D9b. Typical patient teletherapy doses (Gy)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Skin tumour*	*Bladder tumour*	*Prostate tumour*	*Testis*	*Other urological tumours*	*Tumour of colon and rectum*	*Other digestive tumours*
Health-care level I							
Croatia	50	60	74	35	50	50	45
Czech Republic	65	74	24	45	45	45	
Hungary	50	60	60	25.2	50	50.4	45
Japan	50	50	60	30	30	50	50
Latvia	51	60	70	36	50	50	64
Lithuania	60	54	57	45	53	40	50
Luxembourg	60	60	74	26	60	50.4	60
Norway	60	60	70	25	60	50	50
Poland	50	64	50	30	60	50	50
Slovenia	40	48	72	16.2	46.8	50.4	45
South Africa	30	66	30	30	30	45	54
Spain	60	60	76	25	50	50	50
Switzerland	50	60	75	30	45	50	55
The former Yugoslav Republic of Macedonia		66.8		25.2		50.4	
Average	54	55	67	30	39	49	50
Health-care level II							
Costa Rica	46		76	25		45	45
El Salvador		45					
Trinidad and Tobago			65			50	
Average	46	45	73	25		49	45

Table D9c. Typical patient teletherapy doses (Gy)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Bone and soft tissue sarcomas*	*Palliative treatments*	*Benign diseases*	*Other*
Health-care level I				
Croatia	10	24	12	60
Czech Republic	30	10	5	
Hungary	60	30	8	
Japan	40		35	
Latvia	60	30	50	40
Lithuania	55	30	3	43
Luxembourg	66	30		
Norway		30	12	
Poland	60	20	20	50
Slovenia	50.4	20	20	48
South Africa	40			15
Spain	60	30	30	
Switzerland	55	30	10	55
Average	42	23	8	52
Health-care level II				
Costa Rica	66	30		50
Average	66	30		50

Table D10a. Typical paediatric teletherapy doses (Gy)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Brain*	*Lymphomas*	*Neuroblastoma*	*Rhabdomyosarcoma*	*Wilm's tumour*
Health-care level I					
Croatia	55	30	30	45	20
Czech Republic					
Hungary	50	26	30		30
Japan	30	20	10	40	
Lithuania	50				
Luxembourg	54	20			
Norway					
Poland	50	20	21	50	30
Slovenia	18	12			
South Africa					
Spain	54		20	45	20
Sweden					
Switzerland	65	30		50	25
Average	39	20	21	49	29

Table D10b. Typical patient teletherapy special procedure doses (Gy)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Intraoperative RT*	*Total body irradiation*	*Total lymphoid irradiation*	*Stereotactic irradiation*	
				Intracranial	*Extracranial*
Health-care level I					
Croatia			42		
Czech Republic		12		30	
Hungary		12		18	
Norway				25	
Poland	20	10	36		
Slovenia		14			
Spain	15	12			
Switzerland	10	10	18		
Average	18	11	37	27	

Table D10c. Typical patient brachytherapy doses (Gy)
Data from the UNSCEAR Global Survey of Medical Radiation Usage and Exposures

Country	*Head/neck tumour*	*Breast tumour*	*Gynaecological tumour*	*Prostate tumour*	*Intravascular brachytherapy*	*Other*
Health-care level I						
Croatia			30			32
Czech Republic		10	30			
Hungary	4	4.3	6	10		10
Latvia			35			
Lithuania			48			
Luxembourg			14			
Norway			27		20	
Poland		10	35	30		
Slovenia	20		30			19
Spain	30	10	30			
Switzerland	19	17	20	100	14	50
The former Yugoslav Republic of Macedonia			21			
Average	29	10	26	47	17	28
Health-care level II						
Trinidad and Tobago			40	145		
Average			40	145		

Table D11. Number of dedicated stereotactic installations by country

Country/area	*GammaKnife installations [E2]*	*CyberKnife installations [A6]*	*Novalis installations [B8]*
Argentina	1		
Austria	3		
Belgium	1		1
Brazil	1		
Canada	3		2
China	15	4	1
China, Taiwan	6	4	2
Croatia	1		
Czech Republic	1		
Democratic People's Republic of Korea	2		
Denmark			1
Egypt	2		
Finland			1
France	2	3	2
Germany	4	1	3
Greece	1	1	
Hong Kong	1	1	
India	3		
Iran, Islamic Rep.	2		
Italy	4	3	
Japan	46	19	6
Jordan	1		
Malaysia		1	

Country/area	*GammaKnife installations [E2]*	*CyberKnife installations [A6]*	*Novalis installations [B8]*
Mexico	2		2
Netherlands	1	1	3
Norway	1		
Philippines	1		
Republic of Korea	11	5	1
Romania	1		
Russian Federation	1		2
Singapore	1		
Spain	1	1	1
Sweden	2		
Switzerland	1		
Thailand	1		1
Turkey	3	2	
United Kingdom	3		
United States	116	87	44
Viet Nam		1	
Total	244	134	73

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